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***A**lliance for **B**atteries **T**echnology, **T**raining and **S**kills*

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Battery Manufacturing

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Executive Summary

The ALBATTS project aims to bring the demand and supply side of skills and competencies together to establish a blueprint for the preparedness of future skills across Europe. This desk research contributes to the ALBATTS project's goals by analysing what a large-scale battery manufacturing plant or a so-called Gigafactory consists of in terms of departments and teams. Who works there, and what kind of skills, competencies, and education do they have.

Drivers Affecting Battery Manufacturing chapter addresses the factors that will affect the environment in which battery manufacturer's function. For example, the climate goals, regulations, and environmental challenges are boosting the need for batteries, but at the same time, reducing CO_2 emission from the battery manufacturing itself means that the manufacturers need to address sustainability themselves. Globalisation brings such addressable elements as access to raw materials, global regulatory dialogue and restructuring to facilitate the intermittent renewable energy sources. With new technologies, cybersecurity, global technical harmonisation, standardisations, and smart grid will require further development.

We also look into the **EU framework** and EU's commitment to becoming the first climate-neutral continent globally that translated into the European Green Deal. Finally, we go through the main EU strategies, initiatives, and projects relevant to battery manufacturing, such as New Industrial Strategy for Europe, European Raw Materials Alliance, Horizon Europe, European Battery Alliance, and European Skills Agenda.

The **Battery Passport** is an essential part of the new Batteries Directive proposal to ensure the sustainability and competitiveness of the EU battery value chain. We analyse the background and the implications of the passport to the battery value chain.

In the **Stakeholders** chapter, we investigate the business environment in which battery manufacturers operate. Who manufacture batteries and the emergence of Gigafactories in Europe? In addition to the Gigafactory level manufacturers, we also examine smaller niche manufactures that are researching alternative and new technologies. We also study the global business environment to understand where Europe stands vs the rest of the world in terms of battery manufacturing. One outcome of this analysis is that Europe should focus more on niche markets, present new technologies and develop green batteries.

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Additionally, we look at the supply chain in which battery manufacturers operate. Who are the leading operators concerning material, component, and machine suppliers to battery cells and beyond? We also investigate the main customer categories: automotive, other transportation and stationary applications.

Anatomy of a Gigafactory addresses the main topic of this research. What does a Gigafactory consist of? What departments and teams are there, who work in them, and what skills, competencies, and education do they have? We learn, for example, that battery manufacturing consists of two main sections, upstream and downstream manufacturing. The latter is the most labour intensive with the most extensive recruitment needs in the battery assembly. We analyse the steps of the battery manufacturing, from the preparation of input materials all the way to cell assembly and finishing. We also learn about how the future will be increasingly automatized and digital with an impact on the skills throughout the layers and stages of a battery manufacturing plant.

In **Job Roles and Skills** chapter, we analyse the central departments of a Gigafactory for various staff competencies. For the analysis, we gathered information from the related job advertisements. The studied competence categories include soft, academic, general transversal, cross-sectoral specific and sector-specific competencies. We built a model of the most desired skills per the main departments for each of these competence categories. We, for example, learned that the most desired academic competencies with production and maintenance are chemistry, mechanical engineering, and electrical engineering.

Finally, we investigate the **Education** needs and trends, focusing on the vocational and professional technician sectors of education, EQF 4 and 5, and especially battery manufacturing. We identify and study five trends that include Horizontal European initiatives, Battery-/electromobility profiled adult education and training programmes, simulated training environments, more flexible and blended learning solutions from institutional providers and Education programmes and courses from new or untraditional providers.

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Introduction

This research studies the anatomy of a large-scale battery manufacturer, a Gigafactory, and the environment in which it operates. It examines its departments, teams, and functions. The purpose is to generate further understanding about the job roles and related skills and competencies needed by battery manufacturers. We also study the related education by focusing on the vocational and the professional technician sectors of education, EQF 4 and 5, with battery manufacturing.

We investigate the circumstances that affect the battery manufacturing business, including drivers of change, European Framework, and the coming Battery Passport with related implications. In addition, we look into the position of the European battery industry vs the rest of the world and study the stakeholders of a battery manufacturer by examining both suppliers and customers.

This Desk Research has been prepared under ALBATTS Work Package 4, and it was supported by a close collaboration with the members of Work Package 5, led by AIA. It represents the second release of the desk research of the project ALBATTS (Alliance for Batteries Technology, Training and Skills).

List of Abbreviations

8D	...	Eight Disciplines Problem Solving Process
ACC	...	Automotive Cells Company
AGV	...	Automated/Automatic Guided Vehicle
APQP	...	Advanced Product Quality Planning Process
APQP	...	Advanced Product Quality Planning
ARPA-E	...	Advanced Research Projects Agency-Energy
BESS	...	Battery Energy Storage Systems
BEV	...	Battery Electric Vehicle
BMA	...	Bayesian Model Averaging
BMS	...	Battery Management System
CAGR	...	Compound annual growth rate
CE	...	Conformitè Europëenne (French)
CEAP	...	Circular Economy Action Plan
CEDEFOP	...	European Centre for the Development of Vocational Training
CP	...	Cyber-Physical
Cpk	...	Process Capability Index
Cpk	...	Process Capability
CPO	...	Chief Product Officer
DFMEA	...	Design Failure Mode and Effect analysis
DMAIC	...	Define, Measure, Analyse, Improve and Control
DoC	...	Drivers of Change
DoE	...	Design of Experiments
EBA	...	European Battery Alliance
EERE	...	Energy Efficiency and Renewable Energy
EESC	...	European Economic and Social Committee
EPRS	...	European Research Service
EQF	...	European Qualifications Framework
ERP	...	Enterprise Resource Planning
ESG	...	Environmental, Social and Governance
ESS	...	Energy Storage Systems
EV	...	Electric Vehicle
eVTOL	...	Electric Vertical Take-off and Landing
GHG	...	Green House Gases
GWh	...	Giga Watt hour 10^9
HMI	...	Human-Machine Interface
IATF16949	...	Global technical specification and quality
ICE	...	Internal Combustion Engine
ICT	...	Information and Communication Technologies
IoT	...	Internet of things
IPCC	...	Intergovernmental Panel on Climate Change
IPCEI	...	Important Projects of Common European Interest
ISO14001	...	Environmental management system
ISO9001	...	Quality management system
KPI	...	Key Performance Indicator

MEI2	…	Maryland Energy Innovation Institute
MOOC	…	Massive Open Online Courses
MSA	…	Measurement System Analysis
MWh	…	Mega Watt hour 10^6
NASA	…	National Aeronautics and Space Administration
NMP	…	N-Methyl-2-pyrrolidone
NZE	…	Net-Zero Emissions by 2050 Scenario
OEM	…	Original Equipment Manufacturer
PDSA	…	Plan, Do, Study Act
PFMEA	…	Process Failure Mode Effects Analysis
PhD	…	Doctor of philosophy
PHEV	…	Plug-in Hybrid Electric Vehicle
PPAP	…	Production Part Approval Process
PSA	…	Peugeot S.A
PV	…	Photo voltaic
QC	…	Quality Control (of the final product)
QMS	…	Quality Management Process
QR	…	Quick Response code
R&D	…	Research and Development
RES	…	Renewable Energy Sources
SAF	…	Sustainable Aviation Fuels
SPC	…	Statistical Process Control
TQM	…	Total Quality Management
TWh	…	Tera Watt-hour 10^{12}
UK	…	United Kingdom
VDMA	…	Deutche Maschinen- und Anlagenbaus
VW	…	Volkswagen

Glossary

Algorithm	…	Step-by-step procedure for solving a problem mathematical or accomplishing some end.
Alistore-ERI	…	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.
Anode	…	Negative electrode at discharge (electrode from where the electrons “leave”)
Artificial Intelligence (AI)	…	Branch of computer science dealing with the simulation of intelligent behaviour in computers.
Augmented Reality (VR)	…	Images produced by a computer and used together with a view of the real world
Automotive Skills Alliance	…	Mission is to bring together different kind of stakeholders involved in the Automotive ecosystem and to ensure continuous, pragmatic, and sustainable cooperation on the skills agenda in the ecosystem.
Battery	…	An association of battery-cells (usually some cells are associated in series to obtain a certain voltage)
Battery 2030+	…	A long-term initiative for research on ultrahigh-performance, reliable, safe, sustainable, and affordable batteries. 7 projects.
Battery Anxiety	…	Feeling of overwhelming fear experienced as your smartphone battery dies, causing you to live your life on your phone's terms rather than your own.
Battery Directive	…	An EU directive of which objective is to minimise the negative impact of batteries and waste batteries on the environment.
Battery Energy Storage Systems (BESS)	…	Enables power system operators and utility providers to store energy for later use and enhance the flexibility of the grid.
Battery Management System (BMS)	…	Monitors battery functions including temperature, voltage, capacity, power consumption, and charging cycles
Battery Thermal Management System (TMS)	…	Keep cells within an optimum temperature range and to maintain an even temperature distribution from cell to cell, is vital for the high efficiency.
Big Data	…	Extensive datasets — primarily in the characteristics of volume, velocity, and/or variability — that require a scalable architecture for efficient storage, manipulation, and analysis.
Carbon footprint	…	Greenhouse gas (GHG) emissions caused directly and indirectly by an individual, organization, event, or product.
Cathode	…	Positive electrode at discharge (electrode to where the electrons “arrive”)
CE marking	…	Represents a manufacturer's declaration that products comply with the EU's New Approach Directives.
Cell	…	The cell is single, composed of electrodes, electrolyte, separator, and current collectors. It does not include any cell association.
Current collectors	…	Conductors, usually metals such as copper and aluminium that facilitate electric conduction in the battery (connect the external circuit through the tabs to the active material in the electrodes)
Cycle life	…	Number of cycles yielded by the battery (usually measured until the capacity is 80% of the initial capacity of the cell)

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Digital Twin	…	A virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity
Digitalisation	…	To change something such as a document to a digital form (= a form that can be stored and read by computers).
Electrodes	…	Negative electrode is the cathode on charge and anode on discharge (usually termed anode) Positive electrode is the anode on charge and cathode on discharge (usually termed cathode)
Electrolyte	…	Solution, polymer, gel, or solid containing mobile ions. The electrolyte should be an insulator (not conducting electrons) and a good ion conductor
Energy density	…	Energy per unit volume ($Wh.L^{-1}$)
Energy Storage	…	Capture of energy produced at one time for use at a later time to reduce imbalances between energy demand and energy production
EQF level	…	8 levels define the learning outcomes relevant to qualifications; theoretical or factual and/or knowledge, skills, responsibility, and autonomy
European Battery Alliance (EBA)	…	Project-driven community which brings together more than 600 industrial and innovation actors, from mining to recycling, with the common objective to build a strong and competitive European battery industry.
European Green Deal	…	New growth strategy of the EU, aiming to set Europe on the path of transformation to a climate-neutral, fair, and prosperous society, with a modern, resource-efficient, and competitive economy.
European Skills Agenda	…	The European Pillar of Social Rights and notably its first principle spelling out the right to quality and inclusive education, training, and lifelong learning.
Extended producer responsibility	…	Ability to predict based on the different data set than on which was the algorithm trained (Marek, https://towardsdatascience.com/real-artificial-intelligence-understanding-extrapolation-vs-generalization-b8e8dcf5fd4b)
Extended Reality (XR)	…	Inclusive term used to describe a variety of immersive technologies encompassing Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and technologies that have yet to be imagined.
Extrapolation	…	The process of using information that is already known to guess or think about what might happen.
Gigafactory	…	A massive battery factory
Globalisation	…	Describes the increasing connectedness and interdependence of world cultures and economies.
Harmonisation	…	Act of making systems or laws the same or similar in different companies, countries, etc. so that they can work together more easily
IATF16949	…	The International Standard for Automotive Quality Management Systems.
Internet of Things (IoT)	…	System of interrelated, internet-connected objects that are able to collect and transfer data over a wireless network without human intervention

ISO14001	…	Environmental Management Systems - General Guidelines on principles, systems, and support techniques. The standard covers issues such as the establishment, implementation, maintenance, and improvement of an EMS.
ISO9001	…	The international standard that specifies requirements for a quality management system (QMS).
Kaizen	…	Method is a concept of Japanese management that stands for incremental that is gradual and continuous change or improvement
Lean Manufacturing	…	Six steps required to implement and used to describe each step: sort, set in order, scrub, safety, standardize, and sustain. Create a safe and organized work area
LFP	…	Lithium Iron Phosphate ($LiFePO_4$)
Li-ion	…	Lithium-ion battery is an advanced battery technology that uses lithium ions as a key component of its electrochemistry.
Liquid immersion cooling	…	Liquid immersion cooling is the processing of removing the waste heat generated by operating electronics, batteries, and electric motors by fully submerging them in a dielectric fluid
Li-S	…	Lithium-Sulphur batteries
Measurement System Analysis (MSA)	…	Tool for analysing the variation present in each type of inspection, measurement, and test equipment.
MOOC (massive open online course)	…	A model for delivering learning content online to any person who wants to take a course, with no limit on attendance.
NCA	…	Lithium Nickel Cobalt Aluminium oxide ($LiNi_xCo_yAl_zO_2$ with x + y + z = 1)
NMC	…	Lithium Nickel Manganese Cobalt oxide ($LiNi_xMn_yCo_zO_2$ with x+ y + z = 1)
NTNU	…	Norwegian University of Science and Technology. Located in Trondheim, Gjøvik and Ålesund. Specializing in technology and the natural sciences. 40 000 students.
Oligopoly	…	Market form with limited competition in which a few producers control the majority of the market share and typically produce similar or homogenous products.
Paris Agreement	…	Sets out a global framework to avoid dangerous climate change by limiting global warming to well below 2°C and pursuing efforts to limit it to 1.5°C.
Plan, Do, Study Act (PDSA)	…	Iterative, four-stage problem solving model used for improving a process or carrying out change.
Pouch cells	…	Battery cell or cell association wrapped in a rectangular polymer covered in an aluminium flat bag with external tabs to connect to the circuit
Power grid modernization	…	More than only smart metering, sending data in two directions and adding power to the grid in the opposite direction
Power train	…	System of mechanical parts in a vehicle that first produces energy, then converts it in order to propel it, whether it be an automobile, boat, or other machinery.
QR code	…	Two-dimensional version of the barcode, typically made up of black and white pixel patterns.
Range Anxiety	…	The fear that a driver will run out of battery or fuel before you can reach the charging/fuelling station.

Separators	…	In a battery, separators are insulating membranes that prevent short circuits between the two electrodes; in the SSE, the solid electrolyte may also play the role of the separator
Six Sigma	…	Disciplined, data-driven approach and methodology for eliminating defects (toward six standard deviations between the mean and the nearest specification limit) in any process -- from manufacturing to transactional and from product to service.
Smart Grid	…	Electricity network/grid enabling a two-way flow of electricity and data, between producer and customer.
Solid-state battery	…	Uses a solid electrolyte to regulate the lithium ions instead of a liquid one.
Total Quality Management (TQM)	…	Management practices throughout the organization, geared to ensure the organization consistently meets or exceeds customer requirements.
Virtual Reality (VR)	…	A set of images and sounds, produced by a computer, that seem to represent a place or a situation that a person can take part in

1 Methodology

This Desk Research has been conducted under ALBATTS Work Package 4, and it was supported by Work Package 5, led by AIA. The sources for the information gathered for this research includes various scientific, technical, and other publications, press releases and battery manufacturers' websites. Additionally, the information yielded by the previous research work within ALBATTS has been used where applicable. In this research, we cover battery manufacturing, especially from the large-scale production, Gigafactory point of view. In that context, we are privileged to have Northvolt, which has a Gigafactory project in progress in Skellefteå, Sweden as an ALBATTS member. Therefore, we utilized this opportunity by conducting a few interviews with Northvolt to collect first-hand information from a large-scale battery manufacturer.

The main aim of this research was to analyse the anatomy of a major battery manufacturer, a Gigafactory, to identify the departments, teams, and functions there. This is essential to understand the job roles and the skills and competencies required for these roles. From the basis of this information, it can be assessed the needs of the battery manufacturers in terms of skills and competencies now and in the future.

Additionally, we analysed the circumstances in which battery manufacturers operate today. What are the drivers of change currently affecting the business, and what is the business environment like from the global perspective? Where does European battery manufacturing stand against the rest of the world? We also studied the main stakeholders by examining suppliers of battery manufacturers to understand the supply chain. Additionally, we examined the customer side by looking into automotive and other transportation sectors and naturally to the stationary applications.

Job roles and skills were also studied with a deeper analysis concerning the main areas identified within battery manufacturing. This information was gathered by examining job advertisements and further analysed with a competence matrix. Education was also examined by focusing on the vocational and the professional technician sectors of education, EQF 4 and 5, especially battery manufacturing.

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2 Drivers Affecting Battery Manufacturing

2.1 DRIVERS OF CHANGE

2.1.1 Introduction and Methodology

The methodological approach adopted by ALBATTS project partners includes maintaining an updated overview of the Drivers of Change (DoC) influencing the battery sector (i.e., those crucial factors to transforming an industry). We used the same methodology for the first desk research, focusing more on recently published reports of a more technical nature. For the most part, the reports represented the whole battery value chain and are compiled by respected consultancy organisations or projects. As a complement to the literature review, recent project results were integrated and one-to-one interviews to eventually validate such results.

This approach was aimed at confirming, complementing, or amending the three macro areas of DoC and the nine sub-categories already identified, which were:

- **Climate goals, regulation, and environmental challenges**

  Batteries are one of the most important drivers for decarbonising land and maritime transportation and transitioning to a renewable power system. Managing the complete lifecycle from concept to design, manufacture, service, and disposal contributes to reducing waste and pollution whilst providing opportunities for significant cost reductions and calling for new skills in different areas. For this macro area, the following sub-categories had been identified:

  a. Reducing CO_2 emissions from battery manufacturing: A significant step would be to increase the share of renewable energies and energy efficiency in the production and battery value chain.

  b. Electrification and green energy: batteries are a systemic enabler and play an essential role in contributing to greenhouse gas neutrality in the transport and power sectors.

  c. Widespread charging/refuelling infrastructure: a robust and suitable charging infrastructure network is key to boost the development of storage-based technologies, easing access to more affordable battery systems.

- **Globalisation**

EV batteries production is expected to grow in the global markets heavily, and the EU must be prepared to get a competitive advantage, particularly within the following sub-categories:

d. Access to raw materials is critical to producing key components, so smart solutions are urgent to overcome shortages of some resources (limited in terms of quantity or geographical presence).

e. Global regulatory dialogue: The Commission, Governments and public administrations in Europe will need to work in tandem for the elaboration of policies and strategies from which the battery sector could benefit

f. Restructuring: to facilitate the intermittent renewable energy sources, structural changes are expected in the battery sector to adapt to a zero-emission mobility

- **New technologies**

To swiftly act and mitigate climate change and make renewable energy a reliable alternative source, it is essential to invest in storage systems, like batteries, for mobile and stationary usage. Technological features are intrinsically connected, and the identified sub-categories require further developments:

g. Cybersecurity: exponential growth of Internet of Things (IoT) into BMS connected to a network, cloud infrastructures, and the navigation and location information necessary to optimise the smart grid infrastructure can compromise private and collective security. This threat landscape requires the industry to modify the security approach and the resilience of the infrastructures to cyber-attacks.

h. Global technical harmonisation and standardisations: introducing new technology and changing market conditions will require the sector supply chain structure to adjust and meet the challenges.

i. Smart Grid: storage is one of the most important smart grid components due to its key role in complementing renewable energy generation. With the proper amount and type of storage broadly deployed and optimally controlled, renewable

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generation can be transformed from an energy source into a dispatchable generation source.

Also, for this desk-research process, the identified DoC were analysed based on:

- **Occurrence**: whether a DoC is cited multiple times in the same report or different DoC are cited, their occurrence is counted as 1.
- **Importance**: a ranking from 0 to 5 (0 = not possible to evaluate, 1= not important, 5 very important) reflect the future status and direct implications on changes in the sector.
- **Urgency**: recognise a DoC overwhelming significance in a specific time frame (year).

One potential limitation of this methodological approach is that it is not explicitly focused on the main topics of this second desk research – *battery manufacturing* and *energy storage*. This is because narrowing the approach would have prevented a harmonised aggregation of data and trend analysis between the first and the second desk research exercises, the first one broader in terms of topics analysed.

2.1.2 Highlights of Drivers of Change

Based on the above-mentioned methodological approach, the trend evolution regarding the occurrence, importance, and urgency of each DoC, per sub-category, are compared.

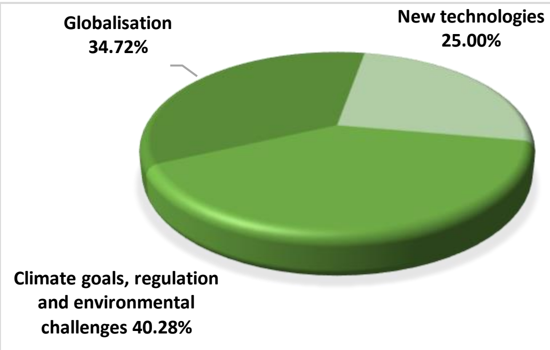

Figure 1: DoC occurrence - 2020 desk research

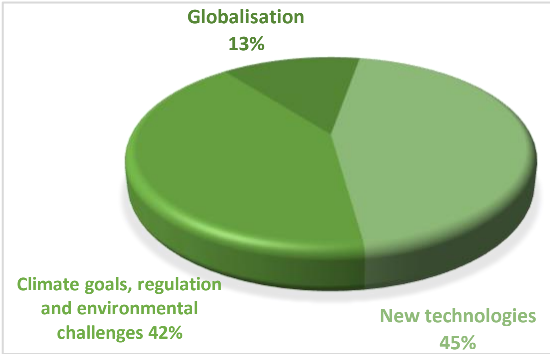

Figure 2: DoC occurrence - 2021 desk research

Overall, by comparing the occurrence of the DoC in both sections of our desk research (Figure 1 and Figure 12 Figure 2), the consistency is confirmed. “Climate goals, regulation, and environmental challenges” have almost the same weight, but “new

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technologies" has a higher rate of occurrence (from 25% to 45%), and "Globalisation" decreased its weight (34,72% to 13%).

Thanks to further inputs from ALBATTS project partner experts[1] meetings, the three above mentioned categories can be further integrated with a more specific set of Drivers of Change that, given their importance, can be considered as trends on their own as listed below:

- **Battery capacity/energy density:** climate goals and environmental challenges are key drivers to push the sector to invest into improving battery capacities, i.e., get electric vehicles with a more extended range are likely to push forward climate goals.
- **Improved charger performance:** energy demand shift from oil to electricity is one step for the decarbonisation process depending on battery capacity and better and faster charging tools to boost Battery Electric Vehicles (BEV).
- **Country independence:** resulting from COVID-19, countries and companies recognised the need to be more independent in battery construction and materials (e.g., fabrication of own cells). This is, of course, linked also to an economic factor.
- **Battery as a structure:** this refers to using any structure (foundation of a house, chassis of a car, structure of an aeroplane) as a battery. The purpose is to reduce needed space while maintaining the optimal weight and centre of gravity and improving the charging infrastructure.
- **Heat conversion into electrical energy:** investing in processes to reconvert heat waste (kinetic energy) into electrical power is essential in the circularity of the process.
- **Safety:** the global adoption of regulations and standards in safety issues, especially regarding charging/recharging/ and discharging of batteries, is necessary.
- **Energy accessible everywhere:** energy storage systems and appropriate fuel cells are essential for the transition to sustainable energy sources, such as solar and wind energy, helping maintain (and grow) current energy infrastructure stable and continuous everywhere.

[1] One-to-one meeting with Professor Helena Braga, Engineering Physics Department, University of Porto (PT), 25.05.2021

Comparing research analysis for each sub-category, Figure 3 and Figure 4 show "Electrification and green energy" remaining equally relevant while "Reducing CO_2 emissions from battery manufacturing" jumped to second and "global regulatory dialogue", lowered to rank 7.

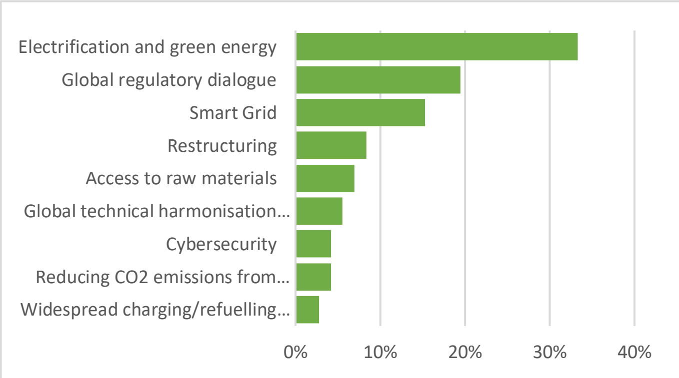

Figure 3: occurrence of DoC sub-categories - 2020 desk research

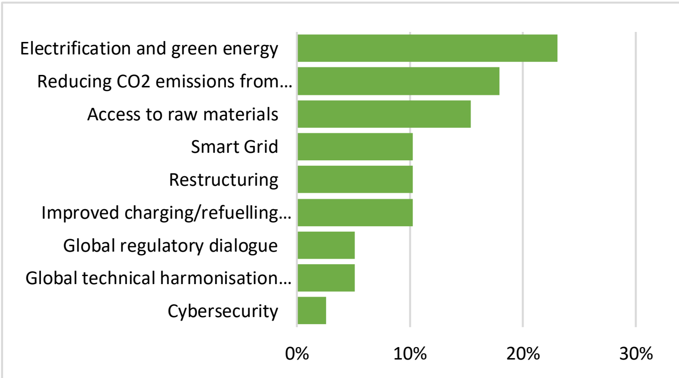

Figure 4: occurrence of DoC sub-categories - 2021 desk research

"Access to raw materials" is the 3rd, replacing "smart grid", now ranked 4th. This second desk-research process qualified the most minor importance to "cybersecurity".

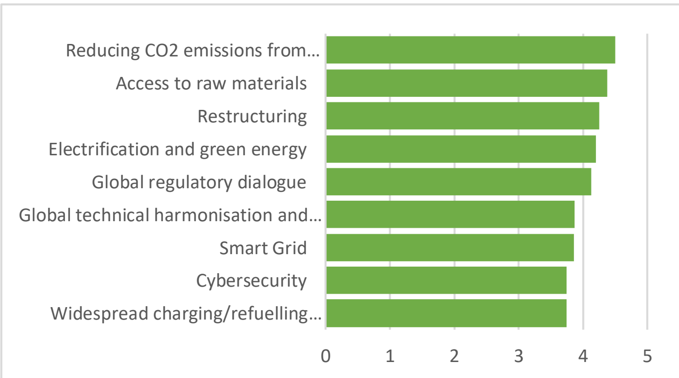

Figure 5: the importance of DoC sub-categories - 2020 desk research

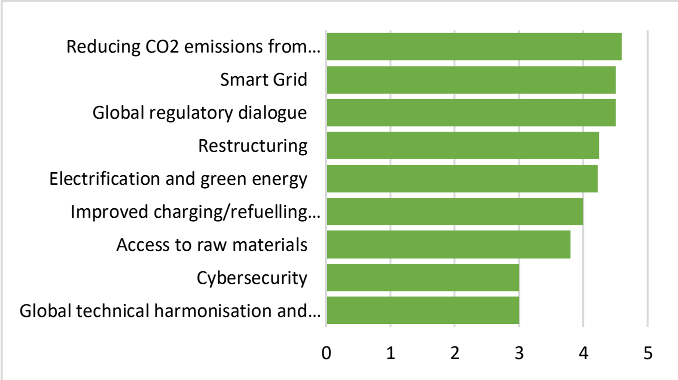

Figure 6: the importance of DoC sub-categories - 2021 desk research

When analysing the importance of each sub-category in both pieces of research (Figure 5 and Figure 6), it is similarly evidenced that "reducing CO_2 emissions from battery manufacturing" is the most important. At the same time, "access to raw materials" became less significant (from 2nd to 7th in the ranking) and "global regulatory dialogue" has instead been upgraded (from 5th to 3rd). However, it is essential to highlight that such changes are pretty minor considering the numbers (indeed, "access to raw materials" decreased only by 0.58 points - 4.38 and now 3.8).

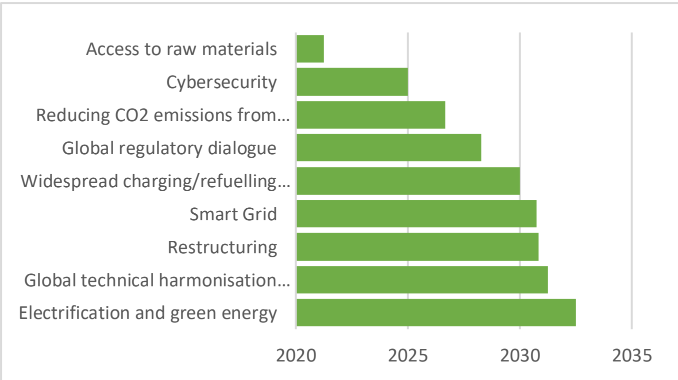

Figure 7: the urgency of DoC sub-categories - 2020 desk research

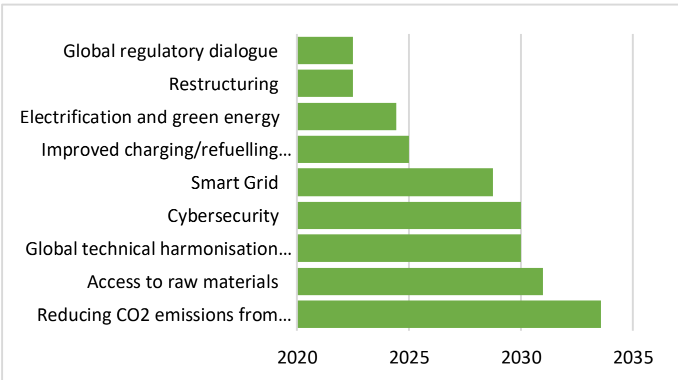

Figure 8: the urgency of DoC sub-categories - 2021 desk research

Lastly, Figure 7 and Figure 8 analyse and compare the urgency of each DoC sub-categories. “Global regulatory dialogue” turned to be the most urgent to tackle together with “restructuring”. “Reducing CO_2 emissions from battery manufacturing”, despite being the most important and frequently quoted in the literature, is challenged to be faced in the long term (after 2030).

2.2 EU FRAMEWORK

The EU commitment to become the first climate-neutral continent globally translated into the European Green Deal. The goal is to reduce net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels, which requires changes in many domains, including mobility and the energy sector. As a result, the demand for battery capacity in Europe would amount to 400 – 1 000 GWh by 2030. At the same time, production capacities are being built in Europe, announced at the level of 800 GWh by 2030 or possibly over 1 TWh[2], be it by Asian, American, or European companies.

Apart from the goals set in the legislation, the EU and its Member States need to create favourable framework conditions. Some of the main EU strategies, initiatives, and projects relevant to battery manufacturing are mentioned below.

An overall strategy at the EU level is the **New Industrial Strategy for Europe**, published by the Commission in March 2020 (focused on encouraging the twin ecological and digital transition) and updated in May 2021 following the COVID-19 pandemic[3]. The updated strategy was accompanied by mapping EU strategic dependencies and capacities, presenting six in-depth reviews of strategic areas, among them raw materials and batteries. Furthermore, in the Action Plan on Critical Raw Materials framework, the **list of critical raw materials** was updated in 2020 and lithium was added to the list for the first time. Also, European Raw Materials Alliance was established in September 2020 to address the challenge of securing access to sustainable raw materials, advanced materials, and industrial processing know-how.

[2] VDMA Roadmap Battery Production Equipment, Update 2020
[3] https://www.europarl.europa.eu/doceo/document/TA-9-2020-0321_EN.html

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In the area of research, development and innovation, **Horizon Europe**[4] is the EU's key funding programme for the period 2021 -2027, building on a tradition of research (and innovation) framework programmes. Climate, Energy and Mobility cluster or the Missions like "Adaptation to climate change including societal transformation" and "Climate-neutral and smart cities" belong to the elements of Horizon Europe relevant to batteries.

To further accelerate the upscaling of pre-commercial projects, the Commission launches calls for **IPCEIs** in areas of strategic importance to the EU economy. For example, an Important Project of Common European interest is a tool to support research and innovation under specific EU State aid rules. The rules have a specific provision for the Member States to fund disruptive and ambitious research and development and the first industrial deployment of the technology in case of market failure. So far, the Commission approved two Batteries IPCEIs in 2019 and 2020[5].

Recognising the need and urgency for the EU to develop a battery value chain, the Commission launched, already in 2017, the **European Battery Alliance** (EBA) and adopted the Strategic Action Plan on Batteries in 2018. EIT InnoEnergy has been entrusted by the European Commission to drive forward and promote EBA250 activities, acting as a network manager and project facilitator. To address the challenge of training, upskilling, and reskilling several tens of thousands of workers every year, EIT InnoEnergy is also building a pan-European education sharing platform, the **EBA250Academy**. It should provide local training providers access to industry-proven training content for distribution to their industry clients and end customers[6].

As around 2030, up to 300 thousand jobs related to battery manufacturing could emerge in Europe[7], skills and education need to be one of the areas to pay close attention to. The **Commission updated the European Skills Agenda** in 2020 with the action Pact for Skills. The European Skills Agenda is also implemented through various sectoral initiatives, such as Automotive Skills Alliance. And there are other initiatives and projects aimed at supporting

[4] https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en, last accessed on 07.07.2021
[5] https://ec.europa.eu/commission/commissioners/2019-2024/sefcovic/announcements/keynote-speech-vice-president-maros-sefcovic-battery-summit-portugal_en
[6] https://www.eba250.com/eba250-academy/about-eba250-academy/?cn-reloaded=1 last accessed on 07.07.2021
[7] EIT RawMaterials, Fraunhofer: Future Expert Needs in the Battery Sector, Report March 2021

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specifically the growth of the battery industry in Europe in education, training, and skills, such as Alistore-ERI, Battery 2030+ or the ALBATTS project itself[8].

Coming back to legislation, the proposal for a **Regulation concerning batteries and waste batteries**[9] from December 2020 establishes various requirements on sustainability (carbon footprint, recycling content etc.). These include information about performance, durability, safety, labelling, supply chain due diligence and other information for allowing the placing on the market or putting into service of batteries. In addition, there are also requirements for the collection, treatment, and recycling of waste batteries. Finally, for industrial and electric vehicle batteries, it also introduces an electronic record, the so-called “battery passport”.

2.3 BATTERY PASSPORT

The Battery Passport is an integral part of the new Batteries Directive proposal to ensure the sustainability and competitiveness of the EU battery value chain[10].

The Battery Passport is a digital representation of a battery that points out all applicable ESG and lifecycle requirements, completely covering a definition of a sustainable battery. A battery passport would support data sharing on dimensions such as materials chemistry, origin, the state of health of batteries, or chain of custody. It could provide a powerful means to identify and track batteries throughout the lifecycle and support the establishment of life extension and end-of-life-treatment systems.

The process started in 2006 when the batteries and waste directive entered into force. The Battery Passport will become active in 2027 Figure 9.

The paragraphs of the chapters 2.3.3 and 2.3.4 that mention and discuss the articles of the EU law contain direct excerpts from the EU law text.[11]

[8] https://eepower.com/news/battery-2030-initiative-starts-to-power-up-europes-battery-revolution/# last accessed on 07.07.2021

[9] https://ec.europa.eu/environment/topics/waste-and-recycling/batteries-and-accumulators_en, last accessed on 26.07.2021

[10] https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/689337/EPRS_BRI(2021)689337_EN.pdf last accessed on 02.06.2021

[11] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020PC0798&qid=1613426366165 last accessed on 02.06.2021

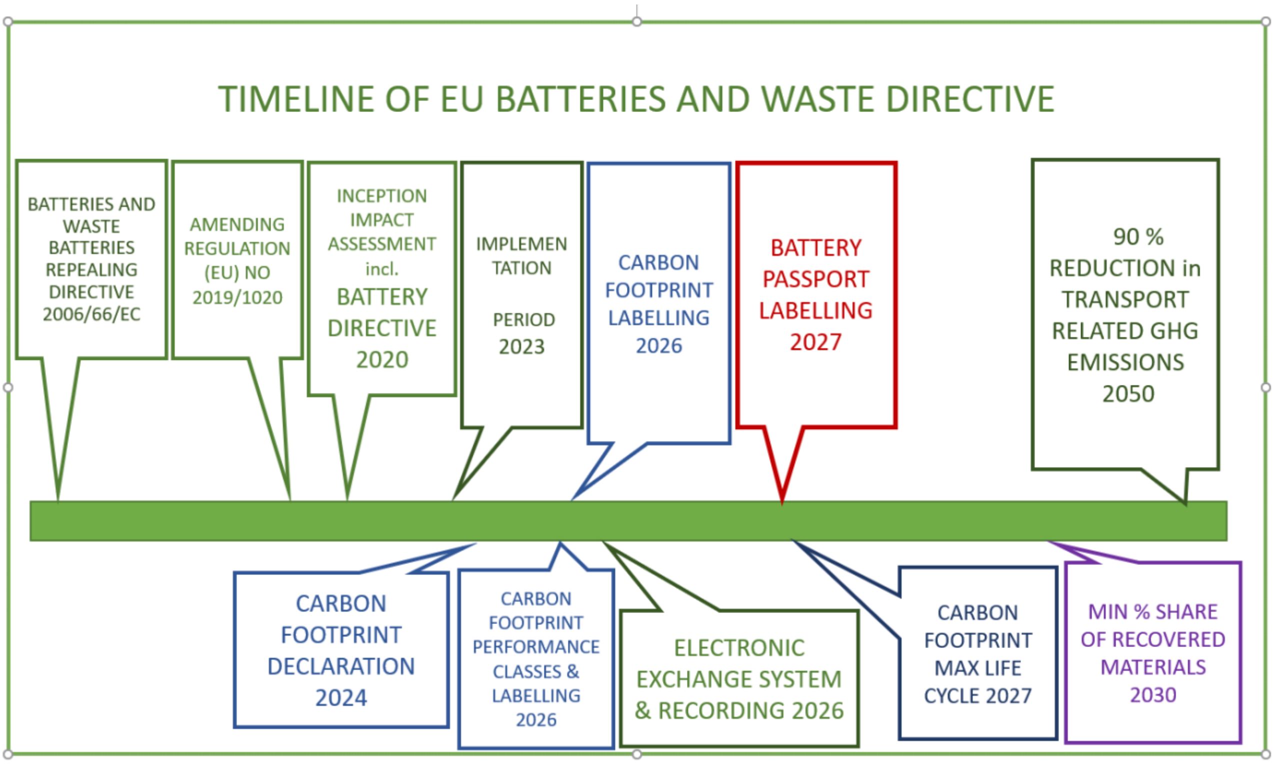

Figure 9. Timeline of EU Batteries and Waste Directive

2.3.1 Batteries are a key technology to achieve sustainability goals

The Paris Agreement has set out the ambition to "keep global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius". This 1.5°C target would require net-zero global human-caused CO2 emissions by 2050, according to a recent Intergovernmental Panel on Climate Change (IPCC) special report[12].

The Battery Directive is a central piece of EU legislation on waste batteries, including recycling. The Battery Directive entered into force on the 26th of September 2006. In April 2019, the European Commission published its evaluation of the Batteries Directive[13]. The results of this review were used to prepare the European Commission report on the implementation and impact on the environment and the functioning of the internal market of the Batteries

[12] https://www.ipcc.ch/sr15/ last accessed on 27.05.2021
[13] https://ec.europa.eu/info/news/commission-publishes-evaluation-eu-batteries-directive-2019-apr-09-0_en last accessed on 27.05.2021

Directive. The aim of the proposal, published in May 2020[14], is to modernize EU battery legislation, including the Batteries Directive, which contains existing relevant laws, standards, and regulations. The Battery Directive represents **the minimum standard** that the individual Member States must transpose into their national law. Still, every EU country has the right to expand it to satisfy domestic demands. Once implemented, the new rules are expected to take effect, following an implementation period, from 2023. See Figure 10.

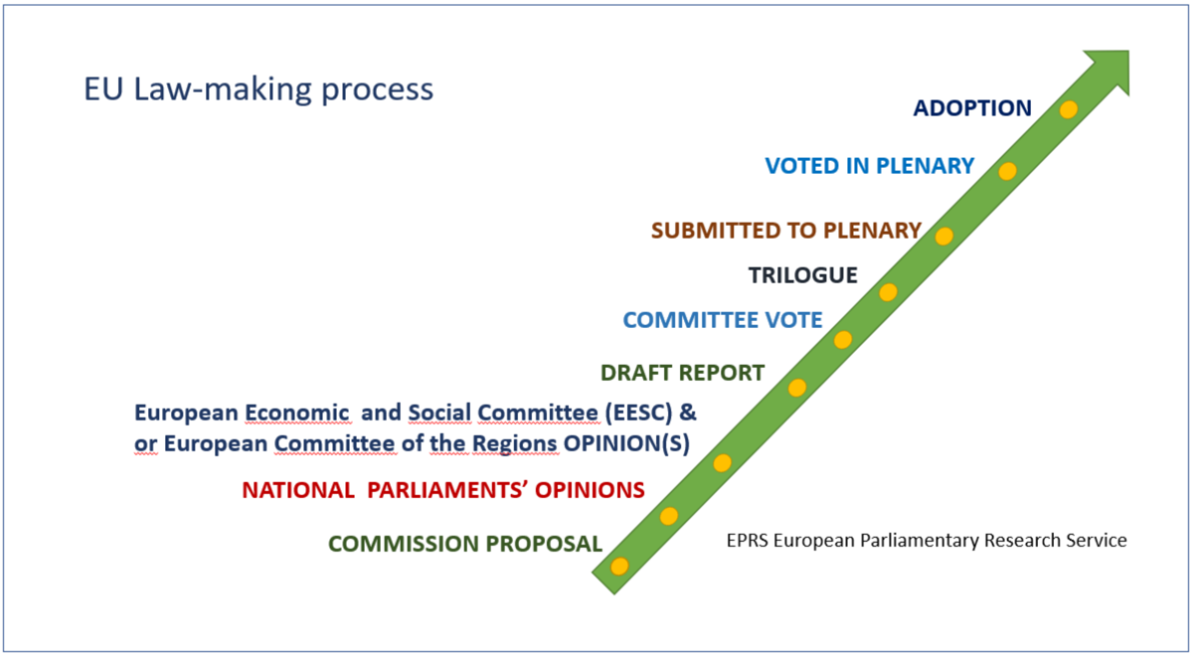

Figure 10. EU Law-making process

2.3.2 Green Deal

The EU's Green Deal is a new growth strategy and an integral part of this Commission's strategy to implement the United Nation's 2030 Agenda and the sustainable development goals[15]. The purpose is to transform Europe into a modern, resource-efficient, and competitive economy where:

- there are no net emissions of GHGs by 2050
- economic growth is decoupled from resource use

[14] file:///C:/Users/Sari%20Rintakoski/Merinova%20Oy/Merinova%20Oy%20Team%20Site%20-%20Documents/Yleinen/ALBATTS/DR2/EPRS_BRI(2021)689337_EN_schedule.pdf

[15] https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF last accessed on 01.06.2021

- no person and no place are left behind
- including the strategic action plan on batteries
- the new circular economy action plan
- the new industrial strategy for Europe
- sustainable and smart mobility strategy

Accelerating the shift to sustainable and smart mobility is one way to increase the EU's climate ambition for 2030 and 2050. Mobilising industry for a clean and circular economy by financing research and innovation The Commission will present a Sustainable Europe Investment Plan to help meet the additional funding needs. It will combine dedicated financing to support sustainable investments and proposals for an improved enabling framework conducive to green investment. At the same time, it will be essential to prepare a pipeline of sustainable projects. Technical assistance and advisory services will help project promoters to identify and prepare projects and to access sources of finance[16].

2.3.3 Labelling

The Battery labelling supports the assembly-, maintenance-, service- and recycling staff to distinguish and separate items from each other qualitatively and act safely when handling them.

In the Battery directive, the Battery Passport is mentioned under Chapter VIII and Article 65, the electronic exchange of information. Article 65 concerns the battery passport and requires that by **1 January 2026**, industrial and electric-vehicle batteries whose capacity is higher than 2 kWh shall have an electronic record ("Battery Passport") for each battery they place on the market. The records shall be unique for each battery, to be identified through a unique identifier. In addition, the battery passport shall be linked to the information about the

[16] https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF last accessed on 01.06.2021

essential characteristics of each battery type and model stored in the system's data sources established according to Article 64 and shall be accessible online.

The Commission shall set up the electronic exchange system at the same time, and it will contain information and data:

- sortable
- searchable
- respecting open standards for third party use
- machine-readable format

The Commission shall set up the electronic exchange system mentioned in Article 64 on the 1st of January 2026.[17] The system shall contain the information and data on rechargeable industrial and electric vehicle batteries with internal storage, as laid down in Annex XIII. That information and data shall be sortable and searchable, respecting open standards for third party use. The relevant economic operators shall be able to feed the system with information in a machine-readable format. In addition, the Commission shall publish certain information mentioned in Article 62[18], which lay down details concerning the architecture.

> "Chapter III[19] of the Regulation lays down labelling and information requirements.
> Article 13 and Annex VI require that as of **1 January 2027**, batteries shall be labelled in a visible, legible, and indelible manner to provide information necessary for the identification of batteries and their main characteristics. Various labels on the battery or the battery packaging shall also inform about lifetime, charging capacity, the requirement on separate collection, presence

17 https://ec.europa.eu/environment/pdf/waste/batteries/Proposal_for_a_Regulation_on_batteries_and_waste_batteries.pdf, page 93, last accessed on 1.7. 2021

18 https://ec.europa.eu/environment/pdf/waste/batteries/Proposal_for_a_Regulation_on_batteries_and_waste_batteries.pdf, page 90, last accessed on 1.7. 2021

19 https://ec.europa.eu/environment/pdf/waste/batteries/Proposal_for_a_Regulation_on_batteries_and_waste_batteries.pdf, page 55, last accessed on 1.7. 2021

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of hazardous substances and safety risks. In addition, the QR code to be printed or engraved on the battery shall, depending on the type of battery, give access to the information that is relevant for the battery in question. The Commission shall be empowered to, by implementing the act, establish harmonised specifications for certain labelling requirements."

"(53)[20] When placing a battery on the market or putting it into service, every importer should indicate on the battery the importer's name, registered trade name or registered trademark, as well as the postal address. Exceptions should be provided in cases where the size of the battery does not allow it. This includes cases where the importer would have to open the packaging to put the name and address on the battery or where the battery is too small to affix this information. "

2.3.4 Who will be affected?

A Regulation[21] will set direct requirements for all operators, thus providing the necessary legal certainty and enforcement possibility of a fully integrated market across the EU. A Regulation also ensures that the obligations are implemented simultaneously and in the same way in all 27 Member States. The instrument will also set out several mandates for the Commission to develop implementing measures, which will allow the Commission to elaborate further on the regulation if necessary, allowing for more timely setting of common rules. The Regulation will also reduce uncertainties over timelines during the transposition process typically associated with a Directive in an area where time and legal certainty are critically important due to forecasted increases in market size and changes in market dynamics more generally.

[20] Proposal for a Regulation on batteries and waste batteries.pdf (europa.eu), page 33, last accessed on 1.7. 2021

[21] https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/689337/EPRS_BRI(2021)689337_EN.pdf last accessed on 02.06.2021

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Stakeholder Consultations

The inception impact assessment on the proposed Battery Directive[12] regulation was published on 28 May 2020, and the period to provide feedback ended on 9 July 2020. In total, 103 responses were received, largely supporting positions set out by stakeholders earlier in the process (for example, during the targeted stakeholder consultations).

Stakeholders who participated in the public consultations generally acknowledged that technological, economic, and social changes justify creating a new regulatory framework for batteries. Accordingly, the proposed Battery Directive should comprise standard and more stringent sustainability rules for batteries, components, waste batteries and recycles, to establish clear and common rules to guarantee the functioning of the EU single market.

Stakeholders also agreed that there should be better harmonisation of existing rules and an EU framework covering the entire battery life cycle.

Impact Assessment

The proposal is based on an impact assessment[22]. Within each of the 13 broad policy measures, several sub-measures were considered. In many cases, these sub-measures are alternative to each other (e.g., for Measure 3, collection-rate targets for portable batteries can be either 65% or 75%, but not both). In other cases, the sub-measures are designed to be cumulative and/or complementary (e.g., for Measure 13, a battery 'passport' for industrial batteries works in addition to information obligations). The sub-measures are grouped into four main policy options compared against a business-as-usual scenario to facilitate the analysis.

- "Option 1, business-as-usual, is an option that keeps the Batteries Directive, which primarily covers the end-of-life stage of batteries, unchanged."
- "Option 2, the medium level of ambition option, is an option that builds on the Batteries Directive but gradually strengthens and increases the level of ambition. To

[22] https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/689337/EPRS_BRI(2021)689337_EN.pdf last accessed on 02.06.2021

bring in information and basic requirements as a condition for batteries to be placed on the EU market."

- "Option 3, the high level of ambition option, is an approach that is a bit more disruptive but still within the limits of what is technically feasible."
- "Option 4, the very high level of ambition option, includes measures that would go significantly beyond the current regulatory framework and current business practices."

The Commission's preferred option is **a combination of Option 2 and Option 3**. The variety chosen provides a balanced approach in terms of effectiveness (achievement of the objectives) and efficiency (cost-effectiveness).

The principle of Option 3, an electronic exchange system and battery passport, as proposed by the Global Batteries Alliance, is accepted by several global organisations. The electronic exchange system will have a one-off administrative cost for setting it up but will lead to administrative simplification and lower implementation costs in the long term. Furthermore, the battery passport should enable second life operators to take informed business decisions and allow recyclers to plan their operations better and improve their recycling efficiencies.

Requirements of Battery Directive[23]

This Regulation establishes requirements on sustainability, safety, labelling and information to allow the placing on the market or putting into service of batteries and conditions for the collection, treatment, and recycling of waste batteries. This shall apply to all portable batteries, automotive, electric vehicles, and industrial batteries regardless of their shape volume, weight, design, and material composition use or purpose.

Economic operators that will be affected[25]

Economic operators are battery manufacturers, importers, distributors, service providers and recyclers. The manufacturer should provide sufficiently detailed information on the intended

[23]https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/689337/EPRS_BRI(2021)689337_EN.pdf last accessed on 02.06.2021

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use of the battery to allow its correct and safe placing on the market, putting into service, use and end-of-life management, including possible repurposing.

Importers & Distributors

"(48) All economic operators intervening in the supply and distribution chain should take appropriate measures to ensure that they only make available on the market batteries that conform to this Regulation. It is necessary to provide for a clear and proportionate distribution of obligations that correspond to each economic operator's role in the supply and distribution chain."

"(53) When placing a battery on the market or putting it into service, every importer should indicate on the battery the importer's name, registered trade name or registered trademark, as well as the postal address. Exceptions should be provided in cases where the size of the battery does not allow it. This includes cases where the importer would have to open the packaging to put the name and address on the battery or where the battery is too small to affix this information."

"(55) Any importer or distributor that either places a battery on the market or puts it into service under the importers or distributor's name or trademark or modifies a battery in such a way that compliance with the requirements of this Regulation may be affected or modifies the purpose of a battery that is already placed on the market should be the manufacturer and should assume the obligations of the manufacturer and distributors."

Service providers

"(57) Ensuring traceability of a battery throughout the whole supply chain helps make market surveillance simpler and more efficient. Furthermore, an efficient traceability system facilitates the market surveillance authorities' task of tracing economic operators who made non-compliant batteries available on the market or put them into service. Therefore, the economic operators should be required to keep the information on their transactions of batteries for a certain period. "

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Recyclers

Article 60 contains requirements for the provision of information regarding waste batteries. This includes obligations to producers or their producer responsibility organisations to end-users and distributors regarding their contribution to the end-of-life treatment. The Article also sets up obligations to provide information relevant to safety during the collection and storage of waste batteries to distributors and operators involved in the collection and waste treatment and provide those operators information to facilitate the removal of waste batteries and subsequent treatment.

Article 65 concerns the battery passport and requires that, by 1 January 2026, industrial batteries and electric-vehicle batteries manufacturers shall have an electronic record for each individual battery they place on the market. The records shall be unique for each battery, to be identified through a unique identifier. In addition, the battery passport shall be linked to the information about the essential characteristics of each battery type and model stored in the system's data sources established according to Article 64 and shall be accessible online.

> “(29) (Information about the performance of batteries is essential to ensure that end-users, as consumers, are well and timely informed and that they have a common basis to compare different batteries before making their purchase.) Therefore, portable batteries of general use and automotive batteries should be marked with a label containing the information on their minimum average duration when used in specific applications. Additionally, it is important to guide the end-user to discard waste batteries appropriately. “

> “(36) The CE marking on a battery indicates the conformity of that battery with this Regulation. General principles governing the CE marking and its relationship to other markings are set out in Regulation (EC) No 765/2008. Those principles should apply to the CE marking on batteries.”

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3 Stakeholders

3.1 BATTERY MANUFACTURERS

3.1.1 Gigafactories

3.1.1.1 Context of the emergence of Gigafactories in Europe

In 2017, European Commissioner Maroš Šefčovič made a commitment to batteries due to them being critical to the competitiveness of the EU in the future. Europe is not going to compete with price but can manufacture the best performing and the greenest batteries[24] and launched the EU Battery Alliance.

Battery production is currently scaling up rapidly. We are moving from battery plants with a capacity of 4-10 GWh/year to maybe 40 GWh/year and even 80 GWh/year. Producing many more batteries in each plant automatically results in much higher efficiency.

The boom in battery-electric mobility is having an impact on value chains. However, it is also generating increased demand at numerous other companies, encouraging efforts to establish and convert production capacities, and creating a need for external services such as maintenance, among other things.

For example, every battery cell is based on chemical process technology to produce anodes, cathodes, and electrolytes. The starting materials are produced both by established European manufacturers, who are building up production capacities for this purpose and in particular by Southeast Asian companies, which are setting up new plants in Europe.

In cell production, too, established European vehicle manufacturers are building up their own capacities — either in-house or in cooperation with partners — on the one hand, and cell production plants are being set up by Southeast Asian companies establishing themselves in Europe on the other. Moreover, the assembly of cells into modules and modules into finished battery packs usually occurs in close coordination with or in the vehicle manufacturers' facilities.

The conversion of factories and the build-up of battery production capacities are in full swing. Tesla is known to be one of the pioneers in this field, but German manufacturers are also in the process of conversion. To date, most vehicle manufacturers have focused on battery pack

[24] https://cicenergigune.com/en/blog/gigafactories-europe-commitment-economic-recovery-battery-factories, accessed on 05.05.2021

assembly[25]. While most cell production sites are located in Southeast Asia, in Europe, and Germany in particular, numerous production facilities are currently being planned, built, and commissioned along the entire value chain of batteries for cars. In this context, regional focal points are emerging in Europe, such as Berlin-Brandenburg, the Wolfsburg-Hanover region, Kaiserslautern/Stuttgart, or Hungary. Operators have different reasons for their choice of location and regional clusters. Among the most publicly cited are the following:

- Existing infrastructures (motorways, railway connections) to ensure the delivery of raw materials and shipment of manufactured components
- Proximity to existing plants (including VW Salzgitter, PSA Kaiserslautern)
- Proximity to assembly plants (especially for Southeast Asian third-party manufacturers)
- Adequate availability of skilled workforce
- Availability of land for substantial factory buildings
- Availability of renewable electricity

3.1.1.2 "Who is who" in Europe

In the context mentioned above, the first big project was announced by **Northvolt** (Sweden), a start-up with plans to manufacture the world's greenest battery cell and establish a European supply of batteries to enable the future of energy[26].

Northvolt Ett is Northvolt's first European-owned Gigafactory. It plans to start production in late 2021. Northvolt Ett has a long production line, from active material preparation and cell assembly to recycling operations and auxiliary processes. Although to be developed as a phased build, the first phase of Northvolt Ett will be operational in 2021, and the annual capacity will ramp up to at least 32 GWh by 2024. When complete, the factory will be one of the largest globally – producing about 60 GWh of energy storage per year.

[25] Technical Services for Battery Production in Europe. Operational Excellence for the Automotive Industry, A publication by Lünendonk & Hossenfelder GmbH in cooperation with Leadec; https://www.leadec-services.com/leadec-pulse-what-moves-us/whitepaper-technical-services-battery-production, accessed on 05.05.2021
[26] https://chronicles.northvolt.com , accessed on 05.05.2021

Northvolt Labs in Västerås hosts a demo manufacturing line used to qualify and industrialise their products and processes together with customers. It is a 19,000 m^2 building with an annual production capacity of over 350 MWh.

Northvolt Battery Systems was in October 2018 established in Gdańsk, Poland, for the industrialisation and assembly of battery modules and energy storage systems. It also serves as an R&D platform for industrialising battery solutions. As of spring 2019, the plant is in production and ramping up to 10,000 battery modules per year and have ambitious growth plans.

Following the company's investment into Northvolt in June 2019, the Volkswagen Group entered into a joint venture with Northvolt to establish a second Gigafactory, **Northvolt Zwei**, in Salzgitter, Lower Saxony (Germany), starting operations in early 2024. The factory is planned for an initial annual output of 16 GWh and later up to 40 GWh/year[27]. It takes its design from the blueprint for battery manufacturing developed for Northvolt Ett. In March of 2021, the VW Group bought the Northvolt part in the joint venture, making this designated to produce Lithium-Ion cells exclusively for VW Group.[28] From 2025, the plant will focus on a new 'prismatic unified cell' for VW Group's high-volume segment[29].

Volkswagen's investments with Northvolt are part of more expansive plans to build **six Gigafactories** in Europe with a total capacity of 240 GWh/year by 2030 to secure battery supply. **VW** is apparently considering further potential partners and sites for these other factories, including possible locations in Germany, Spain, Portugal, and France, and Central and Eastern Europe. As a result, the plan could potentially increase overall battery capacity in Europe by 25%.[30]

Another important project in Europe in recent years has been the one planned by **Tesla** in Germany. The company expects to open its first European Gigafactory at the beginning of 2022, hoping to an annual production capacity of up to 100-gigawatt hours (GWh) at the start, "and then possibly" increase to 200 or 250 GWh/year[31].

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[27] https://www.volkswagen-newsroom.com/en/press-releases/power-day-volkswagen-presents-technology-roadmap-for-batteries-and-charging-up-to-2030-6891, accessed on 05.05.2021

[28] https://insideevs.com/news/494412/volkswagen-increases-stake-northvolt-acquires-joint-venture/ accessed 26.08.26

[29] https://chronicles.northvolt.com , accessed on 05.05.2021

[30] https://www.automotivelogistics.media/electric-vehicles/vw-strengthens-ties-with-northvolt-to-expand-battery-capacity-in-europe/41676.article, accessed on 05.05.2021

[31] https://www.cleanenergywire.org/factsheets/teslas-berlin-gigafactory-will-accelerate-shift-electric-cars, accessed on 05.05.2021

A recent project is the **ACC – Automotive Cells Company**, a European joint venture of French PSA and its German subsidiary Opel with French battery cell manufacturer Saft (a subsidiary of energy company Total). The agreement includes an R&D centre in Bordeaux (France), a pilot site in Nersac (France) as well as two Gigafactories in Douvrin (France) and Kaiserslautern (Germany)[32].

The ACC project is divided into three main phases[33]:

1. The construction of an R&D centre in Bruges near Bordeaux (33) and of a pilot plant in Nersac, near Angoulême (16).
2. The construction of the battery production plant in Douvrin / Billy-Berclau, with a first block with a capacity of at least 8 GWh/year in 2023, then between 2023 and 2028, between 24-32 GWh/year.
3. The construction of a second battery production plant in Germany in Kaiserslautern in 2025, with a capacity between 24-32 GWh/year.

FREYR plans to develop a Norwegian Gigafactory with up to 43 GWh annual production capacity for battery cells by 2025 and position itself as one of Europe's largest battery cell suppliers. The manufacturing plant will be located in the Mo-i-Rana industrial complex, Northern Norway[34]. In addition, recent news reveals a technology partnership with the US-based 24M company to shorten the production line for lithium batteries from about 17 conventional steps to 7 or 8.[35]

The giant factory will consist of four factories and will be built in five construction stages. The first stage is a pilot plant set up in the first half of 2022 (375 MWh/year).

- Factory 1: 5.3 GWh/year (2023)
- Factory 2: 8 GWh/year (2024)
- Factory 3: 10.6 GWh/year (2025)
- Factory 4: 10.6 GWh/year (2025)

Morrow Batteries is another Norwegian start-up founded in 2020. with plans for a battery cell factory with a capacity of 32 GWh/year in the city of Arendal in the Agder region, southern Norway. Construction of the plant is planned to start in 2023. The first of the four planned

[32] https://www.ocoglobal.com/general/who-will-win-the-battery-race-in-europe, accessed on 05.05.2021
[33] https://www.concertation-acc-batteries.fr/le-projet-en-bref, accessed on 05.05.2021
[34] https://news.cision.com/no/freyr/r/freyr-sikrer-milliardfinansiering-til-gronn-batteriindustri-i-norge-og-borsnoteres-i-new-york,c3276121 accessed on 05.05.2021
[35] https://www.powerelectronics.com/technologies/batteries/article/21862703/new-manufacturing-techniques-safety-advances-could-overhaul-liion-battery-business accessed on 30.08.2021

construction phases, with each step adding eight GWh/year, will be ready for production in 2024. According to the company, up to 10,000 jobs will be created in the Agder region[36].

Britishvolt is another new company entering the European battery market with plans to build a plant in Blyth, Northumberland. The construction will begin in the summer of 2021 to produce the first Lithium-Ion batteries in 2023[37].

Britishvolt has ambitions to become the "first Gigafactory in the UK", aiming at a final production of 30 GWh/year Lithium-Ion batteries per year (pouch- & cylindrical cells). In the first year of production, 2023, 10 GWh of Li-Ion batteries will be produced [38].

By the project's final phase in 2027, it will be employing up to 3000 highly skilled people, producing Lithium-Ion batteries enough for 300,000 new electric vehicles yearly for the UK automotive industry[39].

SVOLT Energy Technology is a spin-off from the Chinese automaker Great Wall Motors. S-volt plans to break ground on two factories, at a combined cost of about 2 billion euros ($2.42 billion), in the western state of Saarland, Germany, by the yearend of 2021. SVOLT aims to have completed the first construction phase, with a capacity of 6 GWh/year, by 2023. Then, depending on how demand develops over time, more manufacturing capacity can follow, as much as up to 24 GWh/year in the final stages[40].

Farasis Energy (Ganzhou), which sold a 3% stake last year to the Daimler group, aims to start a Gigafactory in the eastern town of Bitterfeld, Germany and create at least 600 new jobs in the final stages[41]. Farasis aims to put out 6 GWh/year of batteries from Bitterfeld by next year on the way to a total output of 10 GWh/year [42].

Asian-Pacific companies are also investing in the European battery supply chain. **LG Chem/LG Energy Solutions** already has a plant in operation in Wroclaw, Poland[43], with a capacity of 15

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[36] https://www.en-former.com/en/europes-battery-industry-is-booming/, accessed on 05.05.2021
[37] https://www.en-former.com/en/europes-battery-industry-is-booming/, accessed on 05.05.2021
[38] https://britishvolt.com/about-us/, accessed on 05.05.2021
[39] https://britishvolt.com/news/britishvolt-selected-blyth-northumberland-as-the-site-of-its-first-battery-gigaplant/?cn-reloaded=1, accessed on 05.05.2021
[40] https://www.en-former.com/en/battery-boom-meet-germanys-gigafactories/, accessed on 05.05.2021
[41] https://www.investieren-in-sachsen-anhalt.de/batterie, accessed on 05.05.2021
[42] sed on 05.05.2021
[43] https://www.argusmedia.com/en/news/2119394-european-battery-revolution-starts-now-vdma, accessed on 05.05.2021

GWh/year, which is planned to increase steadily over the years to come – to at least 65 GWh. LG batteries are installed in electric vehicles from VW, Renault, and Hyundai, among others[44].

Contemporary Amperex Technology Co (CATL) is the leading battery maker in China and globally. CATL is now building a plant in Erfurt (Germany), the first factory outside China. They intend to reach a production capacity of 14 GWh of Lithium-Ion cells and modules annually in 2022. It will later grow to accommodate up to 24 GWh/year, creating around 2000 jobs by 2024[45]. CATL also have further expansion plans, up to 100 GWh of battery production per year in Germany.

SK Innovation completed a 7.5 GWh/year Battery Plant 1 in Komarom, Hungary, at the end of 2019, which is currently in operation. Another unit is under construction with plans to produce 9,8 GWh per year, starting in late 2022. Furthermore, an additional SK Innovation EV battery plant will be built in Iváncsa, Hungary, with an annual production capacity of 30 GWh.

InoBat Auto is building a Slovakian battery Gigafactory in Bratislava to start production before the end of 2021. Construction of an additional factory with a capacity of 10GWh per year is set to begin in 2024[46].

Italvolt will build the first Italian Gigafactory, with an initial capacity of 45 GWh/year, later reaching 70 GWh/year. This will demand an estimated 4,000 workers employed and a total of 10,000 new jobs created. The Italvolt Gigafactory thereby becomes one of Italy's most important industrial projects in recent years, with a total investment of about 4 billion Euros. The first phase of the Gigafactory project will be completed in the first half of 2024[47].

3.1.1.3 Conclusions

Batteries are becoming one of the globe's most essential commodities. Until now, European electric vehicles (EVs) have been dependent on batteries from abroad, primarily from Asia. This, however, is about to change. Only a few years ago, Europe did not have the industrial

[44] https://www.en-former.com/en/europes-battery-industry-is-booming/, accessed on 05.05.2021
[45] https://www.en-former.com/en/battery-boom-meet-germanys-gigafactories/, accessed on 05.05.2021
[46] https://www.en-former.com/en/europes-battery-industry-is-booming/, accessed on 05.05.2021
[47] https://www.italvolt.com/batterie-a-ioni-di-litio-per-veicoli-elettrici, accessed on 05.05.2021

facilities or the expertise to produce batteries. Although Asia is still dominant in global battery production, the EU is progressing towards achieving battery independence by 2025[48].

As we can see, Europe is now decided to have a solid and relevant position in the global production of batteries for the automotive market.

According to Maros Šefčovic, Vice-President of the European Commission for Interinstitutional Relations and Foresight:

> "*With some 70 industrial battery projects announced across Europe and record-high levels of investment (€ 60 billion in 2019) outpacing even China, Europe has become a global battery hub and is well on track to achieve open strategic autonomy in this critical sector. We have achieved by far the best progress in the battery cells segment. Europe's announced lithium cell projects will largely satisfy the domestic demand for batteries by 2025 driven by e-mobility, which saw over 1 million electric vehicles sold in 2020*".[49]

For a comprehensive general view of the plans concerning LIB manufacturing capacities in Europe until 2025[50] and a little bit beyond, see Figure 11, which shows the situation in April 2021. Some of the operators in the figure were not included in the analysis above.

[48] https://www.theexplorer.no/stories/energy/anticipating-the-european-battery-boom/, accessed on 05.05.2021

[49] Keynote speech by Vice-President Maroš Šefčovič at the Battery Summit in Portugal, 22.3.2021, https://ec.europa.eu/commission/commissioners/2019-2024/sefcovic/announcements/keynote-speech-vice-president-maros-sefcovic-battery-summit-portugal_en. accessed on 05.05.2021

[50] https://cicenergigune.com/en/blog/gigafactories-europe-commitment-economic-recovery-battery-factories , accessed on 05.05.2021

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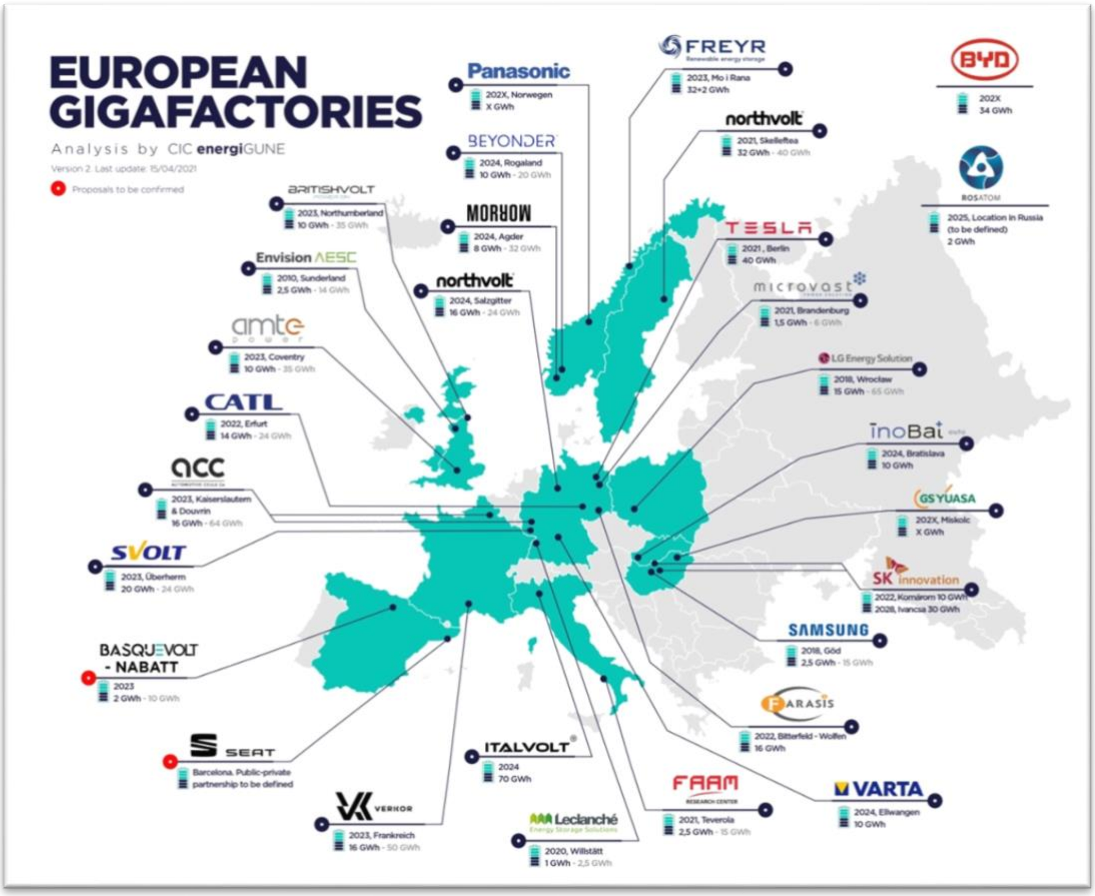

Figure 11. European Gigafactories

3.1.2 Smaller Scale and Niche Manufacturers[51] [52]

3.1.2.1 Introduction

The following list of six niche manufacturers and one extra technology worth mentioning will show a more diverse perspective onto other potential important market players besides the large billion-Euro market automotive leaders. Although there is a clear strategy of what kind of technology is being used, besides lithium-ion, its greatest rival is the solid-state battery technology.

Therefore, there is a mix of potential successors and unique technologies for specific market sectors. The last key parameter to consider is the team behind the company, their background, and how they are looking for new employee candidates.

[51] https://battec.eu/en/company/ accessed on 23.08.2021
[52] https://www.energystartups.org/top/battery/ accessed on 23.08.2021

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Key companies investing in solid-state batteries

The electrification of transport might take some time, and large automobile producers are still earning a substantially high portion of the profit from the automobile market. However, companies such as VW, BMW, Ford, Hyundai, and others are actively investing hundreds of thousands of dollars into various future battery technologies, including solid-state batteries. Here is a list of technological start-ups which some of which will be discussed separately.

- Volkswagen – QuantumScape
- Ford, BMW & Hyundai – SolidPower[53]
- GM and SK Innovation – SES[54]

3.1.2.2 List of potential small scale & niche battery manufacturers

Factorial Energy

Factorial Energy is a US-based R&D company working with large automakers and other OEMs to provide the world's first solid-state battery for EVs and other applications[55]. The company has been developing under the radar since 2015. In April of 2021, it came with its first press release about the first of its kind 40 Amps solid-state battery for EVs[56].

Besides the breakthrough technology the company researched and developed, it also has a substantially elite solid team on board, including former higher managers from Ford, Mercedes-Benz, and Panasonic Energy North America. Apart from the top executives, the company is now searching for new employees such as Senior Scientists, Engineers, and Battery Engineers[57].

SES (SolidEnergy Systems)

The SES company, founded in 2012, was initially researching for creating solid-state batteries on Li-metal background. However, the company has developed what they consider a more

[53] https://www.bloomberg.com/news/articles/2020-12-10/ford-s-battery-bet-says-automotive-testing-will-start-in-2022 accessed on 23.08.2021
[54] https://techcrunch.com/2021/04/19/general-motors-leads-139-million-investment-into-lithium-metal-battery-developer-ses/?guccounter=1 accessed on 23.08.2021
[55] https://factorialenergy.com/ accessed on 23.08.2021
[56] https://factorialenergy.com/ accessed on 23.08.2021
[57] https://careers.smartrecruiters.com/factorial accessed on 23.08.2021

practical and powerful Li-metal system than current solid-state alternatives. The Li-metal cells have a higher energy density, are optimised for fast charging by AI algorithms, and have ready-to-apply scalability for existing Li-ion infrastructure[58].

According to the company website, current batteries are designed for drone applications[59]. The SES company has two significant investors behind it. GM and SK Innovation are investing heavily in the Li-metal technology. Possible real applications into EVs are predicted for 2022. The key innovation relies on "improving the lithium metal electrolyte on the anode and cathode, and the scalability of current iPhone battery into the large cell for EVs", said SES chief executive, Mr Hu Qichao.

Regarding jobs related to the battery field, the company SES has numerous open positions across the company corporate ladder[60]. Besides the named positions on their website, more specific details can be nicely organised and found on the LinkedIn website[61].

EnerVenue

The EnerVenue company is focused on the metal hydrogen battery technology for the aerospace industry. The technology of a similar nickel-hydrogen battery has been proven for years in the field, including the International Space Station[62]. However, while nickel-hydrogen batteries have remarkable performance, longevity and are comparably maintenance-free, they are also costly. EnerVenue aims to bring to the market a highly competitive battery with similar abilities for a fraction of its price using new low-cost materials.

In the summer of 2021, EnerVenue signed a distribution deal with the Hong Kong company Towngas to become its exclusive partner for a zero-carbon smart energy platform. Towngas is

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[58] https://www.autonews.com/suppliers/battery-supplier-ses-takes-spac-path-capital-deal-values-company-36b accessed on 23.08.2021

[59] https://launch.ses.ai/ accessed on 23.08.2021

[60] https://www.linkedin.com/jobs/search/?currentJobId=2519086793&f_C=3256760&keywords=solidenergy%20systems&location=worldwide accessed on 23.08.2021

[61] https://www.ses.ai/career/ accessed on 01.06.2021

[62] https://enervenue.com/ accessed on 23.08.2021

one of the largest energy suppliers across China[63]. The two companies will begin installing a sizeable renewable energy integration application in extreme or remote locations. In terms of hiring new employees, the company has not publicly announced new positions[64].

Ion Storage Systems

Ion Storage Systems is a spin-off company from the University of Maryland's Energy Innovation Institute. It develops and manufactures battery solutions for military applications and aerospace systems. Following the solid-state battery structure, the main idea is to use ceramic separators and other materials from low-cost sources. The company has also changed the architecture and design of its battery to become both lighter and non-flammable[65 66].

StoreDot

An Israeli-based StoreDot company is developing a fast-charging battery specially designed for EVs to overcome their user's range and charging anxiety. Its prototype was successfully presented in 2020 by charging and launching a drone. After that, the company has signed a deal with the EVE Energy company, a top-tier supplier for the Chinese EV and ESS battery market, to push its strategy to manufacture a "5-Minute charge EV battery"[67].

One of the latest improvements towards implementing the technology into the mass EV market was to demonstrate their ability to use standard Li-ion manufacturing lines for the samples manufactured at the EVE Energy facility in China. As StoreDot's CEO said, "*The ability to use current manufacturing lines reduced the additional costs to increase the scalability of our technology"*[68]. The company is currently hiring into R&D positions such as Data Scientist, Cell development researcher, and few others.

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63 https://www.globenewswire.com/news-release/2021/04/21/2214113/0/en/EnerVenue-Announces-Distribution-Partnership-with-Towngas-to-Supply-Metal-Hydrogen-Renewable-Storage-for-Towngas-Clean-Energy-Transformation.html accessed on 23.08.2021

64 https://enervenue.com/enervenue-launches-with-12-million-in-funding/ accessed on 23.08.2021

65 https://energy.umd.edu/news/story/umd-energy-startup-receives-8m-investment accessed on 23.08.2021

66 https://ionstoragesystems.com/#advantages accessed on 23.08.2021

67 https://www.store-dot.com/post/first-ever-5-minute-charge-li-ion-battery-samples accessed on 23.08.2021

68 https://www.store-dot.com/post/new-agreement-with-eve-to-manufacture-xfc-battery-for-evs accessed on 23.08.2021

Co-funded by the Erasmus+ Programme of the European Union

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GBatteries

While other companies are trying to change the actual battery, GBatteries from Canada has an alternative strategy, leaving the batteries untouched. Their breakthrough technology relies on charging batteries using an adaptive pulse charging algorithm, speeding up the process of charging. As a result, the company has attracted investments[69]. Although GBatteries is on its way to start demonstrating the technology on large devices, including the EVs, there is a lack of information on actual cases being tested. As a result, the company has created a promotional video comparing a wall driller being charged normally and using GBatteries technology. According to these laboratory tests, the charging took half the time compared to the usual charging process.

The company is actively hiring new positions such as Battery Test Engineer, Technical Project Coordinator, and others publicly placed on the company website. Other than working positions, the company also announces internships, which is rare among start-ups[70].

OXIS Company

The company is developing a unique technology using lithium-sulphur (Li-S) on the cathode and lithium-metal on the anode. The OXIS battery cell chemistry does not contain cobalt, manganese, nickel, or copper. Together with safe electrolytes, the battery becomes a lightweight and high-energy-density cell. To test the technology's safety, nail penetration and a bullet shot were used to a fully charged cell without any functional damage.

In terms of tangible achievements, the OXIS Company has secured a grant to develop a 425 Wh/kg cell as part of the Aerospace Technology Institute Zephyr Innovation Program with Airbus Defense and Space. Another contract is to create a battery for a two-seater electric passenger plane. Unfortunately, the company has currently no open positions for new employees.

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[69] https://www.cleantech.com/ev-adoption-breaking-down-barriers-gbatteries-makes-the-2020-50-to-watch-list/ accessed on 23.08.2021

[70] https://www.gbatteries.com/careers#internships accessed on 23.08.2021

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3.1.2.3 Summary

Although there is battery related news almost every day, many of them are from the university environment and still far from the real-world in terms of scalability towards building a Gigafactory. From discovering the facts and receiving first grants and solid financial support, there is a need to have a massive economic and human capital to enter the market with price and technologically competitive battery cell to succeed.

The last but most important factor is to have a professional team of scientists, electrical engineers, and other professionals. Unfortunately, these can be hard to recruit due to Gigafactory locations and competition for a specialised workforce. There is also a lack of specialised educational offers for students interested in the renewable energy and battery industry.

Further into details, we see above new tech companies emerging under the radar, with skilled employees and good funding. The SES company covered by GM and SK Innovations is a good mixture of companies that seriously searched for professionals on the market via LinkedIn. Their strategy of creating a concrete and structured list of potential candidates makes an excellent reputation from the beginning on the job market. The company consists of people working together, and it is a most challenging task to find the best ones and create functional teams.

3.1.3 Outlook: Europe vs the World

3.1.3.1 General considerations

The electrification in general and of the transport is gaining massive terrain in all important markets worldwide. When it comes to transport electrification, though, the speed of the deployment of this technology is impressive, to say the least, despite the slow, hesitant start in the early 2000s. The year 2020 will go down in history as the sales of EVs and PHEVs finally took off in the EU. The combined sales of these two types of vehicles jumped from 387.808 units in 2019 to 1.045.831 units[71] in 2020, the year the overall passenger car market shrunk by 23.7%. Figure 12.

[71] ACEA, "Statistics – Registration Figures", available at: www.acea.be accessed on 23.06.2021

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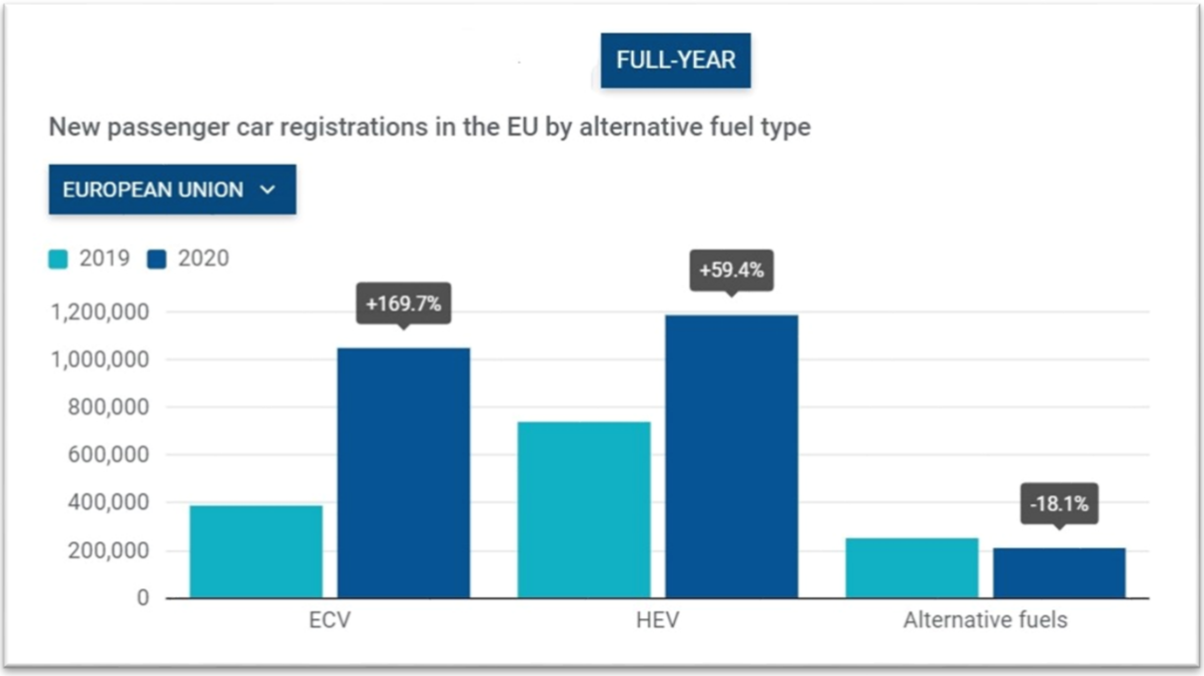

Figure 12. New passenger car registrations in the EU by alternative fuel type

This surge in electric car registrations in Europe, despite the economic slump, reflects mainly two policy measures. First, 2020 was the target year for the European Union's CO_2 emissions standards that limit the average carbon dioxide (CO_2) emissions per kilometre driven for new cars. Second, many European governments increased subsidy schemes for EVs as part of stimulus packages to counter the effects of the COVID-19 pandemic.

Europe has 2.7 million direct manufacturing jobs in the automotive sector[72]. Electrification will impact these jobs, while the job losses from the introduction of electric mobility are likely to be substantially lower in vehicle manufacture than global studies have predicted. According to a study commissioned by the Volkswagen Group and elaborated by Fraunhofer Institute [73], on average, employment requirements in vehicle manufacture are forecasted to decline by 12 per cent by the year 2029. Still, these effects are only to a limited degree the result of product changes. Instead, they primarily reflect planned output volumes and improvements to factors that affect processes and production locations. Consequently, the increase in electric mobility

[72] "Statistics – Direct Automotive Manufacturing jobs in the EU, by Country", https://www.acea.be/statistics/article/direct-automotive-manufacturing-jobs-in-eu-by-country, accessed on 27.5.2021

[73] https://www.iao.fraunhofer.de/en/press-and-media/latest-news/the-changing-face-of-the-automotive-industry-employment-prospects-in-2030.html, accessed on 27.5.2021

will directly affect employment in only a limited way. Additionally, it will trigger further improvements in a variety of areas.

The situation is different with component manufacturers. The labour requirements are 70 % higher to produce a conventional powertrain than to produce a powertrain for an electric vehicle. Consequent future employment effects can be mitigated by boosting output volumes and the production of new components such as battery cells. This shift in employment will make it necessary to train employees to be able to manufacture new products.

3.1.3.2 Current situation - main figures

Right now, there is a severe imbalance in the cell manufacturing market with an Asian oligopoly formed by a series of Chinese, Korean and Japanese companies (CATL, Panasonic, LG Chem and BYD) accounting for around 75% of the total output at the end of 2020[74] – 385 GWh/year out of a total of 455 GWh/year[75]. Figure 13

Global lithium-ion battery capacity by region
(Gigawatt hours)

		2018	2019	2020	2021	2022	2023	2024	2025
Australasia	Australia	0	0	0	1	1	1	4	7
Asia	China	260	268	350	558	718	884	944	944
Asia	Indonesia	0	0	0	0	0	0	0	0
Asia	Japan	17	17	17	17	17	17	17	17
Asia	South Korea	11	18	18	18	18	18	18	18
Asia	Thailand	0	0	0	1	1	1	2	2
Europe	Czech Republic	0	0	0	1	1	1	1	1
Europe	France	0	0	0	0	0	20	32	32
Europe	Germany	0	0	0	11	52	83	128	164
Europe	Hungary	3	14	20	28	37	47	47	47
Europe	Poland	6	6	6	22	54	70	70	70
Europe	Slovakia	0	0	0	0	0	0	5	10
Europe	Sweden	0	0	0	4	14	23	32	32
Europe	UK	2	2	2	2	2	5	12	12
North America	US	27	37	42	44	51	76	91	91
Total		**325**	**362**	**455**	**706**	**966**	**1,246**	**1,403**	**1,447**

Data as of Feb. 1, 2021.
Sources: S&P Global Market Intelligence; Company announcements

Figure 13. Global lithium-ion battery capacity by region

[74] "Green batteries: A competitive advantage for Europe`s electric vehicle chain?" study elaborated by IFRI – page 10 accessed on 27.5.2021
[75] https://www.spglobal.com/marketintelligence/en/news-insights/blog/top-electric-vehicle-markets-dominate-lithium-ion-battery-capacity-growth accessed on 27.5.2021

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If we break this down into countries, the Asian output is divided into three shares corresponding to the leading local players: China, with 350 GWh/year (76.9 % of total), South Korea, with 18 GWh/year (4.1 % of total) and Japan, with 17 GWh/year (3.9 % of total).

According to the figures above, China is currently way ahead, within Asia Pacific region which comprises 80% of global manufacturing capacity[76].

Even though North America is obviously behind Asia, it still scores better than Europe with a total cell manufacturing capacity of 42 GWh/year (out of which 35 GWh/year were achieved by Tesla alone), which makes up for a market share of 9.2 %.

A more precise overview of the North American battery manufacturing in terms of companies involved and their output potential is available in Figure 14 and Figure 15.

US lithium-ion battery capacity
(Gigawatt hours)

	2018	2019	2020	2021	2022	2023	2024	2025
Tesla	20	30	35	37	39	39	39	39
LG Chem	5	5	5	5	5	20	35	35
SK Innovation	0	0	0	0	5	15	15	15
Envision AESC	1	1	1	1	1	1	1	1
IM3	0	0	0	0	1	1	1	1
A123 Systems	1	1	1	1	1	1	1	1
Total US	**27**	**37**	**42**	**44**	**51**	**76**	**91**	**91**

Data as of Feb. 1, 2021.
Sources: S&P Global Market Intelligence; Company announcements

Figure 14. US lithium-ion battery capacity

[76] source: China Industrial Association of Power Sources (CIAPS) presentation on April 29th, 2021, at Virtual Battery Exhibition

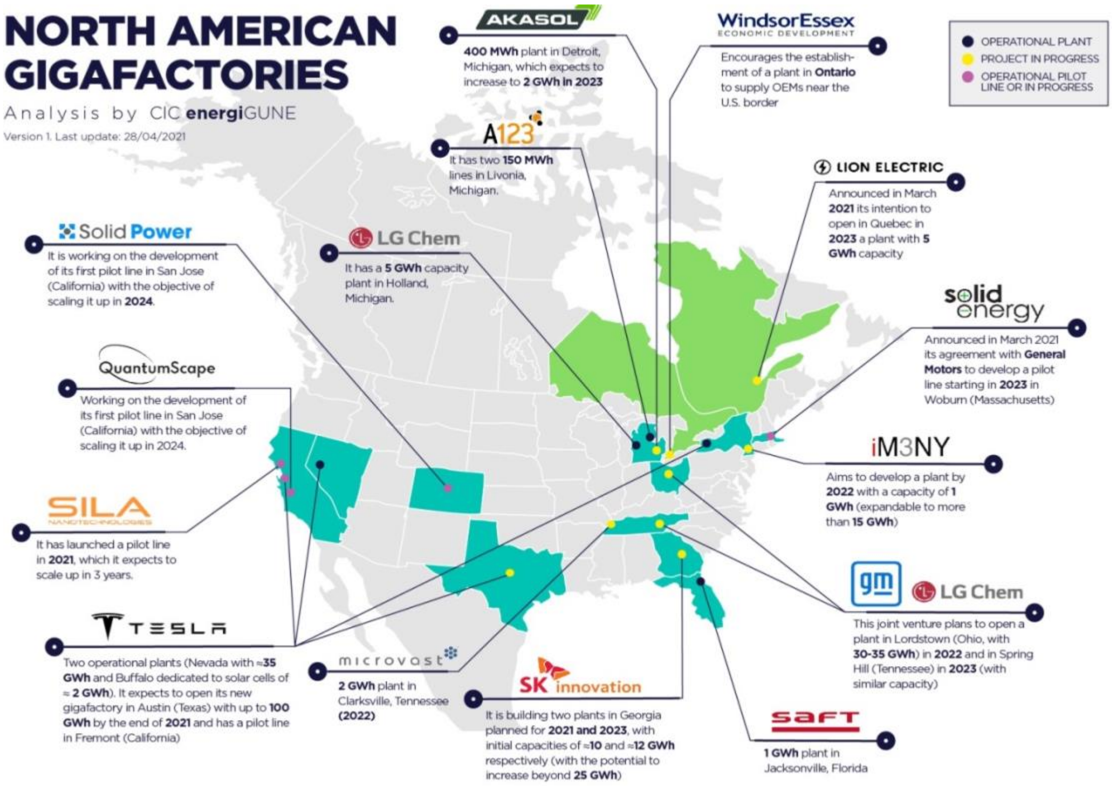

Figure 15. North American Gigafactories

Europe is, now lagging, in terms of battery manufacturing despite having

- Very ambitious legislation on CO2 emissions from vehicles (mandatory targets for passenger cars, light commercial vehicles, and heavy commercial vehicles) and
- Penalties in place for manufacturers missing the targets
- National regulations and vehicle tax schemes tailored to curb CO2 emissions.
- Long term decarbonization objectives compared to the rest of the world (carbon neutrality of the entire economy and society by 2050)
- A globally prominent and technologically advanced automotive industry.

Nowadays, Europe`s market share, from this point of view, is below 7%. In contrast, according to the World Economic Forum, Chinese manufacturers, together with Tesla and its Japanese partner Panasonic, command an 85% share of the global lithium-ion battery market, which is expected to reach the $300 billion mark by 2030.

In other words, the cell manufacturing capacities of the producers located in Europe (mainly in Poland – LG Chem and Hungary – SK Innovation and Samsung SDI) reached, by the end of 2020, the 28 GWh/year mark. This capacity accounts for a mere 6.1 % of the global production

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455 GWh/year) but is a solid improvement over the 3 % achieved in 2017 Figure 16

European lithium-ion battery capacity
(Gigawatt hours)

	2018	2019	2020	2021	2022	2023	2024	2025
Tesla	**0**	**0**	**0**	**10**	**40**	**60**	**80**	**100**
Germany	0	0	0	10	40	60	80	100
LG Chem	**6**	**6**	**6**	**22**	**54**	**70**	**70**	**70**
Poland	6	6	6	22	54	70	70	70
Northvolt	**0**	**0**	**0**	**4**	**14**	**23**	**40**	**48**
Germany	0	0	0	0	0	0	8	16
Sweden	0	0	0	4	14	23	32	32
Saft	**0**	**0**	**0**	**0**	**0**	**12**	**24**	**32**
France	0	0	0	0	0	12	16	16
Germany	0	0	0	0	0	0	8	16
Samsung SDI	**3**	**8**	**13**	**20**	**25**	**29**	**29**	**29**
Hungary	3	8	13	20	25	29	29	29
SK Innovation	**0**	**0**	**8**	**8**	**13**	**18**	**18**	**18**
Hungary	0	0	8	8	13	18	18	18
Verkor	**0**	**0**	**0**	**0**	**0**	**8**	**16**	**16**
France	0	0	0	0	0	8	16	16
CATL	**0**	**0**	**0**	**1**	**10**	**14**	**14**	**14**
Germany	0	0	0	1	10	14	14	14
SVolt	**0**	**0**	**0**	**0**	**0**	**3**	**12**	**12**
Germany	0	0	0	0	0	3	12	12
Britishvolt	**0**	**0**	**0**	**0**	**0**	**3**	**10**	**10**
UK	0	0	0	0	0	3	10	10
InoBat	**0**	**0**	**0**	**0**	**0**	**0**	**5**	**10**
Slovakia	0	0	0	0	0	0	5	10
Farasis	**0**	**0**	**0**	**0**	**2**	**6**	**6**	**6**
Germany	0	0	0	0	2	6	6	6
Envision AESC	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
UK	2	2	2	2	2	2	2	2
MES	0	0	0	1	1	1	1	1
Czech Republic	0	0	0	1	1	1	1	1
Total Europe	**11**	**16**	**28**	**68**	**159**	**248**	**327**	**368**

Data as of Feb. 1, 2021.
Sources: S&P Global Market Intelligence; Company announcements

Figure 16. European lithium-ion battery capacity

European Union has though extensive plans to catch up. Ambitious battery projects are progressing in countries like Germany, France, Slovakia, Poland, Sweden, and Norway. Figure 17

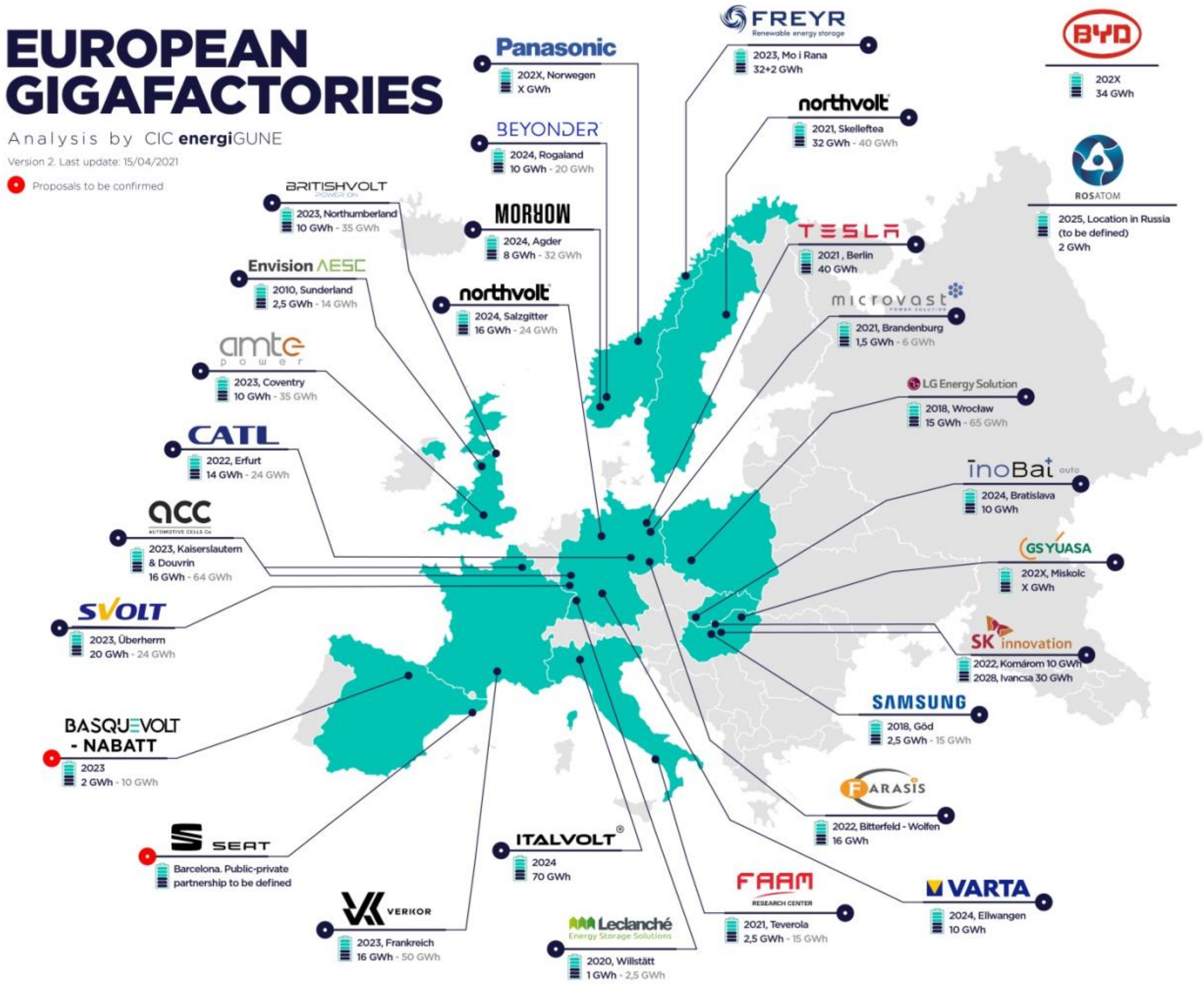

Figure 17. European Gigafactories

3.1.3.3 *Foreseen evolutions*

Based on the recent registration figures, the rise of demand of electric vehicles everywhere around the world implies the skyrocketing of cell manufacturing capacities. However, Europe's capacities are low in absolute terms and comparison to the other major global players.

According to the estimates of S&P, by 2025, the battery market will most likely more than triple compared to 2020. Figure 18

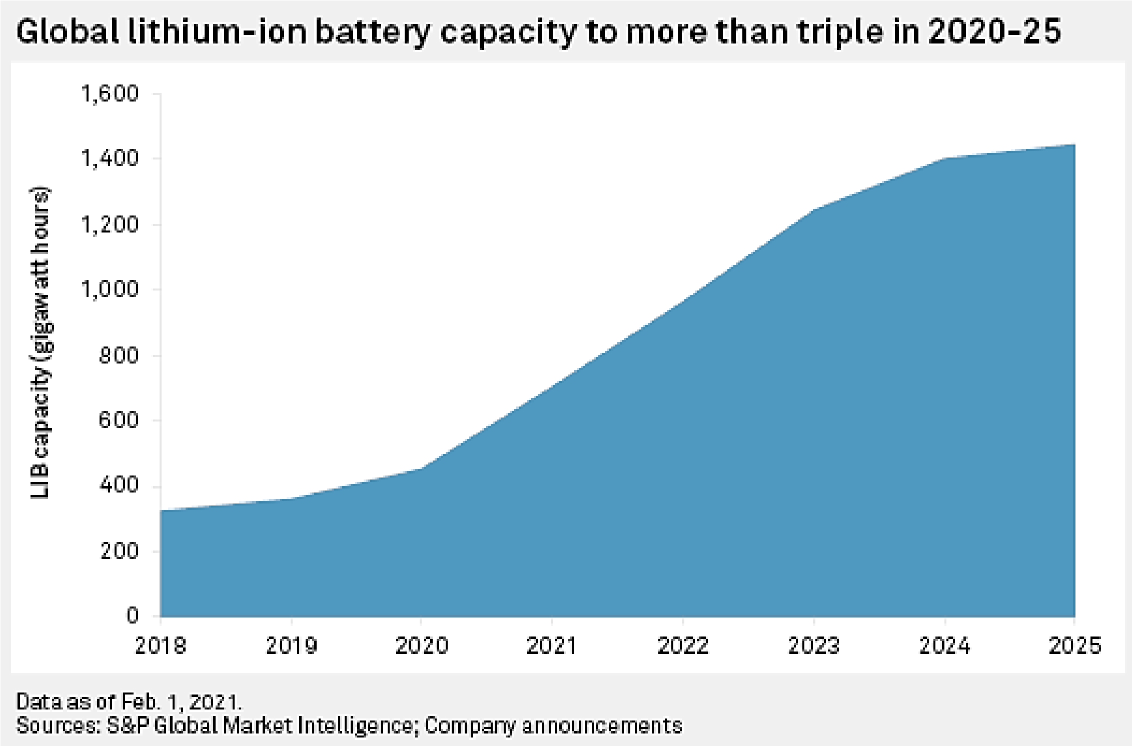

Figure 18. Global lithium-ion battery capacity to more than triple in 2020-25

From the current level of 455 GWh/year (2020), the global Li-Ion battery capacities are expected to reach 1447 GWh/year in 2025, at an annual growth rate of 26%. China and Europe will be the most significant contributors to LIB capacity increases, just as the two regions will also become the biggest drivers of global passenger EV sales.

Although the Chinese production of LIBs is expected to grow, the market share will decrease by about 12%, solely in favour of Europe, which will jump from 6 % in 2020 to a consistent 25 % in 2025, as shown in Figure 19. The current runner up would also shed 3 % to the benefit of the same entity: Europe.

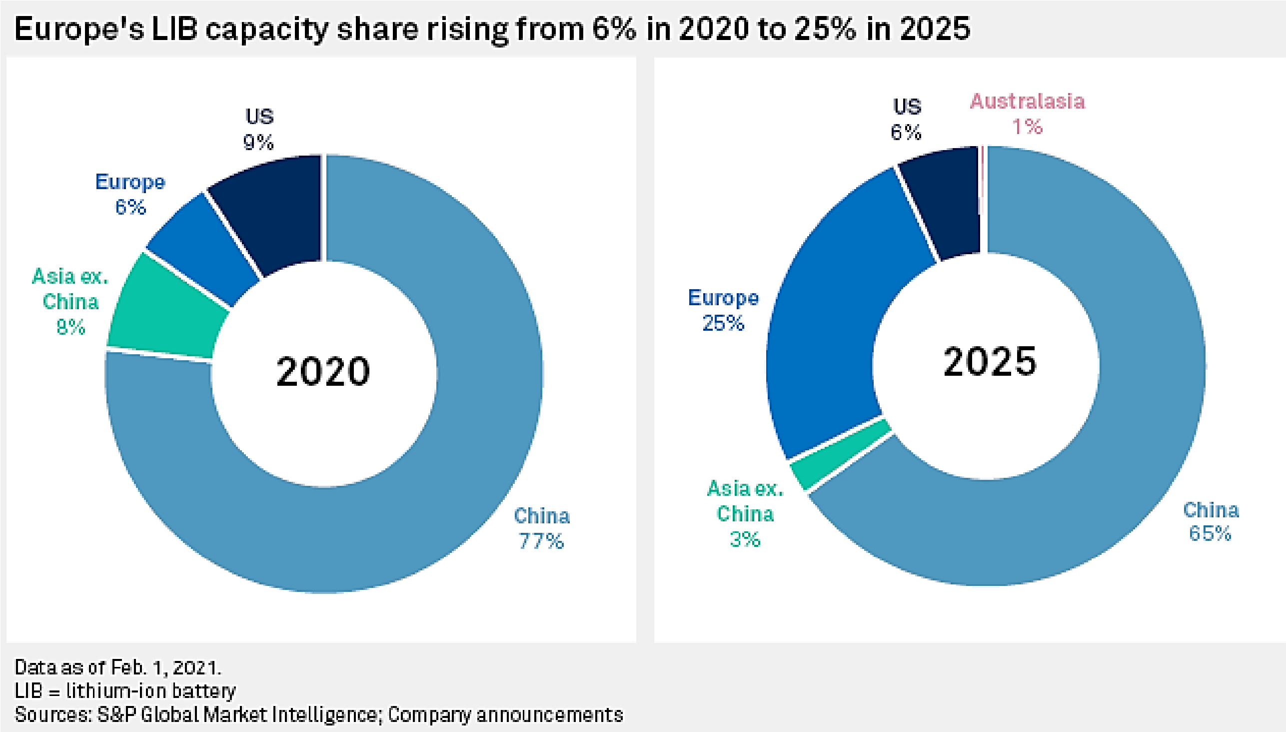

Figure 19. Europe's LIB capacity share rising from 6 % in 2020 to 25% in 2025

With a forecast of 300 GWh manufacturing capacity in Europe by 2029, up to 12,000 direct and 60,000 upstream jobs[77] are predicted to emerge. In addition, Fraunhofer Institute has anticipations of 155,000 jobs to be available in the market by 2033[78]. The main job upstream directions are expected to be system integration and plant maintenance as well as in connection with versatile storage systems. Thus, technicians are anticipated to be extensively needed in the R&D, machine, and plant construction sectors.

Therefore, the analysis will focus primarily on Europe, where the evolution is expected to be fast.

The authorities, mostly continental (the European Commission in particular), already took giant leaps to stimulate the rapid deployment of the cell manufacturing infrastructure across Europe. They also accelerate the development of auxiliary activities (mainly the upskilling and the reskilling of the workforce to "hit the ground running" once the manufacturing facilities are ready to start the production). More precisely, different kinds of cooperative structures were created to boost the

[77]Battery manufacturing is coming to Europe. https://www.pveurope.eu/energy-storage/green-economy-battery-manufacturing-coming-europe#:~:text=According%20to%20Benchmark%20Mineral%20Intelligence,of%20battery%20capacity%20by%202029.&text=By%20way%20of%20comparison%2C%20Europe,30%20GWh%20of%20production%20capacity Accessed 27.5.2021

[78] Fraunhofer ISI "Battery for Electric Cars: Fast Check and Need for Action". https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2020/Fact_check_Batteries_for_electric_cars.pdf Accessed 28.04.2021.

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capability of Europe to cope with the skyrocketing trends in EV and battery manufacturing: the European Battery Alliance, the European Skills Agenda, the Pact for Skills or the "European Battery Innovation" project.

On the other hand, there are the vehicle manufacturers that, confronted with the high demand for electric vehicles, need to take the necessary steps to avoid the potential supply cuts.

A third aspect to consider is the need to "green up" the battery value chain, especially the manufacturing, which is why the energy to be used by the companies manufacturing battery cells should be either fully renewable or as "green" as possible.

Finally, it is also essential to bear in mind the legislative framework at the EU and national levels. Besides the CO2 regulations that will be regularly updated to adjust the emission targets, many major municipalities will ban diesel vehicles' access in the first stage. Shortly after that, the ICE vehicles altogether.

Europe's potential competitive advantages/opportunities

When it comes to European competitive advantage in this battery race, it clearly cannot be achieved with just copying, e.g., Asian technologies. As a result, Europe should focus on niche markets and present brand-new technologies and unique pieces of intellectual property. For instance, Swiss battery technology company Innolith will have prototypes for an NMC 811 cell this year to deliver up to 315 Wh/kg (watt-hour per kg). Furthermore, battery technology company Kreisel Electric is already prepared to license its NMC 811 technology, which uses an immersion liquid cooling system to solve the fire hazards associated with lithium-ion cells in large industrial applications and gives a solid competitive edge over rivals.[79] Generally, Europe aims to green batteries and its automotive industry, one of the most advanced in the world, as the need for high-quality batteries provides an opportunity to European manufacturers to compete against their Chinese equivalents.

Europe's potential weaknesses/challenges

European start-ups are still struggling to build economies of scale to compete with Asian giants, who dominate the mainstream market. For example, there are firm positions held by China's Contemporary Amperex Technology (CATL), Japan's Panasonic and South Korea's LG Chem, Samsung SDI and SK Innovation. In other words, Asian rivals are also planning to build more capacities over the European

[79] Automotive News Europe. European battery makers power up for a green recovery. https://europe.autonews.com/suppliers/european-battery-makers-power-green-recovery Accessed 28.04.2021.

continent in the coming years. According to Susan Zeng, co-president of CATL's European division, Asian manufacturers can bring advantages in cost, product, and service quality.[12]

In addition, Asia Pacific is expected to have a front-of-the-meter battery cost decline by 30% by 2025, along with improvements in battery density. The trend is likely to continue with a region's battery storage industry to take off. This is supported by a proposal for a 100 MW battery storage facility in Queensland, a plan for a 700 MW mega battery in NSW's Hunter Region, Neoen's 500 MW battery expected to be built next to Sydney and AGL's, Australia's largest power producer's, intensions of 850 MW energy storage to be added to its portfolio by 2024.[80]

3.2 SUPPLIERS

This compressed section on suppliers and the batteries and electromobility value chain is mainly elaborated on the recent, open, and detailed report from Automotive Logistics: *Electric Vehicle Battery Supply Chain Analysis - How Battery Demand and Production Are Reshaping the Automotive Industry*, June 2021. The evaluation of the order of importance of a supplier in a field also comes from this report.[81] For all sections of suppliers, there are also smaller players, not mentioned here. All have been checked and, in some cases, corrected, adjusted, and compared to other recent sources and report documents[82]. Comments give European perspectives on sourcing and supply. For an overview, see Figure 20

[80] Pv magazine. WoodMac predicts 30% drop in Asia Pacific front-of-the-meter battery costs by 2025. https://www.pv-magazine-australia.com/2021/01/20/woodmac-predicts-30-drop-in-asia-pacific-front-of-the-meter-battery-costs-by-2025/ Accessed 28.04.2021.

[81] Harrison D. & Ludwig, C (2021) Electric Vehicle Supply Chain Analysis. Downloadable from https://www.automotivelogistics.media/electric-vehicles/electric-vehicle-battery-supply-chain-analysis-2021-how-lithium-ion-battery-demand-and-production-are-reshaping-the-automotive-industry/41924.article

[82]https://investingnews.com/free-report-online/battery-metals-market-stocks/
&
http://battprod.vdma.org/documents/7411591/7483998/VDMA+Roadmap+Battery+Production+Equipment+2030/7acbecf6-0590-4754-984c-ecb378d2227b?version=1.0 Accessed 28.04.2021.

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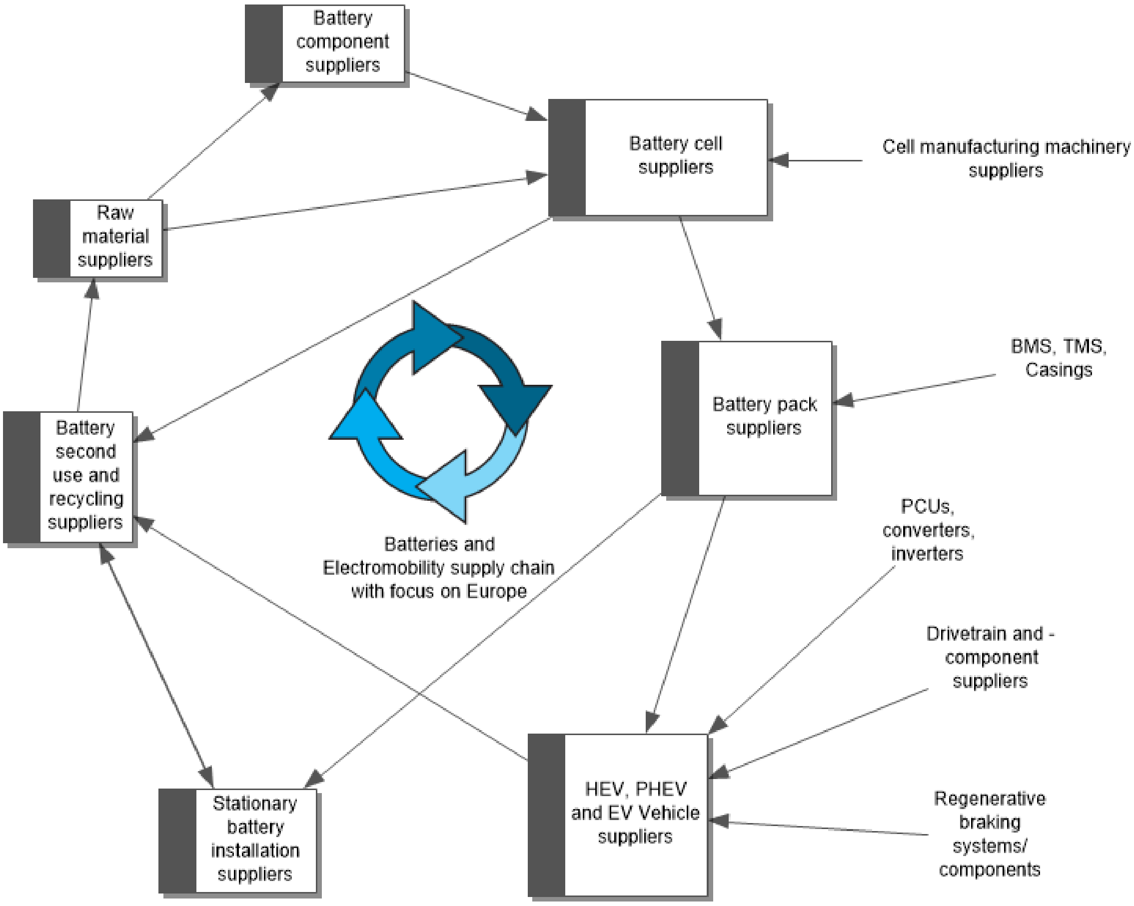

Figure 20. The Battery and electromobility supply chain

Raw material suppliers

Lithium suppliers[83]

Albemarle, Sociedad Quimica y Minera de Chile (SQM), Livent Corp., Tianqi Lithium Industries, Ganfeng Lithium

Most of these Lithium suppliers have operations or joint ventures in mines or brine reserves in more than one country, and some (as Livent) have processing plants distributed over many countries. Australia has the most extensive present production, followed by Chile, China, and Argentina, while the biggest reserves are located in Chile.[84] There are also smaller suppliers – for example, Northvolt and LG Chem have a contract with Canadian Nemaska Lithium. LG

[83] https://www.automotivelogistics.media/electric-vehicles/electric-vehicle-battery-supply-chain-analysis-2021-how-lithium-ion-battery-demand-and-production-are-reshaping-the-automotive-industry/41924.article Accessed 25.08.2021.

[84] https://www.volkswagenag.com/en/news/stories/2020/03/lithium-mining-what-you-should-know-about-the-contentious-issue.html# Accessed 25.08.2021.

Chem also has supply contracts with Ganfeng, as the Volkswagen Group and BMW. VW will build its own battery factories, while BMW secures lithium for its battery producers (as Northvolt). Ganfeng has a joint venture mine in Ireland (Avalonia). Portugal has Europe's most extensive lithium production and reserves (as Montealegre and Barroso). Still, starting mines in these locations seem complex as local community interests oppose lithium mining in these areas.[85] The Finnish mining company Keliber is not yet producing but preparing for lithium mining.[86]

Cobalt suppliers

Glencore, China Molybdenum, Katanga Mining, Umicore, Eurasian Resource Group.

Belgian Umicore, a recycling company, does not operate its own mines but runs cobalt processing plants in China, the USA, Belgium, and Finland. For the procurement of cobalt, Umicore has developed an ethical framework.[87] All other suppliers above have their mines in the DRC, and these can be both very orderly mines respecting human rights regulations and artisanal mines. The German BASF has a "Cobalt for Development" project in the DRC, supported by BMW and Samsung, to promote and develop responsible artisanal cobalt mining.[88] There are many smaller suppliers of cobalt around the world. Northvolt wants to source cobalt from known deposits in Sweden and has recently complained to the Swedish government concerning the long lag time for new mines to open, often 10 to 20 years, because of the Swedish legal framework and bureaucracy. They mean that excessive lag times like this are not sustainable in the shift to electromobility that is fast underway. [89]

Nickel suppliers

Vale, Norilsk Nickel, Jinchuan Group Ltd, Glencore, BHP Billiton.

Glencore, a company based in Switzerland, has a nickel and cobalt refinery in Norway (Kristiansand; Nikkelverk). German BASF and Russian Norilsk Nickel have a supply agreement. BASF will build a plant for cathode material production in Harjavalta, Finland, close to the

[85] https://www.reuters.com/article/us-portugal-environment-lithium-insight-idUSKBN2080GV Accessed 25.08.2021.
[86] https://www.keliber.fi/en/ Accessed 25.08.2021.
[87] https://www.umicore.com/en/sustainability/value-chain-and-society/sustainable-cobalt/ Accessed 25.08.2021.
[88] https://www.basf.com/global/en/media/news-releases/2020/10/p-20-350.html Accessed 25.08.2021.
[89] https://www.di.se/digital/northvolt-vill-se-svensk-brytning-av-kobolt-maste-ske-snabbt/ Accessed 25.08.2021.

Norilsk Nickel cobalt and nickel refinery plant. Norilsk Nickel has the largest known nickel reserves in the world.

Manganese suppliers

South 32, Anglo American, Consolidated Minerals, Eramet, Vale.

South Africa has 78% of the world's known Manganese reserves, followed by China, Australia, and Africa. Only a tiny part, about 2%, of the manganese produced is good enough for the high purity manganese needed in battery manufacturing. The risk of shortage and price spikes is high for manganese.

Graphite suppliers (examples)[90]

Targray, SGL Carbon, Epsilon Advanced Materials, Syrah Resources, Henan Rongxing Carbon Products Co, Elkem, Superior Graphite

Graphite, natural or synthetic, is sold in many varieties and qualities and mixed in various ways. China is the biggest producer of natural graphite, but there are European resources and suppliers[91], as Elkem (Norway) and SAGL Carbon (Germany). On the other hand, synthetic graphite can be produced everywhere, from petroleum and coal.

Battery component suppliers

Cathode Materials suppliers

Umicore, Nichia, Toda Kogyo, Beijing Easpring, Ningdo Jinhe, GEM, Shansan Technology, Xiamen Tungsten, Kingray.

Some battery plants have an upstream production phase for producing cathode materials in-house, as Northvolt. However, other battery plants with shorter production lines must buy these cathode materials, which means less control over their own production and more transports.

BASF is building a cathode plant close to the TESLA Grunheide plant and has already a cathode materials plant in Finland. VW Group owns a 26,5% share in Guoxan High Tech, another

[90] Graphite supply is not a part of Harrison & Ludwig's Electric Vehicle Supply Chain Analysis, so the list constitutes of examples of major players, not necessarily in a volume order.

[91] https://investingnews.com/daily/resource-investing/battery-metals-investing/graphite-investing/europes-graphite-supply-chain/ Accessed 25.08.2021.

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cathode plant. Johnsson Matthey plans to produce the new cathode material *eLNO* in Konin, Poland and Vaasa, Finland.[92]

Anode materials suppliers

Hitachi Chemicals/Shova Denko Materials, BTR Energy, Nippon Carbon, Ningbo Shansan, Hunan Shinzoom Technology, Jiangxi Zhengtuo New Energy Tech.

Purchasing anode materials is viewed as possible even if the cathode materials are made in-house. Northvolt relies on Donjin Sweden AB, which builds a plant close to Northvolt for anode material but produces cathodes of their own.

Copper foil (for the anode) suppliers

Furukawa Electric, Nippon Foil Mfg, Nippon Denkai, Doosan Corp.

South Korean Doosan has branches in Hungary and Luxembourg. All other copper foil suppliers are Japan-based. The copper foil used is very thin, usually about ten µm (0,01 mm) but possibly down to about 1,5 µm and with customisable width for cell factory customers, up to several meters.[93] This explains why no European copper foil producer is yet into this supply chain.

Aluminium foil (for cathode) suppliers

Sumitomo Light Metal Industries, Nippon Foil Mfg

Many European companies produce aluminium foils, but what is needed is a very thin version, usually from 12 µm (0,01 mm). After passing the coating and drying machines, it is customised in width and slit for the battery format after calendaring.

Electrolyte suppliers

CapChem Technology. Tinci Materials Tech, Guotai-Huarong, Panax-Etec, Mitsui Chemicals, Ube, Mitsubishi Chemicals, Ningbo Shanshan, Do-Fluoride Chemicals.

All these suppliers are based in Japan or China, but Guotaiu-Huarong has a branch in Wroclaw, Poland[94], where the LG Chem battery plant is located. A battery plant with an upstream production unit can also produce this in-house.

Separator suppliers[95]

[92] https://www.vasek.fi/vaasa-region-development-company/communication-and-information-2/news/johnson-matthey-chose-vaasa-for-sustainable-battery-materials-plant- Accessed 25.08.2021.
[93] Chu, H. C., & Tuan, H. Y. (2017). High-performance lithium-ion batteries with 1.5 µm thin copper nanowire foil as a current collector. Journal of Power Sources, 346, 40-48.
[94] https://gthr.pl/en/about-us/ Accessed 25.08.2021.
[95] https://www.prnewswire.com/news-releases/global-battery-separator-trends-industry-255510721.html Accessed 25.08.2021.

Ahasi Kasei, Toray Tonen, SK Innovation, Celgard, Entek, Shenzhen Senior Technology Material, Suzhou Victory Precision Manufacture, UBE, Jinhui High-Tech, BNE/HND, Cangzhou Mingszhu, Shanghai Energy New Materials, Xinxiang Zhongke Science and Tech, Donghang, Newmi Tech, Sinoma, SK IE Technology Company.

Evonik and Litarion/Electrovaya are German companies in this market. In addition, Senior is building a factory in Eskilstuna, Sweden, and SK Innovation will build a separator factory in West Poland.[96]

Cell manufacturing machinery suppliers

Cell plant machinery suppliers, examples[97]

Dürr Megtec, Hirano Tecseed, Dongguan Gelon Lib Co, ACEY, TMAX, TOB, PNT, Xiamen Lith Machine Ltd, DT Group, Manz AG, Sovema/Solith, Team Technik, Linyui Gelon Lib Co, Chroma, Digatron,

What brand of machines are used in a Li-Ion Gigafactory is not always public information. Many suppliers sell equipment for all or most production phases, but some sell only one or two types of machines. Asian countries have been producing Li-ion batteries for a long time, so a capacity for production equipment supply is also in place. The same is not valid for Europe. Battery production is ramping up fast, but the machinery of Gigafactory size is often bought from Asian manufacturers, who often also have a more attractive price tag.

Manz, Durr Megatec, Team Technik, Digatron (from Germany and Sovema and Digatron (from Italy) are just some European suppliers. Together with other European companies, they will hopefully be able to adapt to and capitalise on the European demand from Gigafactories.

Battery cell suppliers

Main global battery cell suppliers, some with planned and/or existing European locations

LG Chem (Wroclaw, Poland), BYD, Panasonic (Norway), CATL (Erfurt, Germany) SKI (Komarom, Hungary), Samsung SDI (Göd, Hungary), Guoxan High-Tech/Shanghai Electric, Dynavolt, Farasis, BAK, Lishen, Envision AESC (Sunderland, UK), EVE Energy, DLG, Do Fluoride Chemicals,

[96] https://www.ajudaily.com/view/20190327104444115 Accessed 25.08.2021.

[97] Machinery supply is not a part of Harrison & Ludwig's Electric Vehicle Supply Chain Analysis, so the list constitutes of examples of major players, not necessarily in a volume order.

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Phylion, Microvast (Brandenburg, Germany), Tianneng Energy, SVOLT (Saarland, Germany), SAFT/ACC (Kaiserslautern, Germany and Douvrin, France).

Not all cell plants are listed here, only those of considerable size and with cell production in 2021. Most are located in Asia. Planned European locations are listed within brackets.

About 75% of the current battery cell manufacturing capacity in 2021 is located in Asia, but not all capacity is for vehicle propulsion. Currently, around 13% of capacity is in Europe and 10% in the USA. The European share of this is growing fast, but Asian global dominance will most likely continue.

For a comprehensive analysis of the 20 biggest producers worldwide, see the Harrison & Ludwig 2021 *Electric Vehicle Supply chain analysis*.[98] For frequently updated maps of European cell factories, see Zenn.[99] Finally, for an extensive database of Cell producers, including smaller plants and competing battery technologies, see the downloadable databases from Automotivelogistics.[100]

EV vehicle parts, battery packs and systems suppliers

Battery Management Systems (BMS) Suppliers

BYD, CATL, Eberspächer, Ficosa, Infineon/G-Pulse, Hella, Idneo, Leclanche, LG Chem, Lithium Balance, Nuvation Energy, NXP Semiconductors, Panasonic, Renesas Electronics, Bosch, Roboteq, SVolt, Tesla

Battery Thermal Management Systems (TMS) Suppliers

Borgwarner, Marelli/Calsonic Kansei ,CapTherm Systems, Continental, Dana, Gentherm, Hanon System, LG Chem, MAHLE, Bosch, Samsung SDI, Valeo, VOSS Automotive.

Battery Case Suppliers, general (battery boxes and similar)

ArcelorMittal, Constellium, Thyssenkrupp, EDAG Group, Gestamp, Hitachi, SGL Carbon, Voestalpine.

[98] Harrison D. & Ludwig, C (2021) Electric Vehicle Supply Chain Analysis, p 60-98 . Downloadable from https://www.automotivelogistics.media/electric-vehicles/electric-vehicle-battery-supply-chain-analysis-2021-how-lithium-ion-battery-demand-and-production-are-reshaping-the-automotive-industry/41924.article Accessed 25.08.2021.

[99] Roland Zenn, Farasis, LinkedIn account https://www.linkedin.com/in/roland-zenn/?originalSubdomain=de

[100] https://www.automotivelogistics.media/focus/electric-vehicles

European Battery Pack Assembly plants (–or plants connected to European OEMs as suppliers)

ATW Automation (TESLA, Germany), Audi (Brussels, Belgium), **BMW** (Dingolfing, Munich, Leipzig, Regensburg - Germany), BMZ GmbH (Karlstein, Germany), Bollore (Ergué-Gabéric, France), Continental (Nuremberg, Germany together with Daimler and Deutsche Automotive Gesellschaft), **Daimler** (Nuremberg, Kamenz, Stuttgart-Untertürkheim, Sindelfingen – Germany and Jawor - Poland), Ford (Valencia, Spain and Kocaeli, Turkey), GS Yuasa (Miskolc, Hungary), Hyperbat (Coventry, UK), Jaguar Land Rover (Birmingham, UK), Johnson Matthey (Gliwice, Poland), Kreisel Electric (Freistadt, Austria), Microvast (Brandenburg, Germany), Northvolt Systems (Gdansk, Poland), Renault-Nissan-Mitsubishi (Sunderland, UK, Flins, France and Barcelona, Spain), Scania (Södertälje, Sweden), Stellantis (Nersac France; Trnava, Slovakia; Hauts-de-France, France; Kaiserslautern, Germany; Turin, Italy; Zaragoza and Figueruelas, Spain), TESLA (Grunheide, Germany), Valmet Automotive (Salo and Uusikaupunki, Finland), Volvo (Gent, Belgium; Vigo, Spain), VW Group (Salzgitter, Wolfsburg, Braunschweig, Ingolstadt - Germany).

There are, in addition, many battery pack assembly plants producing packs for Asian car brands, less known and seldom sold in Europe. These are here omitted.[101] Northvolt operates Northvolt Systems in Gdansk and has ambitions to build Europe's largest battery pack facility in this location.[102]

EV drivetrains and components suppliers (examples)

BorgWarner, ZF Group, Bosch, Schaeffler, Univance, Mitsubishi Electric, Magna, Valeo, Mahle, Punch Powertrain.

Power Control Units (PCU), converters & inverters Suppliers (examples)

Calsonic Kansei/ Marelli, Keihin, Rohm, Denso, Mitsubishi Electric, Continental.

[101] See Harrison & Ludwig (2021), p 103-108 for an exhaustive global listing

[102] https://www.rechargenews.com/markets/northvolt-to-build-europe-s-largest-energy-storage-systems-plant-in-poland/2-1-966232 Accessed 25.08.2021.

Regenerative braking systems suppliers (examples)

Bosch, Continental, Punch Powertrain, Eaton Corp., Denso, Delphi Automotive, Hyundai Mobis.

Europe has historically had a strong position in ICE cars components and systems supply for decades. This seems to be similar concerning EVs. Thus, in this engineering supply step, Europe is not as behind as in battery manufacturing field. [103]

HEV, PHEV and EV assembly plants (EV suppliers to consumers)

According to Harrison & Ludwig (2021), the VW group had, in June 2021, 30 assembly plant locations globally where HEV, PHEV and EV vehicles were assembled. Toyota had 28 sites, Renault-Nissan-Mitsubishi 26, Stellantis (Fiat-Chrysler & PSA) 25, Daimler 19, BYD 18, Ford 16, Hyundai-Kia 14, Geely 14, BMW 13, Honda 11, GM 8, Suzuki 7, Jaguar Land Rover 6, Tesla 5, Volvo Group 4, and Mazda 2.[104] These figures change constantly.

Below, in Figure 21, are some known supply relations between vehicle producers and cell producers. The supply lines between cell plants and car plants are diversifying. OEMs sometimes contract several cell producers to minimise the risk of insufficient supply and customise their vehicles for different markets. Some OEMs, for example, BMW, have more than one cell supplier and settle supply agreements directly with raw material suppliers to ensure that their contracted cell producers also have raw materials enough to produce batteries. In addition, they also engage in ethical and qualitative procurement for these raw materials.[105]

Car buyers can have "range anxiety" when changing from an ICE car to an EV. Similarly, car producers (OEMs) who switch their production from ICE cars to EVs instead seem to have "battery anxiety". This can explain the diversification of supply relations and lock-in of supply

[103] Drivetrain, PCUs and Braking systems are not a part of Harrison and Ludwig's 2021 Supply Chain Analysis and its volume and importance estimation, so here are examples of relevant industries, without volume or importance evaluation.

[104] Harrison & Ludwig, 2021, p. 110.

[105] https://cleantechnica.com/2018/02/12/bmw-close-10-year-lithium-cobalt-supply-deal-just-response-news-tesla-locking-supply-deals/ & https://www.argusmedia.com/en/news/2122122-germanys-bmw-signs-fiveyear-cobalt-supply-deal Accessed 25.08.2021.

sources upstream the value chain. „The crunch" online magazine expresses this battery supply anxiety well: "If batteries don't show up, you're bankrupt, you're dead".[106]

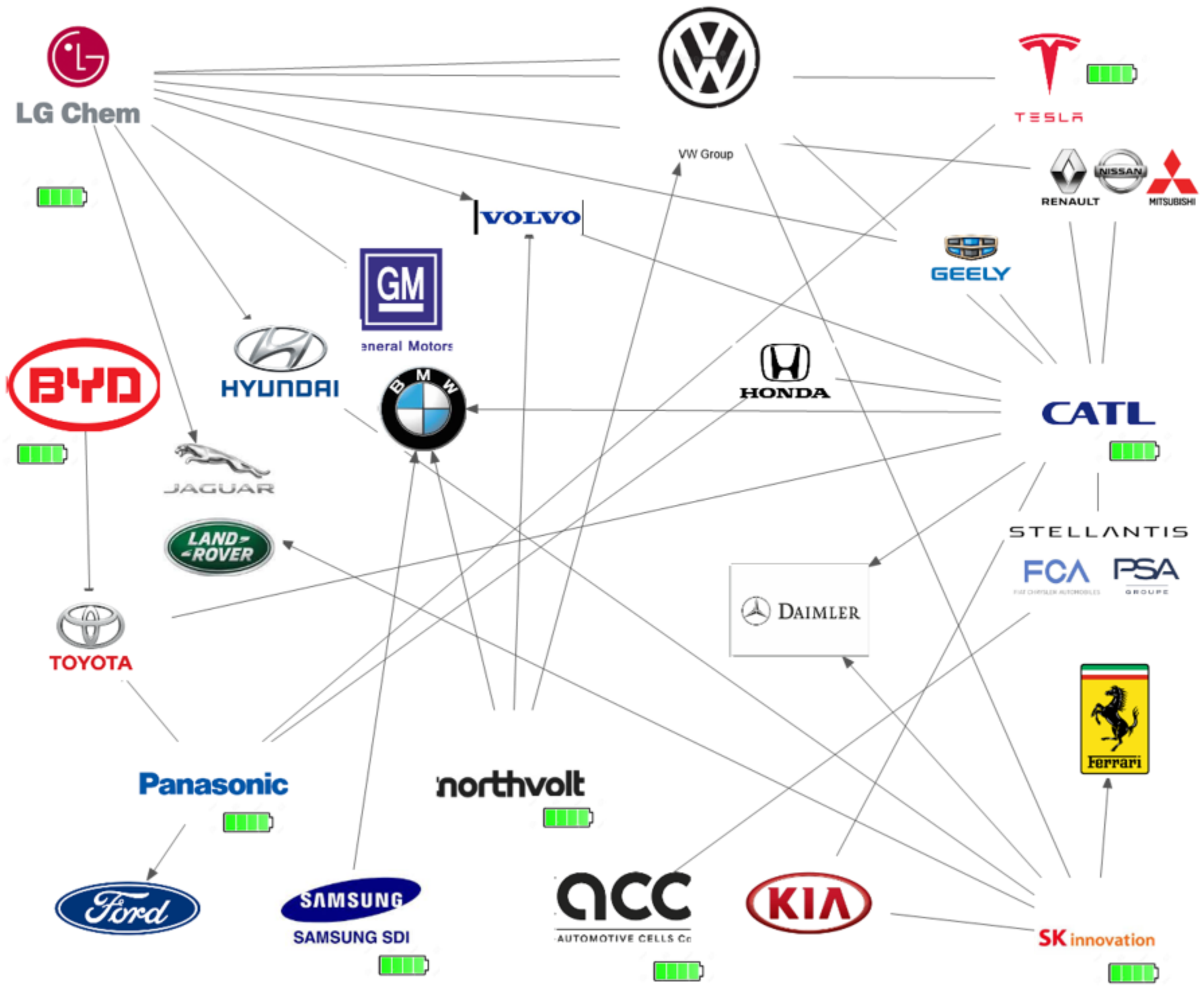

Figure 21. Some known supply relations between cell suppliers and car OEMs. Cell producers marked with green battery symbol. This figure focuses on car brands produced and/or sold in Europe

Summary

There will likely be a long time before we see a complete European supply chain for electromobility with sufficient volumes in each step. The Li-Ion battery suppliers of raw materials, battery materials and machinery are primarily situated in Asia, with China as the dominant supplying country. Moreover, most cell factories are also located in Asia. However, European stakeholders have a significant potential to develop their supplying capacity on raw

[106] https://techcrunch.com/2021/07/23/automakers-have-battery-anxiety-so-theyre-taking-control-of-the-supply/ Accessed 25.08.2021.

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materials, refining capacity and machine production, but this does not happen as fast as European battery cell plants now are emerging.

3.3 CUSTOMERS

3.3.1 Customers – Automotive

3.3.1.1 Global electric vehicle battery market

The global electric vehicle battery market size was valued at $23 billion in 2017 and is projected to reach $84 million by 2025, growing at a CAGR of 17.2% from 2018 to 2025. Li-ion batteries have been the primary solutions for automakers to power plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs). High-energy density, charge retention capacity, and low maintenance are some of the benefits that have accelerated the growth of Li-ion as battery technology. In addition, automobile manufacturers introducing BEVs and PHEVs in the EV battery market are further enhancing the technology and are anticipated to offer Li-ion powered solutions as a primary power source in their vehicles.

In recent years, consumers are more inclined towards battery-electric/plug-in vehicles because these vehicles run without or little fuel, such as petrol, diesel, or LPG/CNG and have lower maintenance costs, which eventually reduces consumers' expenses. Furthermore, the growth of the electric vehicle battery market is driven by the rise in the demand for low or zero-emission vehicles, a decrease in the cost of the electric vehicle battery system, and an increase in global awareness regarding climate change.

The soaring demand for low or zero-emission vehicles, the advancing evolution of Li-ion technology, and rising government regulations on emission control systems are the significant factors that affect the growth of the global electric vehicle battery market. These factors (Figure 222) are anticipated to either drive or hamper the market growth. [107]

[107] https://www.alliedmarketresearch.com/electric-vehicles-battery-market, Accessed on 12.05.2021

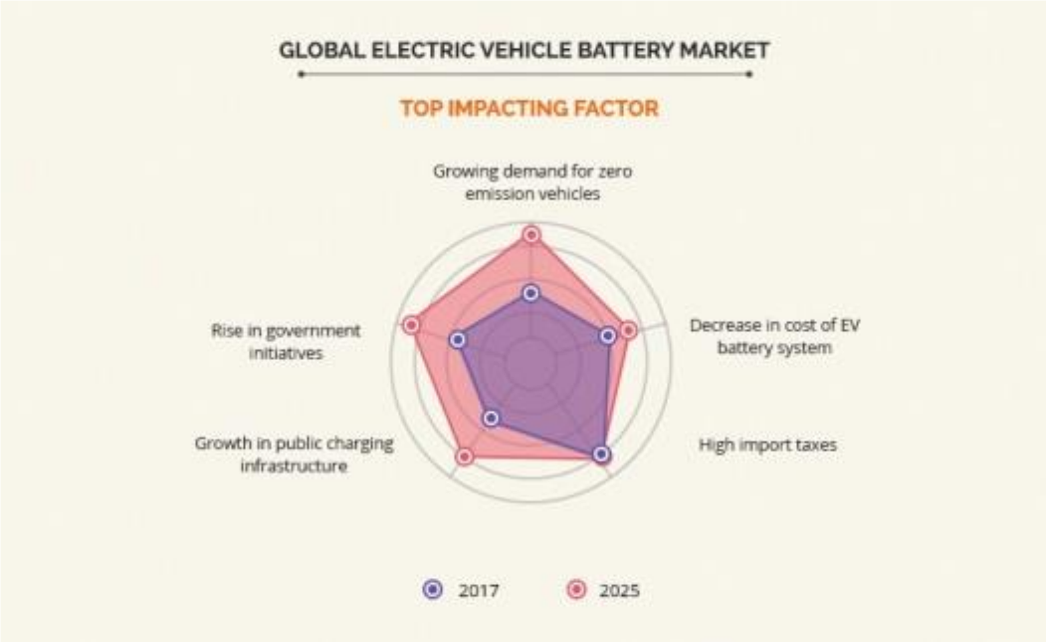

Figure 222. Global electric vehicle battery market, top impacting factor

Favourable initiatives by governments across the globe have promoted the manufacturing of EVs. Strict regulations for vehicle emissions have resulted in fuelling the demand for EVs. For example, the EU set a goal of net-zero greenhouse gas effluents by 2050. Electrified vehicles (BEV, PHEV, FCEV) emit lesser, or no effluents compared to traditional vehicles. Therefore, governments across the globe are promoting the use of electrified vehicles to lower oil consumption, related CO2 emissions, and air pollution[108].

Higher investments in EVs are viewed as a critical driver for this market. Almost all car manufacturers announced large numbers of electrified models[109] Figure 23. Key players are investing extensively to manufacture these vehicles.

[108]https://www.millioninsights.com/industry-reports/electric-vehicles-ev-market?utm_source=prnewswire&utm_medium=referral&utm_campaign=prn_02Mar2021_ev_rd2, Accessed on 22.05.2021

[109]https://www.businesstimes.com.sg/infographics/focus-green-push/legacy-automakers-launch-electric-offensive?utm_medium=social-organic&utm_source=linkedin, Accessed on 20.05.2021

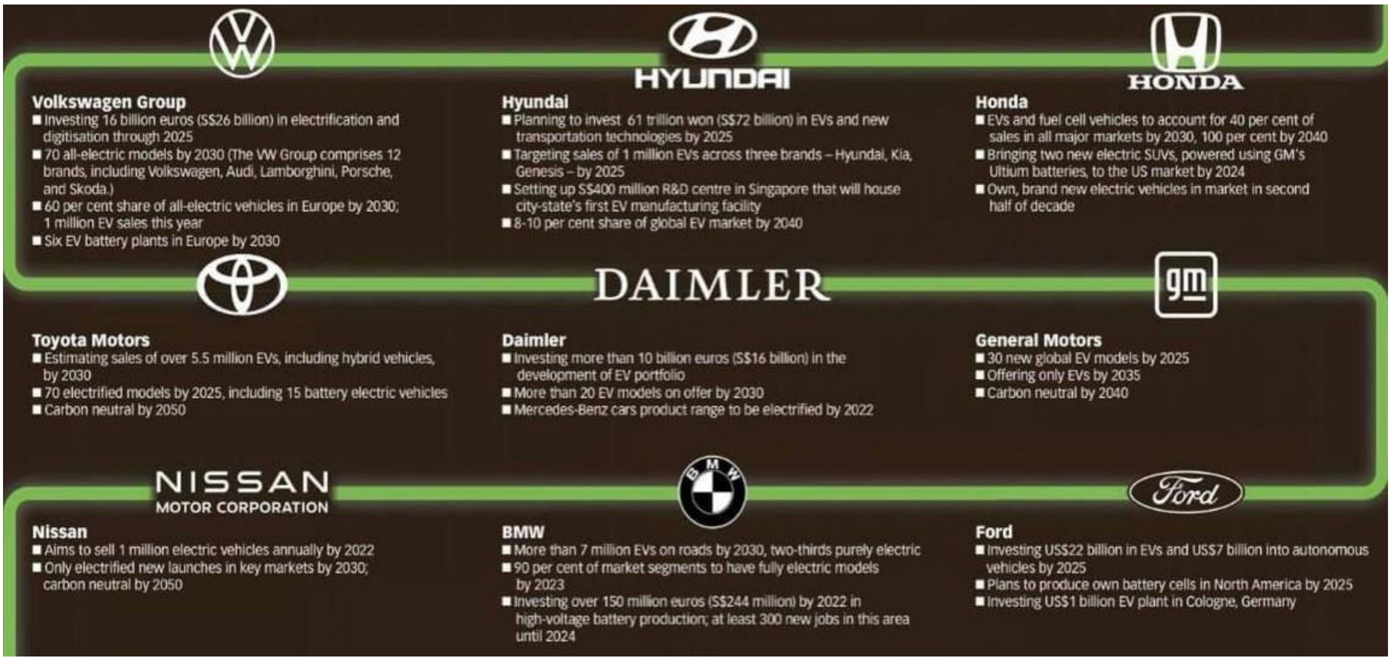

Figure 23. Car manufacturers EV models

Electric vehicle charging infrastructure is essential for the widespread usage of electric vehicles. Charging stations can be built at home, in commercial spaces like offices, malls, etc., and on the highways. Governments are funding the projects of building public charging infrastructure through various schemes, and car manufacturers are also throwing in their resources to expand charging infrastructure.[110]

Policies to support the installation of charging stations through direct investments and public-private partnerships, specifically in urban areas, would equally play a significant role in driving market growth. Multiple charging stations are crucial for ensuring long-distance commuting capability for electric vehicles. However, an integrated electrification system for all kinds of transport vehicles, including freight delivery vehicles, public transport vehicles, two-wheelers, and cars, is yet to be implemented on a large scale[111].

[110] https://www.globenewswire.com/news-release/2021/03/18/2195463/0/en/Electric-Vehicle-Charging-Station-Market-Size-Rising-at-33-CAGR-and-Will-Reach-to-USD-70-Billion-by-2026-Facts-Factors.html#:~:text=%5B225%2B%20Pages%20Research%20Report%5D,USD%2070%20Billion%20by%202026. Accessed on 25.05.2021

[111] https://www.grandviewresearch.com/industry-analysis/electric-vehicle-battery-market, Accessed on 26.05.2021

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Currently, the EV battery market is dominated by Asia. In 2018, companies outside China, Japan, and Korea supplied less than 3 percent of the total global demand for EV batteries, and European companies provided only 1 per cent[112].

If we analyse the most recent data (Figure 24), we could observe that the traction battery market is developing in parallel with the electric vehicle market; the dynamics of individual participants is impressive. For example, the Chinese company CATL, in just one year, increased its share from 17 to 31,5% and increased the volume of battery production by 4,21 times. All Korean manufacturers are inferior to it, even taken together.

In Korea, the entire traction battery market grew by 127% year-on-year to 47,8 GWh. The main progress in the volume of supply of batteries for electric vehicles was demonstrated by the Chinese company CATL, having shipped batteries with a total capacity of 15,1 GWh in the first quarter of this year. The closest competitor was the Korean LG Energy Solution with 9,8 GWh, while the Japanese company Panasonic, collaborating with Tesla and Toyota, with 8,0 GWh, remained in third place[113].

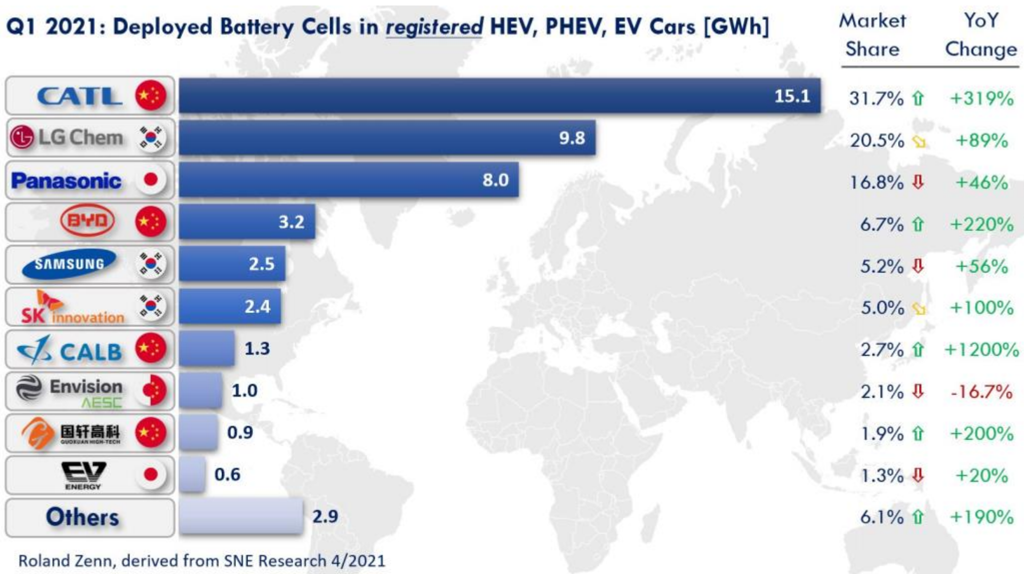

Figure 24. [114] Deployed battery cells in registered HEV, PHEV, EV cars (GWh)

[112] https://coilwindingexpo.com/Articles/competitiveness-in-the-ev-battery-market Accessed on 13.05.2021
[113] https://blogh1.com/2021/05/05/chinas-catl-nearly-doubles-its-traction-battery-market-share-in-just-one-year/ Accessed on 26.05.2021
[114] https://www.linkedin.com/posts/roland-zenn_batteries-battery-lithiumionbatteries-activity-6793829085584863233-wNQu Accessed on 25.05.2021

International Trade in Batteries

Lithium-ion batteries for EVs are categorized in an HS6-digit subheading (8507.60) that includes lithium-ion batteries for all uses. This section explores the available trade data.

For lithium-ion battery trade, in the last years, the United States and Germany are beginning to import almost as much as China, but China still holds a large share of the world's exports.

Battery cells are traded under a broader statistical reporting number for battery parts, making it challenging to track imports and exports globally since that trade data includes many other products.

By value, in 2020, Germany reported the highest amount of imported lithium-ion batteries, followed by the United States and China (Table 1). However, it is difficult to know what portion of imports under this HS subheading were batteries for EVs versus lithium-ion batteries for some other purpose, as the HTS subheadings don't differentiate on an international level.

Table 1. Imports of Lithium-ion batteries by country, 2016-2020 (€ thousand)

Imports of Lithium-ion batteries by country, 2016 - 2020 (Euro thousand)					
Importers	**2016**	**2017**	**2018**	**2019**	**2020**
Germany	1.458.661	1.989.389	2.419.869	3.312.002	5.568.663
United States of America	1.804.650	2.274.195	2.728.803	3.291.852	4.215.974
China	2.762.066	2.890.962	3.288.001	3.326.929	3.098.479
Korea, Republic of	356.538	593.920	1.036.687	1.115.620	1.430.500
Japan	678.598	715.140	920.952	1.269.419	1.172.706
Netherlands	508.137	697.911	845.884	829.455	1.133.312
France	375.926	522.042	694.296	950.311	1.124.255
Belgium	94.829	124.887	218.205	725.346	962.645
Poland	168.228	212.086	343.588	808.399	890.828
Spain	76.804	107.230	152.362	211.735	882.976
Subtotal	**8.284.437**	**10.127.762**	**12.648.647**	**15.841.068**	**20.480.338**
Other	5.435.101	6.975.904	9.195.933	11.952.169	8.130.292
Total WORLD	**13.719.538**	**17.103.666**	**21.844.580**	**27.793.237**	**28.610.630**
Sources: ITC calculations based on UN COMTRADE and ITC statistics					

China's increased lithium-ion battery exports (Table 2) suggest increased Chinese lithium-ion battery production implying that the high volume of its imports may be more cells and modules (components) than packs (finished products). However, like the situation regarding the import trade figures, these export figures differ significantly across countries. It may be that Chinese production and exports of lithium-ion batteries are for different types of batteries (e.g., power drills, cell phones, etc.) that are typically less expensive than EV batteries.

Table 2. Exports of lithium-ion batteries by country, 2016-2020 (€ thousand)

Exports of Lithium-ion batteries by country, 2016 - 2020 (Euro thousand)

Exporters	2016	2017	2018	2019	2020
China	6.157.427	7.112.942	9.163.408	11.640.230	13.966.588
Korea, Republic of	2.104.278	3.114.639	3.718.775	4.179.619	4.274.417
Poland	160.682	228.540	607.108	1.816.640	4.052.279
Germany	535.031	855.308	1.128.199	1.776.439	2.967.171
Hungary	164.636	348.442	584.970	1.157.457	2.393.280
Japan	2.364.921	2.276.383	2.182.619	1.834.561	2.180.024
United States of America	1.007.699	1.143.780	1.185.156	1.356.261	1.445.640
Malaysia	100.918	188.420	716.564	814.082	780.827
Netherlands	178.147	251.109	349.100	369.446	776.451
Singapore	343.437	502.373	595.253	715.797	651.829
Subtotal	**13.117.176**	**16.021.936**	**20.231.152**	**25.660.532**	**33.488.506**
Other	2.935.192	3.752.083	4.862.201	5.567.053	2.228.754
Total WORLD	**16.052.368**	**19.774.019**	**25.093.353**	**31.227.585**	**35.717.260**

Sources: ITC calculations based on UN COMTRADE and ITC statistics

If we analyse the data of battery parts (HS6-digit subheading 8507.90), that includes lithium-ion cells and modules, we observe the main exporters are Japan, Korea and China (Table 3) while importers are led by the USA and Poland, followed by China and Germany (Table 4).

Table 3. Exports of batteries parts by country, 2016-2020 (€ thousand)

Exports of batteries parts by country, 2016 - 2020 (Euro thousand)

Exporters	2016	2017	2018	2019	2020
Japan	557.913	863.671	1.264.582	1.212.369	901.269
Korea, Republic of	513.688	512.340	808.353	843.082	739.379
China	200.624	293.807	319.409	392.338	543.377
United States of America	301.577	278.189	268.871	364.594	271.623
Germany	120.821	143.950	148.669	202.742	267.728
Italy	109.572	115.544	120.101	110.870	99.408
Czech Republic	88.378	131.920	105.482	95.345	80.708
United Kingdom	78.082	74.469	76.205	79.071	69.405
Austria	28.152	35.553	32.842	37.126	58.887
Hungary	2.356	2.610	31.897	32.747	58.111
Subtotal	**2.001.163**	**2.452.053**	**3.176.411**	**3.370.284**	**3.089.895**
Other	921.952	1.205.895	660.789	717.128	373.908
Total WORLD	**2.923.115**	**3.657.948**	**3.837.200**	**4.087.412**	**3.463.803**

Sources: ITC calculations based on UN COMTRADE and ITC statistics

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Table 4. Imports of batteries parts by country, 2016-2020 (€ thousand)

Imports of batteries parts by country, 2016 - 2020 (Euro thousand)					
Importers	**2016**	**2017**	**2018**	**2019**	**2020**
United States of America	764.780	1.309.744	1.363.462	1.350.739	1.409.795
Poland	56.274	81.238	384.366	586.175	920.590
China	253.989	319.120	430.711	437.935	399.239
Germany	165.438	224.301	269.934	436.364	382.130
Singapore	141.148	239.921	310.126	300.058	290.238
Korea, Republic of	66.923	80.625	162.394	173.951	198.596
United Kingdom	55.980	111.904	224.883	226.997	89.338
France	76.469	62.426	67.951	101.234	82.163
Japan	97.132	94.142	87.072	64.554	78.315
Spain	63.798	81.617	80.447	84.821	68.649
Subtotal	**1.741.931**	**2.605.038**	**3.381.346**	**3.762.828**	**3.919.053**
Other	989.561	1.313.095	1.315.460	1.274.904	587.470
Total WORLD	**2.731.492**	**3.918.133**	**4.696.806**	**5.037.732**	**4.506.523**
Sources: ITC calculations based on UN COMTRADE and ITC statistics					

Electric Vehicle Battery Supply Chain

Batteries are the key differentiator between the various EV manufacturers. The amount of energy stored in the battery determines the EV range, thought to be a major limitation of EV sales.

Like many high-technology goods, EV batteries have a complex supply chain in which production can be divided into stages, and those stages can be completed in different locations.

The battery manufacturing supply chain has three main parts: cell manufacturing, module manufacturing, and pack assembly. These three stages can be conducted in the same place or split into two or (theoretically) three locations. Pack assembly tends to occur near the vehicle assembly location because of the cost of transporting battery packs, which are larger and heavier than cells or modules[115].

115 https://www.usitc.gov/publications/332/working_papers/supply_chain_for_ev_batteries_2020_trade_and_value-added_010721-compliant.pdf, Accessed on 13.05.2021

Global installed manufacturing capacity for large-sized (automotive/ESS) lithium-ion battery cells is forecast to surpass 2,000 GWh by 2030, around 4.5x times more than in 2019. This is forecast to reach 4,900 GWh by 2040, approximately 11x times more than 2019, to meet the demand. Most of these capacity expansions will be driven by transport electrification. However, China is expected to maintain its dominant position in battery manufacturing due to its large domestic automotive market and pre-existing upstream battery supply chain.[116]
Cells are an intermediate good in the larger battery assembly process. Different cell producers' list slightly different specifications and components in their battery cell assembly, but the general ideas remain the same. Multiple cells in a case with terminals attached form a module. The number of cells per module varies by manufacturer and cell type. Module production brings less value-added than the cell stage of production. Based on recent estimates, about 11 per cent of the total cost of a finished lithium-ion battery pack comes from the module stage of production. Since most modules are made in the same facility as the battery pack, there is less trade in this component of the supply chain. Modules are assembled using cells that were either imported or made on site. EV battery packs are the final stage of EV battery production. Battery packs are made up of battery modules, electrical connections, and cooling equipment. Manufacturers can assemble them by hand or by using automation. Based on recent estimates, about 7 per cent of the total cost of a finished lithium-ion battery pack comes from the packing stage of production. Battery manufacturers design EV battery packs for specific vehicle models and tend to assemble them near the vehicle assembly plant[117].

Customers OR Users of batteries in the automotive segment

Most battery manufacturers are in China, Japan, and South Korea. With the rapid development of the EV market, the scale of the battery market is gradually expanding. In addition, the industry is being reshaped more rapidly than ever. Except for leading enterprises that have taken up most of the share from the industry, other manufacturers may be marginalized. In 2020, CATL ranked first globally with its installed capacity of 34 GWh (Table 5). Driven by the demand from Tesla and the European market, LG Energy Solution ranked

[116] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC123439/roskill-jrc_classi_ni_market_study_identifiers_final.pdf Accessed on 17.05.2021

[117] https://www.usitc.gov/publications/332/working_papers/supply_chain_for_ev_batteries_2020_trade_and_value-added_010721-compliant.pdf Accessed on 24.05.2021

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second with its installed capacity of 31 GWh, followed by Panasonic, BYD, and Samsung SDI. In the top ten, there were five Chinese companies, two Japanese companies and three Korean companies[118].

Table 5. Installed capacity (GWh)

#	Company Name	Installed Capacity (GWh)
1	CATL	34
2	LG Energy Solution	31
3	Panasonic	25
4	BYD	10
5	Samsung SDI	8
6	SKI	7
7	AESC	4
8	EVE Energy	3.7
9	CALB	3.6
10	Gotion High-Tech	3.3

Battery technology will decide the winners and losers of tomorrow's auto industry. Historically, automakers have spent the bulk of their efforts designing and manufacturing just the vehicles themselves and left the power supply issue to the gasoline and diesel fuel providers. But as more automakers make commitments to shift their entire businesses eventually over to electric vehicles, many are also increasingly investing in the chemistry and manufacturing of their own power supplies.[119]

Carmakers are starting to consider cleaner batteries and climate-friendly production a competitive advantage. A very good representation shows us a general picture of customers of battery in automotive sector (Figure 25)[120]

[118] Virtual Battery Exhibition, 27 April 2021, presentation_CIAPS_Liu_EN
[119] https://www.greenbiz.com/article/car-companies-are-now-battery-companies Accessed on 25.05.2021
[120] https://eiirtrend.com/wp-content/uploads/2020/09/auto-ev-battery-strategy.pdf Accessed on 25.05.2021

Major Auto OEM	EV Battery providers/partners	EV Battery JV
Toyota	CATL, GS YUASA	Panasonic, BYD
Volkswagen	CATL, LG Chem, SK innovation, SAMSUNG SDI	国轩高科, northvolt
Tesla	CATL, LG Chem	Panasonic
GM	CATL	LG Chem
Ford	CATL, LG Chem, SK innovation, SAMSUNG SDI, BYD, SAFT	
Mazda	ELIIY Power, UBE	
Hyundai	CATL, SK innovation, LISHEN	LG Chem
Honda	Panasonic	CATL, GS YUASA
Nissan	CATL, SUNWODA 欣旺达, EDF	NEC
BMW	CATL, LG Chem, northvolt, SAMSUNG SDI, EVE 亿纬锂能	
Daimler	CATL, LG Chem, SK innovation, SAMSUNG SDI	FARASIS 孚能科技 Farasis Energy
Fiat Chrysler	LG Chem, SAMSUNG SDI	
PSA	CATL, LG Chem, GS YUASA	SAFT
Renault	CATL, LG Chem, SUNWODA 欣旺达, LISHEN	

Source: EIIRTrend, Web © 2020 Pareekh Consulting

Figure 25. [121]EV Battery providers/partners

In 2021, 148 of the world's 200 lithium-ion battery Gigafactories in the pipeline (planned or under construction, not yet producing) are in China. In contrast, Europe and North America have only 21 and 11 Gigafactories respectively in the pipeline. While European and North American expansions have begun to increase substantially over the past 12 months, China remains by far the most aggressive country in building lithium-ion cell production capacity to support its electric vehicle and energy storage industry[122].

The main customers (or better say "users") for batteries are car manufacturers. Many joint ventures or cooperation agreements were closed over the last years. Some of them are illustrated in Figure 25. Forming JVs is one option/solution of automakers to secure supply, costs, and quality of the batteries for electric vehicles.

Car manufacturers have traditionally built their own auxiliaries for internal combustion engine (ICE) vehicles, but now they are forced to turn to Asian electronics and chemical firms that control the EV battery market. In terms of the companies that make batteries for electric cars, three EV battery manufacturers are the major players on the global stage.

[121]https://www.linkedin.com/posts/roland-zenn_batteries-battery-lithiumionbatteries-activity-6793829085584863233-wNQu Accessed on 25.05.2021
[122] https://www.benchmarkminerals.com/membership/global-battery-arms-race-200-gigafactories-china-leads-2/, Accessed on 25.05.2021

Today, LG Energy Solutions, CATL, Panasonic, BYD, Samsung SDI, and SK Innovations dominate battery manufacturing. Most of these companies are based in China, Japan, or South Korea.

Nearly 140 GWh of batteries were allocated to the electric and hybrid mobility sector in 2020 (Figure 26**). As a market leader, the South Korean LG Chem alone represents nearly 40 GWh of capacity**[123]**.**

The market leader and the leading supplier of batteries to European carmakers, **LG Energy Solutions** (LG Chem) alone represents nearly 40 GWh of battery volume produced. In addition, the South Korean manufacturer supplies to Tesla in China and has an extensive client portfolio in Europe, including VW, Renault, and Mercedes[124].

Contemporary Amperex Technology Limited (CATL) claimed a distant second place in 2020, propped up by its dominant presence in China and strong entry into the European market in the second half of the year[125].

CATL also operates outside of China, which is the second biggest international market for EVs (the 1.3 million EVs sold in China in 2020 represented 41 per cent of global EV sales), only just behind Europe (42 per cent of the worldwide EV market). The reason why CATL takes the top spot is likely because it has the biggest number of agreements with car manufacturers, including EV companies such as Tesla, BMW, Great Wall, Honda, Hyundai and Volkswagen.

Samsung SDI is now a step closer to becoming No.1 in the global EV battery market[126].

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[123] https://www.automobile-propre.com/breves/voiture-electrique-lg-leader-des-batteries-en-2020/ Accessed on 01.06.2021

[124] https://www.adamasintel.com/passenger-ev-battery-capacity-deployed-2020/ Accessed on 01.06.2021

[125] https://www.adamasintel.com/passenger-ev-battery-capacity-deployed-2020/, Accessed on 01.06.2021

[126] https://www.samsungsdi.com/automotive-battery/index.html Accessed on 25.05.2021

Co-funded by the Erasmus+ Programme of the European Union

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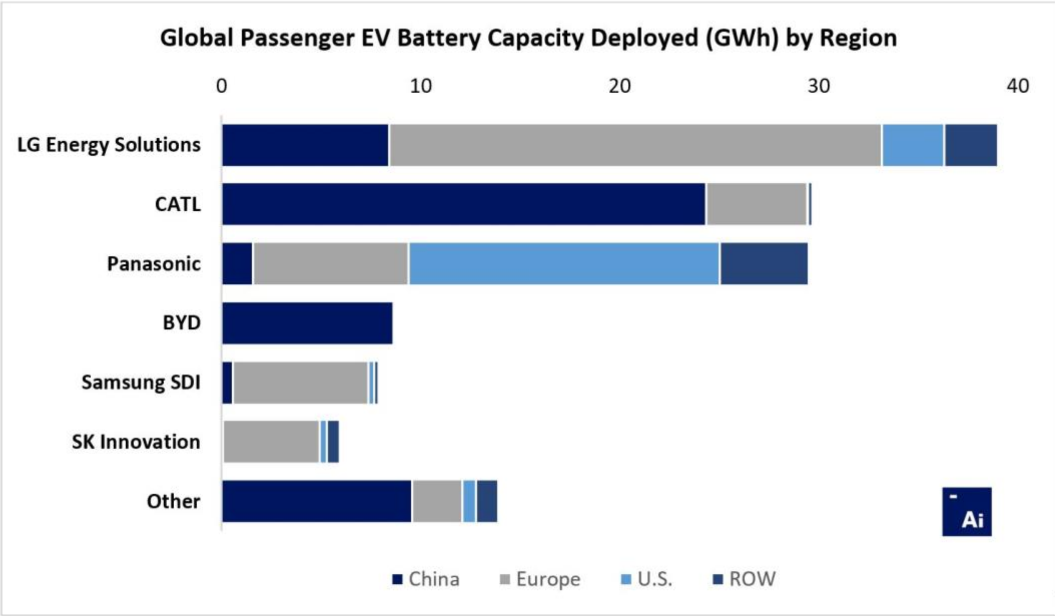

* Chart considers passenger BEV, PHEV and HEV capacity deployed onto roads in 2020.

* Excludes battery capacity in sales channels and pack/automaker assembly lines

Figure 26. Global passenger EV battery capacity deployed (GWh) by region

Not all lithium-ion batteries can be used in all-electric vehicles, though. As a result, there is a fine balance of what Benchmark calls the 'Three Qs' of quality, quantity and qualification for the industry. Every three months, Benchmark assesses each lithium-ion battery cell producer into the following three tiers (Figure 27):

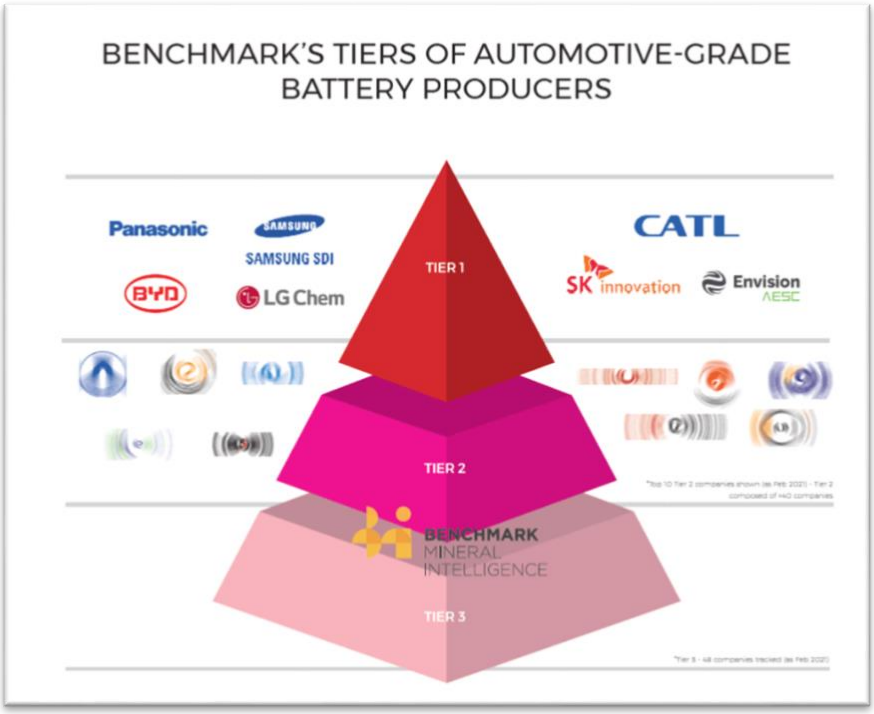

Figure 27. Benchmark's tiers of automotive-grade battery producers

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Tier 1:

Qualified to supply multinational automotive OEMs / EV producers outside of China

Supplier to the domestic Chinese EV market

>5 GWh of annual cumulative capacity (equivalent at the time of assessment)

Tier 2:

Not yet qualified to supply multinational automotive OEMs / EV producers outside of China

Qualified to supply domestic Chinese EV manufacturers

Qualified to supply non EV applications

>1GWh of annual cumulative capacity (equivalent at the time of assessment)

Tier 3:

Not yet qualified to supply EV end markets

>1GWh of annual cumulative capacity (equivalent at the time of assessment)

Primary focus: non EV markets, including portable and stationary

Forecasts

Lithium-ion battery production is expected to increase significantly to meet the demand of the growing electric vehicle fleet worldwide.

The global Li-ion battery market

As the political and social need for green transition increases, the automotive industry needs to keep up with the pace of the change by adapting its products and services to comply with new standards and meet society's expectations. As a result, it is forecasted to increase from 142 GWh in 2018 to 2,333 GWh in 2030. As a result, the global lithium-ion battery market is expected to double in size in the upcoming five years, reaching 71 billion U.S. dollars by 2025[127].

By 2028, it is estimated that battery manufacturer CATL will produce lithium-ion batteries with a cumulative capacity of 307 GWh. Lithium-ion battery production (Figure 28) is expected to increase significantly to meet the demands of the growing electric vehicle fleet worldwide.

127 https://www.statista.com/statistics/1103401/predicted-lithium-ion-battery-capacity-by-company/ Accessd on 27.05.2021

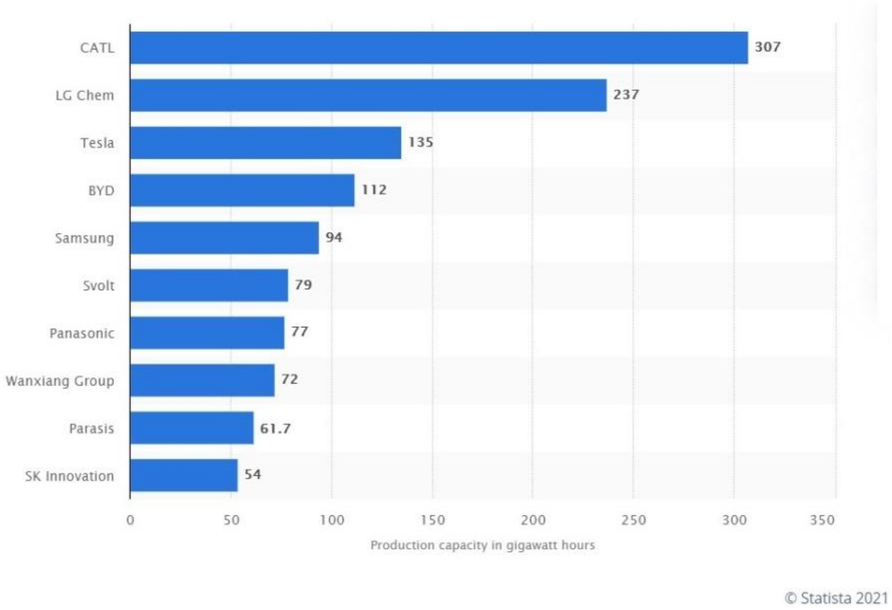

Figure 28. Lithium-ion battery production capacity by 2028, by company (GWh)

Electric vehicles worldwide

Since the global negotiations on climate change action are not unilaterally accepted, huge variations across countries exist. Some countries heavily subsidize and encourage citizens and firms to purchase electric cars, prioritize the green transition, and mitigate climate change. In 2019, over 100,000 new electric passenger vehicles were registered in Germany, more than six times as large as the number registered in Spain. In terms of the electric vehicles in use, the estimated number in China is above 3.3 million units and 1.4 million units in the U.S.[128]

[128] https://www.statista.com/statistics/1103401/predicted-lithium-ion-battery-capacity-by-company/ Accessed on 27.05.2021

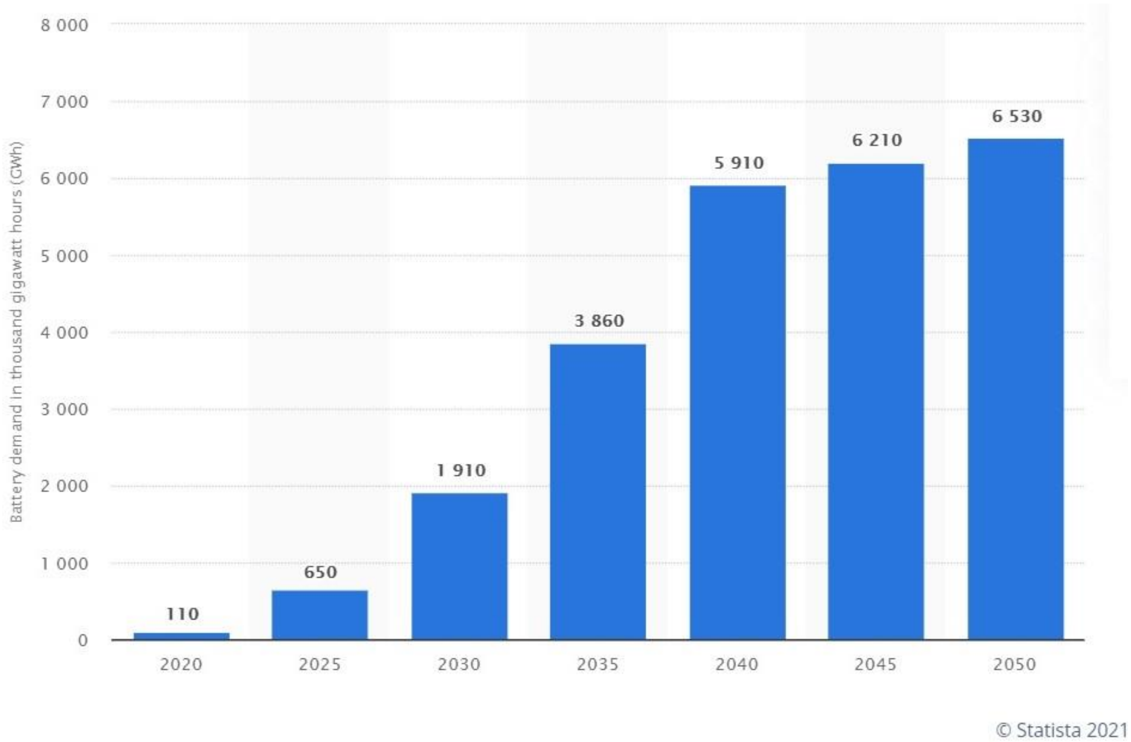

Figure 29. Forecasted demand for electric vehicle batteries worldwide from 2020 to 2050 (GWh)

In 2020, the global demand for electric vehicle batteries (Figure 29) was expected to amount to 110 GWh. This volume is expected to increase drastically worldwide, with a predicted demand of 6,530 GWh in 2050, about 600 times the value at the beginning of the forecasted period.

The advanced battery market is predicted to observe vigorous growth during years to come due to intensifying emphasis on clean energy practice, increasing adoption of electric vehicles and refining economics of battery storage systems. Furthermore, the development in electric vehicles and electronic gadgets is probable to boost the next generation battery market in the coming years. However, advanced batteries incur limitations such as high costs, long recharge time, and short cycle life span, which hampers the market growth[129].

3.3.2 Customers – Other Transportation

"There is a massive, ongoing electrification of the global energy system; where electricity is less than 20% of the energy mix today, it will more than double its share by 2050. During that

[129] https://www.mynewsdesk.com/jp/automotive-industry-desk/pressreleases/Advanced-Battery-Market-Size-Growth-Trends-Scope-and-Forecast-Report-2021-2030-3072527 Accessed on 01.06.2021

period, solar PV will grow 25-fold and wind 10-fold, and in roughly equal shares will together be responsible for over 60% of the electricity generated by 2050. The plunging costs and technological advances in renewables are remarkable and nowhere more so than in fixed and floating offshore wind. Electricity powered by renewables is the main driver of accelerating efficiency gains in our global energy system that will outpace both population and GDP growth, such that the world will reach peak primary energy supply in just over a decade from now"
Remi Eriksen, Group President & CEO, DNV GL Energy Transition Outlook 2020[130]

Although transport services will typically double (or more) over the forecast period, energy use will diminish. The most important reason is the significant efficiency improvement associated with the switch from internal combustion engine to battery-electric propulsion. Roughly half of the world's fleet of passenger vehicles will be electric by 2040. Efficiency gains in the road-transport subsector will more than counterbalance the increases in energy demand in aviation and rail. This trend will also be helped by the maritime sector experiencing dramatic efficiency gains that will strongly reduce energy use, despite substantial growth in the world fleet.

The energy mix in aviation and maritime is similar to the one in the road transport sector, whereas in the rail subsector, 42% of energy use is electric. Biofuel mandates are a prime example of the role of public policy in transport fuels. Decarbonization and fuel efficiency are interlinked, and some regions, notably China and OECD countries, use a mixture of "push and pull" strategies to achieve their decarbonization ambitions. Moreover, UN bodies, such as the International Maritime Organization (IMO), have opted for firm targets.

All sectors will face continued pressure to reduce carbon emissions, but alternatives to fossil fuels are less readily available or not practical in specific demand sectors, like heavy industry, maritime transport, and aviation. In maritime, alternative fuels and power sources vary significantly for different ship segments and their technical applicability and commercial viability. Direct electrification is expected to play a minor role beyond the shortsea segment. However, power-to-x, with X, in this case, being liquids such as hydrogen used directly in its

[130] https://eto.dnv.com/2020 Accessed on 01.06.2021

compressed or liquefied form or used as a basis for different electro fuels (diesel, methane, methanol or ammonia), is expected to play a major role.

1.1.1.1 Maritime Vessels

Maritime transport is by far the most energy-efficient mode of transport in terms of joules/ tonne-kilometre. Almost 3% of the world's final energy demand, including 8% of the world's oil, is consumed by ships, mainly international cargo shipping.

In 2020, the IMO regulation on a global sulphur cap came into force, dramatically altering the types of fuel used by the fleet. The main shift has remained within the category of oil-based fuels. We see a much larger share of lighter distillates, other variants of fuels with less sulphur, and a decent percentage of marine heavy fuel oil still being used on ships with scrubbers. In the longer run, the IMO – supported by both shipowners and governments – targets a 50% reduction in CO2 emissions from 2008 to 2050.

Corvus Energy forecasts that a mixture of improved utilization and energy efficiencies, combined with massive fuel decarbonization, including conversion from oil to gas and ammonia and other low- and/or zero-carbon fuels, will enable this goal to be met.

The maritime transport sector currently emits 820 Mt CO2, some 2.3% of global emissions. We forecast that this will decrease to around 600 Mt by 2050, accounting for about 3.5% of global emissions. As direct electrification is expected to be viable only in the shortsea segment and few low- and zero-carbon fuel alternatives are available and practical today, maritime transport is considered a hard-to-abate sector. We forecast a high share of natural gas, ammonia, and other low- and zero-carbon fuels in 2050, but additional action is needed to reduce emissions to a lower level than we currently forecast.

Co-funded by the Erasmus+ Programme of the European Union

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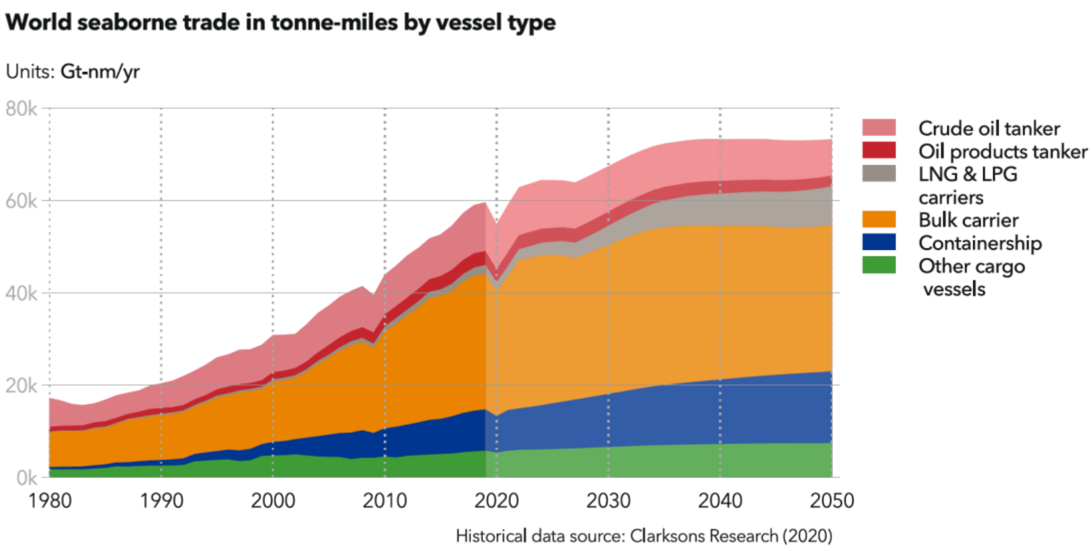

Figure 30. World seaborne trade in tonne-miles by vessel type[131]

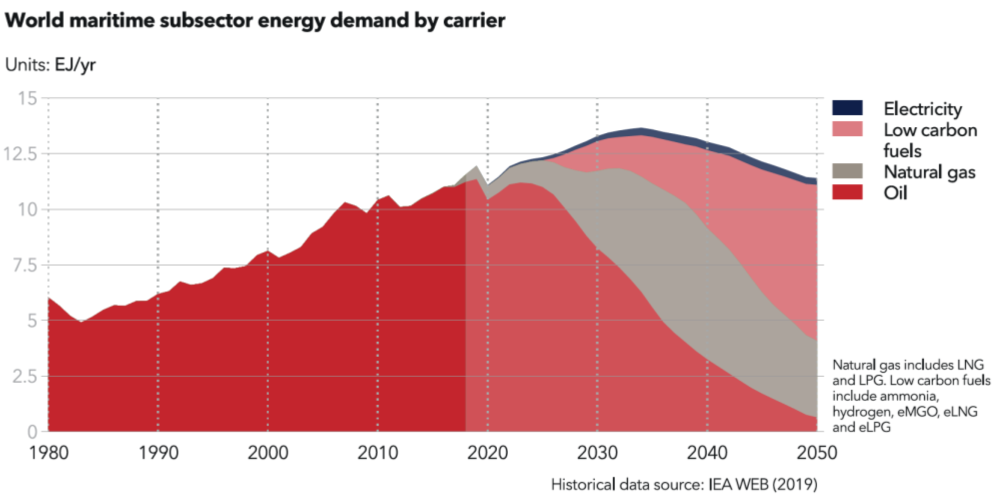

Figure 31. World maritime subsector energy demand by carrier[132]

Market insights - Maritime

The figures are from DNV *Alternative Fuels Insight, May 2021*

[131] https://www.iea.org/reports Accessed on 24.08.2021

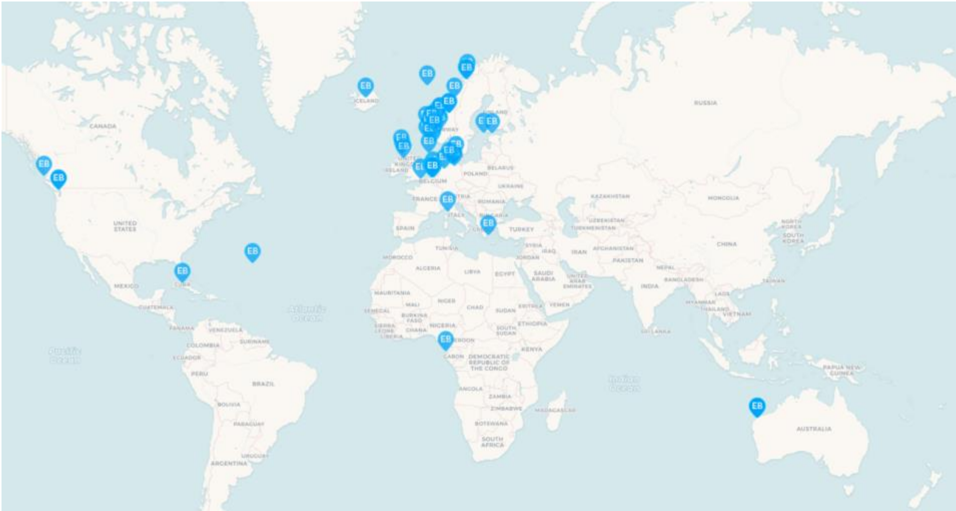

Figure 32. AIS-Positions of ships with batteries installed[132]

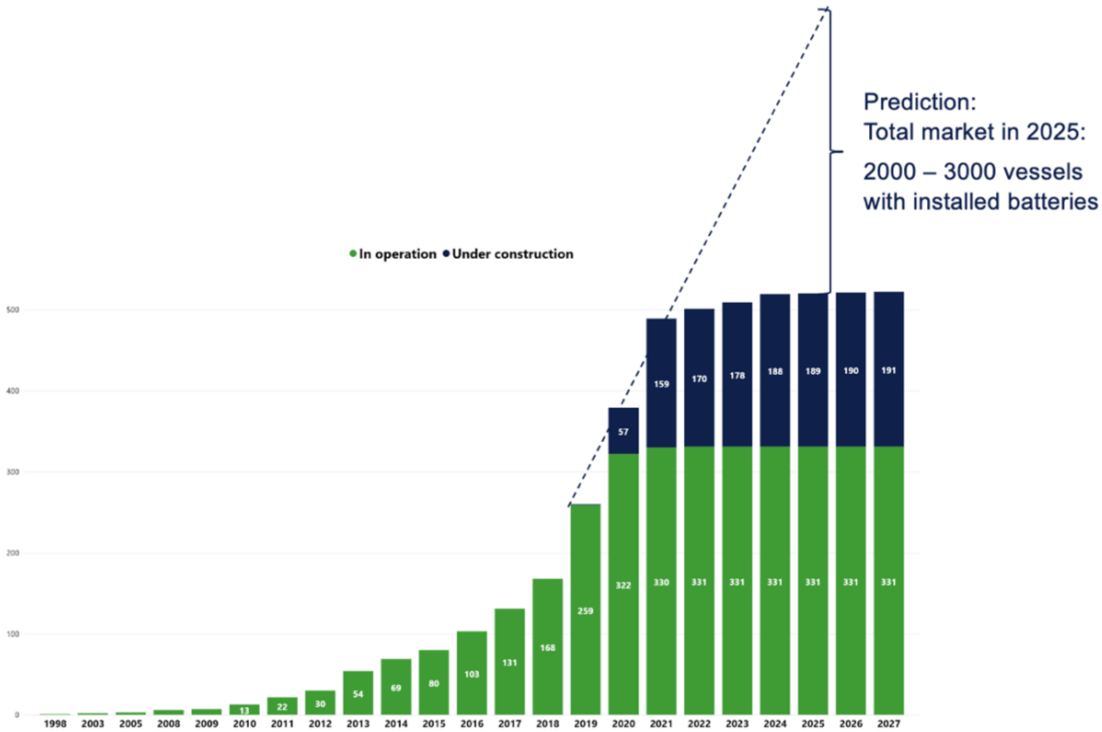

Figure 33. Maritime ESS installations- With predictions[133]

[132] https://www.dnv.com/services/alternative-fuels-insight-128171 Accessed on 24.08.2021

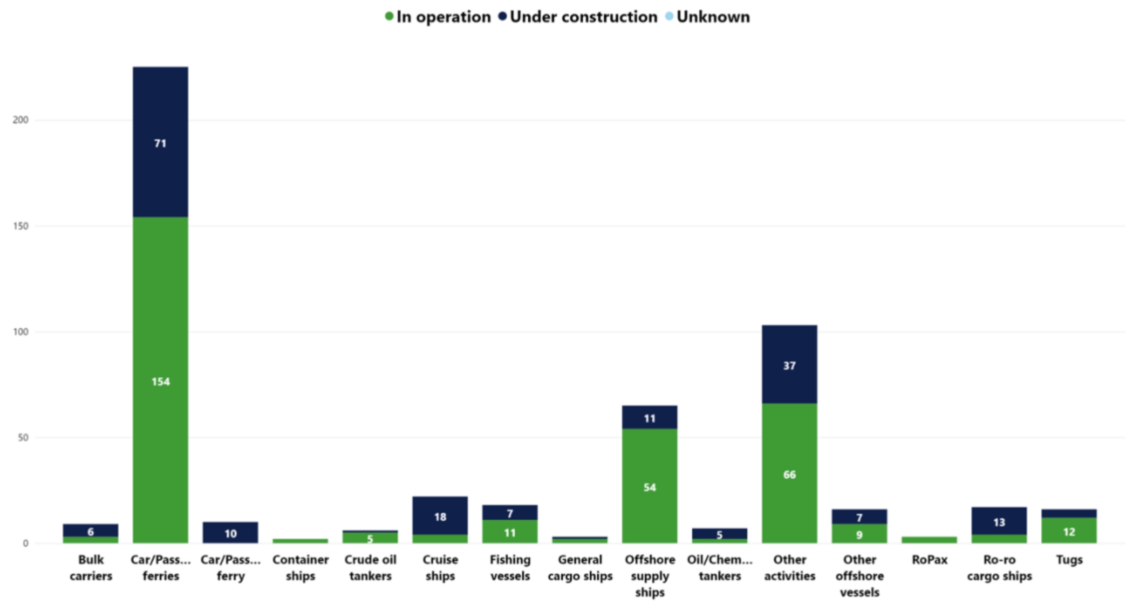

Figure 34. Number of ships with batteries by ship type (2020)[133]

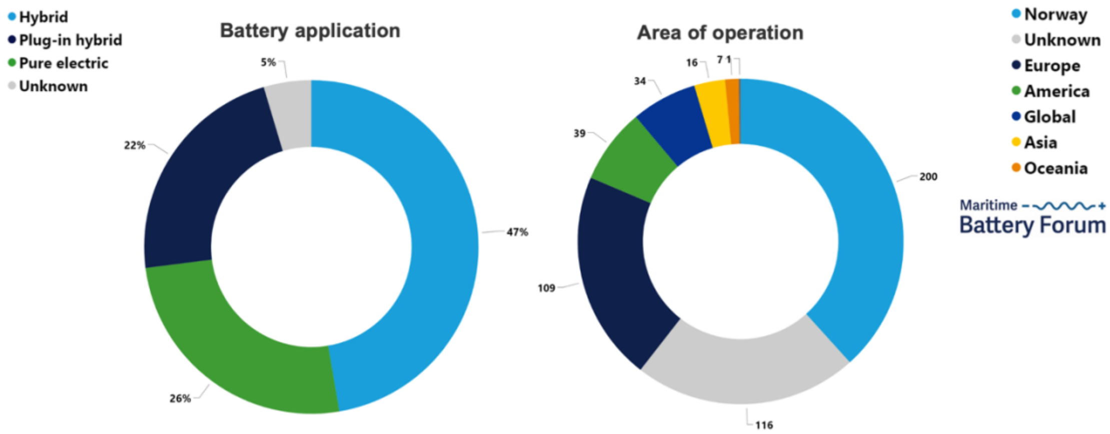

Figure 35. Battery application and geographic area of operation[134]

133 https://www.dnv.com/services/alternative-fuels-insight-128171 Accessed on 24.08.2021

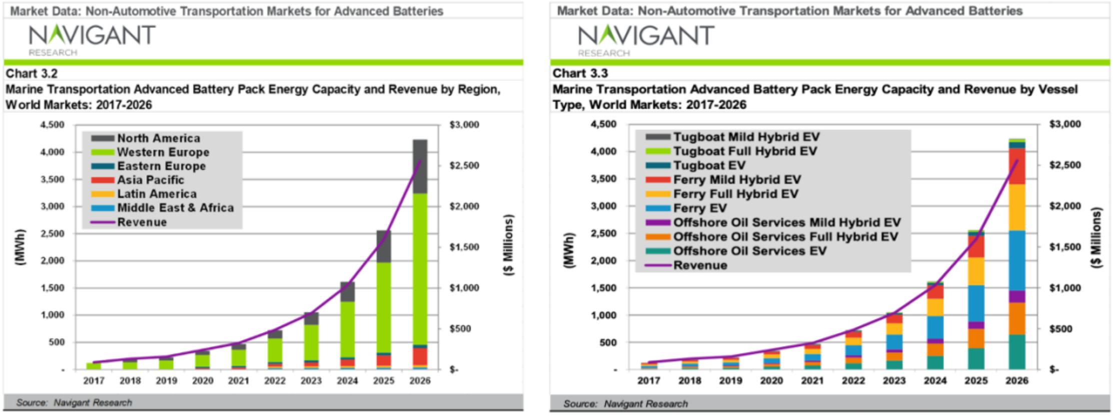

Figure 36. Industry forecast: Non-automotive transportation markets for advanced batteries[134]

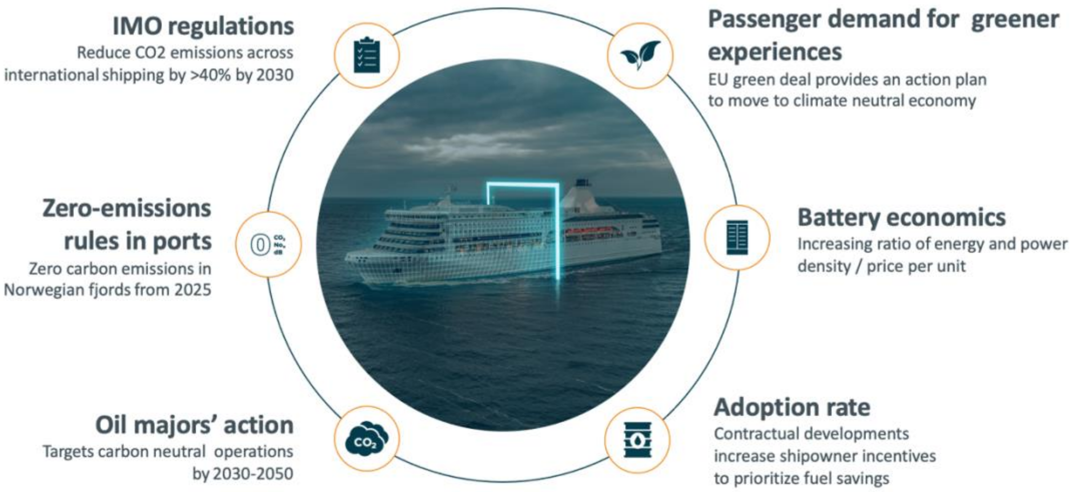

Figure 37. Numerous tailwinds behind the electrification of shipping[135]

Table 6. Drivers towards energy storage in maritime

TECHNICAL	OPERATIONAL	COST	REGULATORY	SOCIETAL
• R&D • Cell chemistry • 1st off projects • Cluster work • Future fuels development	• Safer operations • More flexibility • More resource effective operations • Digital • Charter requirements	• Fuel saving • Cost saving • ROI • Funding • ESS cost, weight and density	• Global, class, local • IMO 2018 - 50% reduction by 2050 • IMO 2019 - Data collection system • IMO 2020 - Sulphur limit in fuel oil reduced from 3,5% to 0,5% (0,1% ECAs)	• The combat against climatechange • Decarbonization • ESG - Environmental Social Governance

[134] Material done by Corvus

1.1.1.2 Electric Aircraft

Almost 4% of the consumed world's energy and 2% of carbon emissions are generated by civilian aircraft. Driven by increasing living standards, influenced by regional geographies and travel cultures, aviation has shown strong growth in the past decades[135].

The number of annual air trips is forecasted to double by 2050 compared with 2018 numbers (Figure 38), with fuel use in aviation only increasing by 9%. This is due to efficiency gains, as higher load factors and developments in engines and aerodynamics will yield impressive improvements in energy efficiency.

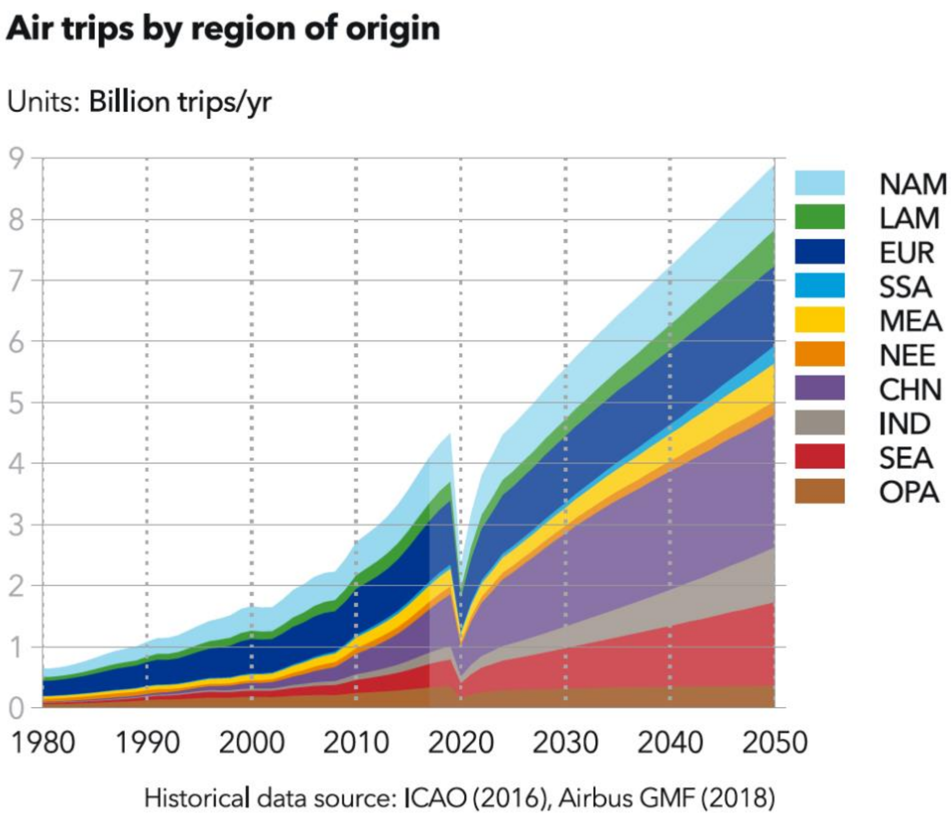

Figure 38. History and forecast of aeroplane trips per year[136]

We see strong passenger – and cargo – growth ahead. As with shipping on keel, we envisage that pockets of short-haul flights will become electrified. A more significant driver of reductions in emissions will be sustainable aviation fuels (SAF), biofuel blends.

[135] https://www.iea.org/reports/ Accessed on 20.08.2021

[136] https://eto.dnv.com/2020 Accessed on 20.08.2021

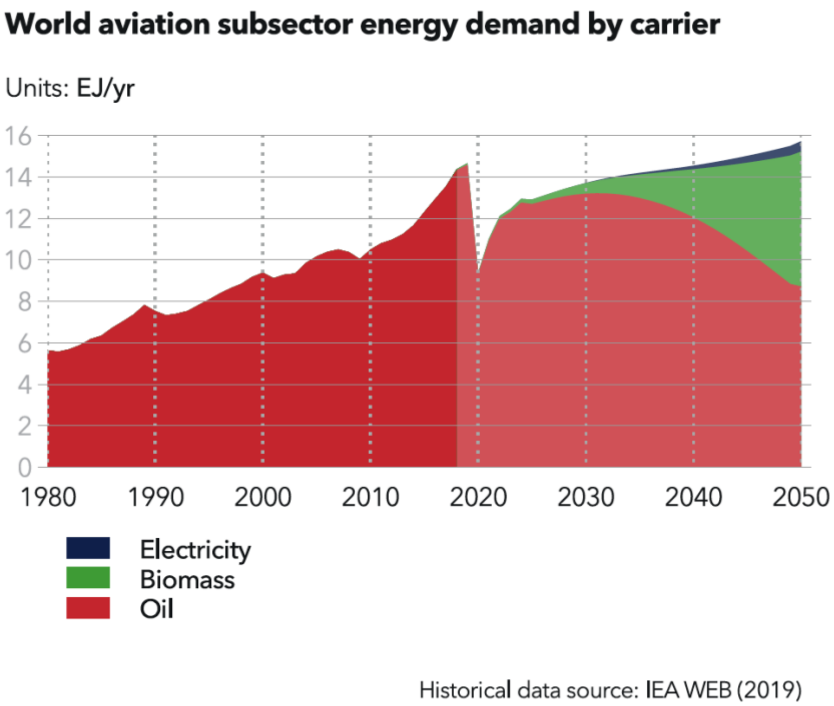

Figure 39. Historical status and forecast of energy source for airplanes[137]

Electric planes have been experimented with since the 1970s. However, no significant results have been achieved. Most recently, with the substantial investment in batteries and specifically in electric aircraft, commercial flights are starting to become a reality. Figure 40 illustrates, the way companies (Table 7) and agencies (Figure 39) notice the market's potential for electric propulsion aircraft. However, due to the weight of the batteries necessary to provide the power and the energy required for long-distance travels, the electric propulsion for aircraft may be limited in the next few years for small air crafts and short commercial flights[137].

[137] https://www.rolandberger.com/en/Insights/Publications/Electric-propulsion-is-finally-on-the-map.html

Accessed on 20.08.2021

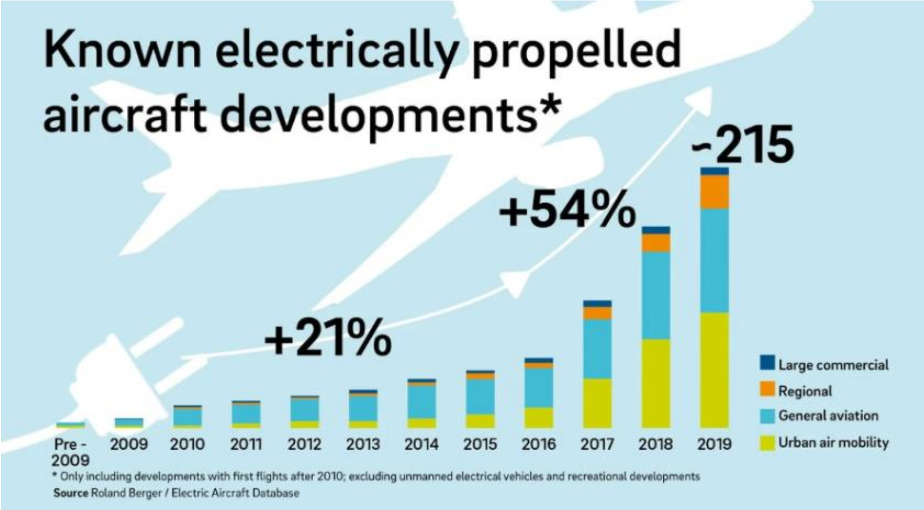

Figure 40. Known electrically propelled aircraft developments until 2019

"Rolls-Royce is entering the development of new energy storage systems for eVTOLs and electric commuter aircraft. The company is investing 80 million pounds (around 93.4 million euros) in this by 2030. Rolls-Royce says that its goal for its battery systems is to operate zero-emission flights of more than 100 miles (160 kilometres). The energy storage systems (ESS) are suitable for all-electric and hybrid propulsion systems of VTOLs or aircraft for up to 19 seats. In March 2021, Rolls Royce and aircraft designer Tecnam partnered with Norwegian regional airline Widerøe to deploy an all-electric passenger aircraft by 2026[138]."

138 https://qz.com/1943592/electric-airplanes-are-getting-close-to-a-commercial-breakthrough/ Accessed on 20.08.2021

Table 7. Major Stakeholders for the electric aircraft business[139] [140]

Country	Key Manufacturers	Market Players	Commercial Electric Aircraft Companies
France	SAFRAN, THALES	SAFRAN, THALES	
United Kingdom	RR, GKN Aerospace	MEGGiTT, BAE SYSTEMS	RR, Loganair, faradair
Netherlands	AIRBUS		AIRBUS
Germany			DUFOUR AEROSPACE, SIEMENS
Switzerland			DUXON AG Industrie-Elektronik
USA		Honeywell, United Technologies, GE Aviation, AMETEK, Esterline, PBS, Hartzell, Radiant Power Corp, Raytheon, Crane Aerospace & Electronics, Astronics, Pioneer Magnetics, Avionic Instruments, Carlisle	GE Aviation, WRIGHT, AMPAIRE, Pipistrel, Bye Aero, Joby Aviation, BOEING, ZUNUM Aero, magniX, Electric Aircraft Corporation
Canada		EaglePicher Technologies, LLC	
Brazil			EMBRAER
Japan		Nabtesco	
Israel			IAI, EVIATION

Figure 41. European Government Agencies supporting electrification of aircraft[140]

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[139] https://www.marketsandmarkets.com/Market-Reports/aircraft-electrification-market-31650461.html Accessed on 20.08.2021

[140] https://www.visiongain.com/report/top-20-companies-developing-commercial-electric-aircraft-2020/ Accessed on 20.08.2021

1.1.1.3 Trains

The rail subsector consists of all rail-using transportation, including urban rail systems. Presently, the rail sector provides little more than 2% of global transport and is responsible for about 0.5% of the worldwide energy use. The rise in passenger numbers will be substantial due to income growth elasticity to above unity, with a global passenger increase of about 135% by 2050. Rail-freight transport will, however, continue its downward slope in many regions, although not all.

For passenger transport, especially in urban areas, the space efficiency of rail transport is superior to other options, and the ease of electrification also makes it a favourable alternative for transport decarbonization[141].

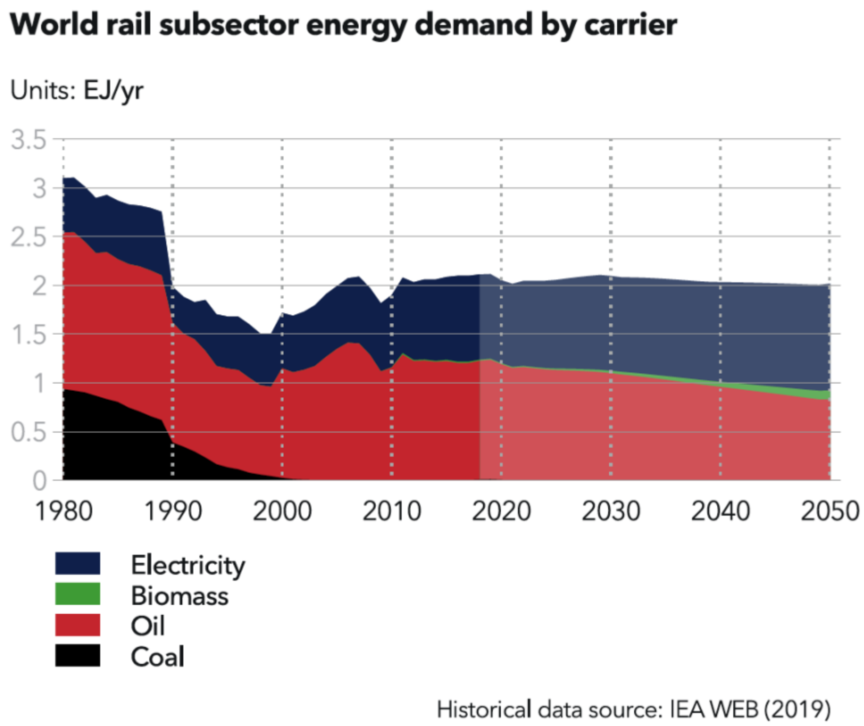

Figure 42. Historical and prediction of energy demand and source for the rail subsector[142]

Electric-powered trains are not a new emerging technology as it is in other vehicles like cars, vessels, or aeroplanes. The technology of an electric engine has been developed to a stage where almost half of the trains in service are powered by electricity. Nevertheless, investment and maintenance in the electrification of rail lines for powering the trains are still needed.

[141] DNV GL Energy Transition Outlook 2020. https://eto.dnv.com/2020 Accessed on 20.08.2021
[142] https://eto.dnv.com/2020 Accessed on 20.08.2021

With the recent developments in energy density and longevity, providing batteries to the trains allows some rail routes to go electric. This can be beneficial in locations where electrification by extending already electrified lines and allowing charging during the service would not be possible, practical, or affordable.[143]

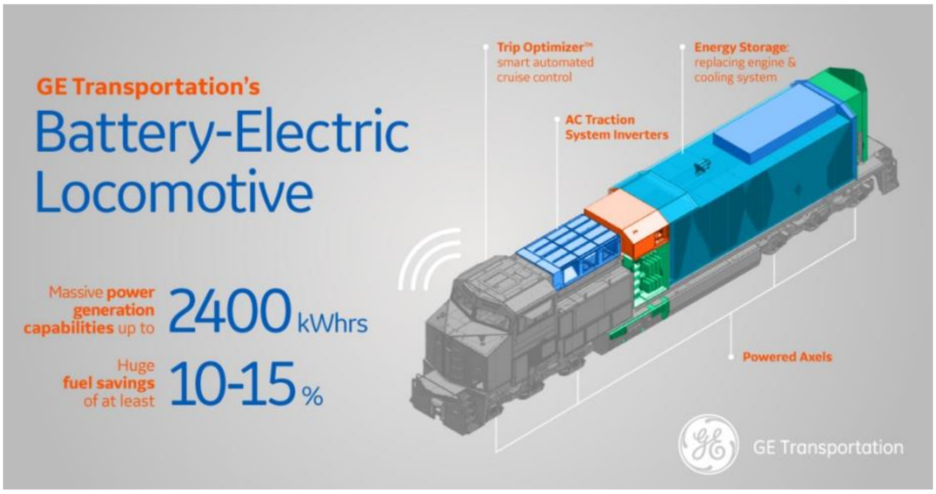

Figure 43. The layout of a battery-powered locomotive for GE Transportation

The global market size for battery-powered trains in 2020 is estimated at 144M US$, and it is expected to reach 257M US$ by 2030. Urbanization in emerging countries and developed countries is the main driver of growth for the next few decades. Transportation by train is one of the most efficient transportation modes and with the lowest pollution, aligning the market increase with the zero CO_2 emission for the energy and transportation sector and other environmentally sustainable goals supported in Europe and the rest of the world[144].

[143] https://www.greencarreports.com/news/1127629_battery-powered-electric-trains-will-soon-bring-cleaner-air-especially-in-europe Accessed on 20.08.2021
[144] https://www.marketsandmarkets.com/Market-Reports/train-battery-market-6068646.html Accessed on 20.08.2021

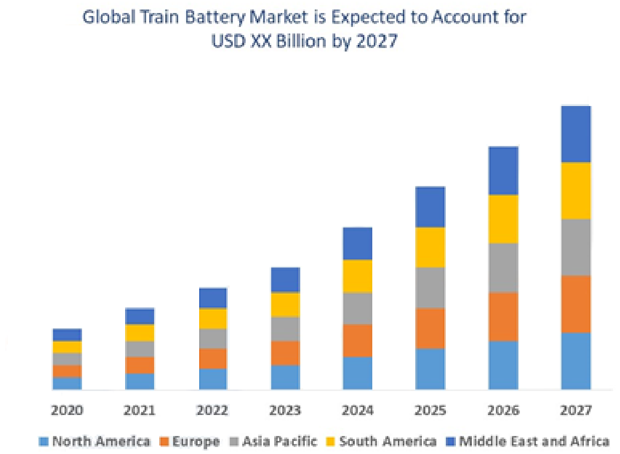

Figure 44. Global train battery market by region[145]

The covid-19 pandemic has negatively affected the train sector by reducing the demand for this transportation method. In addition, the requirements for physical distancing decreased the maximum rail car tenancy, and efforts for disinfection requirements elevated operational costs. In Europe, the tendency was counteracted by using trains as transportation for food, coal, and health-related materials during lockdown[15].

The Canadian firm Bombardier launched an electro-hybrid train with a range of 100 km on a non-electrified rail line. In a partnership with BNSF in the US, GE Transportation is developing a battery-powered locomotive with a 2,4 MWh pack, with a potential autonomy of hundreds of kilometres. This milestone is significant for the US since less than 1% of the rail miles are electrified compared to the global value of 1/3[146].

The Netherlands has already achieved 100% of electric trains running on renewable energy sources: wind energy. Batteries play a major role in storing energy to provide energy when wind levels are low[147].

In Germany, only 40% of the rail lines are electrified. The battery-electric trains will electrify the routes that were not possible to electrify due to impossibility or expensive investment. For example, the Baden-Württemberg state has ordered 20 two-car trains with a top velocity

145 https://www.databridgemarketresearch.com/reports/global-train-battery-market Accessed on 20.08.2021
146 https://eto.dnv.com/2020 Accessed on 20.08.2021
147 https://www.greencarreports.com/news/1108346_all-dutch-electric-trains-now-running-on-100-percent-renewable-energy Accessed on 20.08.2021

of 150 km/h from Siemens. In addition, the Alstom company announced the supply of battery-electric trains to the Leipzig-Chemnitz line[148].

3.3.3 Customers – Stationary Applications

Battery Energy Storage Systems (BESS) are demonstrating to be valuable assets in the decarbonization of the energy sector. Numerous drivers of change contribute to the increasing popularity of integrating batteries in the electric grid, such as decreasing costs, flexibility, stabilization of the electric grid, funding programs, renewable energy sources integration, etc. BESS do not require complex infrastructure projects, while mobile and modular solutions can be provided and quickly installed at every level of the electric grid - Figure 45.

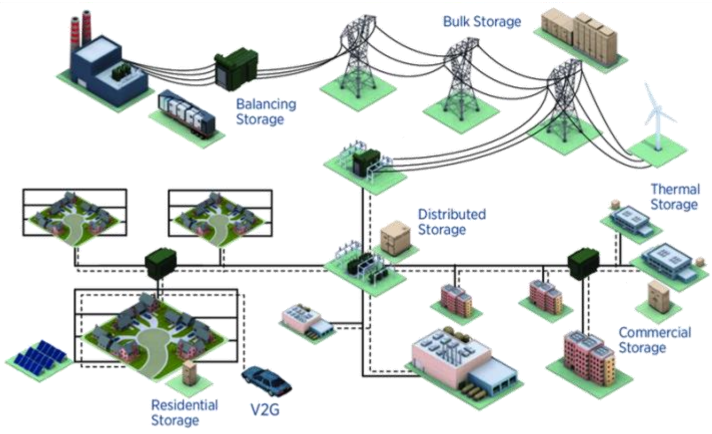

Figure 45. Potential locations and applications of electricity storage in the power system[149]

Battery systems can accumulate or dispatch energy to the electric grid in fractions of seconds, making them versatile assets for different applications. The Rocky Mountain Institute[150] identified thirteen fundamental services for three major stakeholder groups when deployed behind the meter (Figure 46). The further downstream BESSs are in the electricity system, the more services they can offer to the system at large, which may also increase independence from a centralised energy system[151].

[148] https://www.greencarreports.com/news/1127629_battery-powered-electric-trains-will-soon-bring-cleaner-air-especially-in-europe Accessed on 20.08.2021
[149] https://www.irena.org/newsroom/pressreleases/2015/Jun/IRENA-Roadmap-Breaks-New-Ground-on--Renewable-Energy-Storage Accessed on 26.08.2021
[150] https://rmi.org/wp-content/uploads/2017/03/RMI-TheEconomicsOfBatteryEnergyStorage-FullReport-FINAL.pdf Accessed on 20.08.2021
[151] https://www.eurobat.org/images/news/publications/eurobat_batteryenergystorage_web.pdf Accessed on 20.08.2021

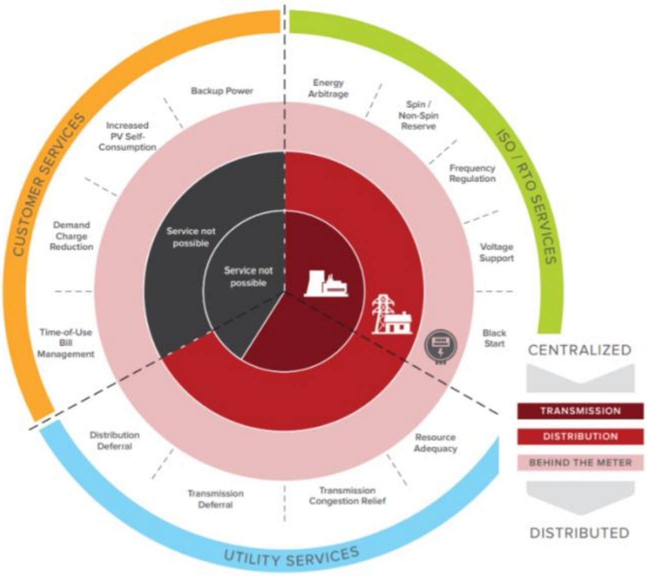

Figure 46. Services batteries can provide[152].

In the long-term outlook, BESS + photovoltaic (PV) and energy shifting applications show the steepest growth until 2030, with an expected annual investment from $8,6 billion in 2020 to $30,1 billion in 2030[153].

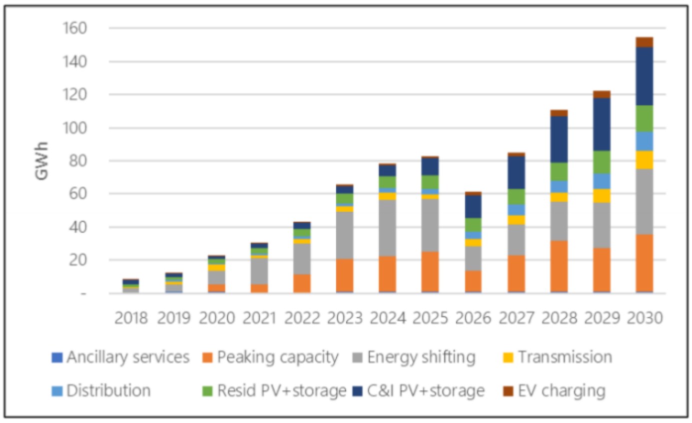

Figure 47. Projected grid-related annual deployment by application[154].

[152]Rocky Mountain Institute "The Economics of Battery Energy Storage", 2015 https://www.slideshare.net/JillKirkpatrick2/energy-storage-summit-2018-day-2 Accessed on 26.08.2021
[153]https://www.energy.gov/sites/prod/files/2020/12/f81/Energy%20Storage%20Market%20Report%202020_0.pdf Accessed on 20.08.2021
[154] Bloomberg New Energy Finance, "2019 Long-Term Energy Storage Outlook," BloombergNEF, New York, 2019. Available: https://about.bnef.com/blog/energy-storage-investments-boom-battery-costs-halve-next-decade/ https://www.energy.gov/sites/prod/files/2020/12/f81/Energy%20Storage%20Market%20Report%202020_0.pdf Accessed on 26.08.2021

Global Market Overview

The global storage capacity has been increasing consistently throughout the years Figure 48 Nevertheless, in 2019, the annual deployment decreased for the first time. The almost 30% drop compared to 2018 can be explained by several factors, such as battery storage still being an in-development technology, present in only a few markets, and being profoundly dependent on policy support[155]. In addition, Covid-19 created turmoil in the global economy. However, grid BESS showed resilience and expanded the global market with 2,4 GW of capacity, and recent forecasts point to 134,6 GW and 437 GWh of accumulated capacity worldwide. Most of the active systems were deployed to provide frequency regulation, which requires high-power and short duration batteries. With future evolutions in the market and regulations, grid storage is expected to grow stronger in other applications, namely in assets that may replace or defer gas peaker plants, new RES plants and transmission lines, requiring storage systems with higher capacity[156].

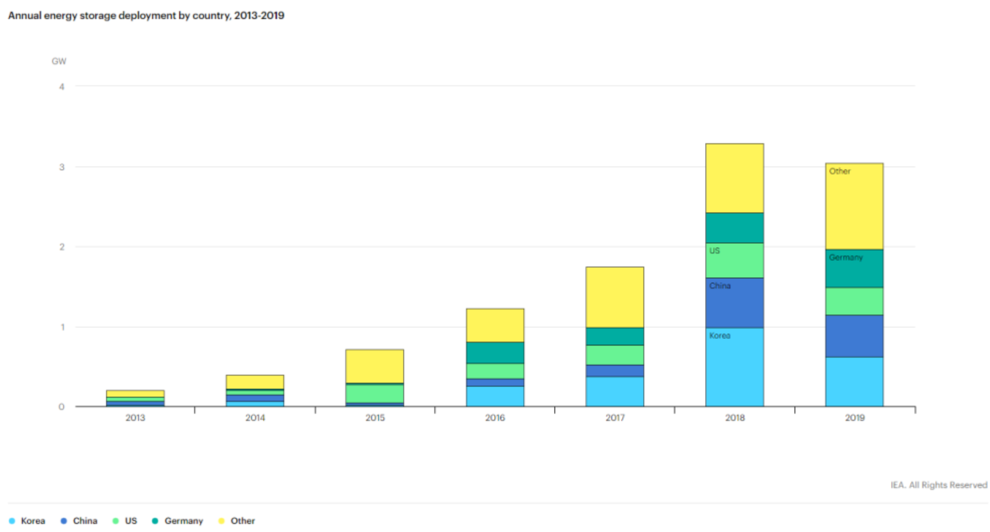

Figure 48. Annual energy storage deployment of battery by country 2013-2019[157]

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155 https://www.iea.org/reports/energy-storage Accessed on 20.08.2021

156 https://www.prnewswire.com/news-releases/worldwide-grid-battery-energy-storage-industry-to-2030---in-2020--the-global-market-expanded-47-3-with-2-4-gw-of-new-power-capacity-301268789.html Accessed on 20.08.2021

157 https://www.iea.org/search?q=Annual%20energy%20storage%20deployment%20by%20country%20%2C%202013-2019 Accessed on 26.08.2021

South Korean installations dropped by 80% after a record in 2018, after growing concern over several fire incidents at grid-scale storage plants in 2018. Although the root cause of the fire incidents was identified and counteracting safety measures were implemented, the confidence was not fully restored.

In the United States of America, after the wildfire disaster in 2019, incentives for installing BESS for backup power facilitated 10 000 behind-the-meter (BTM) storage systems to be sold. Utilities favour the co-location of BESS with PV plants with announced projects of 15 GW. Virginia and Nevada announced long-term targets for 3,4 GW.

In 2019, Australia expanded to over 200 MW of capacity under construction.

The announcement of new projects in China declined by one-third after reviewing its regulations where grid companies no longer may include storage costs in energy transmission and distribution fees. The market tendencies are now showing interest in the allocation of BESS to reduce the curtailment in RES generation.

The co-location of RES facilities and BESS facilitates the stabilization of energy production and safeguards the demand during peak hours. Countries like India and Singapore rewarded this application with PV+storage auctions for 1,2 GW and 200 MW of storage capacity, respectively.

Regulations and legislations are essential for eradicating barriers to stimulate and implement investment in storage technologies[158].

Regulation frameworks need to be clear and transparent to identify the services that transmission and distribution operators are allowed to provide and avoid competition with power generators. Ownership of a storage system is a complex issue as it is considered both a generation asset and a system operator benefiting both transmission and distribution[159].

The market is predicted to stay focused on certain countries with supportive dynamics and regulations. China, the USA, and Australia are predicted to account for 2/3 of the global annual power additions. In most countries, the BESS installations will remain pending cost reductions, market design modernization and supportive regulations and legislations[160].

[158] https://www.ncsl.org/research/energy/energy-storage-for-a-modern-electric-grid-technology-trends-and-state-policy-options.aspx Accessed on 20.08.2021

[159] https://www.eurobat.org/images/news/publications/eurobat_batteryenergystorage_web.pdf Accessed on 20.08.2021

[160] https://www.prnewswire.com/news-releases/worldwide-grid-battery-energy-storage-industry-to-2030---in-2020--the-global-market-expanded-47-3-with-2-4-gw-of-new-power-capacity-301268789.html Accessed on 20.08.2021

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Recently, improvements in batteries' costs and performance (Figure 49) due to the massive investments and growing demand for electric vehicles (EVs) - contribute largely to a favourable future for BESS. Thus, a snowball effect has been achieved linking policies, R&D investment, manufacturing capacity increase to create a learning curve and economy-of-scale effects that continually conduct to cost declines and exponential demand growth[161].

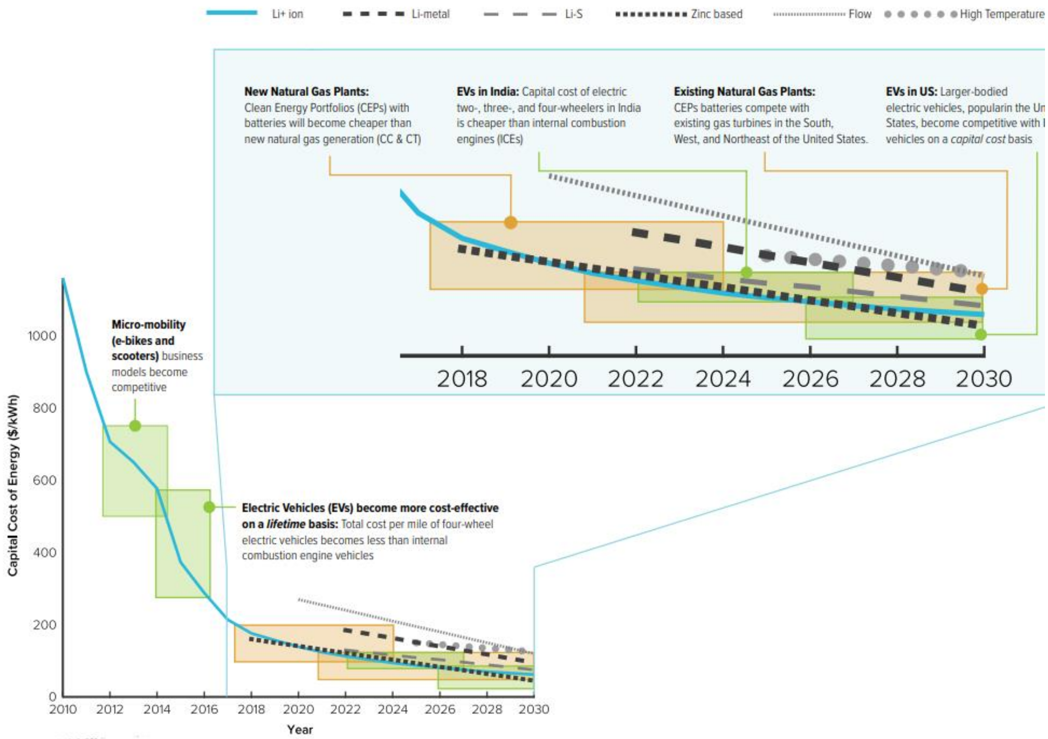

Figure 49. Historical and predicted cost of energy and related events[162]

Lithium-ion batteries (LiB) are predicted to remain as leading technology due to their decrease in CAPEX. Although lead-acid batteries will remain the most important battery market in volume until 2025, the shift to LiB of almost all carmakers is increasing the importance of this technology. Other technologies as nickel-based are also declining in favour of LiB[163].

[161] https://rmi.org/insight/breakthrough-batteries/ Accessed on 20.08.2021
[162]Rocky Mountain Institute "The Economics of Battery Energy Storage", 2015 https://www.slideshare.net/JillKirkpatrick2/energy-storage-summit-2018-day-2 Accessed on 26.08.2021
[163]https://ec.europa.eu/energy/sites/default/files/report-_battery_storage_to_drive_the_power_system_transition.pdf Accessed on 20.08.2021

European Market Overview

In Europe, batteries have been recognized as a key enabler for the transition to the climate-neutral economy for e-mobility and energy generation sectors[164]. The European Clean Energy Package (promoted by the European Commission) defined storage as an independent entity from generation, transmission, or load pocket generation. This action avoids double taxation on charging and discharging and is seen as strong support for energy storage[165]. The European Commission considers the batteries value chain as highly strategic, where the European Union (EU) must invest and innovate to strengthen the industrial policy strategy[166]. From the EU Green Deal, the European Commission began reviewing relevant EU legislation to assess what amendment or additional legislation is required to turn the EU carbon neutral by 2050. As a result, energy storage technologies are expected to become increasingly eligible for funding, consolidating the business and deployment in the EU[167].

While energy storage is being recognized as key to achieving carbon neutrality in the energy sector, batteries are becoming the most demanded technology for energy storage. The main drivers of change for the increasing popularity of batteries are

- the tendency to decrease costs,
- the flexibility of applications such as regulation of voltage and frequency,
- the possibility to reduce peak demand charges,
- the integration of RES,
- the possibility of backup power supply,
- the relative ease of installation,
- the huge potential for market growth in the future.

Although pumped storage still has its share of revenue, the plummeting of the prices in contrast to the electrochemical storage explains its decrease in popularity - Figure 50[168].

[164] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0953&from=ES Accessed on 20.08.2021

[165] https://www.iea.org/reports/energy-storage Accessed on 20.08.2021

[166] https://ec.europa.eu/energy/topics/technology-and-innovation/energy-storage_en#eu-initiatives-on-batteries Accessed on 20.08.2021

[167] https://www.nortonrosefulbright.com/es-es/knowledge/publications/1a7a8794/energy-storage-updater Accessed on 20.08.2021

[168] https://www.mordorintelligence.com/industry-reports/europe-energy-storage-systems-market-industry Accessed on 20.08.2021

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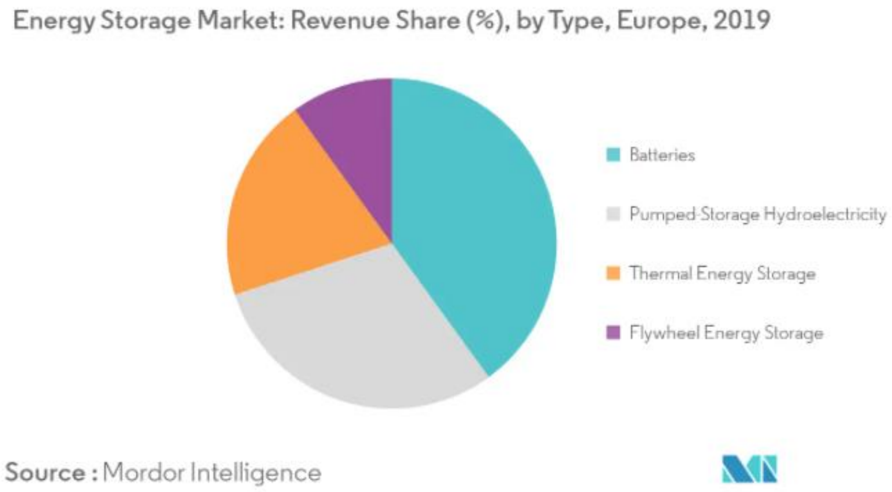

Figure 50. Market revenue share (%) by type of energy storage[169]

Although the Covid-19 pandemic hit several markets, the BESS market remained strong. It is predicted that Europe will increase energy storage capacity by 55% in 2021 compared to 2020, which translates into 3 GWh, and a cumulative capacity of 9 GWh. Although these numbers may look small compared to the rest of the world, one must consider that in 2017 almost no BESS were installed in Europe. The growth reflects Europe's investment in the battery value chain, more intensive than other regions around the globe[169].

European legislative proposals (Clean Energy for all Europeans) are elaborated to remove barriers to implementing BESS in the EU. Germany and the UK are leaders in the implementation of BESS due to financial incentives. Italy, Spain, and France are expected to grow and become relevant in the BESS market[170] - Figure 51 and Figure 52.

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[169] https://www.smart-energy.com/industry-sectors/storage/global-energy-storage-market-trends-through-2030/ Accessed on 20.08.2021

[170] https://ec.europa.eu/energy/sites/default/files/report-_battery_storage_to_drive_the_power_system_transition.pdf Accessed on 20.08.2021

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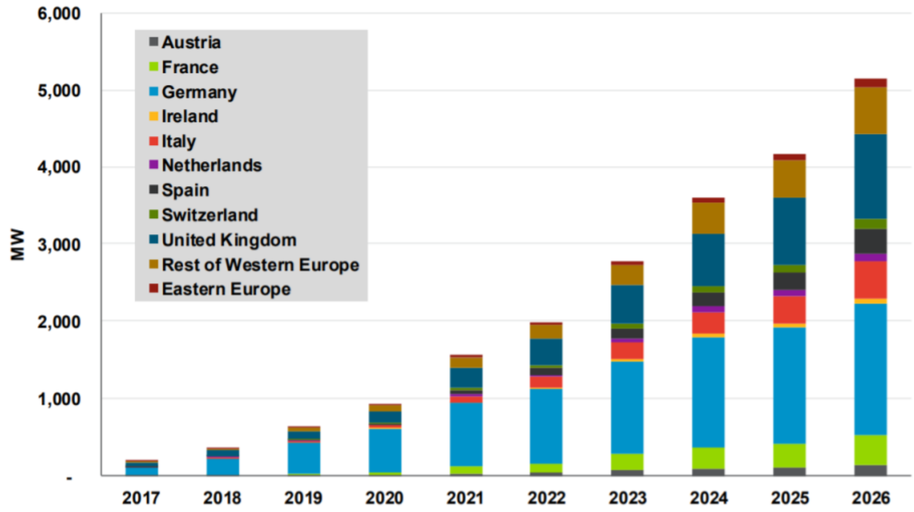

Figure 51. Annual installed distributed energy storage capacity[171]

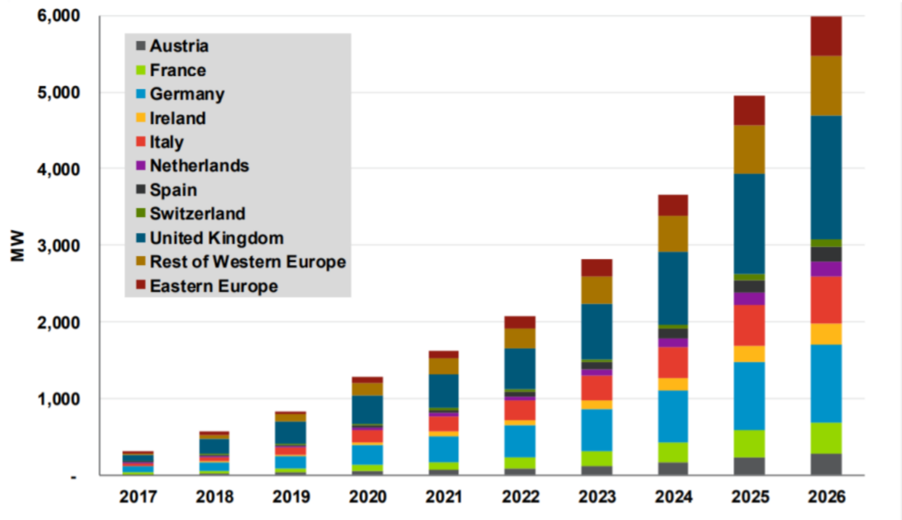

Figure 52. Annual installed utility-scale energy storage capacity[172]

Compared to other countries, eastern European countries still have a very low share of energy storage (Figure 51 and Figure 52). The market in Eastern Europe is still dominated by pumped hydro storage, with around 15 GW of installed and under-construction projects. Ukraine, Poland, and the Czech Republic share the highest capacity with 2,6 MW, 1,2 MW and 1,1 MW, respectively. However, the demand for energy storage continues to increase, mainly for grid support/resiliency and integration of RES. It is expected for 31.1 GW of new capacity to be installed by 2025. Although there is a potential for installing electrochemical storage, heavy

[171] https://ec.europa.eu/energy/topics/technology-and-innovation/energy-storage_en#eu-initiatives-on-batteries Accessed on 6.7.2021

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regulation, and predominantly state-owned enterprises in the electricity market dating from the Soviet era are challenges for implementing battery storage. Overproduction of energy can also challenge the energy transition. For example, Bulgaria has an estimated 80% of excess generation capacity due to extensive, centralized generation facilities and low demand for energy. Nonetheless, there is a potential for growth in the coming decade, being the most attractive markets in countries in the EU since these countries are subjected to the EU laws on the electricity market deregulation and reduction of greenhouse gas emissions. As shown in Figure 53, energy storage is projected to grow at a slow rate due to regulations that make it not profitable to deploy energy storage, as well as the lack of available vendors and project financing, with PV and other renewables being the key precursor to the implementation of energy storage[172].

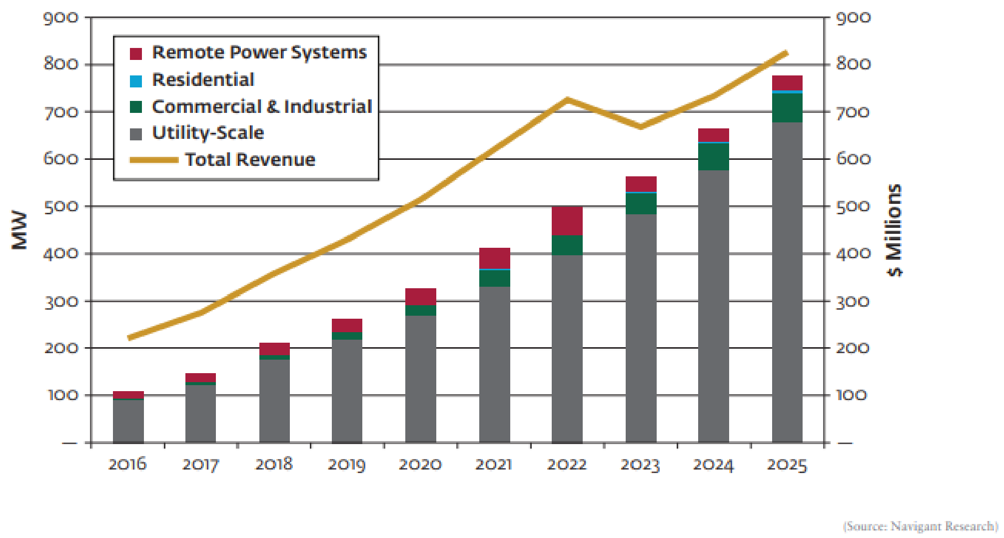

Figure 53. Projected annual stationary energy storage deployments, power capacity and revenue in Eastern Europe

Commercial and Industrial Applications

Europe still heavily relies on fossil fuels for energy generation, the main greenhouse gas emissions source, with around 80% of total emissions[173]. Therefore, different scenarios were created by the European Commission in line with the commitment under the European Green

[172] https://esmap.org/sites/default/files/esmap-files/7151-IFC-EnergyStorage-report.pdf Accessed on 20.08.2021
[173] https://op.europa.eu/en/publication-detail/-/publication/a6eba083-932e-11ea-aac4-01aa75ed71a1/language-en?WT.mc_id=Searchresult&WT.ria_c=37085&WT.ria_f=3608&WT.ria_ev=search Accessed on 20.08.2021

Deal and the Paris Agreement that define the distribution of energy sources by 2050 to reach the defined goals - Figure 54[174].

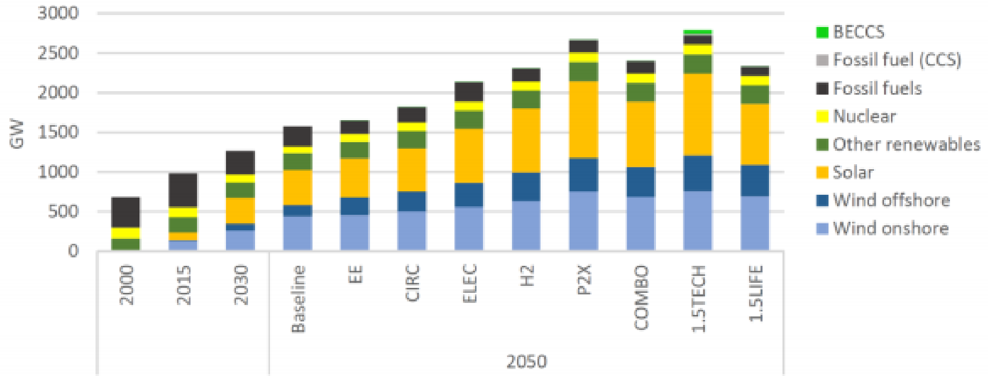

Figure 54. Power generation capacity

In these scenarios, BESS have been used as auxiliaries, which limited their application. However, with the market's evolution and new revenue streams, many new applications are being discovered, and stationary energy storage is becoming a more relevant system in the electric grid instead of solely an "ancillary system". According to Clean Horizon, from January to August 2020, 5,7GW of large-scale energy storage were announced, 1,7GW were operational, and 4 GW were announced or under construction - Figure 55[175].

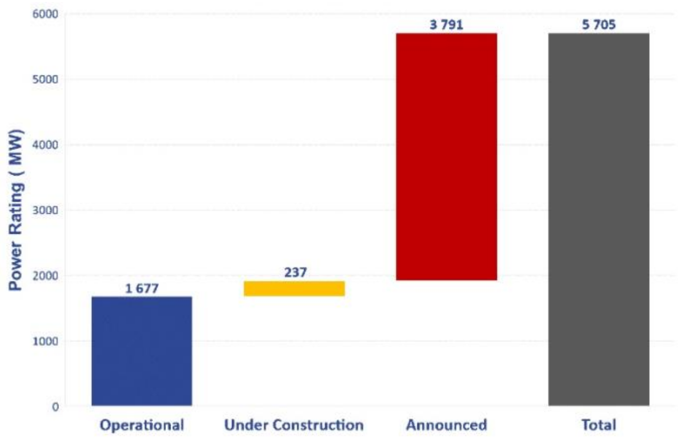

Figure 55. European large-scale energy storage projects by status (August 2020)[176]

[174] https://ec.europa.eu/clima/sites/default/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf Accessed on 26.08.2021

[175] https://www.energy-storage.news/blogs/europes-energy-storage-transformation Accessed on 20.08.2021

[176] https://solar-media.s3.amazonaws.com/assets/Pubs/PVTP24/Europe%E2%80%99s%20energy%20storage%20transformation.pdf Accessed on 26.08.2021

The front-of-the-meter market in Europe increased 72,9% between 2015 and 2018. Although a decrease in 2019 was observed, mostly due to regulatory uncertainty, as the market is susceptible to government auctions and policies, it is expected to rise in the next few years[177]. *Frequency Control* has been the application most sought after in the European market (Figure 56) due to the high probability of resources, accessibility to new battery technologies able to provide a fast response, and the grid operator's remuneration for each MW provided that ensures system resiliency. Nevertheless, the revenues for *Frequency Control* have been decreasing over time, from 26€/MW/h in 2017 to 5€/MW/h in 2020, which may encourage the owners of large-scale BESS to look for other revenue sources with other applications[178].

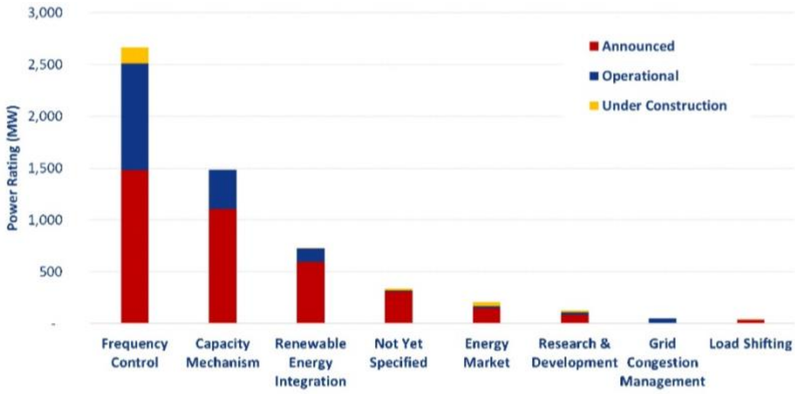

Figure 56. Predominant applications for large-scale BESS in Europe

Residential Applications

As mentioned in previous sections in chapter **Error! Reference source not found.**, the closer the energy storage is to the end-user, the more profitable it can be[179]. Residential BESS (RSS) is installed in the end-user's house. The main functions of RSS are to provide flexibility and balancing services, becoming then possible to maximize the integration of variable RES (the prosumer) and the integration of electric transportation charging.

In 2019, almost 2 GWh of residential BESS had been installed. In 2020, it was predicted for the growth to be 9%, primarily due to the resilience of the German market. Yet, the potential of

[177] https://www.mckinsey.com/business-functions/sustainability/our-insights/battery-storage-the-next-disruptive-technology-in-the-power-sector Accessed on 20.08.2021

[178] https://www.energy-storage.news/blogs/europes-energy-storage-transformation Accessed on 20.08.2021

[179] https://www.eurobat.org/images/news/publications/eurobat_batteryenergystorage_web.pdf Accessed on 20.08.2021

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expansion of the installed capacity is substantial, given that only 7% of residential PV is coupled with energy storage. While electricity prices are increasing, the levelized cost of energy for PV and PV+Storage decreases at a higher rate.

In 2019, 96 000 systems were installed, which correspond to 745 MWh. The top 5 countries with the most installed storage capacity (Germany, Italy, Austria, United Kingdom and Switzerland) account for over 90% of all RSS installations in Europe, both in 2019 and cumulative capacity.

Germany as an Example

Germany is one of the leaders in Europe for Stationary Energy Storage. In 2019, 60 000 new residential energy storage systems were installed, translating into new 250 MW and 490 MWh new installed capacity, adding a cumulative value of 185 000 RSS installed with a cumulative capacity of 750 MW and 1420 MWh. In recent years, the fall of 50% in prices for lithium-ion batteries is the main driver for attracting customers to install RSS. The majority of installed RSS were coupled with PV production. According to the *Deutsche Auftragsagentur GmbH*, 40% of PV inquiries were related to RSS, 20% were not, and 40% were still undecided about looking for advice[180].

By May 1st, 2020, around 700 BESS projects were registered as Industrial Storage System (ISS) – Storage systems above 30 kWh. Most systems are lithium-ion BES and with a capacity between 30 to 100 kWh. In addition, 89% of the systems are connected to the low-voltage grid, almost 9% to the medium-voltage grid, and 2% to the high-voltage grid. Companies installing ISS are interested in performing peak-shaving, self-consumption, and buffer storage for EV chargers[24].

[180] https://www.sciencedirect.com/science/article/pii/S2352152X2031817X Accessed on 20.08.2021

Regarding the large-scale storage systems (LSS) - > 500 kWh, in 2019, they had a cumulative 620 MWh of energy capacity and 460 MW of power. Most systems are used for frequency regulation, smart-grid operation, and RES integration[181].

In Germany, storage facilities are being built at the same location as RES electricity plants, either in self-production or industrial production. The combination provides an advantage in the *Erneuerbare Energien Gesetz* – a package of laws to encourage renewable energy generation. Self-consumption can increase from 30% to 80% by combining PV+Storage, attracting end users as the feed-in tariff for new PV installations decreases. The Federal Government wants to build a flexible electricity system with a well-developed electricity network, including storage systems when appropriate. Research on storage technologies is also an ambition of the government, represented by the Fraunhofer Institute for Storage Technologies plans.

According to the “Energiewirtschaftsgesetzt” (Energy Industry Law) from February 2020, grid connection stipulated that generation would have to pay a tariff to connect to the grid, which storage would be exempted from. Grid-connected storage is exempted from grid charges after 20 years of commissioning. Battery energy storage is seen as a “network component“, and therefore is exempted from electricity consumption tax[182].

[181] https://www.sciencedirect.com/science/article/pii/S2352152X2031817X Accessed on 20.08.2021

[182] https://op.europa.eu/en/publication-detail/-/publication/a6eba083-932e-11ea-aac4-01aa75ed71a1/language-en?WT.mc_id=Searchresult&WT.ria_c=37085&WT.ria_f=3608&WT.ria_ev=search Accessed on 20.08.2021

4 Anatomy of Gigafactory

4.1 INTRODUCTION

The term "Gigafactory" is eight years old, obviously coined by TESLA's Elon Musk in November 2013 in a meeting with investors.[183] The prefix "Giga" means literary 10^9 or "a billion", but the general meaning here is "huge". TESLA's need for batteries for a fast expansion of their car production led to a joint venture with Panasonic and the building of the TESLA Gigafactory One in Reno, Nevada, today called Giga Nevada. Panasonic produces batteries and TESLA drivetrains for Model 3 here. This factory was intended to become the world`s biggest factory measured in land footprint.[184] However, plans are still there, but Giga One is still only 30% ready. Later, TESLA named their photovoltaic solar panel plant in Buffalo, New York, as "Gigafactory 2". After that, the Giga Shanghai, mainly a car factory, which was built at break-neck speed in 2019, followed as number 3. "Giga Berlin", currently under construction in Grünheide, close to Berlin, is becoming Tesla's fourth, and Giga Texas in Austin, the fifth. However, Giga Texas is planned as even more extensive and called "tera-factory".[185]

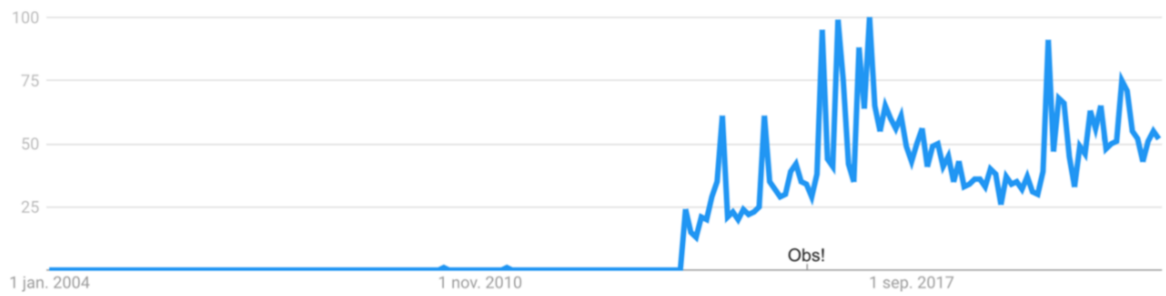

Figure 57. A Google trends search on the term "Gigafactory" shows user' frequency of Google searches. For example, "100" represents the occurring highest number of searches.

Giga Nevada produces batteries, battery packs, TESLA drivetrains and components. Giga Shanghai makes TESLA model 3, but the LFP batteries are bought from CATL, which is expected

183 https://www.inverse.com/article/52637-what-is-a-gigafactory Accessed on 20.05.2021
184 15 million square feet or 139 hectares
185 https://electrek.co/2020/04/30/elon-musk-tesla-battery-day-terafactory/ Accessed on 20.05.2021

to build a battery factory nearby. Finally, Giga Berlin and Giga Texas will both produce cars as well as new Tesla 4680 batteries.[186]

The term "Gigafactory" has since been adopted for similar other use, especially for European battery factories.

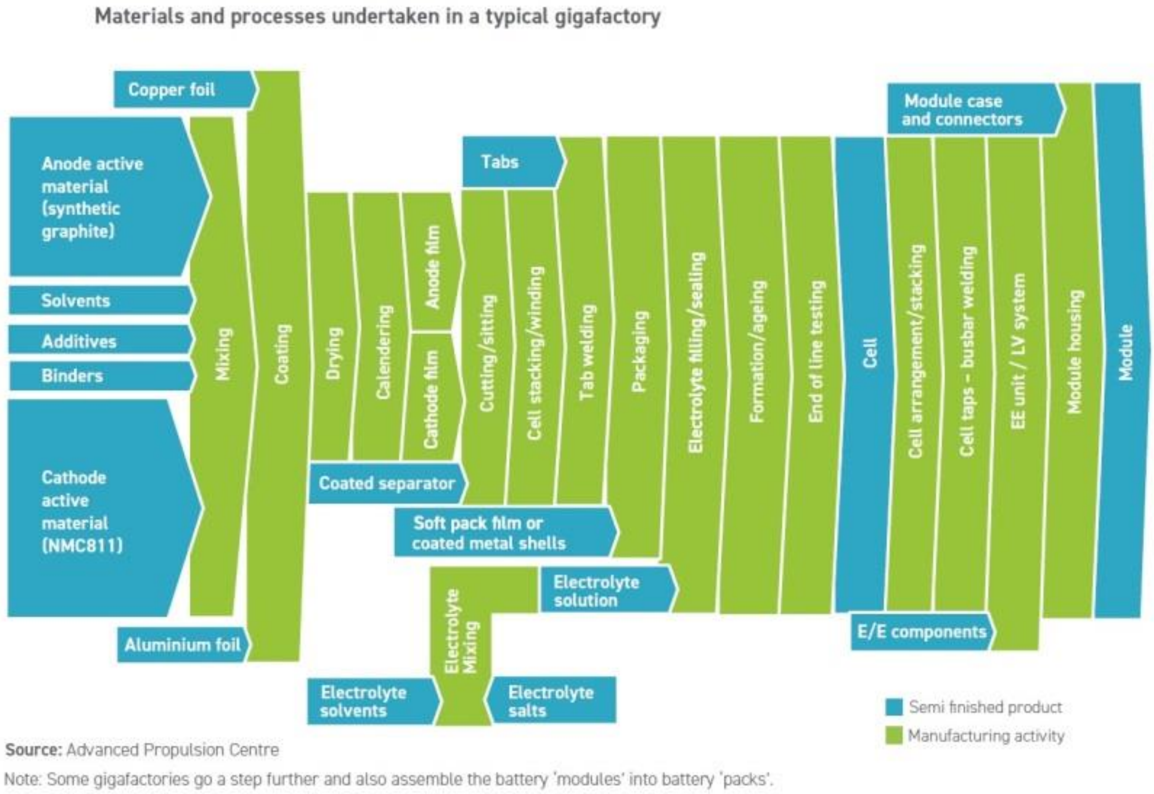

Figure 58. Illustration of the detailed activities undertaken in the manufacture of a Lithium-Ion EV battery module[187].

The term "Gigafactory" in the TESLA meaning included ideas as initially described:

- **Fast upscaling** of urgently needed production (non-fossil-fuel transportation technology)
- **Economies of scale** to lower the end product's price, making EVs affordable for average users.

[186] This 4680 battery production seems now to be delayed, and CATLs batteries will be used instead. https://www.teslarati.com/tesla-giga-berlin-4680-battery-riddle-kato-road-production/ Accessed on 20.05.2021

[187] https://faraday.ac.uk/wp-content/uploads/2019/08/Faraday_Insights-2_FINAL.pdf, accessed on 05.05.2021

- **Energy self-sufficiency** by producing all the energy needed in-house inside or close to each plant using solar panels, wind power and geothermal energy, thus forming a "net-zero energy" plant.[188]
- **Vertical integration** – as much as possible of needed inputs or components should be produced within the plant or nearby and thus be better controlled than in a traditional global just-in-time, just-in-sequence supply chain.
- **A long production line** – ideally, a mine produces raw materials in one end of the factory, and cars are rolling off the assembly line at the other end. TESLAs production lines are, however, in reality, shorter than BYD's and Northvolt's, as upstream production of battery chemicals, or even the batteries altogether, often have been outsourced.
- **Automation and Industry 4.0 technology** use - a Gigafactory is "the machine that makes the machine" – an innovation by itself.
- **A high level of automation in parallel with many employees** to control quality and ensure uninterrupted production by preventive maintenance.
- **A geographic alignment of buildings to true north** is applied for Gigafactory Nevada and Giga Texas to simplify GPS use for placement of equipment and robots' movements.[189]

This was TESLAs use of the "Gigafactory" term as a background.

However, we are interested in "Gigafactory" *as a European concept* to fix the battery and electromobility value chain. The most significant shortcoming in 2016 proved/turned out to be the almost total absence of European-based battery production.[190]

In Europe, the Swedish company today known as Northvolt was founded in 2016 as SGF, "Swedish Gigafactory" by, among others, Peter Carlson, the present CEO, who had been involved in the planning for TESLA Gigafactory One as CPO (Chief Product Officer) and Supply chain manager. This may explain the adoption of the term and concept from TESLA. Another

[188] It is unclear if this only applies to the energy needs of the buildings themselves or is a goal for the whole very energy-demanding production. Other gigafactories, as Northvolt Ett, uses recyclable hydro- and wind-power energy from local power production.

[189] https://www.teslarati.com/tesla-gigafactory-texas-design-explained-elon-musk-video/ It is unknown if this applies to Giga Shanghai and Giga Berlin as well.

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

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factor was the urgency of the situation in Europe, where changes had to happen very fast. Business possibilities were also promising, and also investors became interested in bigger projects.

“Gigafactory“ is becoming a European concept as well – so far, only for battery production plants of considerable size, Gigawatt scale as a minimum. We are here trying to figure out how a European battery Gigafactory should look like by taking a peek into what is known about the "anatomy" of Northvolt Ett in Skellefteå, Sweden, which is expected to start production in late 2021 at a first production line of probably at least six lines by 2021. How can we imagine its departments, supply chains and so on? In what respect Northvolt Ett will be the leading style-forming European example of a Gigafactory we do not know but is an interesting topic to discuss.

4.2 PRODUCTION AND MAINTENANCE

4.2.1 Production

This department is responsible for LIB battery manufacturing as one of the **key activities** performed by a battery manufacturing company. Therefore, it can be considered a **volume department** having a relatively high number of employees, compared to the other departments.

Automated processes help to increase quality since they are generally less prone to errors than manual production.[191] Deployment of Big Data analytics and AI aims to achieve ‘predictive management’ by controlling unpredictable human factors on manufacturing assembly lines.[192] The level of automation in battery production is generally relatively high and can be expected to increase from the ramp-up phase to the **maturity** of a factory. Apart

[191] VDMA (2020). Roadmap Battery Production Equipment 2030. http://battprod.vdma.org/documents/7411591/59580810/VDMA%20Battery%20Production%20Roadmap%20Battery%20Production_Update%202020_EN_1614779649831.pdf/62d997a7-617a-b5ba-1e64-10a625c6beeb, p. 40, last accessed on 24.06.2021

[192] Cooke, P. (2020). Gigafactory Logistics in Space and Time: Tesla’s Fourth Gigafactory and Its Rivals. Sustainability, 12(5), 2044. https://doi.org/10.3390/su12052044, p. 2, last accessed on 24.06.2021

from allowing for the economy of scale, automation helps to further optimize process steps, quality, yield, and throughput.[193]

Factors influencing the selection of the **level of automation** are quantity, complexity, flexibility, production cycle, production volume, quality, investment volume.[194] In addition, selecting the level of automation fitting to the product and company is very important. For example, Tesla was, at some point, criticised for **too much reliance on automation** in its production facility in Freemont and too few assembly line works which caused production problems, some injuries and triggered a new wave of intensive hiring.[195]

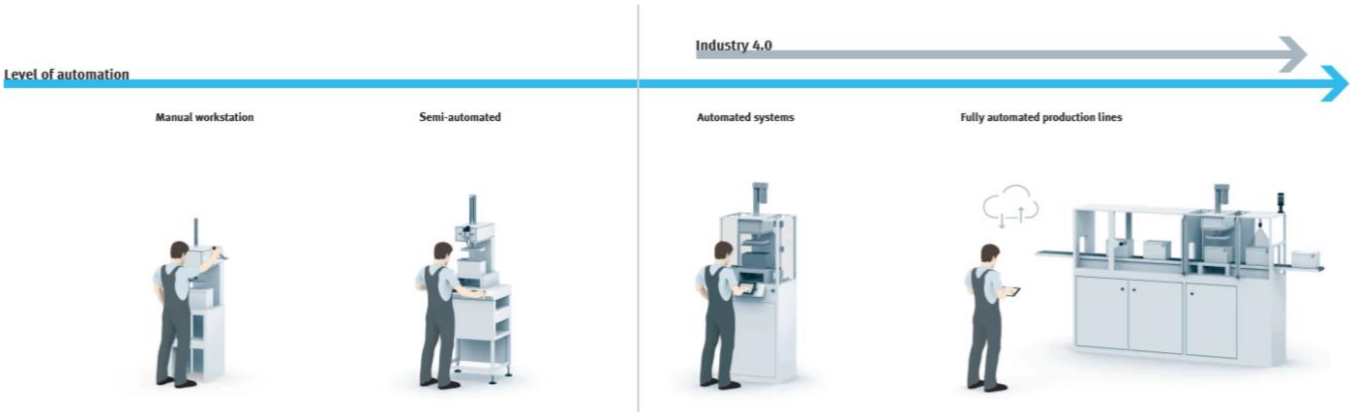

Figure 59. Levels of automation

Within some of the large battery manufactures, the production department can be divided into two main sections: **"upstream"** production preparing the input materials. This production section, where chemical processes take place, can be managed from a control room and requires a much lower number of employees than the following **"downstream"** production section, involving all the other production steps that are more of a mechanical nature (manufacturing, assembly of the electrodes etc.).

[193] VDMA (2020). Roadmap Battery Production Equipment 2030. http://battprod.vdma.org/documents/7411591/59580810/VDMA%20Battery%20Production%20Roadmap%20Battery%20Production_Update%202020_EN_1614779649831.pdf/62d997a7-617a-b5ba-1e64-10a625c6beeb, p. 20, last accessed on 24.06.2021

[194] FESTO. (2021, April). Automation solutions for battery production. Virtual Battery Exhibition, p. 5, last accessed on 24.06.2021

[195] Cooke, P. (2020). Gigafactory Logistics in Space and Time: Tesla's Fourth Gigafactory and Its Rivals. Sustainability, 12(5), 2044. https://doi.org/10.3390/su12052044, p. 5-6, last accessed on 24.06.2021

Battery manufacturing process[196;197]

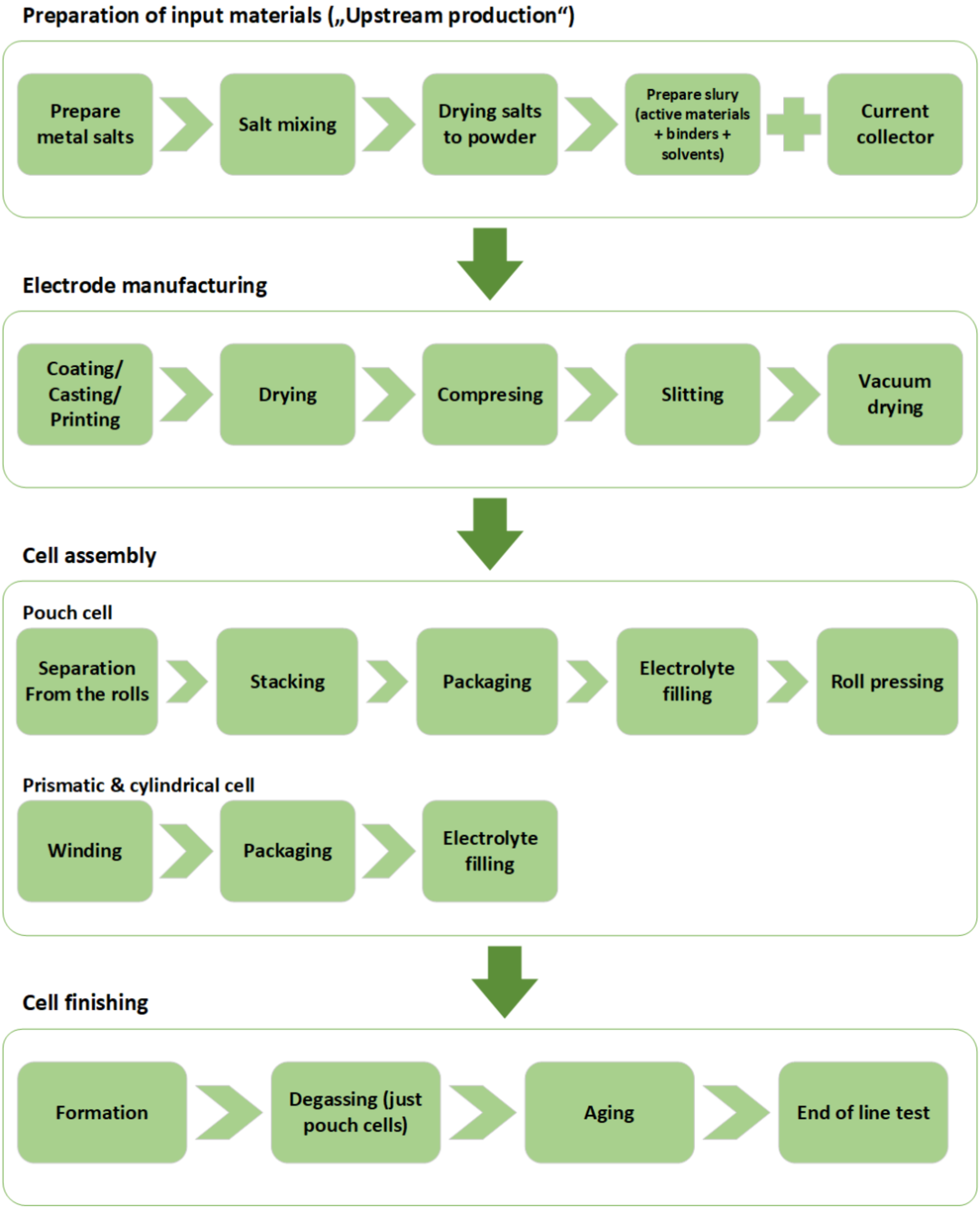

Figure 60. Battery manufacturing process

[196] For more details see ALBATTS report Intelligence in Mobile Battery Applications / Desk Research Report, chapters 3.2.3 Cell Manufacturing and 3.3 Module and pack manufacturing (published 31. 8. 2021), pages 103 - 115 https://www.project-albatts.eu/Media/Publications/4/Publications_4_20200930_12811.pdf, last accessed on 24.06.2021

[197] Source of most of the following information: Heimes et al. (February 2019). Lithium-ion Battery Cell Production Process, RWTH Aachen University & VDMA https://www.researchgate.net/publication/330902286_Lithium-ion_Battery_Cell_Production_Process, last accessed on 24.06.2021

Upstream production (this production step might be done in-house or outsourced)

- Prepare metal salts - nickel, cobalt, and lithium are critical metals used in today's active cathode materials and the chemistries incorporated in high-performance batteries. Also, many other metals play an important role in the battery manufacturing chain, either in the battery chemistry or in other components like current distributors or permanent magnets. The most typical metals are aluminium, manganese, copper, magnesium, and iron. The refined metals are dissolved into salt solutions, for example, Ni to NiS04, Mn to MnSO4 and Co to CoSO4
- Salt mixing - mixing the salt solutions - the salts are added and mixed, then adding the lithium followed by further mixing. Drying salts to powder - the liquid salt mix is dried and filtered to become a fine powder of active material. Anode active material: graphite. Cathode active material: Li (NiMnCo)O2
- Prepare slurry - slurry mixing - active material (additives) and binder are mixed dry then solvent is added, and wet dispersing follows to homogenise the slurry

Electrode manufacturing

- Coating – current collectors: copper (anode) or aluminium foils (cathode) are coated with the slurry on both sides and then dried. Alternative: dry coating - no solvent is used, and the powdered active material is applied to the foil
- Drying – of the active material using heat (alternative: Infrared heating or laser) to remove the solvents. Cooling follows
- Calendaring – compressing of foils by rotating (hot) rollers to ensure the materials are evenly distributed
- Slitting – cutting (e.g., with rolling knives or laser) a wide foil to a smaller one depending on the desired design
- Drying – to get rid of residual moisture, solvents. Using e. g. heat in a vacuum oven or infrared heat

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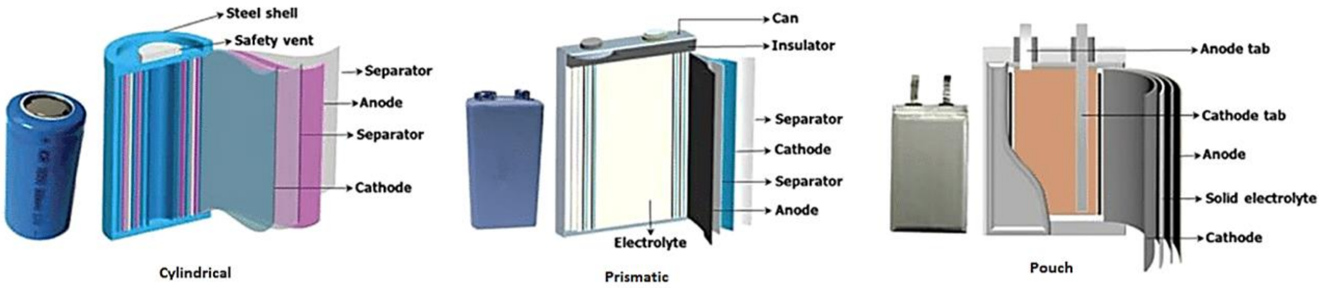

Figure 61. Battery cell geometry[198]

Cell assembly

Pouch cell

- Separation – of cathode, anode, and separator sheets from the roll material - usually by a punching machine– used for the production of pouch cells
- Stacking – cathode, anode and separator sheets are repeatedly stacked into numerous (up to 120) layers. "Z pattern" folding is commonly used. Some manufacturers have their folding methods patented[199].
- Packaging – tabs are connected to the foils, positioning of the cell stack in a pouch, partial sealing
- Electrolyte filling – by a high-pressure needle. Final sealing of the pouch under vacuum
- Roll pressing (optional) – to ensure even distribution and absorption of the electrolyte and thus the maximum capacity of the cell

Cylindrical and prismatic cells

- Winding – the electrode foils and two separator foils are wound around a winding mandrel (prismatic cell) or a centre pin (cylindrical cell) to form a so-called "jelly roll".
- Packaging – prismatic cell: the jelly roll, including contact terminals, is inserted into a metal housing; the housing is sealed. For cylindrical batteries, the jelly roll is inserted in a cylindrical housing, and current collectors are welded to the bottom of the housing (anode) and the lid (cathode)

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[198] Abbas, Q., Mirzaeian, M., Hunt, M. R., Hall, P., & Raza, R. (2020). Current State and Future Prospects for Electrochemical Energy Storage and Conversion Systems. Energies, 13(21), 5847. https://doi.org/10.3390/en13215847, last accessed on 24.06.2021

[199] LG Chem. (2013, July 9). LG Chem Electric Vehicle Battery Production Process [Video]. Youtube. https://www.youtube.com/watch?v=q9HbHZXEEDs, last accessed on 24.06.2021

- Electrolyte filling – and sealing

Cell finishing

Pouch, prismatic, cylindrical cell

- Formation – first charging and discharging of a battery cell. The Solid Electrolyte Interface (SEI) - an interface layer between the electrolyte and the electrode – is created

Pouch cell

- Degassing – getting rid of gasses created during the first charging process. Final sealing, gluing

Pouch, prismatic, cylindrical cell

- Ageing – measuring of cell performance (within different temperature conditions) to ensure quality. This can take up to three weeks
- EOL Testing – discharging of the cells to shipping state of charge (approx. 5 - 20%), testing, sorting of the cells according to their performance (optional)

Requirements for cell production

Significant parts of the production process (particularly until the cells are sealed) are performed in **clean and dry rooms –** a dustproof and low humidity environment. These production environment requirements bring about significant investment and running costs, including increased energy needs and CO2 emissions generated.[200]

Future production concepts

Future battery technologies (e. g., **solid-state** possibly replacing lithium-ion battery technology) will have a significant impact on some battery manufacturing processes. In the increasing competition among the battery produces, **scaling** of the production and process optimisation will be highly desirable as they can significantly reduce the investments and running costs. In addition, the role of **Industry 4.0, AI and IoT** are expected to increase within the production, maintenance, and quality control processes.

[200] VDMA (2020). Roadmap Battery Production Equipment 2030. http://battprod.vdma.org/documents/7411591/59580810/VDMA%20Battery%20Production%20Roadmap%20Battery%20Production_Update%202020_EN_1614779649831.pdf/62d997a7-617a-b5ba-1e64-10a625c6beeb, p. 93, last accessed on 24.06.2021

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A recent VDMA study[201] sees three key "grand challenges" ahead of battery manufacturing:

- **Cost savings** - increased throughput (scale-up or speed-up) and increased productivity (higher yields - minimization of scrap)
- **Quality –** improvements of process stability, cell performance and safety
- **Sustainability** – higher energy and resource efficiency

Technology developments will reduce the material and manufacturing costs, speed up production and enhance the performance of the batteries. Battery manufacturing innovations examples include[202]

- Electrode manufacturing – extrusion, laser drying
- Cell assembly – laser cutting, lamination of the separator
- Cell finishing - integrated product carrier concepts, energy recovery

The battery producers strive to achieve a lean production with fewer **production steps occupying less territory**. Freyr, for example, aims to produce the battery cells with technology that requires fewer employees than its competitors. Freyr is reportedly licensed for a production technology that allows them to have 7-8 production steps instead of up to 15-20, which is common in more conventional production, allowing them to start much faster.[203]
Among areas with the most significant potential for innovations are the formation and ageing processes and the mixing and coating process.[204] Tesla explores the possibility of introducing a **dry electrode** manufacturing process, allowing for skipping several production steps such as

[201] VDMA (2020). Roadmap Battery Production Equipment 2030. http://battprod.vdma.org/documents/7411591/59580810/VDMA%20Battery%20Production%20Roadmap%20Battery%20Production_Update%202020_EN_1614779649831.pdf/62d997a7-617a-b5ba-1e64-10a625c6beeb, p. 5, p. 44, last accessed on 24.06.2021
[202] Heimes et al. (February 2019). Lithium-ion Battery Cell Production Process, RWTH Aachen University & VDMA https://www.researchgate.net/publication/330902286_Lithium-ion_Battery_Cell_Production_Process, p. 34, last accessed on 24.06.2021
[203] Lysvold S. "Trenger (2021, April 10). 1500 arbeidstakere til ny batterifabrikk, men kompetansen finnes verken i Norge eller Europa, NRK.no. https://www.nrk.no/nordland/freyr-skal-bygge-batterifabrikk-i-mo-i-rana-_-vil-trenge-1500-ansatte-1.15445805, 11. 4. 2021, last accessed on 24.06.2021
[204] Roland Berger, PEM, RWTH Aachen University. (2020). Rising opportunities for battery equipment manufacturers. https://www.rolandberger.com/de/Insights/Publications/Lithium-ion-batteries-for-the-global-automotive-industry-and-beyond.html, p. 9, last accessed on 24.06.2021

mixing the materials with solvent, heating, and recovering the solvent. According to Tesla, this could lead to up to **10x reduction** of both production space needed and energy consumed.[205]

Job roles and skills

Northvolt[206]

In the case of Northvolt they are in the process of building their Gigafactory, Northvolt Ett in Skellefteå, Sweden. Their manufacturing is divided into

- upstream and
- downstream manufacturing teams
- Production technology (an engineering team)
- Maintenance
- Production planning
- Internal logistics and operations

The staff volumes are highest in downstream production with cell assembly being the number one labour intensive and biggest recruiter.

Most employees in manufacturing are blue collars working as operators and technicians. Their share is 80-90 % of the manufacturing staff.

Besides running the manufacturing process all operators and technicians are responsible for material handling and sampling/testing by the machine/in the dry/clean room.

The different manufacturing steps requires different skills from the operator but what is common throughout the process is the automated way of working (which requires problem solving skills, 5S mindset and machine understanding) and the need to have a strong quality mindset (ability to follow procedures and understand consequences downstream/process flows). To ensure few and short disruptions, the operator needs to be able to identify errors early on, this requires the ability to spot risks through hearing, smell, and vision. Also common for all employees, including workers, is the ability to speak and understand English. This is due to the current international working environment.

[205] Tesla. (2020, September 9). Tesla Battery Day [Video]. YouTube. https://www.youtube.com/watch?v=l6T9xleZTds&t=5657s, last accessed on 24.06.2021
[206] Northvolt interview, 31.5. 2021

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All operators start within one production area but with the ambition to broaden their skills to additional areas. Hence a broad educational base/understanding, covering the full battery production process is necessary.

In the case of white collars, they are usually working in such roles as production planning, production managers, shift managers and production engineers. They usually have a production related education within engineering. Main challenge when searching for production engineers is the lack of large-scale manufacturing experience as well as insight in battery production and more specifically understanding of the chemical process.

Upstream roles include for example:

- Outdoor operator – work within the area of dissolution, calcination and/or precursor. Rotates on the shopfloor, includes tasks as filling materials, manual quality checks, operator maintenance etc.
- Indoor operator/technician – monitor, steers, analyse, and controls process from control room
- Shift leader / manager
    - People and process responsibility for dedicated areas for a specific shift within the process area
    - Includes tasks as people planning, process organisation and safety, performance and development of staff, quality of output
- Production area manager (white-collared). P&L responsibility for specific production area.
- Production planners (white-collared)
- Production engineers (prod. technology team, white-collared)

The above-mentioned control room in upstream production which is not unlike what can be commonly seen for example in the in the process industries such as chemical, pharma and paper. The control room operators' tasks include monitoring and adjusting computerized controlling of for example pressure, temperature, and speed of the machines.

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The production and material engineers work side-by-side with the operators on the production floor or control room. Maintenance engineers/technicians work with preventive maintenance.

The skills the upstream production workers such as process operators, technicians and engineers need to have include for example chemical knowledge to understand the risks, safety and how chemicals behave. Since the upstream process is much like traditional process industry the skills and competence related to valves, pressure, reading drawings etc. is critical.

Downstream roles:

The downstream manufacturing roles have a similar set up with process area specific operator roles and supporting functions as quality, maintenance, and engineering. There is no control room in downstream production where machines are steered through a Human-Machine Interface (HMI).

Operator roles are divided in electrode manufacturing, cell assembly and cell finishing. Electrode manufacturing have similarities to other roll to roll industries but what is typical with battery manufacturing is the much higher quality requirements. Cell assembly is a fully automated assembly line. The type of assembly is mostly related to fine mechanics. The skill of the operator includes machine understanding and the ability to troubleshoot. To ensure employee engagement Northvolt's ambition is to include job rotation among machines in for example, cell assembly.

Due to the lack of experienced blue-collar employees many of them come directly from vocational education. To bring in experience Northvolt is looking at industries with similarities to battery production. For example, in the case of electrode manufacturing those hired from the other industries that work with coating and pressing (paper industry etc.) are likely to be placed to dry electrode process that involves material pressing as well.

Future:

Northvolt is aiming to automatize production almost fully eventually. This would include also material inputs as well with AGVs (Automatic Guided Vehicles) and automatic material handling systems. In that scenario the roles of the operators would evolve to be more about data analytics, maintenance, product process optimization etc. However, despite automatization and digitalization one still needs manual skills and understanding of the actual real-world systems/processes behind "touchscreen buttons".

Examples from elsewhere in the industry:

According to an important entity in the industry, “battery cells and their manufacturing process are characterized by complex interactions between the processes, the structure of the individual intermediate products, and the properties of the final cell. These interactions require a **high level of understanding in the fields of electrochemistry, electronics, mechanics, process engineering, and manufacturing technology**. The lack of comprehensive knowledge of the interactions along the process chain, especially in battery cell production, is currently reflected in the high reject rates (low double-digit percentage range) and very long start-up phases up to robust series production.”[207]

“Sarah Karin Larsen is one of the very first Norwegian process operators to be employed in the young battery industry in Norway. In March, she skipped a bachelor's degree in mechanical engineering at the University of Stavanger in favour of a job at Beyonder, a company that focuses on producing lithium-ion condenser batteries for industrial use. There, she is one of two newly hired Norwegian process operators who learn to operate the machines in a new production line for battery cells in the company's new prototype factory at Forus, an industrial area in Stavanger. The training gets done by **10-12 battery experts from China** and Korea to assemble and get the machines started in the new production line. Some of them are recruited among the machine operators.”[208]

[207] VDMA (2020). Roadmap Battery Production Equipment 2030. http://battprod.vdma.org/documents/7411591/59580810/VDMA%20Battery%20Production%20Roadmap%20Battery%20Production_Update%202020_EN_1614779649831.pdf/62d997a7-617a-b5ba-1e64-10a625c6beeb, p. 5, p. 121, last accessed on 24.06.2021

[208] Nilsen, J. (2021, April 9). Sarah læres opp av kinesiske batterieksperter og får kompetansen industrien tørster etter. TU.no. https://www.tu.no/artikler/sarah-laeres-opp-av-kinesiske-batterieksperter-og-far-kompetansen-industrien-torster-etter/508478, last accessed on 24.06.2021

"The key expertise that the battery company needs are **direct experience from battery production**, which is hardly available in Norway. There are also no relevant **educational courses** that provide specific expertise in battery production."[209]

"At the moment, Beyonder is recruiting for the battery centre at Forus, which now counts around 40 employees. By the end of the year, they will be up to around 100 employees here. When the main factory is scheduled to be ready in 2024 with 500 employees, around 70 per cent will ideally have the **expertise in process and electrical chemistry at the vocational or professional school level**. In addition, 150 employees will work in the **R&D centre**."[210]

(Referring to Tesla battery production facilities in the US) "Initially, Panasonic **recruited chemical engineers** from other sectors and **trained them** to handle lithium-ion batteries. Now, 3000 employees operate the plant with some **200 technical assistants from Japan** to keep it running"[211]

"… considering the total and manifold value chain from battery materials, cells, modules, packs, systems to end products (e.g., electric vehicles, stationary applications), their **use phase** and recycling, the number of jobs affected can be possibly **up to 5–10 times higher** than the jobs directly or indirectly connected with the battery (materials, cells to pack) **production only**. In the mid to long-term, this number of jobs needed might be **up to 10 million around 2030** and much more **beyond 2030**. In the long-term (well beyond 2030), there might be 2–3 million jobs globally connected only with battery (materials, cells to pack) manufacturing. **Thus, around 2030, up to 1 million** (e.g., 3300 GWh x 300 jobs/GWh) jobs could emerge globally and **up to 300,000 jobs in Europe** (e.g., 1000 GWh x 300 jobs/GWh)."[212]

[209] Nilsen, J. (2021, April 9). Sarah læres opp av kinesiske batterieksperter og får kompetansen industrien tørster etter. TU.no. https://www.tu.no/artikler/sarah-laeres-opp-av-kinesiske-batterieksperter-og-far-kompetansen-industrien-torster-etter/508478, last accessed on 24.06.2021

[210] Nilsen, J. (2021, April 9). Sarah læres opp av kinesiske batterieksperter og får kompetansen industrien tørster etter. TU.no. https://www.tu.no/artikler/sarah-laeres-opp-av-kinesiske-batterieksperter-og-far-kompetansen-industrien-torster-etter/508478, last accessed on 24.06.2021

[211] Cooke, P. (2020). Gigafactory Logistics in Space and Time: Tesla's Fourth Gigafactory and Its Rivals. Sustainability, 12(5), 2044. https://doi.org/10.3390/su12052044, p. 6, last accessed on 24.06.2021

[212] EIT RawMaterials Fraunhofer. (2021, March). Battery Expert Needs. https://eitrawmaterials.eu/wp-content/uploads/2021/03/EIT-RawMaterials-Fraunhofer-Report-Battery-Expert-Needs-March-2021.pdf, p. 5, last accessed on 24.06.2021

“Freyr has received hundreds of applications for jobs and has already hired several employees. But to get the right battery skills, Freyr has hired several recruitment companies. Initially, 30-50 new employees will work with and in the **pilot facility**.”[213]

But there are other sectors in Norway where Freyr can acquire expertise, according to Ljungquist. "We are also looking for people with experience in the **automotive and oil and gas industries**.[214]

Freyr's chief technology officer Ryuta Kawaguchi:
"The level of education in Norway is high, and the country has many skilled industrial workers with high levels of competence. We are already recruiting battery cell experts and have new employees waiting for the border of Norway to reopen.” He also believes Norway’s reputation as an electric car nation will play positively in recruitment.[215]

“Among other things, Freyr has employed 10 master's degree students from NTNU…NTNU is working with several companies struggling to establish battery factories by 2025. As Freyr, Morrow, Beyonder, Hydro and Equinor.“[216]

[213] Lysvold, S. S. (April 2021). Trenger 1500 arbeidstakere til ny batterifabrikk, men kompetansen finnes verken i Norge eller Europa. Nrk.no. https://www.nrk.no/nordland/freyr-skal-bygge-batterifabrikk-i-mo-i-rana-_-vil-trenge-1500-ansatte-1.15445805, last accessed on 24.06.2021
[214] Lysvold, S. S. (April 2021). Trenger 1500 arbeidstakere til ny batterifabrikk, men kompetansen finnes verken i Norge eller Europa. Nrk.No. https://www.nrk.no/nordland/freyr-skal-bygge-batterifabrikk-i-mo-i-rana-_-vil-trenge-1500-ansatte-1.15445805, last accessed on 24.06.2021
[215] Lysvold, S. S. (April 2021). Trenger 1500 arbeidstakere til ny batterifabrikk, men kompetansen finnes verken i Norge eller Europa. Nrk.No. https://www.nrk.no/nordland/freyr-skal-bygge-batterifabrikk-i-mo-i-rana-_-vil-trenge-1500-ansatte-1.15445805, last accessed on 24.06.2021
[216] Lysvold, S. S. (April 2021). Trenger 1500 arbeidstakere til ny batterifabrikk, men kompetansen finnes verken i Norge eller Europa. Nrk.No. https://www.nrk.no/nordland/freyr-skal-bygge-batterifabrikk-i-mo-i-rana-_-vil-trenge-1500-ansatte-1.15445805, last accessed on 24.06.2021

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4.2.2 Maintenance

The battery production line is a very complex system, and the manufacturing needs special conditions. Unplanned production outages can bring significant losses, so that quick repair is vital.[217] The **dry and clean rooms** need periodic maintenance. During the maintenance, the filters should be changed, and moving parts lubricated. The correct functioning of the system and the measurement of **room contamination** must be verified.[218] [219]

According to the actual trends such as Industry 4.0 or **predictive maintenance**, parts of the line should monitor themselves and predict when maintenance will be needed. During the maintenance, moving parts are lubricated, filters are replaced, and operation fluids are changed. Another type of maintenance is **software maintenance**, where software and automation engineers can update the software of the production line.

Companies are trying to introduce **preventive maintenance** concepts aiming to prevent failures during production and outages.

Job roles and skills[220]

For example, Northvolt approaches the maintenance in the manner explained in this section. Due to different process areas, they need a number of teams that can do different types of maintenance, which exist in both Upstream and Downstream process areas. They include for example

- Mechanical team: all the mechanical maintenance (more manual work)
- Electrical maintenance team
- Automation team
    - Maintain software systems together with the machines

[217] Roland Berger, PEM, RWTH Aachen University. (2020). Rising opportunities for battery equipment manufacturers. https://www.rolandberger.com/de/Insights/Publications/Lithium-ion-batteries-for-the-global-automotive-industry-and-beyond.html, p. 18, last accessed on 24.06.2021

[218] Cappello, A. (2019, August 30). How To Maintain A Clean Room Environment. Workstation Industries. https://resources.workstationindustries.com/blog/how-to-maintain-a-clean-room-environment last accessed on 16.06.2021

[219] Systems, S. C. (1111). Low Humidity Controlled Rooms - Custom Dry Rooms | Scientific Climate Systems. Scientific Climate Systems. https://www.scs-usa.com/dry-rooms.html last accessed on 16.06.2021

[220] Northvolt interview, 31.5. 2021

Considering start-up companies, the importance of maintenance personnel is especially significant in the beginning when setting up all the machines in the production lines. The white- and blue-collar ratios are approximately 50-50 at Northvolt currently. Blue collars function more in technician roles such as mechanical technicians, electricians, instrument technicians and warehouse technicians. White collars include engineers: maintenance, mechanical, electrical, automation, industrial etc. and managers in upstream/downstream production.

The skills needed include for example understanding of setting up the production, preparing the related structures, commissioning the machines. Experience from chemical and mechanical assembly plants is valued. Automation experience, mechanical understanding of the automated system combined with understanding the related software and calibration, is beneficial as well. Naturally, skills gained from battery related education are also valuable.

In the future it is expected that the importance of software will become more important along with general IT and data analysis skills. This development will also cover such job roles as electricians and mechanical technicians.

4.3 LOGISTICS

This is a short overview of what is publicly known about transport logistics for the Northvolt Ett factory in Skellefteå, an example of how it can look like for other European Li-Ion battery plants. The Northvolt Ett logistics manager calls this logistics "Giga logistics for Gigafactories"[221], which may be a suitable new term. This overview does not cover in-house production flow logistics, only transport of supplies, products, and workforce to and from the plant.

Environmental priorities. Northvolt aims at sustainable battery production to contribute to fossil-free global transport. To manufacture a kWh of battery storage, about 60-80 kWh are needed before the battery can be used in a car at all.[222] If the battery is produced all the way with the use of fossil-fuelled electricity, the CO2 debt is burdensome already from the

[221] https://www.linkedin.com/posts/bartek-bartosz-borczy%C5%84ski-9a43721a_kilo-and-mega-is-so-last-year-or-decade-activity-6830792324700786690-J8hd Accessed on 24.06.2021

[222] Batteritillverkning ska bli grönare – energiåtgången ett dilemma – Byggnadsarbetaren Accessed on 24.06.2021

beginning. Northvolt wants to act differently to produce batteries with a very low CO_2 footprint by using green electric power in the plant, secured through the local electricity producer Skellefteå Kraft (hydro- and wind power only). Northvolt´s strategy aims at vertical integration of manufacturing and a long in-house production chain. If more of what is needed to make batteries is produced from raw materials in the plant itself, fewer transports are needed. Northvolt buys raw materials directly from producers to make active battery materials in their upstream production. Many existing and planned battery Gigafactories have a shorter production chain without integrated upstream production. They must, for example, buy electrode material from subcontractors and wholesalers in Asia and worldwide, which means more transport and less control over own production and probably a higher price for the end product.

When looking at the whole value chain, the mining stage is problematic but can be addressed with electrified solutions in mining and new technology in the refining stage. This is hard today when the main battery raw materials are seldom mined in Sweden. Still, with better demand and more active procurement, local and regional sourcing will develop, and Northvolt will be able to specify more conditions for raw material extraction for their suppliers. Furthermore, Northvolt aims at supplying battery production in 2030 with 50% of the raw materials reclaimed from old, recycled EV batteries. Other priorities include complete traceability of raw materials and other production inputs. For now, Northvolt does not use cobalt from the DRC, but it can be a cobalt source in the future, depending on how the cobalt is mined and refined. With all this in mind, Northvolt aims at a climate footprint of 10 kilograms CO_2 per kWh, instead of 170-180 kilograms, CO_2 which is not uncommon in other battery producing plants outside Europe.[223] [224]

Construction logistics

Logistic Contractor and PEAB are the main building contractors, but there are a large number of subcontractors from Scandinavia, continental Europe, and Asia.[225] For these, 600 temporary

[223] https://www.di.se/digital/northvolt-chefen-om-miljardprojektet-fortfarande-enormt-komplicerat/ Accessed on 24.06.2021
[224] https://northvolt.com/articles/a-binary-choice/ Accessed on 24.06.2021
[225] https://nordicpropertynews.com/article/2749/logistic-contractor-to-build-europes-largest-battery-factory Accessed on 24.06.2021

accommodations have been erected close to the building site on an old industrial site for a paper mill, and many rent other lodgings.

For the installation of machinery, many large components are transported via sea and then special trucks cover the remaining 11 kilometres.[226] A lot of the production equipment originates in Asia. The first shipping in the autumn of 2020 was made by Wallenius SOL ro-ro ships. Wallenius has since become a long-term contractor for sea freights with new dedicated Northvolt ro-ro vessels.

Inbound logistics

Northvolt Ett needs only for the first two production lines (16 GWh of 60 GWh) considerable volumes of raw materials and other supplies.[227] Examples, in metric tons per day / per year Table 8.:

Table 8. Northvolt Ett volumes of raw materials per year and per day

For two production lines, 16 GWh	Metric tonnes/day	Per year
Cobalt	8	2920
Lithium hydroxide monohydrate	51	18 615
Graphite	83	30 295
Nickel (elementary)	64	23 360
Nickel-plated steel	40	14 600
Aluminium foil	11	4 015
Copper foil	24	8 760
H2SO4	107	39 055
N2	67	24 455
O2	160	58 400
NaOH or similar base	219	79 935

For supplies like these, materials for about ten days of consumption will be warehoused at the site. Additional warehousing will be developed in the Skellefteå harbour. Northvolt wants or

[226] https://northvolt.com/articles/nv1-sept2020/ Accessed on 24.06.2021
[227] Environmental Impact Statement: *Teknisk beskrivning Northvolt Ett – Utökad anläggning för storskalig produktion av litiumjonbatterier*, Northvolt. Link: https://docs.google.com/viewer?url=https%3A%2F%2Fwww.nexi.go.jp%2Fenvironment%2Finfo%2Fpdf%2F18-028_EIA2.pdf Accessed on 24.06.2021

demands significant suppliers to be located nearby with both production and warehousing if possible. Examples of companies now establishing plants close to the NV1 are

- the Korean Donjin SemiChem subsidiary **Donjin Sweden A**B that are contracted to make Carbon Nano-tube slurry (CNT on a core of synthetic graphite) for the battery anode[228],
- the Chinese-owned company **Kedali Sweden A**B that will be placed on the plant area and produce battery casings in aluminium. This location makes long transports of light empty casings unnecessary.
- The Australian firm **Ecograf,** specialized in natural graphite processing, has reserved a plant location close to Northvolt Ett.

A large factory for battery separator films for Northvolt, with about 600 new jobs, is being built in Eskilstuna, in Mid-Sweden, by **Senior** Technology Material ("Senior"). The distance to the Northvolt Skellefteå plant can be covered by overnight freight train.

Apparently, a Gigafactory is big enough to demand close production and warehousing locations from essential suppliers. This is a different approach to the "just-in-time" supply chain, where the warehouse is on the road and supplies arrive just when needed. Just-in-time logistics can be a risky solution for a Gigafactory production process. Every minute of production standstill is very costly.

Outbound logistics

The 16 GWh battery production with the first two lines will result in 85,000 tons of Li-Ion batteries per year in cylindrical and prismatic formats to be shipped. Thus, the volume of inbound supplies is about double the outbound product volumes. Northern Sweden, at the present, exports big volumes of raw materials but has a small population which is not importing as much in volume and weight. This unbalanced proportion can now be balanced, filling the present wasted capacity in sea-freight volumes northbound. These can now be better balanced, meaning fewer empty northbound ships.[229]

The main transports will be by railway and sea transport, connecting at the Skellefteå harbour (Skelleftehamn) 11 km from the site, where a special section of the harbour is being prepared

[228] https://norran.se/artikel/jnxqm48r Accessed on 24.06.2021
[229] https://northvolt.com/articles/meet-bartek/ Accessed on 24.06.2021

for Northvolt. The idea from the beginning was a railway connection between plant and port. Still, high elevations on the short distance made a conventional railway difficult, so a road solution has been chosen instead. The plans for the near future are to run this link with EV autonomous trucks on a separate road as a demonstration project. At full production, in 2025, about 900 trucks will load and unload every day at the Northvolt Skellefteå plant, or once every 4 minutes.

The railway connections to and from Northern Sweden are presently not optimal. The main railway ("Norra stambanan") runs south/north about 70-90 kilometres into the interior of Northern Sweden land with a side-track to Skellefteå and Skelleftehamn. There are plans since a long time for the new coastal railway, "Norrbotniabanan", connecting to the coastal railway Botniabanan, which is now ending in Umeå, 140 km south of Skellefteå. This coastal railway track seems to become a reality now, partly thanks to Northvolt's needs and other substantial industrial projects in Northern Sweden (as the Hybrit project – fossil-free steel production).[230] This new railway is also a part of the EU-policy-driven and co-financed Scandinavian-Mediterranean railway network, which now becomes connected to the Finnish railway in Haparanda-Tornio on the Swedish-Finnish border.[231]

For international logistics planning, the Swedish company Scanlog was contracted by Northvolt[232], and the cooperating shipping company Wallenius SOL has already begun to transfer machinery and production equipment through Skellefteåhamn. Furthermore, from the autumn of 2021, two dedicated new con-ro vessels (both **co**ntainers and **ro**lling cargo) with a deadweight of 27 000 tons each and with LNG as main fuel (liquified natural gas) that can be switched to LBG (liquified biogas) will enter service.[233] These new ships will be the world's largest ro-ro ships with the highest ice-class. The first main connection for these Wallenius' ships will be Travemünde, but it can be changed to Gdansk or another Polish harbour soon, as Northvolt's battery pack plant is located in Gdansk.

Inhouse logistics

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230 https://www.svt.se/nyheter/lokalt/norrbotten/infrastrukturministern-haller-presstraff-om-norrbotniabanan Accessed on 24.06.2021

231 https://ec.europa.eu/transport/themes/infrastructure/scandinavian-mediterranean_en Accessed on 24.06.2021

232 http://www.scanlog.se/en/northvolt-nominates-scanlog/ Accessed on 24.06.2021

233 https://www.di.se/nyheter/rekordstora-fartygen-ska-skota-transporterna-at-northvolt-jatteviktigt/ & https://www.sjofartstidningen.se/far-lng-system-fran-man-cryo/ Accessed on 24.06.2021

We do not have details on in-house logistics, but as the Northvolt Ett will be a very automated plant with an Industry 4.0 concept, internal transports will also be highly automated. The Industry 4.0 concept means integrating automation with IoT (Internet of Things) and AI/Machine Learning. Therefore, we can expect highly automated warehouses and driverless transports of supplies within the factory. Further information will be provided.

Recycling logistics

Northvolt plans to source 50% of its raw material from decommissioned batteries in 2030.[234] This includes both used collected batteries and substandard batteries recycled directly from the production line. A recycling plant, Revolt, will be built in the direct vicinity of the production units, as Northvolt also has a co-venture with Norwegian Hydro; Hydrovolt, with a recycling facility in Fredrikstad, Southern Norway. The collection and transport of used batteries will be complex, and the loads will be classified as dangerous cargo. Both transport companies, for example, DHL[235]and metal scrapping companies, as Kuusakoski, are planning for recycling collection and transports. Customised shipping containers exist and are developed further for various LI-Ion batteries transport: raw materials transport, transports of battery components, new batteries, battery packs and collected batteries for recycling. There are also special battery containers for use in stationary Li-Ion applications and marine applications.[236]

Staff logistics

The Northvolt Ett plant will have over 3000 employees in 2025. Many will live with families in Skellefteå and neighbouring communities, but some, especially experts and consultants, will probably commute in periods from other parts of Sweden, Europe, and the world. They all need housing – which is now being built by public and private housing firms all over the region. These workers will come to the factory partly by car (900 cars per day is estimated) but

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[234] News chat with Peter Carlsson, Northvolt's CEO https://norran.se/artikel/northvolts-vd-peter-carlsson--blir-det-en-ny-fabrik-i-umea-har-kan-du-lasa-chatten-i-efterhand/jv91k7yl Accessed on 24.06.2021

[235]https://www.dhl.com/global-en/home/insights-and-innovation/thought-leadership/brochures/auto-mobility/battery-logistics.html#parsysPath_video_103386305 Accessed on 24.06.2021

[236] https://klingecorp.com/blog/transporting-lithium-ion-batteries-overseas/#Shipping-Containers Accessed on 24.06.2021

hopefully more by public transport, with eight buses at the beginning and end of each shift.[237] The Skellefteå airport is located about 27 km from the cell plant, but a community-driven project has been started to provide transport with electrical helicopters directly to the plant.[238]

Summary

Northvolt is the first all-European, all-green pilot for many Gigafactories to come. Northvolt shows excellent ambitions to be a good example of sustainable battery production and logistics. However, it can be hard in the beginning as many suppliers are still Asia-based or -dependent. However, with increased European sourcing of raw materials and the development of recycling, European battery manufacturing can be in a much better position to reach such objectives in a few years. In addition, Northvolt is bound by customer delivery contracts, which we hope will not conflict with sustainability goals.

Job roles and skills

Skills concerning automated transport and logistic planning will be in high demand, as well as knowledge on how to handle hazardous goods, especially in the recycling. The job roles include[239] mainly white-collar positions such as logistics developers, logistics business analysts and those who work with compliance with logistics. Blue collars do exist in such positions as material handlers. Many of the white collars have master's degree (master's degree in logistics etc.). The ratio between senior and junior workers, for example, in the case of Northvolt, is currently 50-50. Many of the juniors are hired from internships. There is a significant portion of seniors preferred in the beginning to contribute building the foundation. More senior staff is also preferred to certain positions such as logistics experts working with dangerous items and materials.

The future development is expected to bring such skill needs as understanding automatic flow, automatically guided vehicles, warehouse automatization, IoT etc.

[237] https://norran.se/artikel/kommande-trafikproblem-bara-northvolt-kommer-att-krava-atta-lokalbussar--per-skift/jd6mo8xl Accessed on 24.06.2021

[238] https://norran.se/artikel/skapar-teststracka-for-lufttaxi-mellan-skelleftea-airport-och-northvolt/r2me3g3j Accessed on 24.06.2021

[239] Northvolt interview on 28.5. 2021

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4.4 QUALITY

4.4.1 Quality as a part of a Gigafactory's functions

Quality is monitored and practiced throughout the entire manufacturing process in a Gigafactory. This can be executed, for example, by several teams that function for various purposes. These teams may include, for example, Quality Control, Construction Quality, Quality Postproduction, Quality Management System Team, Customer Quality and Continuous Improvement Team[240]. The team setup may vary from company to company.

Quality Control

The application of different quality control methods and sampling are coordinated with production lines' laboratories. The quality control activity must ensure the compliance of the processes with the stipulated requirements yet not impair the production process and maintain the associated costs to an acceptable level. In the early production stages, intensive quality control can be advantageous to stabilize processes and gather information on disturbances. Once production runs stably, measurement effort can be reduced to lower costs for quality assurance.

Construction Quality

Their tasks for a construction quality team include setting up the cleanrooms and maintaining quality with all the constructions in the facility. The proper setup of the entire production facility is also essential to the quality level of the end product. The battery production process is sensitive to ambient conditions (temperature, humidity, and cleanliness). Specific steps could be compromised by undesired interferences, including pollution hazards (the common organic solvent -NMP for cathode slurry is toxic and has strict emission regulations).[241] During the initial phase of the production process, there are many steps such as mixing, coating, drying, slitting, and calendering that need to be carried out under strict conditions to achieve the desired performance and quality levels.

[240] Northvolt interview on 28.5. 2021

[241] https://www.sciencedirect.com/science/article/pii/S258900422100300X accessed 26.08.26

Alliance for Batteries Technology, Training and Skills ALBATTS – Project number 612675-EPP-1-2019-1-SE-EPPKA2-SSA-B. The European Commission support for the production of this publication under the Grant Agreement Nº 2019-612675 does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Quality Postproduction

This quality postproduction team executes quality checks with the manufactured products. Material and cell validations are performed in a variety of ways in laboratories. Testing methods can be intrusive or non-intrusive and destructive or non-destructive, depending on the envisaged set of parameters to be determined and according to the specific requirements that may come from the battery manufacturer itself, the authorities, through legislation or direct notification or the vehicle manufacturer. The testing infrastructure includes testbeds, mule vehicles, and special devices to reproduce normal use events and out-of-ordinary events borderline abuse and misuse. During the ramp-up phase, the setup of this process will solely rely on the experience and knowledge of the battery manufacturer staff. Once the batteries roll off the production lines and get embedded into vehicles in large numbers, the feedback from the vehicle manufacturers using these batteries will serve as the basis for further postproduction quality checks. Joint testing sessions will also be considered to assess the quality level of the batteries properly.

Customer Quality[242]

For example, the customer quality team is responsible for developing, defining, and executing the qualification process and documentation for customers. It will ensure that the quality of the products meets or exceeds customer expectations and collaborates with the customers to meet their requirements.

Continuous Improvement Team

The responsibility of the continuous improvement team is to monitor the quality of the output for the entire production of the company. It cooperates closely with the research and development team to address all production stages, isolates the weak points where testing is prone to error and identifies the state-of-the-art methods and devices that could be easily and quickly adapted to the production process to enhance the reliability and accuracy of the testing methods.

[242] https://emp.jobylon.com/jobs/19142-northvolt-customer-quality-engineer/ last accessed on 14.6.2021

4.4.2 Quality Management Systems in a Gigafactory

The Quality Management Systems, QMS, in a Gigafactory require many specialists who have unique skills to guarantee these systems' smooth and efficient functioning. The key responsibilities of these specialists might involve:

- development and improvement of a Quality Control Plan designated for Li-Ion batteries production
- execution of PFMEA (Process Failure Mode Effects Analysis) and high-risk areas elimination
- monitoring of quality data using statistical process control to identify gaps in the assembly process
- creation and updating of Pareto charts to identify and quantify quality issues
- troubleshooting and root causing, e.g., 8D
- providing support for successful implementation of standards and continued certification
    - IATF16949 and ISO9001, ISO14001

IATF16949

Quality Assurance during Design and Manufacturing Process consists of, according to IATF 16949:2016[243], a global technical specification and quality management standard for the automotive industry based on ISO 9001:2015[244].

It applies the following quality management tools during the design and manufacturing process:

- Advanced product quality planning
- Production part approval process
- Control Plan
- Failure Mode and Effects Analysis
- Measurement System Analysis
- Statistical Process Control
- Design of Experiment Analysis
- Total Productive Maintenance
- Tolerance Analysis

[243] https://www.iatfglobaloversight.org/iatf-169492016/about/ last accessed on 17.6.2021
[244] https://advisera.com/16949academy/what-is-iatf-16949/ last accessed on 6.7.2021

ISO9001 and ISO14001

Additionally, the manufacturing unit must comply with and have certification based on the quality management system ISO9001: 2015[245] and environmental management system ISO14001: 2015[246].

The quality of the final product is affected by the quality of the processes and the materials the battery cells are made of. Therefore, the quality of the product (assessed through quality control processes - QC) is critically important and starts with the raw material analysis.

The production processes used has a significant impact on the cost and quality of the batteries. The production chain can be subdivided into three phases, i.e., electrode production, cell assembly and pack formation.

There is a diversity and a variety of processes and relations between process steps and intermediate products among the plethora of engineering disciplines. The battery production consists of a large diversity of cell manufacturing processes, mostly unknown and ambiguous interactions of process parameters and intermediate products, as well as a partial time-variability of processes and relations.

The complicated nature of Quality Management Systems needs their operations to be supported by a team of experienced technicians and engineers[247]. Their tasks also presume, for instance, conducting of MSA's (Measurement System Analysis) and processing of versatile flow charts; setting up quality monitoring procedures, quality KPI's, evaluating performance and making improvement proposals, i.e. process capability: SPC and Cpk; co-ordinating quality gate reviews in the Product Development process; being an expert in a complex problem solving and process optimization, i.e. skilled in DMAIC and DoE, multivariant data analysis etc. and collaborating closely with customer quality engineers and working across many parts of the organization.

[245] https://www.iso.org/standard/62085.html last accessed on 17.6.2021
[246] https://www.iso.org/standard/60857.html last accessed on17.6.2021

[247] https://northvolt.com/career/roles/?d=Manufacturing%2CQuality, last accessed on 15.6.2021

4.4.3 Quality audits

Continuous Improvement Methodologies

An internal audit is a function where the quality staff will check the company QMS processes. The goal is to ensure that records are in place to confirm compliance of the processes and to find problems and weaknesses that would otherwise stay hidden[248].

Quality auditors are mainly focused on monitoring the quality of a company's products or services, which is also applicable to a battery manufacturing process. The auditors set specific testing parameters used as benchmark standards to oversee any gaps in a manufacturing process. In addition, the products should be reviewed for industry compliance, and production procedures should be assessed. Key responsibilities of a quality auditor involve[249]:

- developing and implementing quality control audit plans
- evaluating production stages
- testing the composition appearance and functionality of completed products.
- training other employees on quality standards and procedures
- documenting defects and suggesting improvements
- presenting quality audit reports to senior management

There are several methodologies regarding continuous improvement, and below are shown the seven steps by Mark Hammer Figure 62. One of the most significant difficulties lies in understanding the difference between "correction" and "corrective action." "Correction" is when you find a problem and fix the immediate problem, such as changing the oil in a machine that fails due to the uncompliant oil quality and is making bad parts. Therefore, corrective action goes deeper and finds the underlying root cause of the problem (in this case, waiting too long to change oil) and fixes that root cause (implementing a preventive maintenance program to change the oil on a schedule before bad parts are made).

[248] https://advisera.com/9001academy/what-is-iso-9001/ last accessed on 03.7.2021
[249] https://www.betterteam.com/quality-auditor-job-description#:~:text=Quality%20auditors%20monitor%20the%20quality,and%20oversee%20quality%20control%20teams last accessed on 14.05.2021

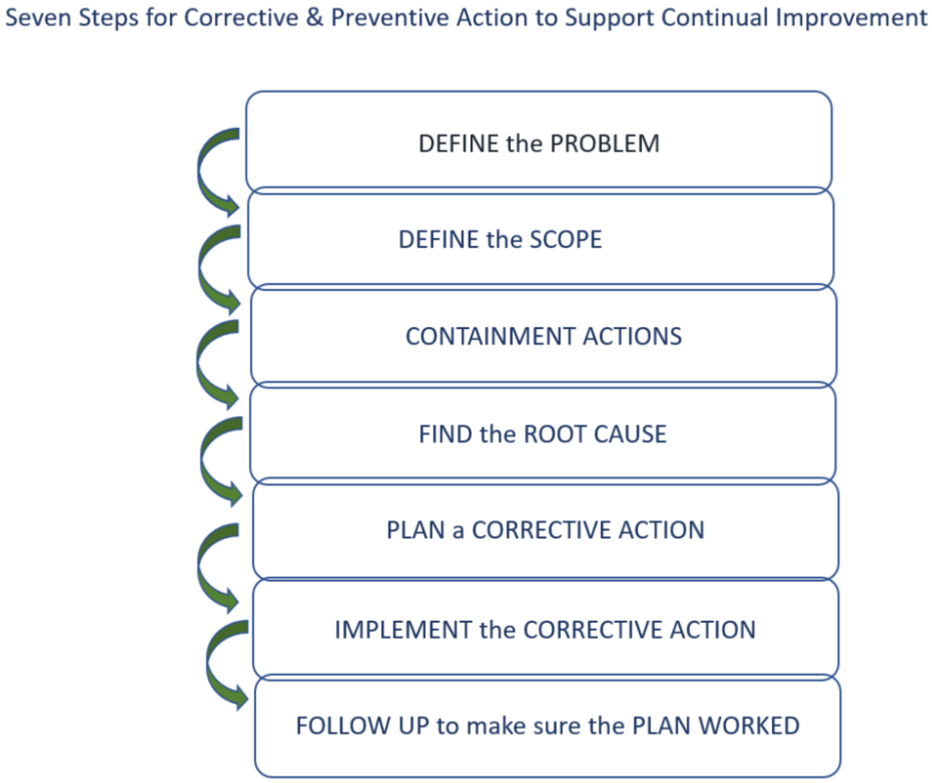

Figure 62. Seven Steps for corrective and preventive action to support continual improvement[250]

Many Gigafactories use several types of QMS such as those listed in the following subchapters (1.1.3.2 – 1.1.3.6).

Total Quality Management (TQM)

The central concept of the TQM methodology is focused on having all employees (from executives to blue-collar workers) involved in facilitating a continuous improvement of quality, which, in turn, would deliver customer satisfaction. Furthermore, TQM aims to eliminate any waste in a battery production process by ensuring all production stages' smooth, well-planned functioning. Therefore, the main features of the TQM framework are[251]:

- customer-focused quality improvement activities
- high-performance work systems and environment, which guarantee employee empowerment along all lines of operations and departments.

[250] https://advisera.com/9001academy/blog/2013/10/27/seven-steps-corrective-preventive-actions-support-continual-improvement/ last accessed on 02.7.2021

[251] https://searchcio.techtarget.com/definition/Total-Quality-Management last accessed on 15.6.2021

- process-cantered thinking
    - all internal and external outputs from a variety of suppliers
    - customers
    - constituents

According to the Total Quality Management framework, an additional key to continuous improvement is efficient communications among employees of all levels. This includes their shared understanding of the main mission, vision, operational goals, tactics, and objectives in the Li-Ion battery manufacturing process.

As a result of TQM's successfully implemented methodology framework, the manufacturing process might give many benefits[252]. First, the batteries are produced according to commonly known and accepted standards, which helps to eliminate defects in a manufacturing process. Less production-caused defects help the company save costs related to customer support, product replacement, field service etc. Furthermore, high-quality batteries will meet customer expectations, which will generate battery sales and will increase the company's market share.

Kaizen

Kaizen philosophy is also focused on continuous improvement achievement[253]. As a continuous improvement philosophy, Kaizen aims to maximise all levels of employee involvement into different developmental events, which facilitate improvement activities. A particular focus of Kaizen is set on floor level workers, who are abundant in a battery manufacturing process. Therefore, they are motivated to make suggestions to certain stages of a whole manufacturing process, which might improve their overall performance. Since Kaizen is a continuous improvement philosophy, it cannot be defined as a single improvement event. It is more of a natural way of thinking or a deliberate improvement mindset.

This improvement mindset can be broken down into six key steps:

- brainstorming some standardized improvements to specific activities
- measuring effectiveness of a new way of addressing the same process execution

[252] https://searchcio.techtarget.com/definition/Total-Quality-Management last accessed on 15.6.2021

[253] https://www.reliableplant.com/Read/10818/kaizen-lean-manufacturing last accessed on 14.05.2021

- comparing data measurements
- continuing to bring about further improvement to these activities
- in case of success standardizing,
- repeating recently integrated process changes

In the long run, Kaizen methodology leads to a multi-disciplinary waste reduction[254]. It concerns avoiding overproduction, helps prevent capital loss because of unprocessed inventory, eliminates unnecessary motion in the battery production process, facilitates defects exclusion and removes all unnecessary steps in the production.

Plan, Do, Study, Act (PDSA)

PDSA is a continuous improvement methodology, which has been developed by one of the greatest quality management experts, Dr W. Edwards Deming. Simply put, the philosophy seeks continuous improvements to a manufacturing process, so once some improvements have been implemented, the process of identifying further improvements continues. *The Planning stage* involves planning in its conventional sense, communication of clear objectives to the parties involved in the process, so everyone has a good understanding of the root cause of the problem. Finally, *the Do stage* presumes realizing the objectives, which have been set in the Planning stage, so action or improvement can be implemented[255].

The *Study time* is one of the most essential stages in the whole process, as it helps individuals and organizations to learn, based on implementation made throughout the previous stages. For example, the typical *Study stage* might involve questions such as: Have the implemented improvements brought real benefits? Were the problems and issues resolved? Etc.

The final stage in the PDSA framework is *Act*, which assumes a standardization of the best practices before moving to the next improvement cycle.

[254] https://www.leanproduction.com/kaizen.html#:~:text=Kaizen%20(Continuous%20Improvement)%20is%20a,a%20powerful%20engine%20for%20improvement. last accessed on 15.6.2021

[255] http://www.advice-manufacturing.com/Lean-Manufacturing-PDCA-Deming.html last accessed on 14.6.2021

Six Sigma

Six Sigma is a manufacturing process improvement framework, which has been developed in 1986 by Motorola[256]. According to Six Sigma methodology, an organization must follow, identify, and remove defect-causing elements and quantify the targeted value of the process. As a result, production costs, pollution and time cycle might be reduced, whereas the quality of products might be increased. The organisations, which implement Six Sigma in their operations, include measurable metrics in their manufacturing and follow the Six Sigma four-phase process once a project or goal is defined.

The first step is *Measure*, which helps the organization evaluate its existing practices and set the baseline activities. The next step is *Analyse*, which aims to identify defects, the roots, and the causes of the problem. The step of *Improving* is a practical-oriented stage, which includes seeking optimal solutions to previously identified problems and developing a plan of action to improve a process/ goal. The final step of *Controlling* is the modification of operating instructions and policies, which makes the Control step an ongoing process.

Lean Manufacturing

Lean manufacturing is a methodology primarily aimed at minimizing waste within the manufacturing process with simultaneous maximization of productivity. Waste is usually defined as any activity that does not add value from the customer's viewpoint. Lean has five main principles[257]:

- Value
- Value stream mapping
- Flow creation
- Pulling system establishment
- Perfection striving

[256] https://www.simplilearn.com/six-sigma-role-manufacturing-industry-rar406-article last accessed on 14.6.2021

[257] https://www.twi-global.com/technical-knowledge/faqs/faq-what-is-lean-manufacturing#HowDoesLeanManufacturingWork last accessed on 15.6.2021

Co-funded by the Erasmus+ Programme of the European Union

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First, value is determined from a customer's perspective and is calculated according to their willingness to pay for the product. Second, the value stream covers the entire lifecycle of a product, from raw materials to disposal. As a result, each stage of the production cycle needs to be examined for waste elements. The more complex the manufacturing process is, the more combined efforts are required from engineers, scientists, designers, and other manufacturing contributors.

The third principle, Flow Creation, helps remove all the barriers along the manufacturing process and improve lead times. The next step in establishing lean manufacturing is shifting to a pull system if production planning, which acts only in case the demand occurs. The pull system is the opposite of the push system, which is utilized in many ERPs. It determines inventory in advance based on sales or production forecasts. Due to their inaccuracy, push systems might incur significant money losses. The last principle of lean manufacturing can be defined as a pursuit of continuous perfection, which means ongoing assessment and improvement of processes are required[258].

4.4.4 Job roles, skills, and competences

Staff and recruitment[259]

Northvolt case is used as an analogue for the staff structure in the overall quality function in Gigafactories in this subchapter.

The quality team consists of engineers and technicians. The engineers are normally experienced personnel with PhD or master's degree educational backgrounds. They function in such job roles as Quality Control Engineers, Analytical Chemists, Technical Writers (they write the methodologies and work instructions that are developed by quality control engineers and analytical chemists), Customer Quality Engineers and Supplier Quality Engineers. Technicians often come from educational backgrounds of high school or vocational levels. They perform quality controls within the manufacturing labs and often work in shifts following the production planning.

[258] https://www.projectmanager.com/blog/what-is-lean-manufacturing last accessed on 15.6.2021
[259] Northvolt interview, 28.05. 2021

The industry backgrounds of the hired quality staff are for example in pharmaceutical industry, food and confection production, chemical industry, and cosmetics industry. The essential similarity between these industries and the battery manufacturing related quality work is that a lot of work involves laboratories, cleanrooms, and dry rooms. Consequently, people with experience from industries that have similar standards are sought after.

Training and upskilling of the quality staff are provided with an extensive internal training program. Additionally, the learning while in the job method is being applied.

Northvolt is in a phase where the quality processes and procedures are being defined and set. The nature of the current quality organisation is not fully representative of the future state of the organisation. Due to the lack of experienced people within the field, the educational level is generally high also within technician positions.

Challenging to find skills and competencies, and positions that are difficult to fill

- Cleanroom managers and specialists who can support building the cleanrooms
- Researchers with laboratory experience, especially with batteries
- Methodology development experts/specialists (with battery backgrounds)
- Quality engineers (with battery backgrounds)
- Many quality staff with relevant battery experience come from research-related positions
    - In addition to the research background, one needs to be fast, agile and make decisions that are not entirely based on one’s exact knowledge, which means it`s worth bearing risks to be fast. These qualities are challenging to find for the quality function in the overall paradigm.

The future staff development

The personnel need to stay on track and develop themselves along with the development of battery technology. This implies continuous internal upskilling. Furthermore, with the new technologies and increasing production volumes, there is a need to look into automated systems and material flows also in the quality control process. The importance of automation comes from the fact that it is impossible to operate similarly to a standard research laboratory since there is a need to take many quality samples (thousands). Consequently, technology is needed to help to process the vast volumes of samples and stay scalable.

4.5 RESEARCH AND DEVELOPMENT

In the case of research, we can talk about the three main phases thereof. The first phase is theoretical research, where scientists try to prove an idea. The second is laboratory validation to prove the idea and then a more extensive laboratory validation test, confirming that the technology will work in actual operation. Finally, the last phase is focused on proving that the technology works in a real operating environment.

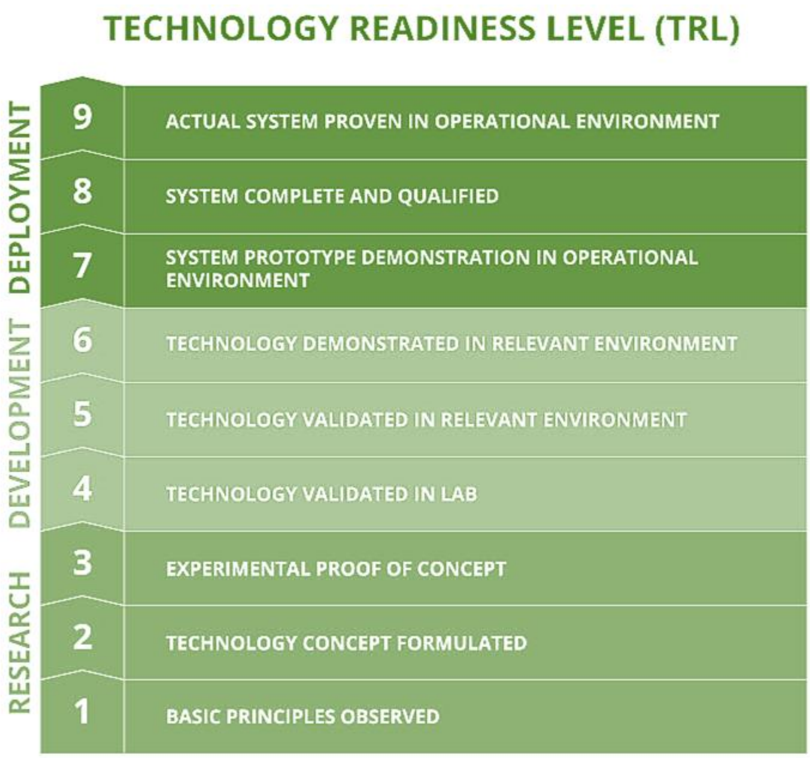

Figure 63. R& R&D phases[260]

In battery research, research institutes and universities typically carry out the first and a part of the second phase. The other part of the second phase is usually performed in cooperation with companies and institutions to demonstrate the technology is viable, not on a small scale

[260] What Does TRL Mean? (n.d.). [Illustration of TRL]. https://www.twi-global.com/technical-knowledge/faqs/technology-readiness-levels, last accessed on 12.05.2021

in a laboratory but also as a larger prototype. Finally, the third phase is long-term testing in actual conditions and optimization of technology for manufacturing.

There is a big difference between small producers and big ones in battery manufacturing research, also given the available resources and capabilities. Small manufacturers usually have their own research and development department within their battery factories unlike large manufacturers, such as LG Energy Solutions, Samsung, BYD, etc., that usually have separate R&D campuses or centres.

Samsung SDI has its research centre in Suwon, Korea, and it is the only Samsung SDI R&D centre in the world.[261] LG Chem has split off into LG Chem and LG Energy Solution at the end of the last year. Those two divisions share the R&D campuses Gwacheon and Daejeon, Korea[262]. SK Innovation has its R&D centre located in Daejeon, Korea, and, in 2020, it started cooperating with Nobel laureate and "father" of LIBs, Mr. John Goodenough at The University of Texas, USA, to develop next-generation LIBs[263]. Chinese BYD has several R&D institutes, while its Central research institute is focused on battery research.[264] CATL has begun construction of an innovation laboratory at its headquarters in Ningde in the eastern Chinese province of Fujian. The laboratory, named 21C Lab, will focus on developing next-generation batteries and new energy conversion systems.[265]

Tesla is also very active in battery research. They have cooperated with Panasonic on research NCA LIBs, for instance. In addition, Tesla has its own R&D lab in California, USA[266], comprised

261 https://www.samsungsdi.com/about-sdi/global-network.html, last accessed on 10.06.2021

262 LG Chem Presents Aggressive R&D Investment Plan. (2017, April 2). Businesskorea. http://www.businesskorea.co.kr/news/articleView.html?idxno=17694, last accessed on 12.5.2021

263 SK Innovation opens next-generation battery era together with Nobel laureate John Goodenough. (2020, December 4). SK Innovation Newsroom. https://skinnonews.com/global/archives/1425, last accessed on 26.5.2021

264 https://www.byd.com/en/CompanyIntro.html, last accessed on 10.6.2021

265 https://www.electrive.com/2020/06/25/catl-invests-millions-in-new-battery-research-centre/, last accessed on 10.6.2021

266 Duval, J., & Breton, D. (2016). The Guide to Electric, Hybrid & Fuel-Efficient Cars: 70 vehicles reviewed, plus everything you need to know about going electric. Juniper Publishing. last accessed on 26.5.2021

of its Innovation District and "Tesla Campus"[267]. Besides that, Tesla has a partnership with Dr. Jeff Dahn's lab at Dalhousie University, Canada[268] and carries out R&D&I activities in China.[269] Northvolt has its main research centre in Västerås, Sweden, with an R&D lab, cell production, cell design and cell validation.[270] Since Northvolt also produces battery modules and packs, there is a need for other R&D activities along the value chain. The battery systems team and its engineers can be found in Stockholm. There will be a prototype lab in Tomteboda, Solna[271]. The battery modules and systems assembly factory are in Gdańsk, Poland, with a plan to set up a new engineering research and development centre.[272] Cooperation between battery manufacturers and downstream industries/customers, like automotive, is becoming more and more frequent. For example, VW cooperating closely with Northvolt, has the Center of Excellence for Battery Cells near their expanding battery factory in Salzgitter, Germany. Recently, a joint venture between Northvolt and Volvo was announced. As a first step, they will set up a research and development centre in Sweden with the beginning of operations in 2022 and later also a new Gigafactory in Europe with a potential capacity of up to 50 GWh per year and start production in 2026[273. 274]

Freyr is building a battery R&D centre in Trondheim, Norway, cooperating with the Norwegian University of Science and Technology and research organisation SINTEF[275]. Another Norwegian company (Morrow Batteries) is building its Industrialization Center for battery technology and cell production. The centre will consist of several facilities: the Battery Innovation Center, the Cell Pilot Factory and the Cathode Active Material Pilot Factory (?). The

[267] Cooke, P. (2020). Gigafactory Logistics in Space and Time: Tesla's Fourth Gigafactory and Its Rivals, last accessed on 10.6.2021

[268] Jarratt, E. (2021, February 19). Tesla and Dalhousie University ink new research partnership deal. Electric Autonomy Canada. https://electricautonomy.ca/2021/01/18/tesla-dalhousie-university-jeff-dahn/, last accessed on 26.5.2021

[269] http://autonews.gasgoo.com/new_energy/70017638.html, last accessed on 10.6.2021

[270] https://northvolt.com/manufacturing#manufacturing-locations, last accessed on 10.06.2021;, Northvolt on 02.07.2021

[271] https://www.fastighetsvarlden.se/notiser/northvolt-hyr-4-000-kvm-i-tomteboda/, last accessed on 04.08.2021

[272] https://www.pv-magazine.com/2021/02/19/northvolt-plans-to-expand-gigafactory-in-poland/, last acccessed on 10.6.2021

[273] https://www.media.volvocars.com/global/en-gb/media/pressreleases/283261/volvo-car-group-and-northvolt-to-join-forces-in-battery-development-and-production, last accessed on 04.08.2021

[274] https://www.media.volvocars.com/global/en-gb/media/pressreleases/283261/volvo-car-group-and-northvolt-to-join-forces-in-battery-development-and-production, last accessed on 04.08.2021

[275] Lysvold, S. S. (2021, April 10). Freyr skal bygge batterifabrikk i Mo i Rana – vil trenge 1500 ansatte. NRK. https://www.nrk.no/nordland/freyr-skal-bygge-batterifabrikk-i-mo-i-rana-_-vil-trenge-1500-ansatte-1.15445805, last accessed on 26.5.2021

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Battery Innovation Center, located on-campus in Grimstad by the University of Agder, will be Morrow's competence centre of excellence focused on developing and commercialising new battery technology. [276]

Automotive Cells Company (ACC) has its R&D centre and testing facilities in Nouvelle-Aquitaine, France.[277] InoBat, a smaller battery producer presently focused on niche/premium segments, is building a research lab with a pilot line in Voděrady, near Bratislava, Slovakia. Later, a Gigafactory will follow, probably in Košice, eastern Slovakia.[278]

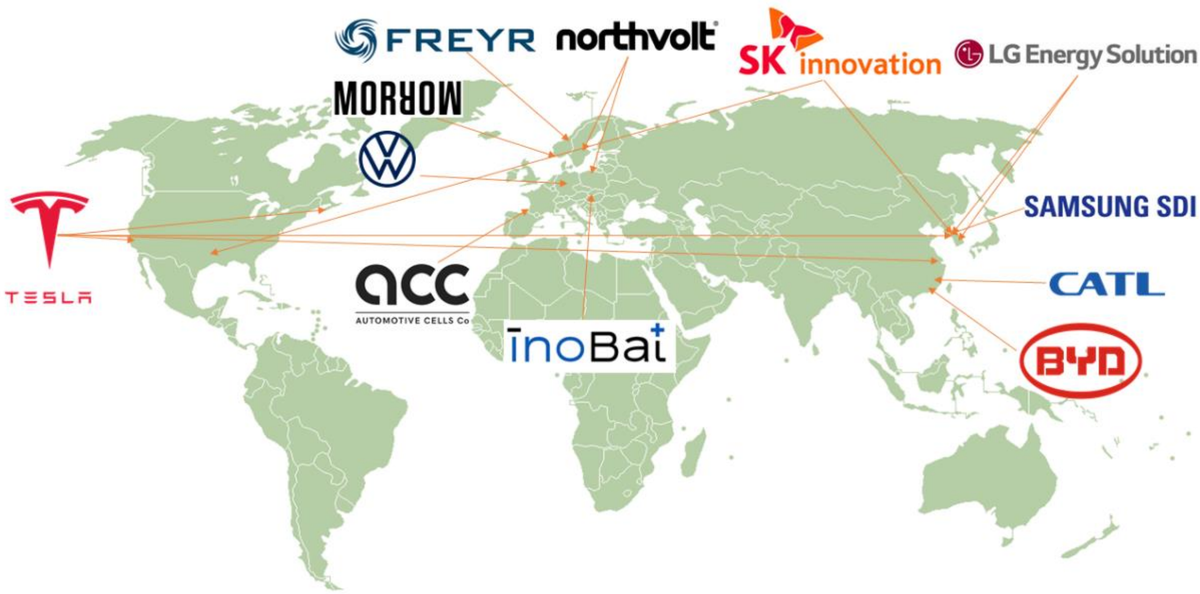

Figure 64. Location of main battery R&D centres

As the battery value chain is still developing in Europe, almost all big players in the field of LIBs have their research out of Europe for now. In contrast, the country with the most concentrated battery research and production is Korea, the homeland of LG, Samsung, and SK Innovation.

R&D is an essential part of every technology company; therefore, companies invest substantial funds in these departments. For example, LG Chem invested in R&D in 2018 more than $850

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[276] https://www.morrowbatteries.com/manufacturing, last accessed on 10.6.2021

[277] https://www.acc-emotion.com/newsroom/en-2023-nous-arriverons-sur-le-marche-avec-des-batteries-letat-de-lart-de-la-technologie, last accessed on 10.6.2021

[278] https://www.e15.cz/rozhovory/slovensky-musk-marian-bocek-stavim-obdobu-tesly-ve-vychodni-evrope-1380988, last accessed on 10.6.2021

million, and more than 30% of the amount went towards battery development[279]. Samsung SDI invested more than $700 million in R&D in 2019, 7% more than in 2018, and they are trying to hold this trend.[280] In 2020, Tesla's R&D expenses were almost $1,5 billion, an 11.02% increase in spending over the previous year.[281]

Also, in Europe, to grab the opportunities of the growing electric mobility and renewable energy business, both private and public investments (for example, under the umbrella of Horizon 2020 - BATTERY 2030+ project, Batteries Europe Platform[282], LiPlanet, IPCEI [283]) are increasing at a fast pace.

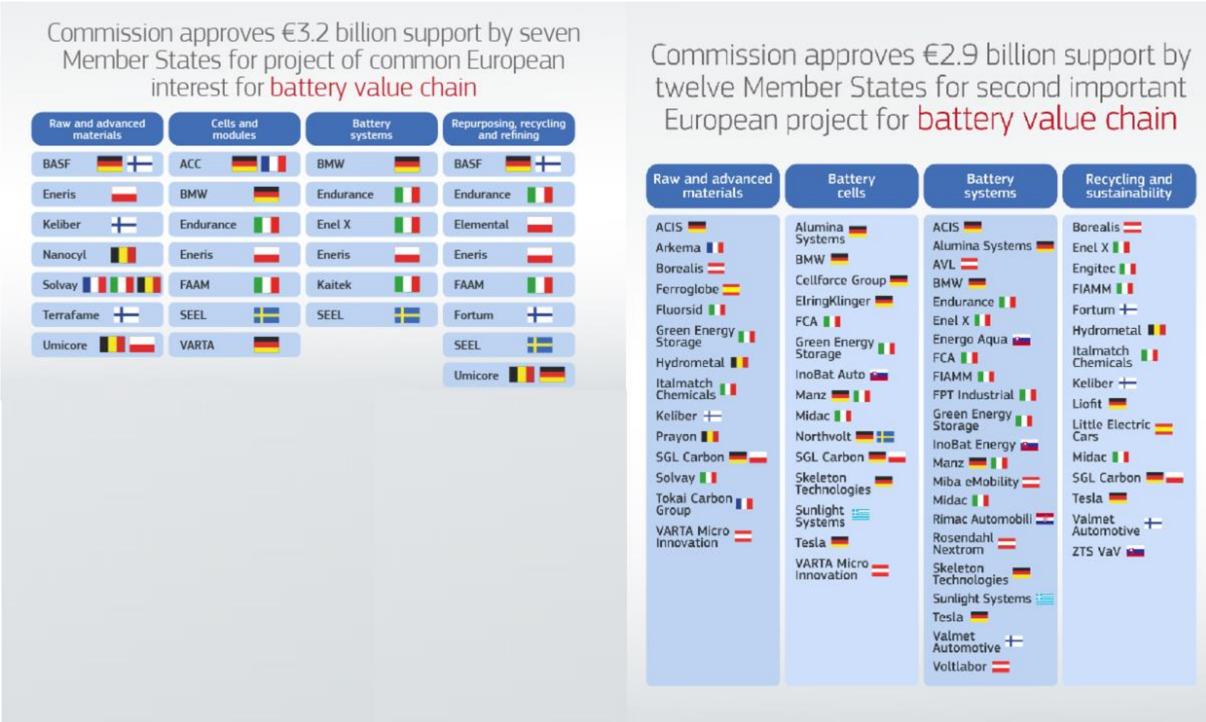

Figure 65. IPCEI 2019 (left) and IPCEI 2021 (right)

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[279] [Guest Report] LG Chem gets ahead with R&D investment. (2019, November 25). Korea JoongAng Daily. https://koreajoongangdaily.joins.com/2019/11/25/nationalGuestReports/Guest-Report-LG-Chem-gets-ahead-with-RampD-investment/3070721.html, last accessed on 26.5.2021

[280] Samsung SDI Concentrating Resources on R&D. (2020, August 31). Businesskorea. http://www.businesskorea.co.kr/news/articleView.html?idxno=51097, last accessed on 26.5.2021

[281] https://www.statista.com/statistics/314863/research-and-development-expenses-of-tesla/ last accessed on 04.08.2021

[282] https://ec.europa.eu/energy/sites/ener/files/documents/batteries_europe_strategic_research_agenda_december_2020__1.pdf, last accessed on 10.6.2021

[283] https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6705, https://www.eba250.com/eu-approves-e2-9-billion-state-aid-for-a-second-pan-european-research-and-innovation-project-along-the-entire-battery-value-chain/, last accesssed on 10.6.2021

Job Roles and Skills

To stay competitive and accommodate various requirements by customers, R&D activities are at the core of battery manufacturing, covering areas like active material development, cell design, or cell performance (testing, validating the cells, etc.)[284]

Since the EU is gradually building up its competence base, human resources for this type of jobs are still scarce in Europe. The battery players established in Europe need to source from abroad like Korea, Japan, China, or India[285], via dedicated headhunting.

They also conduct projects with domestic and international universities and research institutes, co-create bachelor´s and master´s programmes[286], or offer internships. By that cooperation, they also ensure continuous upskilling of their employees. Furthermore, to strengthen the ability of the R&D workforce, battery manufacturers also operate learning groups where employees share their experience and knowledge, support their employees through various systems, including academic training, in-house programmes, and the dissemination of excellent educational content.[287]

Similarly, to other core departments, it is essential to retain talented and skilled people by different means. These include, for example, offering warrants in the companies, incentives, and benefit programmes or having dedicated teams that work with relocation and integration of employees and their families, ensuring they adapt well and can thrive in their new environments.

In the R&D department, white-collar jobs prevail, but blue-collar employees also deal with R&D tasks, like operators working in the validation labs.[288] Samsung SDI, for instance, has around 2,300 R&D experts, and the share of R&D employees with a master's or PhD degree is 39 %.

[284] Northvolt interview on 02.07.2021; https://taleez.com/apply/mechanical-senior-expert-bruges-automotive-cells-company-acc-cdi, last accessed on 04.08.2021

[285]Northvolt Interview on 02.07.2021; https://www.morrowbatteries.com/post/morrow-attracts-leading-international-expertise-as-dr-rahul-fotedar-joins-as-cto, last accessed on 04.08.2021; https://www.nrk.no/nordland/freyr-skal-bygge-batterifabrikk-i-mo-i-rana-_-vil-trenge-1500-ansatte-1.15445805, last accessed on 12.04.2021

[286] https://www.tu.no/artikler/sarah-laeres-opp-av-kinesiske-batterieksperter-og-far-kompetansen-industrien-torster-etter/508478, last accessed on 12.04.2021

[287] https://www.samsungsdi.com/about-sdi/research-development.html, last accessed on 10.6.2021

[288]Northvolt interview on 02.07.2021;

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Based on the previous desk research done by the ALBATTS project, these are the most frequent job roles:

Material Engineers for Cathodes and Anodes, Chemistry Engineers for Electrolyte, Electrical Engineers/Battery Specialists, Manufacturing Engineers and Mechanical Battery Design Engineers. Other profiles cover research in software development/modelling, production, maintenance or testing of the batteries.

When it comes to competence, we can describe specific competencies such as characterisation techniques, cell evaluation/development; thermal management; electrolyte development; cell design; expertise in battery components, or knowledge of different battery chemistries. More general cross-sectoral competencies include product testing, data analysis, product design, prototype development, and manufacturing methods.

Academic competencies that provide background to more specific competencies are chemistry, material science, electrochemistry, electrical engineering, or mechanical engineering.

More information can be found in the parallel report, **Deliverable D5.4 Desk Research & Data Analysis**, developed in the ALBATTS project. Its focus is solely on battery technology and research and development.

4.6 SUSTAINABILITY AND RECYCLING

4.6.1 General considerations on environment and sustainability

Any business or economic activity in the European Union must comply with the EU legal framework in force. Whatever national regulations may apply on top of that would more likely increase the necessary investments and efforts. The EU legal framework alone is based on the circular economy principles (which recently yielded the new circular economy action plan – CEAP[289] - one of the main building blocks of the European Green Deal[290]). It is one of the strictest in the world in terms of air quality, CO_2 emissions, chemical substance management, waste management and energy efficiency if we consider environmental-related legislation alone, which implies considerable compliance investments and efforts for all EU-based manufacturing companies.

[289] https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en, accessed on 10.08.2021
[290] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en, accessed on 10.08.2021

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Mandatory legal requirements need to be observed and complied with, especially the EU and national regulations that impose clear, unabridged provisions, limits, interdictions, or obligations.

It would be helpful to mention the legal mechanisms and principles (mandatory as well) that come on top and are more flexible and maybe a little bit confusing, hence requiring special attention from the economic operators:

Mandatory disclosure of information on how big companies operate and manage social and environmental challenges through the directive 2014/95/EU, also called the *Non-Financial Reporting Directive*, NFRD. ("big companies" means here those with more than 500 employees, which makes up 11.700 economic operators in the EU). This directive is about **to turn into the Corporate Sustainability Reporting Directive** soon. The information required to be disclosed concerns environmental matters, social matters, treatment of employees, respect for human rights, anti-corruption and bribery and diversity on company boards[291];

The Extended Producer Responsibility (EPR) principle can be defined as "an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle"[292]. In the European Union, **extended producer responsibility** is mandatory within the context of the WEEE[293], Batteries[294], and ELV[295] Directives, which put the responsibility for financing collection, recycling, and responsible end-of-life disposal of WEEE, batteries accumulators, and vehicles on producers. EPR seeks to reduce the environmental impact of products, throughout their lifespan, from production through end-of-life. What it does is holding the producer administratively and financially responsible for closing the lifecycle loop of its own products once they reach the end-of-life stage. The framework is operated by various mechanisms implemented by themselves or by third-party entities, such as providing a free take-back collection network or applying a deposit system on the new products. As batteries are included explicitly in the EPR scheme, special attention and consideration are required from battery manufacturers in Europe.

[291] https://ec.europa.eu/info/business-economy-euro/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en accessed on 10.08.2021
[292] https://ec.europa.eu/environment/archives/waste/eu_guidance/introduction.html accessed on 10.08.2021
[293] https://ec.europa.eu/environment/topics/waste-and-recycling/waste-electrical-and-electronic-equipment-weee_en, accessed on 10.08.2021
[294] https://ec.europa.eu/environment/topics/waste-and-recycling/batteries-and-accumulators_en accessed on 10.08.2021
[295] https://ec.europa.eu/environment/topics/waste-and-recycling/end-life-vehicles_en accessed on 10.08.2021

On the other side, it should be noted that compliance with voluntary principles and guidelines does not exonerate the company from the applicable regulations and legal framework.

The voluntary environment and sustainability principles and guidelines the economic operators may also wish to comply with for different reasons are divided into three categories:

- The corporate social responsibility (CSR) mechanism, a self-regulating business model that helps a company be socially accountable—to itself, its stakeholders, and the public[296]. Examples thereof refer to permanent measures such as the implementation of the Green Supply Chain Management[297] (GSCM) or occasional activities such as planting one tree for every vehicle sold or donating vehicles to the law enforcement forces to better apply road safety legislation, etc.
- Environmental and sustainability targets and objectives became trends in the society or are even regulated (such as green labels or eco-labels), which the economic operators want to adhere to.
- Unregulated, usually self-elaborated targets and objectives that economic operators set for themselves individually, such as achieving carbon neutrality in battery production by Northvolt[298] or the early electrification of the entire product line-up by Mercedes-Benz.

All the elements described above and the occurrence of environmental disasters (some out of disrespect of the regulations, some out of just accidents) of a company can have a devastating public image- and economic effects. This implies the utmost care and consideration from all companies operating in the European Union that require considerable resources, including skilled staff. Some companies went the extra mile in this respect and created new positions to handle all these issues properly and avoid all kinds of mishaps. This is the case, for example, with the Swedish company Northvolt that created the Chief Environmental Officer position[299] , which is a top management position. Still, its acronym can be easily confused with the one used for the highest management position in a company – CEO (Chief Executive Officer). Big companies went even further and put together entire structures to deal with the

[296] https://www.investopedia.com/terms/c/corp-social-responsibility.asp accessed on 10.08.2021
[297] https://www.sciencedirect.com/science/article/pii/S2212827114008488 accessed on 10.08.2021
[298] https://northvolt.com/loop accessed on 10.08.2021
[299] https://eit.europa.eu/innoveit/speakers/emma-nehrenheim accessed on 10.08.2021

environmental and sustainability issues: Volkswagen group created the "Sustainability Council"[300] and Daimler Group a "Sustainability Board".

4.6.2 Particularities of the Gigafactories

The "Gigafactory" term refers in Europe to the new factories that produce traction batteries for electric vehicles, other means of transport or energy storage solutions on a large scale and was initially used for a giant factory being built by the electric car manufacturer Tesla near Reno, Nevada.

Given that the demand for EVs (full electric - BEV) is rapidly increasing and is expected to reach around 20% market share in 2030[301] , the need for large amounts of traction batteries is obvious. Most of the European battery factories currently under construction are expected to reach an output of more than 10 GWh/year, peaking at 40 GWh/year (Tesla Giga Berlin) as economies of scale are needed to keep the production costs as low as possible.

The most important issues regarding the Gigafactories, not necessarily in the order of their importance, are the following:

- The pollutant emissions – traction batteries contain several chemical substances harmful to the environment and human health and need to be dealt with correctly.
- The procurement of certain raw materials that are either scarce or sourced in an unsustainable, unethical manner.
- The high energy consumption and the power supply.
- The potential impact of specific greenfield projects that need prior deforestations and land-use change.

Challenges of the Gigafactories

Even if the Gigafactories are a fundamental element in achieving maybe the most critical environmental goal of the 21st century (up to this point, full decarbonization of the transports and the economy is the #1 ecological goal), they are not exempt though of the legal provisions.

[300] https://www.volkswagenag.com/en/sustainability/sustainability-council.html accessed on 10.08.2021
[301] https://www.automotiveworld.com/articles/are-electric-vehicle-projections-underestimating-demand/ accessed on 10.08.2021

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Some of the voluntary, more challenging objectives beyond the legal framework are also to be observed by the actors in the battery value chain.

More precisely, the “Gigafactory phenomenon” comes with a series of challenges that need to be addressed relatively soon to ensure the smooth transition towards sustainable and environmentally sound electrification. According to a study elaborated by the World Economic Forum and the Global Battery Alliance[302] , there are three major challenges regarding the battery value chain

Challenge 1: Battery production has a significant GHG footprint

Challenge 2: The battery value chain has substantial social, environmental and integrity risks

Challenge 3: The viability of battery-enabled applications is uncertain

Although only the first one unequivocally concerns the production of batteries, the other two also have an influence thereabout. In the order of their importance, the most relevant aspects that are included in the abovementioned challenges come as follows:

Environmental pollution triggered by the extraction and the refinement of critical raw materials. According to a study by the Natural Resource Governance Institute and the University of California – Berkeley Law[303], brine-based Lithium extraction in salt deserts uses and discharges significant quantities of water, which can negatively affect neighbouring farms and communities by diminishing and polluting supplies.[304] Cobalt mining in Congo can cause water pollution, air quality impacts, and possible radioactive exposure, affecting both miners and surrounding communities[305] .

The impact on human rights, local governance and economic development in mineral producing countries. According to the same study elaborated by the Natural Resource Governance Institute and the University of California – Berkeley Law, in recent years, mining operations around the world have been linked to human rights impacts such as long-term health risks and dangerous conditions for workers, child labour and underpayment, forced evictions, police detentions and armed conflict. These problems do not permeate all mining

302 http://www3.weforum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf accessed on 10.08.2021

303 https://www.law.berkeley.edu/wp-content/uploads/2020/04/Building-A-Sustainable-Electric-Vehicle-Battery-Supply-Chain.pdf accessed on 10.08.2021

304 https://iopscience.iop.org/article/10.1088/1748-9326/aae9b1/pdf accessed on 10.08.2021

305 https://www.washingtonpost.com/news/in-sight/wp/2018/02/28/the-cost-of-cobalt/ accessed on 10.08.2021

projects, of course. Nevertheless, the global mining industry has taken steps in recent years to enhance its approach to health, safety, security, and community relations[306].

The GHG (carbon) footprint of the battery production, although relatively minimal compared to the GHG footprint of the vehicle over its lifetime (in terms of energy consumption), is a parameter that needs to be thoroughly addressed. According to an analysis elaborated by the University of Melbourne, the GHG emissions (Figure 66) associated with the production of EVs is higher compared to ICE vehicles (lower if we exclude the battery), the extent of the surplus depending on the size of the battery (between 15 and 70%)[307].

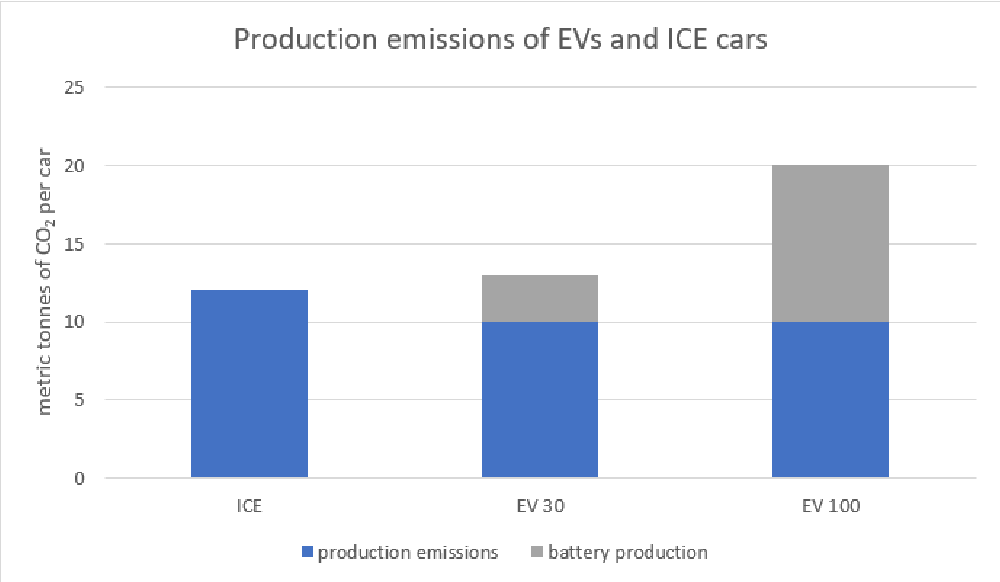

Figure 66. Production emissions of EVs and ICE cars

On the other hand, if we compare the total GHG emission (production, usage, and recycling), the EV, including its batteries, is more environmentally friendly from this point of view (Figure 67)

[306] https://www.amnesty.org/download/Documents/12000/afr620012013en.pdf accessed on 10.08.2021
[307] https://blogs.unimelb.edu.au/sciencecommunication/2019/10/27/are-electric-cars-greener-lets-crunch-the-numbers/ accessed on 10.08.2021

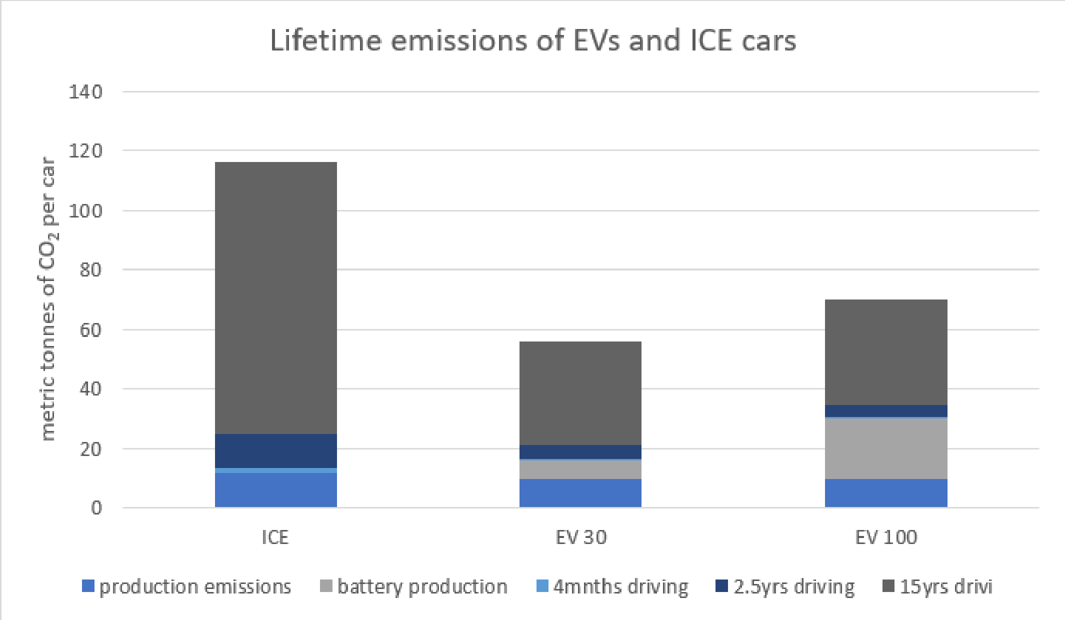

Figure 67. Lifetime emissions of EVs and ICE cars

The EV compensates its production related GHG emissions within a single year if we consider a 30-kWh battery. A second battery of this kind would extend this period by a mere three months. In the case of a 100-kWh battery, the breakeven point is reached within 2.5 years (or 5.5 years if it takes a second battery during its lifetime) (Figure 68.

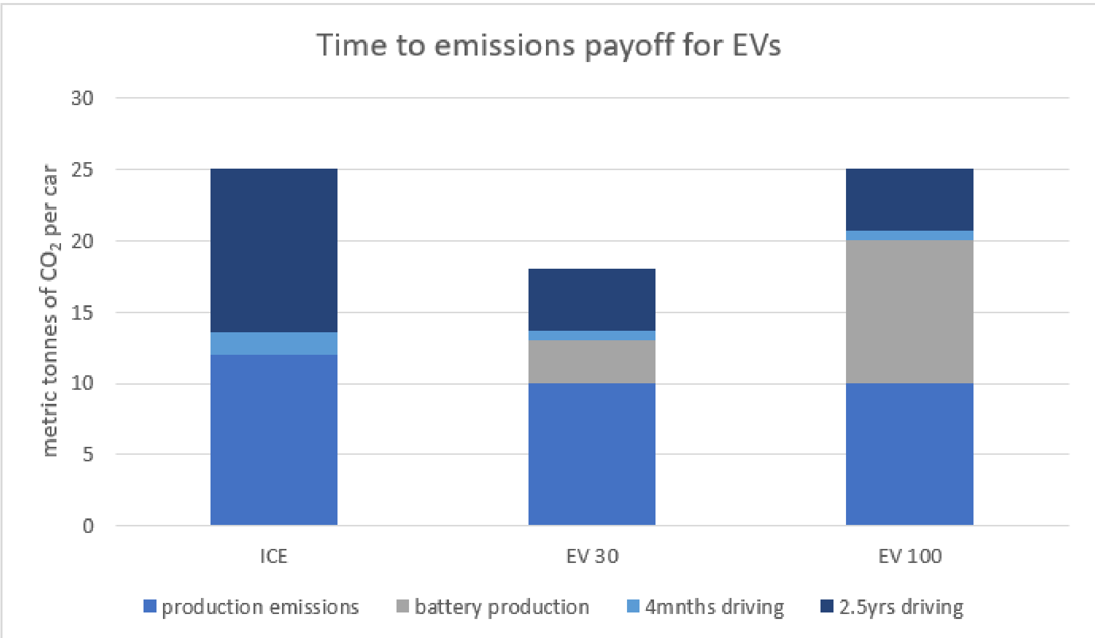

Figure 68. Time to emissions payoff for EVs

The GHG emissions discussed in the previous point are a real concern if the energy in their production comes from non-renewable sources (natural gas/coal power plants), which is a common situation. Currently, the share of renewables is relatively low (19.7%) in the European Union (Figure 69), even below the objective set (truth be told, just shy of the 20% target)[308].

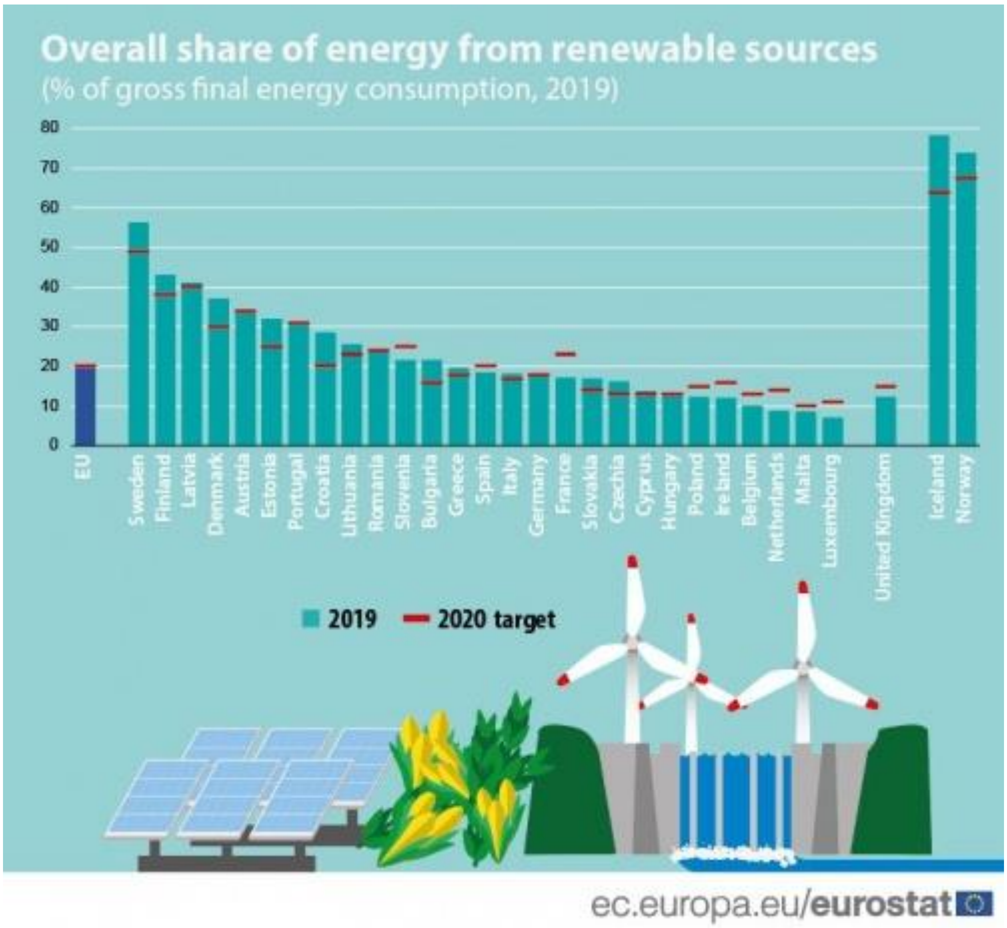

Figure 69. Overall share of energy from renewable sources (% of gross energy consumption, 2019)

1. **Once the traction battery production ramps up in the EU, the energy consumption will increase considerably, hence the GHG emissions.**

Even though the extensive use of electric vehicles will reduce CO_2 emissions, this will only happen in the long run (EV production-related emissions are higher). The switch from fossil fuels to electricity will burden the electricity production infrastructure and the grid. According

[308] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics accessed on 10.08.2021

to EIA estimates[309], the energy demand in 2050 will practically double compared to the 2020 consumption level (**Error! Reference source not found.**).

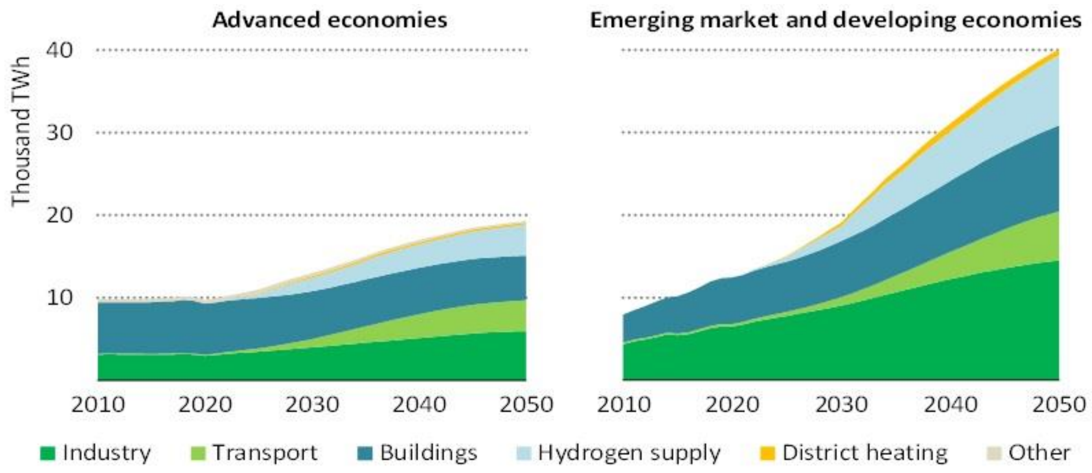

Figure 70. Electricity demand by sector and regional grouping in the NZE

The most significant aspect regarding the European Union is that by 2050, close to 100% of the energy needed will have to be carbon neutral given the objectives envisaged by the European Commission`s vision from November 2018[310] (Figure 71)

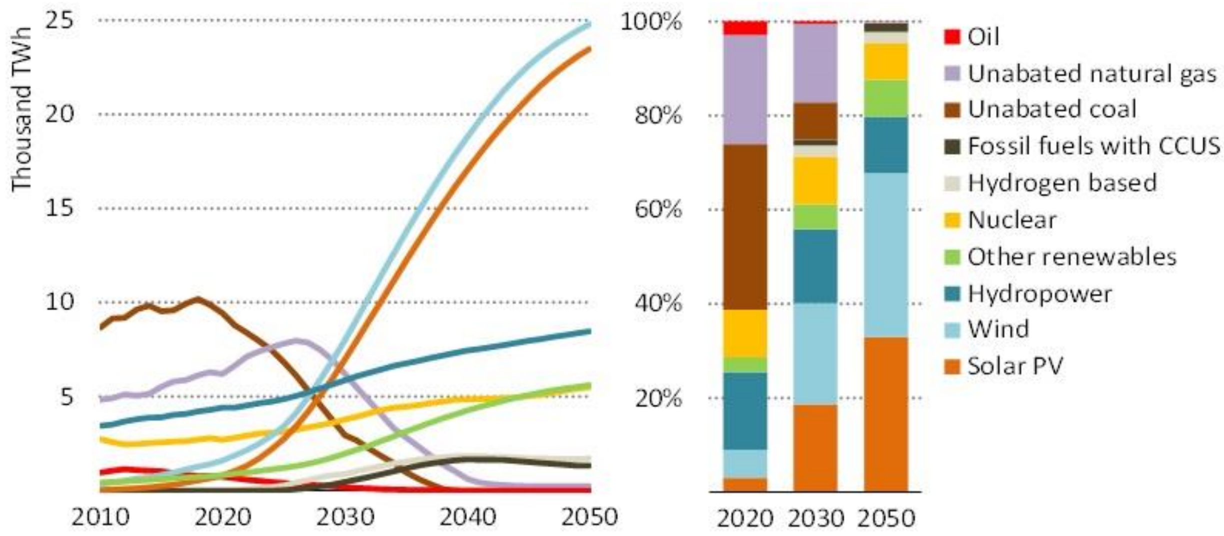

Figure 71. Global electricity generation by source in the APC

[309] https://iea.blob.core.windows.net/assets/063ae08a-7114-4b58-a34e-39db2112d0a2/NetZeroby2050-ARoadmapfortheGlobalEnergySector.pdf accessed on 10.08.2021
[310] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0773 accessed on 10.08.2021

This projection will be confirmed only if massive investments in carbon-neutral energy sources such as solar, wind and hydropower are achieved. Furthermore, EU and national policies will have to heavily incentivize the purchase and use of electric vehicles in the following years to create the wind beneath the wings of the investors in sustainable power production. This is where the EU taxonomy[311] comes in handy in that the most environmentally friendly and sustainable applications and energy production technologies will be more heftily stimulated, and their development will be faster.

The viability of battery-enabled applications, including road transport. Although the legislators are constantly pushing for more ambitious CO2 reduction objectives and the automotive industry has fully embraced the new mobility paradigm, some issues still need to be dealt with for this massive enterprise to succeed. Those issues have to do mainly with the acceptance of the electric vehicle by the end-users, which is still affected by the size and efficiency of the charging infrastructure and the lack of some stimulative measures, especially at the national level.

4.6.3 Sustainability job roles and skills[312]

For example, Northvolt has a team that works with general sustainability-related matters. The team is responsible for sustainability reporting and compliance. It includes chemical compliance that covers rules and laws to protect the environment and people. The tasks include reporting and documentation, data collection, conducting reviews and sample taking. The team members mostly have a mix of environmental degrees (master) from environmental engineering, chemical engineering, and sustainability planning. These types of employees are less challenging to recruit since, due to the trendiness of this topic area, there are potential candidates well available and the tasks they need to conduct are common throughout different industries.

In the future, it is expected that the increased automation and traceability will ease the tasks of sustainability related staff, but, on the other hand, the amount of processed data will increase. Big data will play a much more significant role from the controlling perspective. The

[311] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12440-Sustainable-finance-obligation-for-certain-companies-to-publish-non-financial-information_en accessed on 10.08.2021
[312] Northvolt interview, 2.06. 2021

staff will need to be more and more skilled with analysing and working with data in the future. Additionally, it can be expected that the sustainability demands, and rules will tighten, which means that, from the compliance point of view, one need continuously stay up to date with those demands, rules, and legislation.

Specific sustainability-related job roles include, for example, Energy and Sustainability Engineers[313] and Sustainability Analysts and Environmental Compliance & Sustainability Leaders and Senior Environmental Sustainability Data Analysts[314].

4.6.4 Battery recycling

As stated at the beginning of the subchapter, the foundation of environmental protection and the sustainability regulations are the **principles of the circular economy** (Figure 72). This means that a product or a packaging item should be designed with responsible raw material sourcing, reusability, and recyclability in mind and, once the product leaves the factory, it must be taken care of by a series of stakeholders, including the producer, as the main actor, to avoid the unsound disposal and ensure the proper recycling of the biggest possible share thereof[315].

Figure 72. Green growth and circular economy

[313]https://able.bio/northvolt/jobs/energy-and-sustainability-engineer-mfd-germany-remote/e7dc9d, last accessed 5.8.2021

[314] https://www.tesla.com/careers/search/?query=sustaina, last accessed 5.8.2021

[315] https://ec.europa.eu/environment/green-growth/index_en.htm last accessed 10.8.2021

In the case of traction batteries, these principles are even more applicable for two main reasons: the safety and environmental hazards associated with the improper storage and disposal[316] and the stringent need for raw materials, especially Cobalt and Lithium, to a lesser extent[317 318]).

As stated, the traction batteries may incur high risks of fire/explosion even if they are just improperly handled, let alone abused[319]. On the other hand, the electrolyte is highly corrosive to human tissues, and utmost care is necessary when dealing with this type of battery[320].

The shortage of some critical raw materials[321] is right around the corner, even without the foreseen skyrocketing demand for electric vehicles or the reduction of specific quantities needed (50 % in the case of Lithium and around 75% in the case of Cobalt) as some operators around the world push for domination in the extraction and processing of these materials[322]. Therefore, the necessary infrastructure meant for the recycling of traction batteries must be capable of properly collecting and storing the envisaged volumes of decommissioned batteries and achieving ultra-high levels of reclaimed critical raw materials and close to 100% overall recyclability rates. Currently, the most optimistic recycling rate for Lithium-Ion batteries achieved is 5%, considerably less in some parts of the world[323] , which is not necessarily disconcerting. The volumes of decommissioned batteries are still very low (mostly batteries from crashed vehicles and early EVs). Some batteries removed from EVs because of their fainting state of health - SoH (below 80%), which makes them unsuitable for mobile use, could still be integrated in various second life stationary applications, mainly for grid stabilization or green energy storage. Second life mobile applications are also taken into consideration, yet considerably less likely than stationary applications. Once the economy of scale is envisaged,

[316] https://www.sciencedirect.com/science/article/pii/S2095495620307075 last accessed 10.8.2021
[317] https://www.wired.com/story/a-cobalt-crisis-could-put-the-brakes-on-electric-car-sales/ last accessed 10.8.2021
[318] https://www.forbes.com/sites/arielcohen/2020/03/25/manufacturers-are-struggling-to-supply-electric-vehicles-with-batteries/?sh=7aa292b71ff3 last accessed 10.8.2021
[319] https://www.newpig.com/expertadvice/how-to-care-for-defective-lithium-ion-batteries last accessed 10.8.2021
[320] https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/12848-lithiumionsafetyhybrids_101217-v3-tag.pdf last accessed 10.8.2021
[321] https://www.transportenvironment.org/sites/te/files/publications/2021_02_Battery_raw_materials_report_final.pdf last accessed 10.8.2021
[322] https://www.automotiveworld.com/articles/risky-business-the-hidden-costs-of-ev-battery-raw-materials/ last accessed 10.8.2021
[323] https://www.bbc.com/news/business-56574779 last accessed 10.8.2021

much higher recycling rates are to be achieved, up to 100% in the long run, with high levels of reclaimed critical raw materials.

According to the official communications from Northvolt, a company that builds several Gigafactories in Europe, battery recycling will be an essential part of the activity of the plant that is currently under construction in Skellefteå, Sweden. This will allow the company to integrate a high share (50%) of reclaimed material into the new cells by 2030[324].

4.6.5 Battery recycling-related job roles and skills[325]

Our example battery manufacturer, Northvolt with its Revolt programme has built a prototype recycling plant in Västerås, Sweden. It will be followed by a full-scale recycling plant at their Skellefteå-based Gigafactory, Northvolt Ett.[326] The plant applies hydrometallurgical treatment.[327] Northvolt regards recycling as an important part of their business and mission to be sustainable.

The recycling related job roles include for example operators, shift leaders, production managers and recycling managers. When recycling plants are set up, most of the staff are university educated white-collar employees, including, for example, researchers and personnel needed with the production setup. Northvolt has a team of people that have been hired directly from the field of battery recycling research. They develop recycling processes as process engineers and planners. Additionally, the recycling process needs to be developed including, for example, strategies for battery collection, methods, and systems. When the activity of the plant is more established, the share of blue-collar employees with vocational education will increase, eventually comprising a half of the staff. The valued experience can include background in another battery or other recycling facility and previous work history with wastewater treatment, chemical handling, active material production and material production in general. Additionally, experience from working with hazardous materials as well as processes that involve crushing and sorting would be beneficial. The biggest recruitment challenges have been encountered while hiring engineers and researchers.

[324] https://northvolt.com/loop/ last accessed 10.8.2021
[325] Northvolt interview, 2.6. 2021
[326] https://northvolt.com/articles/announcing-revolt/, last accessed 5.8.2021
[327] https://northvolt.com/products/revolt/, last accessed 5.8.2021

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Northvolt trains and upskills its staff with a mixture of external education programs combined with internal training. There are educated staff members with vocational level education and higher education such as universities of applied sciences. For example, Northvolt collaborates with a local university of applied sciences to provide courses on battery recycling and battery specifics. After the training/education session, one has the general qualifications to work at Northvolt.

In terms of future changes affecting job roles and the skills needed with them, similarly to many other departments/functions, automation is expected to increase in the future. For example, material handling is expected to become more automated with the increasing use of robots, AGVs, conveyor belts and different kind of other fully/semi-automatic systems. The increasing automation will mean that the tasks will change to certain extent. While less automated routine tasks existing today will potentially diminish, at the same time, there will need to be operator level staff that is also skilled with providing maintenance for those automated systems applied with recycling of batteries.

4.7 OTHER DEPARTMENTS AND TEAMS

4.7.1 Purchasing[328]

This department deals with purchasing in different areas such as materials, equipment, services, construction, and infrastructure or purchasing dedicated to a certain project. In the case of Northvolt, they have also a localization team within the purchasing department responsible for attracting suppliers to locate their facilities nearby, helping to reduce the travel distances of the supplies and thus reduce the productions costs and environmental impact. This team works in tandem with local or regional authorities and help suppliers to navigate in the process of establishing themselves into the proximity of the battery manufacturing plant.

Job roles and skills

Most of those working for purchasing are white collars working in such roles as purchasing coordinators, purchasing specialists, category managers etc.

[328] Northvolt interview, 28.5. 2021

Purchasing team members need to be, among other things, aware of laws and regulations. They need to have high social responsibility awareness, orientation about global politics and mineral conflicts complexities. Furthermore, they need to have a good orientation of and connections to suppliers.

Foreign language knowledge can be a plus. Purchasing related tasks and duties in battery manufacturing may not differ generally from other industries, but there are areas that are notable. For example, one needs to have experience in the raw material market if purchased directly by a battery manufacturing company. Additionally, there is purchasing of equipment that is battery specific. Master's degrees in purchasing, logistics, sourcing is among ideal education backgrounds.

The biggest recruitment challenges exist, for example, with finding such workforce that is experienced with Battery specific equipment, raw material specialists and those that understand raw materials and the related production equipment. In terms of the future development that will affect the skill needs include mastering global trends such movement of information, increasing need for transparency in such areas as raw material origins and localisation by bringing supply chain steps closer.

4.7.2 Human resources[329]

Like other industrial and manufacturing companies, the human resources department in a Gigafactory can deal with various issues including recruitment, headhunting, retention of workers, brand/talent attraction issues, personal development, work contracts, payrolls, workplace issues, labour law, and may also be dealing with trade unions.

It administrates personal data of the employees, deals with relocation (visas, migration, housing, schools, “feel at home” programs), and is responsible for onboarding and training (virtual, on the job, internships turned to employment), etc. Women might be the dominating gender within the human resources department.

[329] Northvolt interview, 28.5. 2021

Since employees of the Gigafactories are being recruited from various countries, tens of different nationalities with different cultures and backgrounds may be expected to work side-by-side, requiring a sensitive intercultural approach of the human resources personnel.
With the increasing number of people being hired into newly built Gigafactories, automation of recruitment processes can be introduced helping to handle the workload, e. g. pre-processing of job applications.

Job roles and skills

Industry background is less critical: no need to have specific battery education or background. An ideal candidate has worked in recruitment before and thus understands it. A good recruiter can "sell" the company he/she represents to a potential employee. Creativity, ability to get used to swift thinking in the fast-growing industry, quick adaptation to the start-up situation in case of some of the Gigafactories are being looked for.
With regards to the nature of the workforce and the expected speed of the organizational growth in upcoming Gigafactories additional resources working with migration, relocation, onboarding, and integration is expected compared to already established industries.
Since most employees that will be joining the industry will lack necessary experience the internal technical training team will also be of highest importance.

4.7.3 Finance[330]

A finance department in Gigafactories has virtually no differences from similar departments in other companies in other fields of business. What is currently characteristic for battery manufacturers is that most of them are in a start-up or early stage. This means that a lot of injected capital is needed to finance building and developing a company, including all its functions from R&D to business development, recruitment, buying materials, ramping up production, etc. For example, in the case of Northvolt, they have regular huge investment rounds occurring once or twice per year. Due to the need to raise capital and consequent investment rounds, the financial departments in battery manufacturing companies are significantly bigger than in start-up or early-stage company in general. Additionally, having

[330] Northvolt interview, 2.7 2021

several sites in different locations in different countries, as it is the case with Northvolt, adds to the need to have more staff for financial controlling, reporting, and accounting.

Job roles and skills[331]

Depending on the position, the education requirements include a degree in accounting, business, finance, controlling, economics or similar. Several years of work experience is preferred. Occasionally, experience beyond finance may be required. For example, in the Analytics and Performance Manager's position, manufacturing business experience from a technical environment is required.

Skills required in a financial department include experience with ERP systems and proficiency with Microsoft Office tools, business intelligence solutions, and working in teams. Additionally, good communication skills, flexibility, sense of quality, can-do attitude, ability to cope with high-pressure international environments and willingness to take new challenges are desired skills and abilities. Battery manufacturing is a fast-moving business, thus requiring a high level of energy and enthusiasm.

Northvolt has such job roles in finance, for example[332]:

- Business Controller
- Tax Manager
- Financial Controller
- Accountant
- Project Controller
- Analytics and Performance Manager

4.7.4 Sales[333]

In the case of battery manufacturers and using Northvolt as an analogue battery manufacturer start-up here, generally, the sales as a function have evolved from merely attempting to find customers into business development. In the company's early stage, it was about creating strategic partnerships, finding, and approaching connections. However, the tides have been

[331] https://northvolt.com/career/ last accessed 5.8.2021
[332] https://northvolt.com/career/ last accessed 5.8.2021
[333] Northvolt interview, 2.7. 2021

turning more recently, and it is not uncommon for customers to approach battery manufacturers. This is a consequence of the development of the past five years, during which the markets have woken up more to the use of batteries in different areas of applications.

What is characteristic of a sales department of a battery manufacturer is the emphasis on building partnerships with customers. Depending on their products and field of business, each customer wants their battery cells to behave differently and uniquely. Consequently, a high engineering involvement is needed in these teams, if compared to many other industries. There are dedicated engineers involved with the sales processes. They, for example, work with the sample development. Achieving customer satisfaction is the ultimate objective, and engineers have a specific role in ensuring it.

Job roles and skills

Northvolt has formed key account teams around its customers. These teams usually consist of 15-25 members in different roles. The positions in these teams include, for example, key account managers, technical project managers and coordinators. Key account managers also collaborate internally with cell designer teams. Technical project managers also work with customers. The coordinator's role is about fulfilling documentation requirements that are tough among target industries.

In terms of education, most of the sales staff do have engineering backgrounds. However, there are also those with a pure business background experienced working within automotive or any other target industry.

The usually recruited staff members have a technical background and previous experience. For example, existing relationships and know-how about navigating within the target industries are precious and challenging to find. On the other hand, those working in coordinator roles can be rather junior and freshly graduated.

Sales/business development related roles include for example:[334]

- Key Account Manager
- Business Development Manager
- Senior Director Business Development

[334] https://northvolt.com/career/ last accessed 5.8.2021

- Lead Application Engineer
- Sales & Customer Support Specialist

Regarding the future development of sales and the related roles, it can be assumed that the importance of having and managing relationships will never disappear. What remains an interesting question mark is the impact of Covid-19 since, before the pandemic, it was common to visit customers in person. The challenge is that how does one maintain good relationships without visits and face-to-face interaction.

4.7.5 Digitalisation[335] [336]

Digitalisation as a current trend covers multiple areas and aspects of battery manufacturing. Different concepts on how to digitalise and automatize battery production is being developed by different producers, such as iQ Power Licensing AG from Switzerland that came up with a modern, industrial 4.0-capable battery factory that was entirely computer-controlled and relied on technologies for production automation and networked machine communication. This approach indicated that the production's human resources requirement could be cut in half, and production times can be reduced by more than 60% with additional energy savings of 25%. Furthermore, integrating this concept with the in-house recycling department can further lead to enhancements and savings, also avoiding additional storage and transport costs.

Research on these topics and concepts was done by the Fraunhofer institute as well. As a result, it has been identified that the overall improvements in battery production and manufacturing will be connected to mechanisation, automation, and digitalisation. This encompasses “smart factories” and an interconnected production environment with IoT devices and Cloud services and infrastructure.

Digitalisation tools will help optimise and reduce scrap management and increase production efficiency along the whole manufacturing process chain. This can be achieved by

[335] https://www.hannovermesse.de/en/news/news-articles/battery-manufacturing-relies-on-digitization-and-recycling, last accessed 10.8.2021

[336] https://www.tugraz.at/fileadmin/user_upload/tugrazExternal/4778f047-2e50-4e9e-b72d-e5af373f95a4/files/lf/Session_H4/846_LF_Kaus.pdf, last accessed 10.8.2021

implementing digital twins and traceability. Benefits of the digitalisation can be seen in Figure 73.

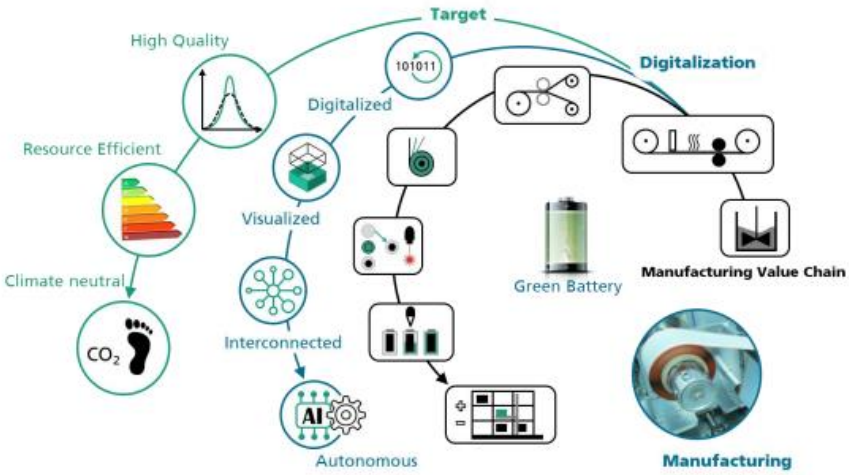

Figure 73. Key benefits of digitalization in battery cell manufacturing[341]

The case of Northvolt's Gigafactory[337]

Northvolt has embraced digitalization in the context of establishing Europe's first Gigafactory, Northvolt Ett. This includes high levels of data collection and usage, and process automation. The main motivators for the digital approach are production capacity ramp-up and operations enhancement (?).

Capacity ramp-up:

Digital solutions promise a streamlining of the deployment of production lines and minimizing delays in reaching target efficiencies of machines, lines, and the factory as a whole.

Operations:

Digitalization supports activities in and around production, including maintaining and extending the efficiency of production lines, reducing material and resource consumption, and assuring product quality.

337 Connected factory: the path to smart manufacturing (Northvolt), https://northvolt.com/articles/connected-factory/ last accessed on 24.6.2021

4.7.5.1 Traceability

Traceability is the ability to track all manufacturing and overall processes from raw materials to product or recycling. In other words, to know when and where, and under which conditions was the product manufactured.

The main idea of implementing such a concept is to gather data throughout the manufacturing processes and, based on it, create the digital twin models – if the data are coherent and thus the analysis of the process performance can be done. Following aspects of the production processes should be considered to achieve traceability: (1) process speed and time; (2) availability and accessibility of sensor information; (3) missing information on process parameters and product characteristics and possibilities to integrate additional sensors; (4) sampling rates; and (5) performance of data collection and handling.

4.7.5.2 Digital Twin

Digital twin (a virtual representation of the battery cell or system) can be developed after enough data is gathered – this will reflect the characteristics of the physical product. The creation of the digital twin can be a continuous process that self-adapts based on the previous data and learns along the way (machine learning/deep learning). This leads to the establishment of predictive maintenance.

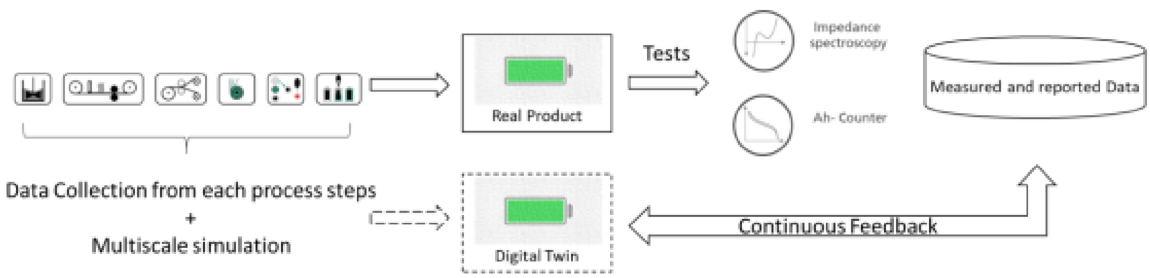

Figure 74. Digital Twin engineering at cell level[341]

With this setup, it is possible to predict ageing and determine the battery states with high accuracy depending on the quality of the measured data and the proper selection of extrapolation methods.

Digital Twin, including Virtual Reality based technology, is also applied, or planned to be involved with upskilling and reskilling of employees.[338] Additionally, it is already used in education to train incoming operational people by investigating systems they will be working on with Digital Twins Figure 74.

4.7.5.3 The implications on job roles, skills, and competences[339] [340]

Battery manufacturers and new Gigafactories are expected to leverage digitalization and may have dedicated digitalizing teams of which name and setup vary from company to company. These teams support production and related traceability by working with the software used in various machines, integration, cloud management and data handling, and general IT support.

The automatization of systems in various levels and functions such as production, quality, logistics, human resources will require personnel, not excluding blue-collared, to be more and more IT skilled. In addition, earlier mentioned application of Digital Twins and Virtual Reality for training and education further emphasizes the need for IT/digital skills.

In terms of staff and talent, there is a substantial need for IT skilled people in various levels from production floor operators to engineers, etc.

Software developers are generally very much in demand. For example, in maintenance, the teams responsible for maintaining the machines must do it together with maintaining software systems.

[338] Northvolt interview, 31.5. 2021
[339] Northvolt interview, 16.4 2021
[340] Northvolt interview, 28.5 2021

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5 Job Roles and Skills

Job roles, skills/competencies, and knowledge within the battery manufacturing life cycle were gathered via the job advertisement analysis. The occurrence of skills concepts is analysed in the form of a competence matrix. This analysis covers three main areas within the production plant: (1) Production and Maintenance, (2) Logistics and Purchasing, and (3) Quality. In addition, smaller sub-areas or departments (HR, Finance, Sales, Construction, Intellectual, Legal, Recycling, Environment, IT & Digitalisation) are described more qualitatively. Information about R&D can be found in the parallel report, Deliverable D5.4 Desk Research & Data Analysis, developed in the ALBATTS project. Its focus is solely on battery technology and research and development.

Altogether, 179 job position advertisements and job roles from other sources were analysed, and consequent skills/competencies and other requirements were categorised into five main categories according to the classification provided by sectoral intelligence methodology:

(1) soft competencies – the combination of individuals, skills, social skills, communication skills, character or personality traits, attitudes, career attributes, social intelligence, and emotional intelligence quotients, among others, that enable people to interact with their environment, work well with others, perform well, and achieve their goals with complementary hard or sector-specific/transversal skills; **(2) academic competences** – basic and complex skills that are the primary focus of academic institution, henceforth to provide knowledge for further development in student's career; **(3) general transversal competences** – general ability or expertise which may be used in a variety of roles or occupations; **(4) cross-sectoral specific competencies** – specific ability or expertise that can be used across multiple sectors or domains in more concrete context; **(5) sector-specific competencies** – are particular or specialised skills necessary to perform particular jobs in specific sectors.

Results for each category is depicted by a 100% stacked bar where the percentage represents the distribution of selected skills within the set. Some competencies were omitted due to the low occurrence.

5.1 PRODUCTION AND MAINTENANCE

Analysed job advertisements represent an occupational profile or a set of job roles depending on the scope and detail of the description provided within the advert. For example, the production and maintenance area cover a wide range of job roles across different levels of education from blue-collar workers such as operators, machine operators, battery stackers within the up- or downstream production. Other types of technicians are also present: maintenance technicians (mechanical, electrical), calibration technicians, automation technicians, instrument, and equipment technicians. When it comes to the white-collar workers, different engineering positions include production or manufacturing engineers, automation engineers, material and maintenance engineers, cell engineers, battery, and battery pack engineers, and mechanical, electrical and (electro)chemical engineers. Shift leaders are also needed. Finally, a variety of manager roles are present.

Soft Competencies

Soft competencies comprise selected skills and knowledge concepts, as seen in Figure 75. The most frequently occurring soft competencies are teamwork, problem-solving and troubleshooting, and communication.

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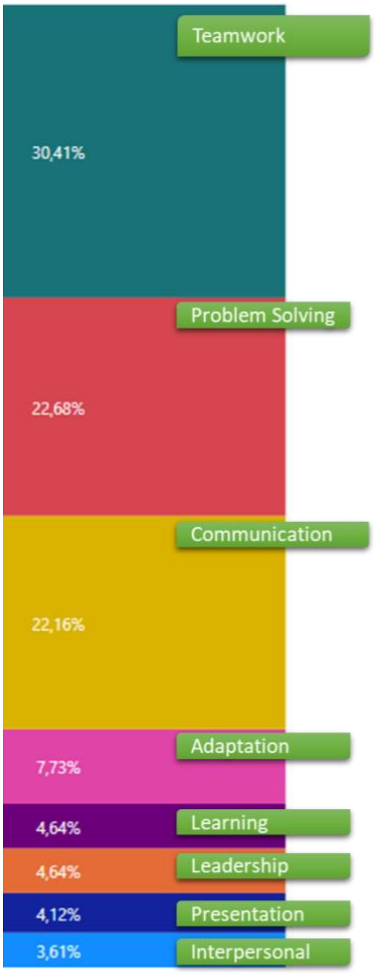

Figure 75. Academic Competencies

Academic competencies comprise 10 selected skills and knowledge concepts as seen in Figure 76. The most occurring academic competencies are chemistry, mechanical engineering, and electrical engineering.

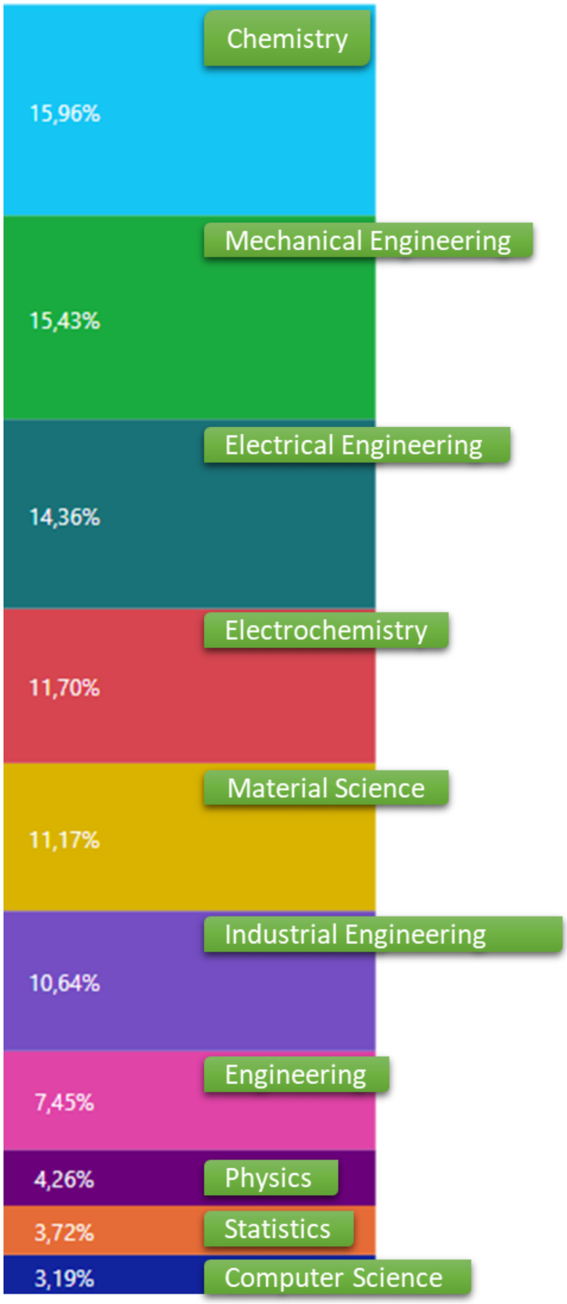

Figure 76. Production and Maintenance – Academic Competences

5.1.1 General Transversal Competences

General transversal competencies comprise 11 selected skills and knowledge concepts as seen in Figure 77. The most occurring soft competencies are health and safety standards, reporting, and documentation.

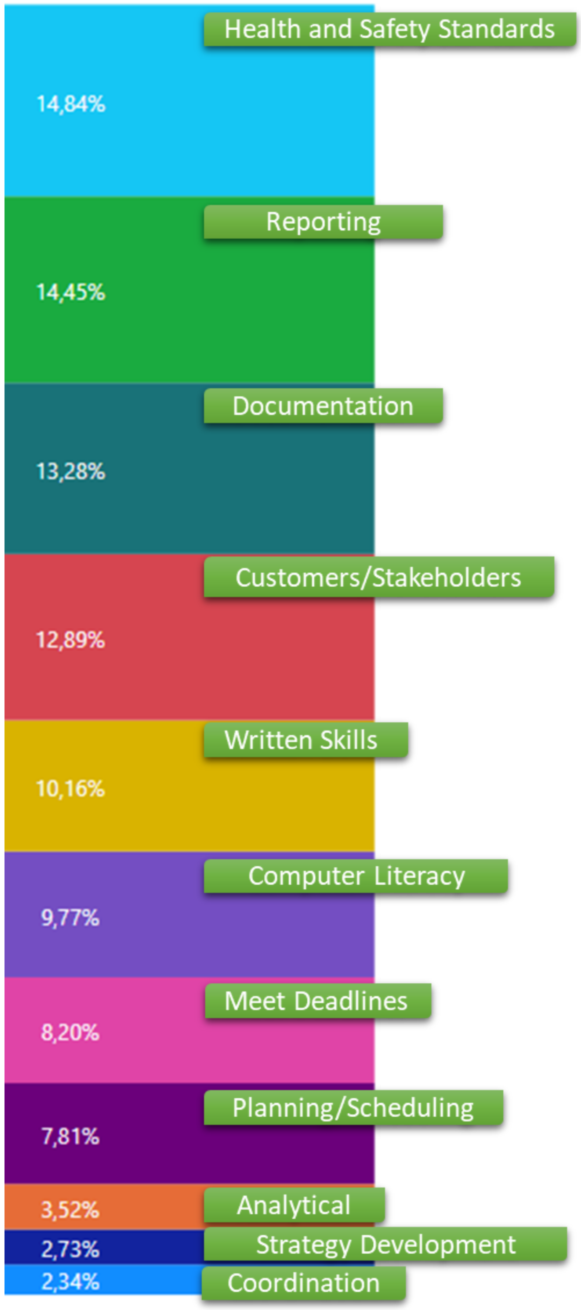

Figure 77. Production and Maintenance – General Transversal Skills

5.1.2 Cross-sectoral Specific Competences

Cross-sectoral specific competencies comprise 19 selected skills and 19 knowledge concepts, as seen in Figure 78 and Figure 79. The most frequently occurring competencies are **(1) skills** – inspection of product quality/sampling and process improvement as well as product testing and test data analysis; **(2) knowledge –** analysis methods, production processes, as well as safety procedures and product quality assurance.

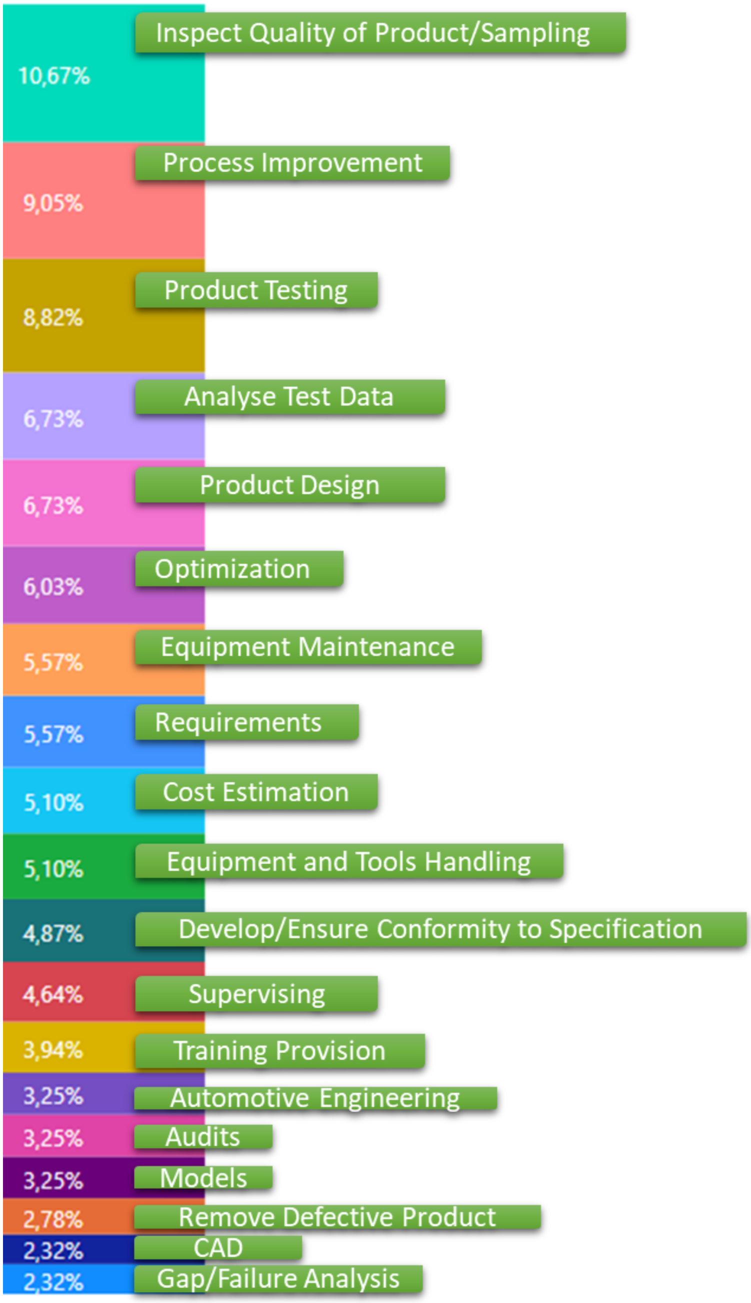

Figure 78. Production and Maintenance – Cross-sector Specific Skills

Figure 79. Production and Maintenance – Cross-sector Specific Knowledge

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5.1.3 Sector Specific Competences

Sector-specific competencies comprise 11 selected skills and 11 selected knowledge concepts as seen in Figure 80 and Figure 81, respectively. The most frequently occurring competencies are **(1) skills** – characterization techniques, cell assembly methods, battery dismantle, or battery assembly; **(2) knowledge –** lithium-ion battery chemistry, battery components, battery material, battery, or cell design.

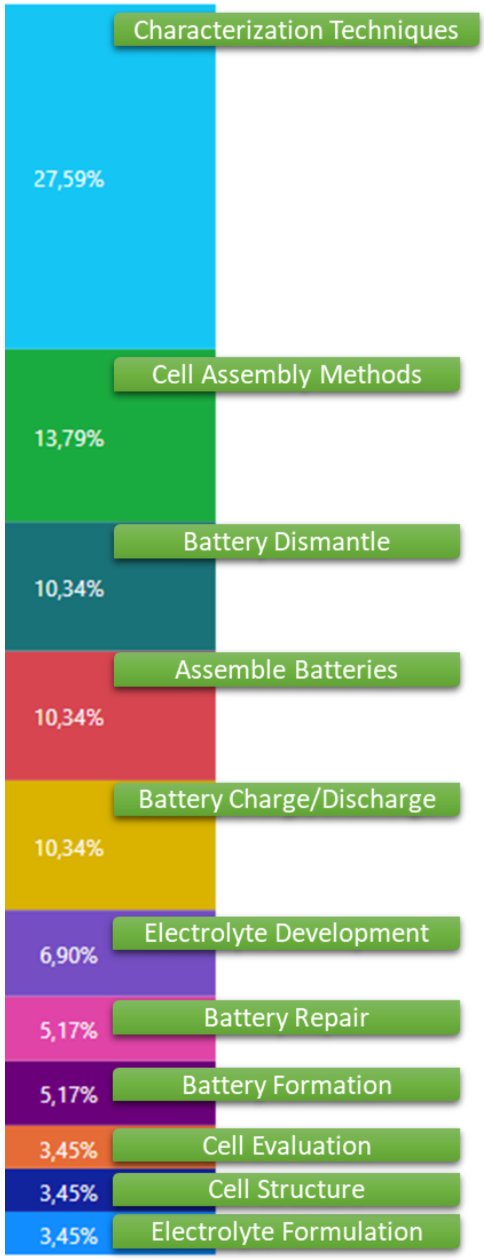

Figure 80. Production and Maintenance - Sector Specific Skills

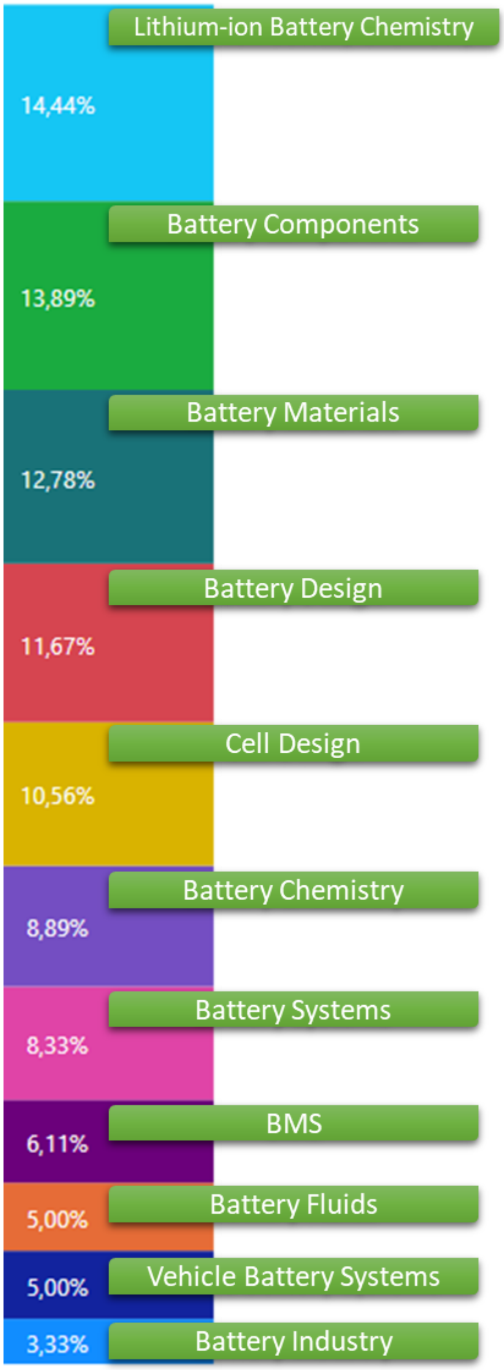

Figure 81. Production and Maintenance - Sector Specific Knowledge

5.2 QUALITY

Analysed job advertisements represent an occupational profile or a set of job roles depending on the scope and detail of the description provided within the advert. The quality area covers a wide range of job roles across different levels of education from blue-collar workers such as

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industrial cleaners, clean/dry room personnel or process operators. Other types of technicians are also present: battery/cell test (automation, simulation, or development) technicians or quality and inspection technicians, calibration technicians and metrologists. Customer and supplier quality technicians are to be considered as well. When it comes to the white-collar workers, different engineering positions are to be seen process (lean and kaizen), quality engineers or test engineers. ISO auditors, mechanical supervisors, or inspection engineers are present in standardisation and regulatory compliance.

5.2.1 Soft Competences

Soft competencies comprise 8 selected skills and knowledge concepts, as seen in Figure 82. The most frequently occurring soft competencies are teamwork, communication and problem-solving.

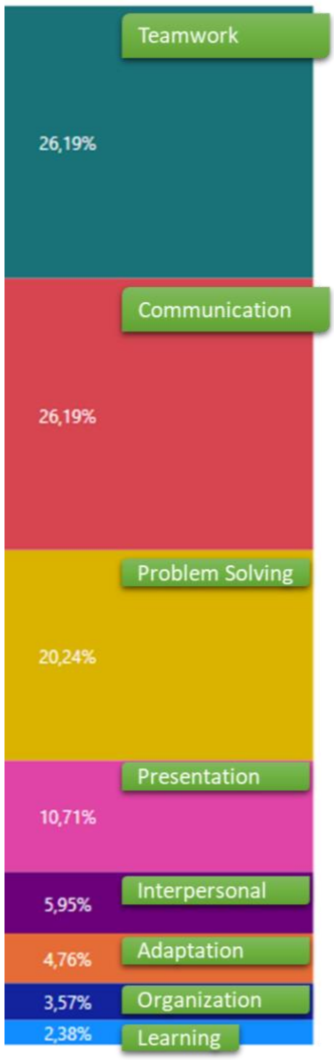

Figure 82. Quality - Soft Skills

5.2.2 Academic Competences

Academic competencies comprise 11 selected skills and knowledge concepts, as seen in Figure 83. The most frequently occurring academic competencies are electrical engineering, mechanical engineering, and chemistry.

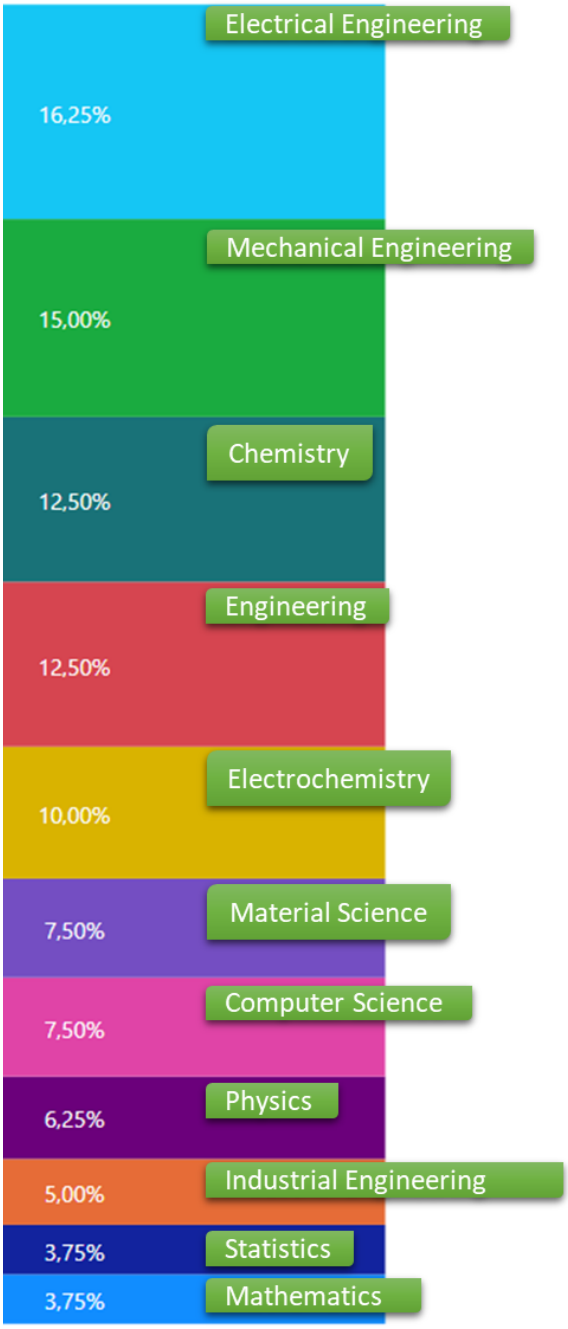

Figure 83. Quality – Academic Competences

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5.2.3 General Transversal Competences

General Transversal competencies comprise 11 selected skills and knowledge concepts, as seen in Figure 84. The most frequently occurring soft competencies are reporting, computer literacy, and health and safety standards.

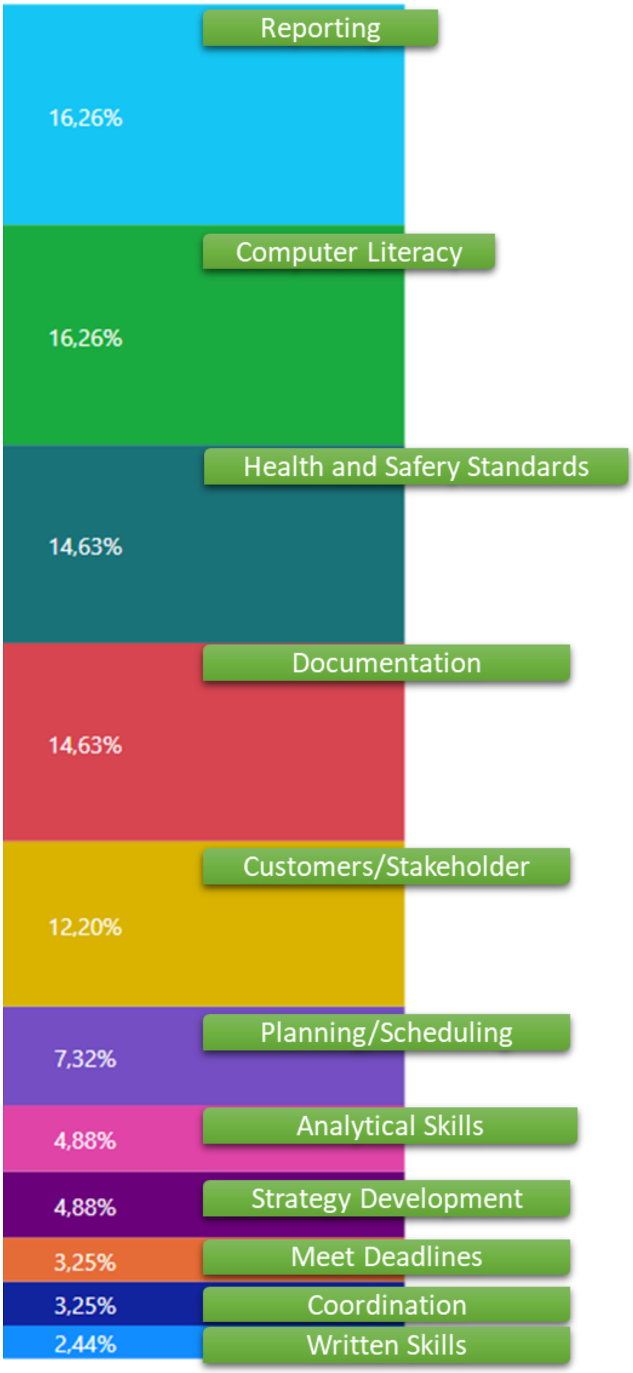

Figure 84. Quality – General Transversal Skills

5.2.4 Cross-sectoral Specific Competences

Cross-sectoral specific competencies comprise 19 selected skills and 17 knowledge concepts, as seen in Figure 85 and Figure 86. The most frequently occurring competencies are **(1) skills** – clean/dry room procedures, product testing/quality and sampling and process improvement and test data analysis; **(2) knowledge –** product quality assurance, automation, analysis methods and data analysis/science.

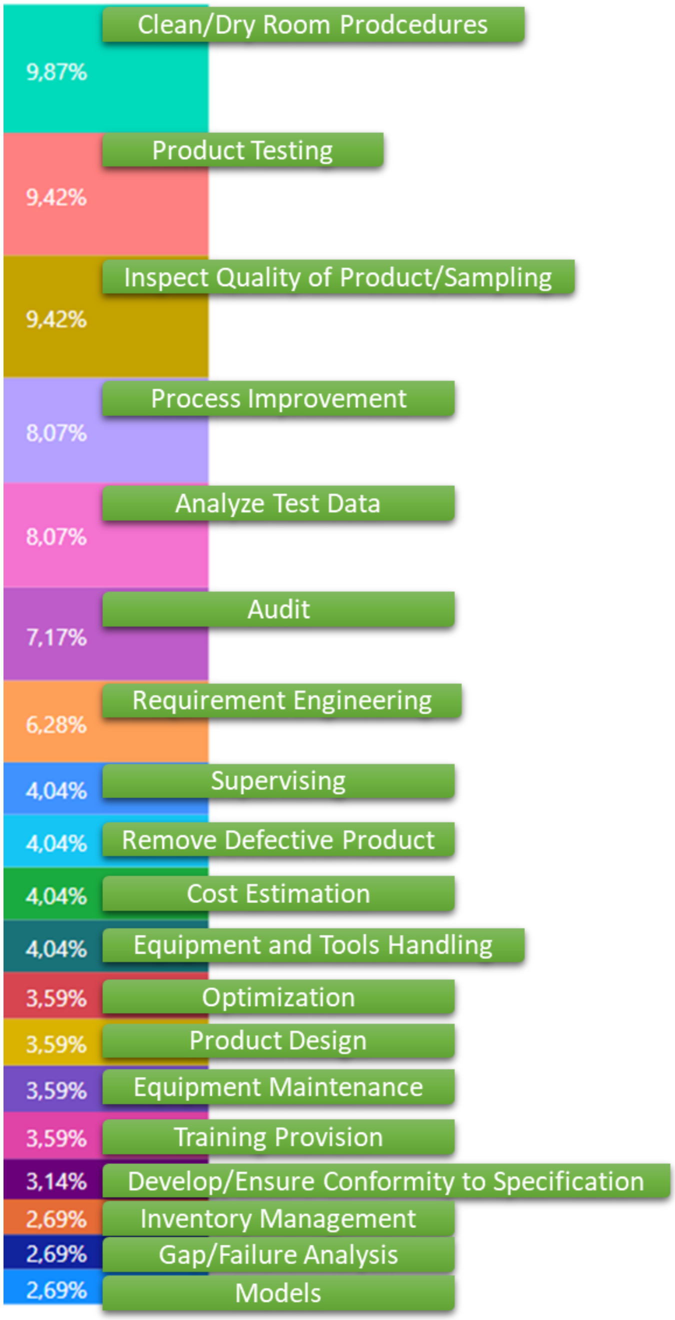

Figure 85. Quality – Cross-sector Specific Skills

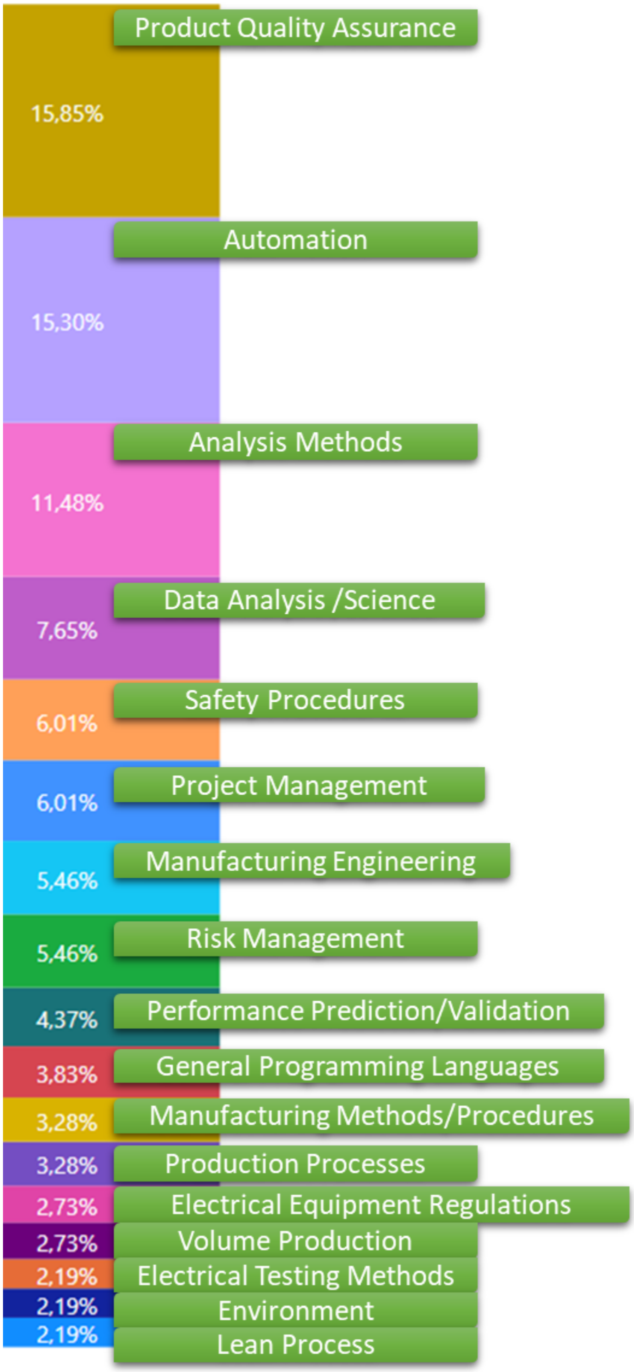

Figure 86. Quality – Cross-sector Specific Knowledge

5.2.5 Sector Specific Competences

Sector-specific competencies within the quality section are not occurring as much since overall quality assurance and testing can be applied across different domains and sectors. However, significant skills cover characterizations techniques, battery dismantling/removal, repair, or charge/discharge skills, when it comes to the knowledge: awareness of battery chemistry, components and materials and overall battery system design.

5.3 LOGISTICS AND PURCHASING

Analysed job advertisements represent an occupational profile or a set of job roles depending on the scope and detail of the description provided within the advert. For example, the logistics and purchasing areas cover a wide range of job roles across different levels of education from blue-collar workers such as material handlers or planners and various purchasing roles. Other types of technicians are also present, such as content technicians, inventory, and logistics technicians. When it comes to white-collar workers, different engineering positions are mainly seen as battery material engineers focusing on other active materials and cell components. Finally, management roles are present in value chain management, purchasing or overall logistics or inventory management.

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5.3.1 Soft Competences

Soft competencies comprise 10 selected skills and knowledge concepts, as seen in Figure 87. The most frequently occurring soft competencies are communication, problem-solving and troubleshooting, and teamwork.

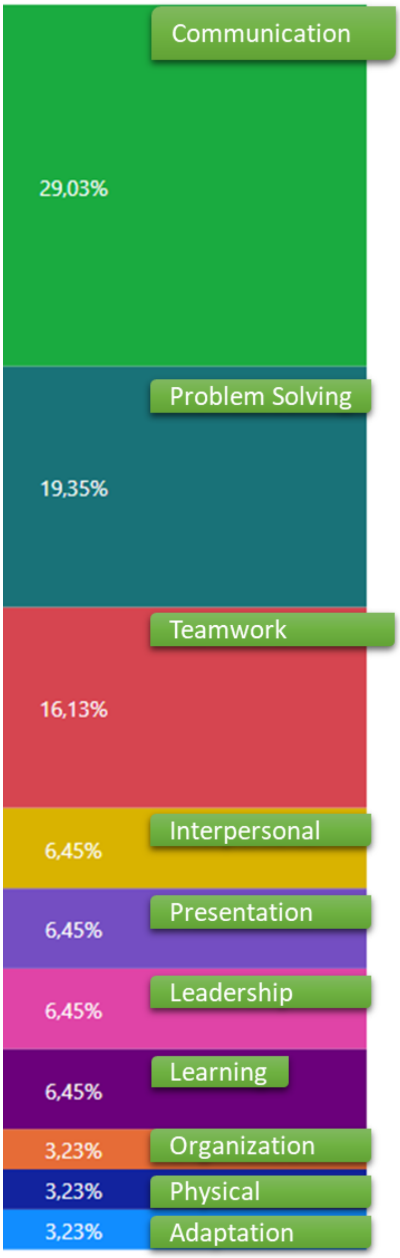

Figure 87. Logistics and Purchasing - Soft Skills

5.3.2 Academic Competences

Academic competencies in logistics and purchasing are not significantly demanded. However, general knowledge of chemistry, material science or electrochemistry is needed when working with battery material.

5.3.3 General Transversal Competences

General Transversal competencies comprise 12 selected skills and knowledge concepts, as seen in Figure 88. The most frequently occurring soft competencies are negotiation with customers and stakeholders, computer literacy, and documentation.

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Figure 88. Logistics and Purchasing – General Transversal Skills

5.3.4 Cross-sectoral Specific Competences

Cross-sectoral specific competencies comprise 19 selected skills and 19 knowledge concepts, as seen in Figure 89 and Figure 90. The most frequently occurring competencies are **(1) skills** – inspection of product quality/sampling and process improvement as well as product testing and test data analysis; **(2) knowledge –** analysis methods, production processes, as well as safety procedures and product quality assurance.

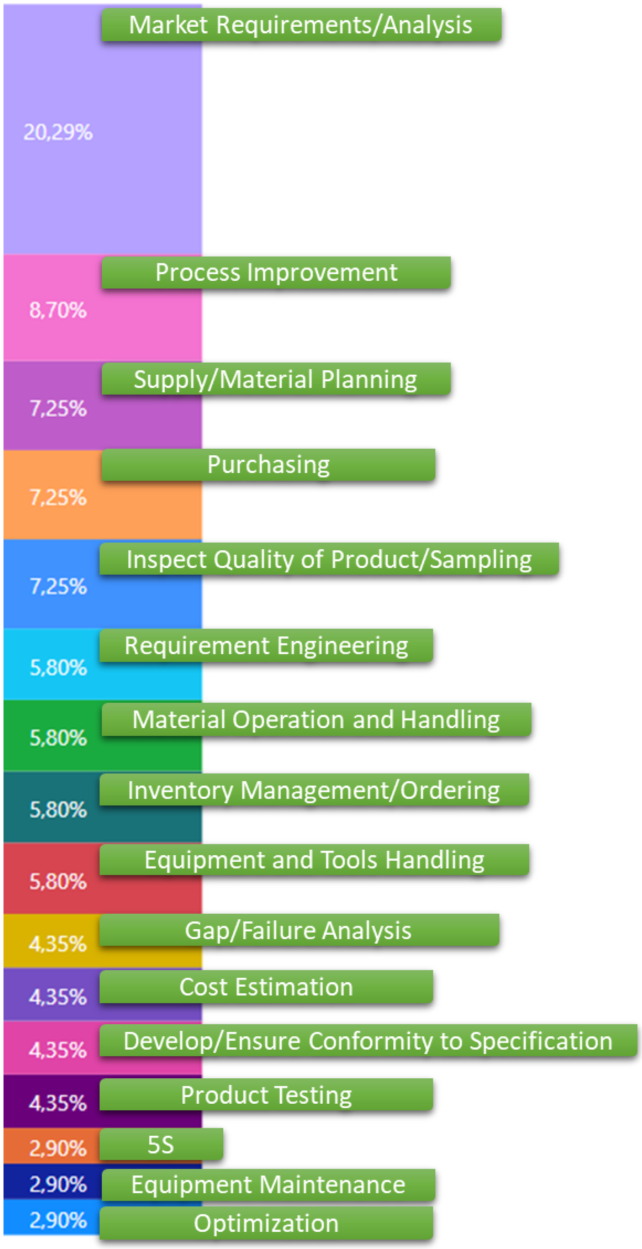

Figure 89. Logistics and Purchasing – Cross-sector Specific Skills

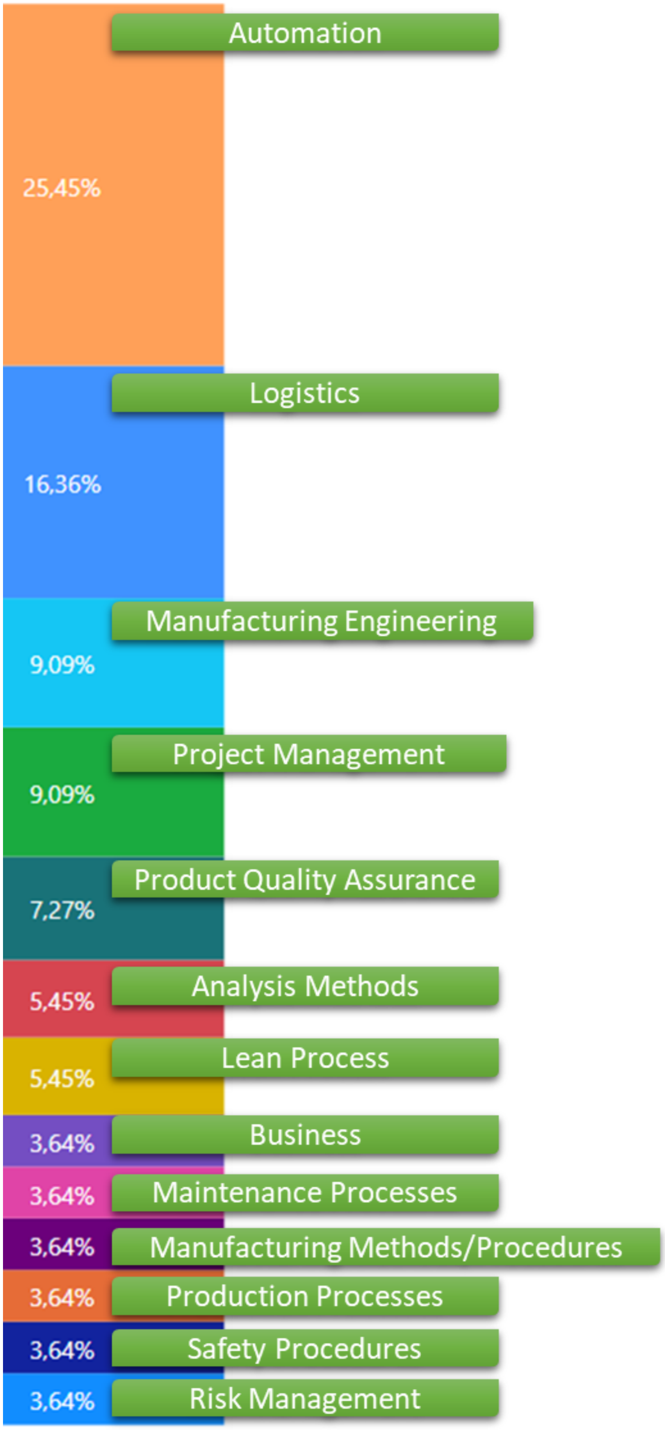

Figure 90. Logistics and Purchasing – Cross-sector Specific Knowledge

5.3.5 Sector Specific Competences

Sector-specific competencies within the logistics and purchasing section are not occurring as much since overall purchasing and logistics can be applied across different domains and sectors. Major competencies cover battery material knowledge, battery chemistry, volume production or battery/cell design.

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6 Education

In the WP5 report on Future Energy Storage, education needs and trends for the R&D-sector education, EQF 7 and 8, are discussed. This section below will focus on the vocational and the professional technician sectors of education, EQF 4 and 5, especially battery manufacturing.

In Deliverable 6:1[341], released in February 2020, an overview of existing examples of customised and relevant education and training for the battery sector was provided. There have been developments since, but not so many new programmes as expected have been noticed. This is likely due to the Covid-19 pandemic, during which universities often closed campuses and taught existing programmes online instead. This slowed development in the differentiation of offerings but instead caused other opportunities to emerge through the increased use of modern ICTs in teaching and learning.

Below, we will discuss some trends and opportunities with importance for the supply of competency for the battery manufacturing sector's machine operators, material handlers and other blue-collar workforce. It is important to remember that these categories are about 75% of all employees in a battery factory. Work roles and needed skills are discussed in the chapter 5 (Job Roles and Skills) as well as in the chapters that are related to specific departments and teams.

Trend 1: Horizontal European initiatives

The **Pact for Skills**[342] initiative was launched in November 2020. At the same time, a "pilot ecology" initiative was launched within this pact, **Automotive Skills Alliance**[343], led by ACEA and with most ALBATTS and DRIVES partners as initial members. The focus is on more ambitious up- and reskilling in the industry than before, with initiative and funding in cooperation between EU, national, regional, and private stakeholders. In ASA, ALBATTS is leading a battery workgroup in collaboration with other workgroup leaders in the sector. A lot of networking, planning and discussions have been going on, and we focus on becoming more operational in member countries and regions in times to come.

[341] "Report on state-of-art of job roles and education in the sector" https://www.project-albatts.eu/Media/Publications/6/Publications_6_20201011_133916.pdf accessed on 24.08.2021
[342] https://ec.europa.eu/social/main.jsp?catId=1517&langId=en accessed on 24.08.2021
[343] https://automotive-skills-alliance.eu/ accessed on 24.08.2021

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On March 12th, 2021, EC Vice President Šefčovič came with the **EBA250 Academy** initiative. This happened at the fifth ministerial meeting of the European Battery Alliance. The background was the 3-4 million European jobs that will be affected by the electrification of transport. VP Šefčovič wanted EBA, or rather EIT Innoenergy, "to team up with interested Member States to prepare their country-specific project proposals [and to] launch a so-called EBA250 Academy, developing curricula and training content based on the industry's skills needs and in partnership with local training professionals.".[344] The coordination of this initiative was assigned to EITInnoenergy.[345]

These two initiatives are compatible with one another and quite similar in both objectives and methods, but at present, they are not directly integrated. However, ALBATTS works in and together with both. They are clearly in line with what the project wants to achieve concerning developing new education opportunities, the final implementation of results, and ensuring long-term effects. ALBATTS has also invited EBA250 Academy to work together with the vocational part of the Sectoral Skills Roadmap that we will deliver later in 2021.

In addition, "**BatteryEdu**" has been formed, an informal group for communication and collaboration between EC projects and initiatives that deal with battery education and training, in one way or another, and at different levels. Participants are, for example, the Battery 2030+ projects, EITInnoEnergy/ EBA250 Academy, Fraunhofer Batterien Allianz[346], the MESC master education network[347], etc.

Trend 2: Battery-/electromobility profiled adult education and training programmes

Training programmes for adults for entering jobs as machine operators in a battery cell factory are yet not so many. Similar industries have previously often trained people themselves and just demanded a finalised upper-secondary education. A battery plant is not so well suited for education and training on a bigger scale due to both IPR restrictions, the clean- and dry-room environment and fast-moving production flow. But, on the other hand, it has advantages to prepare workers before onboarding on the job.

[344] https://ec.europa.eu/commission/presscorner/detail/en/speech_21_1142
[345] https://www.eba250.com/eba250-academy/ accessed on 24.08.2021
[346] https://www.fraunhofer.de/de/institute/institute-einrichtungen-deutschland/fraunhofer-allianzen/batterien.html accessed on 24.08.2021
[347] https://mesc-plus.eu/ accessed on 24.08.2021

Northvolt Ett in Skellefteå is a European pilot project for many coming European battery plants.[348] The about 30 factories that are now being built all over Europe will probably, most of them, have local education and training solutions outside the factory, provided by public or private educational institutions, and in the local language.

The most concrete example we have of a training programme designed directly for blue-collar work in battery production is the 24 weeks long *Automation Operator* programme. It is offered by the adult education (VUX) in Skellefteå, Sweden, where Northvolt's Gigafactory is about to start in late 2021. The course package has been operating at physical locations during the pandemic but in smaller groups and organised social bubbles during the autumn of 2020 and the spring of 2021. New groups are starting continuously, also running in the summertime. The short programme does not include content about batteries but about working in a modern process industry. The model for this package is similar to the shorter course packages at Truckee-Meadows Community College in Reno, Nevada, serving Panasonics battery manufacturing at TESLA Gigafactory 1.

Examples of the courses in the Automation Operator programme are Industrial processes, Remedial maintenance, Production Equipment, Employed in the Industry, Technical English, Digitalisation. Certificates for operating forklift trucks, overhead cranes, and licenses for Hot works handling are also included. Some of the trainees in the first cohort are now employed at Northvolt and teach - at the Northvolt pilot plant in Västerås – others who can become employed shortly before the production start. The course package is recurring, more flexible versions are under development, although exclusively online versions are challenging to design. More so-called "blended learning" may be appropriate, as many learning tasks need equipment to practice skills, physically present instructors, etc. A new profile, "Material Handler", will start this autumn.

This adult course package solution can become an interesting European prototype for basic adult education for blue-collar employees in Li-Ion cell factories. It will be changed and improved in every iteration. A special lab environment for training has been built up in a classroom at Campus Skellefteå. It contains one Festo CP Factory[349] (Cyber-Physical Factory),

[348] We do not have information about education for the LGChem and Samsung-SDI plants in Hungary and Poland, and for these factories staff was probably trained directly in South-Korean battery plants.

[349] https://www.festo-didactic.com/int-en/learning-systems/learning-factories,cim-fms-systems/cp-factory/cp-factory-the-cyber-physical-factory.htm?fbid=aW50LmVuLjU1Ny4xNy4xOC4xMjkzLjc2NDM accessed on 24.08.2021

one CP Labs unit[350], five application units (for pneumatics, mechatronics,[351] communication, smart maintenance, and PLC programming), four mechanical training units and one AGV robot (Automated Guided Vehicle) for transport between the CP labs and CP Factory units. There is also a small unit for training procedures to enter clean- and dry-rooms. Northvolt experts have been involved in the planning of both the curricula and the lab equipment for optimal learner preparation for onboarding training at the Northvolt Ett.

Trend 3) Simulated training environments

It is difficult to get practice in an actual full-scale, running battery plant as a learner before employment. A pilot plant can be an alternative. However, the pilot plants owned by the industry are IPR-sensitive and filled with R&D activities. Universities and research centres own some pilot plants, but these are also difficult to access for training today – but perhaps the capacity will be improved in the future. The conventional alternative that the education provider has some old or sponsored training equipment is hardly economically viable for battery production equipment.

For Northvolt and other battery manufacturers, a feasibility study on how to use XR, VR and AR environments for operator skills training was carried out from September 2020 to March 2021, led by RISE, Research Institutes of Sweden, and an application for EIT Manufacturing funding has been submitted. Partners are RISE and Fraunhofer as research institutes and Chalmers and Braunschweig as universities. In addition, four ALBATTS partners, including Northvolt, are members of a reference and testing group.

EIT Innoenergy has developed VR training modules and games, and Université de Picardie Jules-Verne in Amiens, France, has produced five VR games for learning.[352] These are not for learning the battery production environment, but three of them aim at understanding battery chemistry and physics, and another three aim at raising interest in electromobility. A web page for access to these games is upcoming. However, there is already much experience and

[350] https://www.festo-didactic.com/int-en/learning-systems/mps-the-modular-production-system/qualification-for-industry-4.0/cp-lab/cp-lab-system-overview.htm?fbid=aW50LmVuLjU1Ny4xNy4xOC4xNjA0LjUzNzUx accessed on 24.08.2021

[352] Franco, A. A., Chotard, J. N., Loup-Escande, E., Yin, Y., Zhao, R., Rucci, A., ... & Lelong, R. (2020). Entering the Augmented Era: Immersive and Interactive Virtual Reality for Battery Education and Research. Downloadable from https://chemrxiv.org/engage/api-gateway/chemrxiv/assets/orp/resource/item/60c74bc59abda206e7f8d15f/original/entering-the-augmented-era-immersive-and-interactive-virtual-reality-for-battery-education-and-research.pdf accessed on 24.08.2021

available resources such as virtual labs, simulations, and similar for general chemistry teaching and learning, including electrochemistry.

Trend 4) More flexible and more blended learning solutions from institutional providers. The ALBATTS deliverable 6.1 released in February 2020 listed categorised European examples of education programmes, course packages, courses, and modules relevant to battery manufacturing and stationary and mobile applications. In March 2020, the pandemic closed many schools and university campuses and changed traditional teaching into mainly an online mode, not using campuses. This development has been somewhat back-and-forth in some countries, but everywhere with physical distancing requirements. The situation has been challenging to education providers, but it has also brought valuable insights into alternative ways to organise and run education. Teachers have suddenly been forced to develop more experience and skills in using ICTs in education. The focus on a campus or school as the default location for organised learning has mitigated. We may expect more flexible and accessible education and training programmes in the future, based more on rational decisions on what kind of learning situations and type of communication are needed for a specific teaching/learning case. Models of new normalities for education and training access are now being formed. However, the development of new programmes to offer education has slowed down. It seems that the challenge of running the existing ones in new ways has been more than enough for most institutions.

Many of the upskilling and reskilling short and fee-based courses from different organisers have also transferred online instead of being offered at institutions or conference centres. Time management has, in many cases, also changed them into more stretched-out part-time courses instead of concentrated full days. This can be a rational change, enabling better access but also demanding more from a learner. For example, it was earlier common to give a course certificate just for physical attendance without any demanding assessment procedures. Still, when a learner is online, more than attendance is often demanded for a certificate.

The conventional MOOC courses on battery and electromobility are mostly the same as listed in D 6:1 in February 2020, with one good European addition: EIT Manufacturing's MOOC on Futurelearn: *Battery Manufacturing: Trends in Battery Engineering*.[353] The corporate MOOC

[353] https://www.futurelearn.com/courses/trends-in-batteries-manufacturing accessed on 24.08.2021

provider Udemy has only fee-based course access but with certificates and at relatively low fees. Udemy has developed a set of very concrete orientation courses around batteries and electromobility.[354]

Trend 5) Education programmes and courses from new or untraditional providers

A clear trend is the plethora of emerging courses on battery and charger safety and handling by worker's health and protection authorities, transport branch organisations, etc. This is a sign that Li-ion battery equipment is becoming more common in many contexts, and handlers and the public need to be aware of the risks.

Some companies providing consultancy services, solutions, and equipment for battery manufacturing or cell factories provide courses or start "academies" consisting of video, animation, and text content. These can sometimes be interesting and instructional but are often mainly confusing promotion material of the company.[355]

Several YouTube channels have educational ambitions, besides other motivations. Here we mention just one quite interesting and ambitious; The Limiting Factor.[356] ALBATTS is in contact with the creator about embedding part of these films in learning modules.

A new, unconventional, and very interesting education and training provider is **Battery Associates**[357] – a network of professionals in the field led by Dr. Simon Engelke, a scientist and entrepreneur in the sector. They run a **"Battery MBA"** that is not an MBA per se (?) but a programme with a series of weekly lectures from professionals working in the industry, interactions, discussions and even labs with distributed equipment. It is meant for already active professionals that are interested in leadership positions in the battery sector. The fee-based programme admits people by CVs and interviews and has a gender balance policy. The programme is certified by British CPD.[358]

[354] https://www.udemy.com/courses/search/?src=ukw&q=battery accessed on 24.08.2021
[355] https://fo-fo.facebook.com/PanasonicBatteryWorld/videos/battery-academy/499685264183491/ accessed on 24.08.2021
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[357] https://www.battery.associates/ accessed on 24.08.2021
[358] https://cpduk.co.uk/ accessed on 24.08.2021

Conclusions

The adult and technician education vocational level is the central focus for the ALBATTS project. We will increase our overview over what is happening by concentrating on the known Gigafactory "hot-spots", the cities close to new gigaplant locations. So far, it has been much easier to contact and get reactions from universities. Vocational education providers seem less used to European communication. Our present idea is to go through CEDEFOP to national boards or committees for vocational education, point out the locations where Gigafactories are building or planned, and ask for help to contact these providers. ALBATTS can likely be of interest to them in designing relevant education and training offerings.

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