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Alliance for Batteries Technology, Training and Skills

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Intelligence in Battery Sector

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D3.3 Desk Research & Data Analysis – Release 1

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List of Abbreviations

5G	…	Fifth-generation mobile network
Al	…	Aluminum
ALBATTS	…	Alliance for Batteries Technology, Training and Skills
BESS	…	Battery Energy Storage System
BEV	…	Battery Electric Vehicle
BMS	…	Battery Management System
BMW	…	Bayerische Motoren Werke AG
BTM	…	Behind-The-Meter
BTMS	…	Battery Thermal Management System
C	…	Carbon
CATL	…	Contemporary Amperex Technology Co.
Co	…	Cobalt
CO_2	…	Carbon Dioxide
COM	…	Communication
Cu	…	Copper
DNC	…	The Democratic National Committee
EBA	…	European Battery Alliance
EoL	…	End of Life
ERASMUS+	…	European Commission’s Programme for education, training, youth, and sport
ESS	…	Energy Storage System
EU	…	European Union
EV	…	Electric Vehicle
FTM	…	Front-of-The-Meter
GHG	…	Greenhouse Gas
GST	…	Grid Storage Technologies
ICE	…	Internal Combustion Engine
IMBA	…	Intelligence in Mobile Battery Applications
ISIBA	…	Intelligence in Stationary and other Industrial Battery Applications
ISO	…	Internal Organization for Standardization

kW	…	Kilowatt
LFP	…	Lithium Iron Phosphate
LG	…	LG Corporation
Li	…	Lithium-ion Battery
LiB	…	Lithium Battery
LTO	…	Lithium Titanite Oxide
Mn	…	Manganese
NCA	…	Lithium Nickel Cobalt Aluminium Oxide
Ni	…	Nickel
Ni-MH	…	Nickel-Metal Hydride
NMC	…	Lithium Nickel Manganese Cobalt Oxides
NOx	…	Nitrogen Oxide
RES	…	Renewable Energy Source
SEI	…	Solid-Electrolyte Interphase
SoH	…	State of Health
STEM	…	Science, Technology, Engineering, and Mathematics
TESLA	…	Tesla Inc.
USA	…	United States of America
USD	…	United States Dollar
WP3	…	Work Package 3
WP4	…	Work Package 4
WP5	…	Work Package 5

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

Executive Summary

Battery production autonomy is strategic for the European Union due to its revolutionary impact in the transport and energy sectors. It is also a pathway to achieve the 2050 clean energy transition objectives.

This EU strategic goal requires high investment in energy storage, in the production of high energy density cells, and new technologies, but also calls for the creation of a skilled labor force that sustains the whole battery value-chain, tackling both sides of competence need and supply.

ALBATTS (Alliance for Batteries Technology, Training, and Skills) is the ERASMUS+ project focused on the future of skills in the battery sector. It is meant to enable interaction between industrial and educational stakeholders and their engagement in the analysis of the state of art and the directions towards the future of competence need.

The partnership will play an important role in contributing to the European Skills Agenda by strengthening skills intelligence to ensure defining the right jobs for a sustainable competitive emerging battery European ecosystem and a swifter move towards a climate-neutral Europe. This includes the definitions of new job roles and new curricula for the whole value chain from raw materials, cell production to battery systems and stationary and mobile applications.

This is the first of a set of reports on Detailed Desk Research and Data Analysis for the overall sector, providing a quantitative and qualitative evaluation on the equal importance of researching new technologies and identifying new job roles and new needs of learning and upskilling to achieve battery production autonomy in the European Union.

The present report integrates activities dedicated to assessing sectoral intelligence within the battery ecosystem with an umbrella overview of the mobile and stationary industrial subsystems. It builds on dedicated work and reports from the desk research performed respectively by WP4 - Stationary and Industrial Battery Applications and WP5 - Mobile Battery Applications, resultant from the overarching methodological guidance of WP3 on Sectoral Intelligence. It is a combination of desk and field research that, on the one hand, analyses available bibliographic work in both stationary and mobile subsectors and, on the other, collects tangible perspectives from stakeholders in these battery ecosystems.

Overall, the present document defines several goals structured in different sections, covering aspects going from current technologies, job roles, and education to an overview of the battery value-chain. Finally, a gap analysis is done for each researched topic and defined correspondent **Challenges** to deploy designed solutions in the future.

These will be the basis for a roadmap to synchronize the demand for new competences from enterprises, with the supply of education and training services, customized to meet the demands.

Introduction

The present report integrates activities dedicated to assessing sectoral intelligence within the battery ecosystem with an umbrella overview of the mobile and stationary industrial subsystems. The focus is on understanding state-of-the-art among the stakeholders to further assist in identifying and projecting present and future skill needs.

The document builds on dedicated work and reports from the desk research performed respectively by WP4 - Stationary and Industrial Battery Applications and WP5 - Mobile Battery Application, resultant from the overarching methodological guidance of WP3 on Sectoral Intelligence. It is a combination of desk and field research that, on the one hand, analyses available bibliographic work in both stationary and mobile subsectors and, on the other, collects tangible perspectives from stakeholders in these battery ecosystems.

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DOCUMENT STRUCTURE

This document is structured into different sections:

Section 1 gives a brief overview of project ALBATTS Sectoral Intelligence methodology and on the work package structure as well as the research approach.

In **section 2** the gathered information about drivers of change, sectoral stakeholders, current technologies, job roles, and skills and education is summarised for the whole battery sector.

In **section 3** the most important and interesting findings are described with a corresponding gap analysis which is a basis for **section 4** which outlines challenges to be considered in the battery sector and to ultimately form the complete roadmap in the future development of the project.

1 Methodology and Approach

This section provides an overview of the methodological approach used to depict the state-of-the-art of battery sector. This section evaluates report benefits as well.

1.1 METHODOLOGY OVERVIEW

Desk Research activity in the project ALBATTS was carried out based on the defined methodology and overall approach. Desk Research covers the whole battery sector which in this document is based on the analysis of the battery sub-sectors for Stationary and other Industrial Applications and Mobile Battery Applications as shown in **(Figure 1)** below.

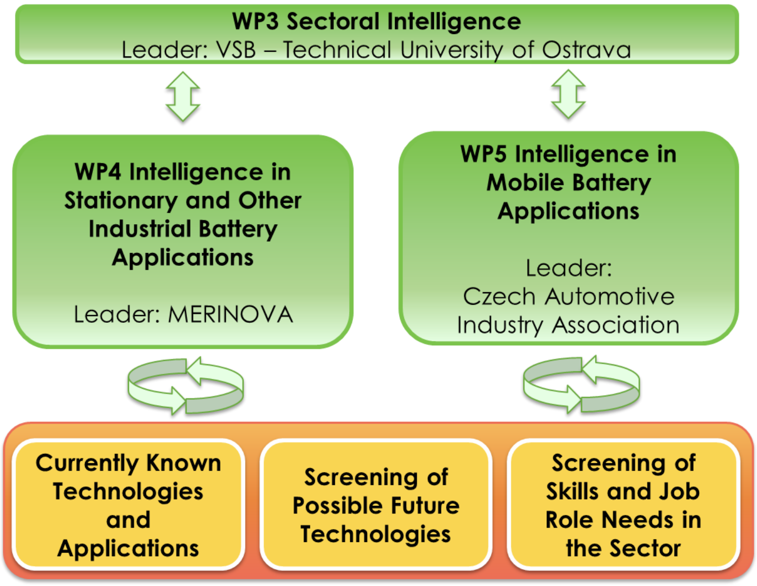

Figure 1 Approach to the Research of Battery Sector

Research in the battery sector, as well as the application sub-sectors, covers the outlined battery value chain which is seen below in **(Figure 2)** with the focus on the current state-of-the-art at the date of the first releases of the desk research reports.

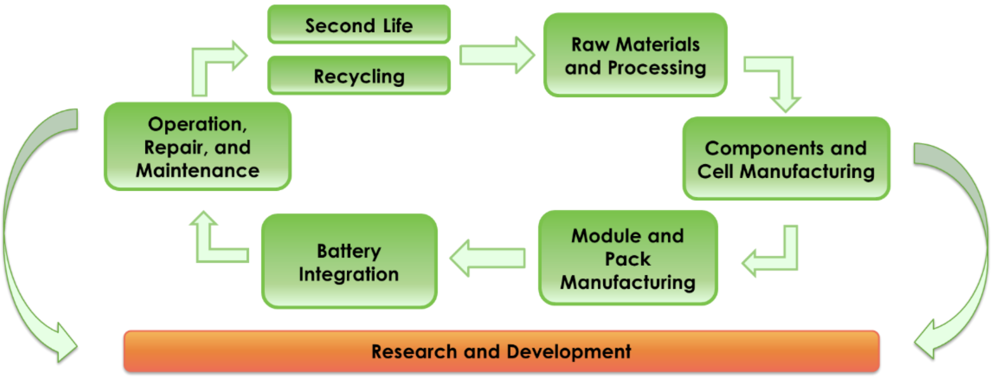

Figure 2 Battery Value Chain

Topics covered by the sectoral intelligence research were defined to be examined either for the battery value chain as a whole **(Figure 3)** or separately for each phase of the battery value chain **(Figure 4)**.

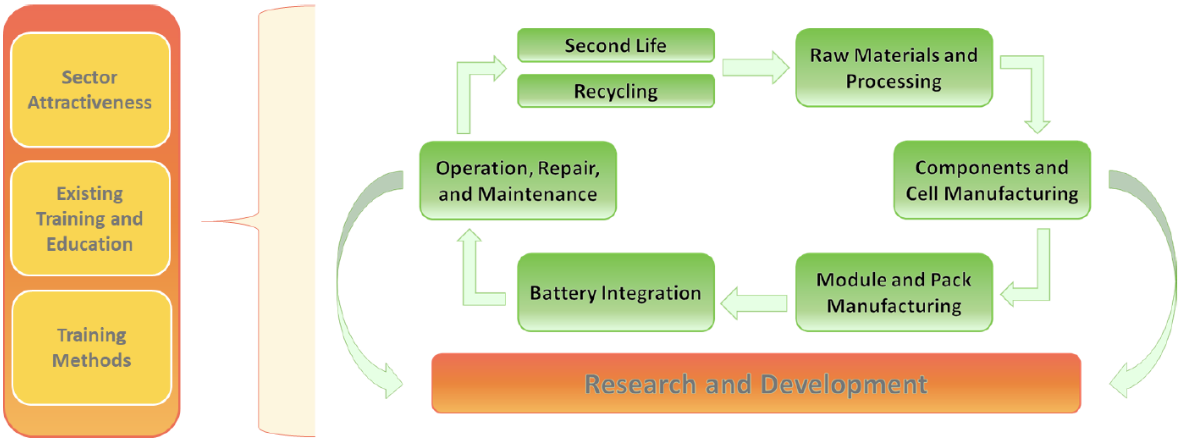

Figure 3 Topics of Sectoral Intelligence Covering Whole Battery Value Chain

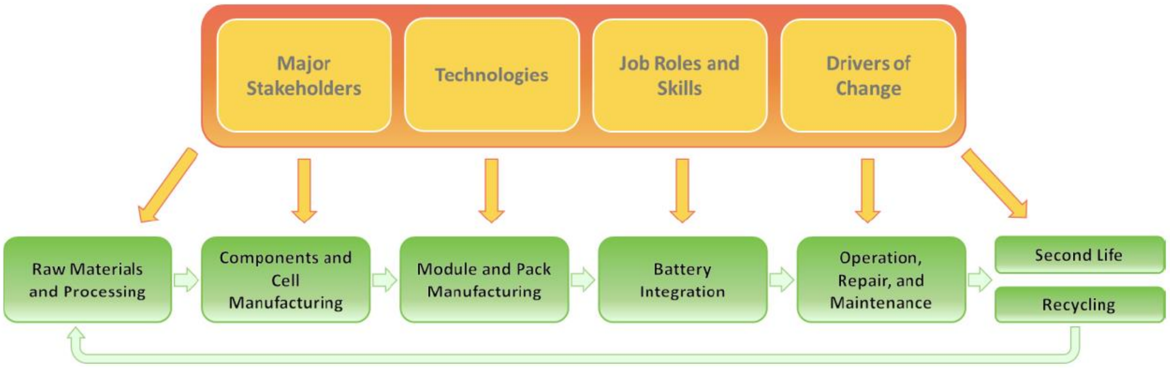

Figure 4 Topics of Sectoral Intelligence Covering Each Individual Phase of Battery Value Chain

This first release of the desk research will be continuously updated throughout ALBATTS lifetime, completed by further work gathered through field research (online surveys and workshops). Ultimately these three main sources of information will lead to the creation of sectoral intelligence (roadmap) for each application sub-sector forming the overall picture of the whole battery sector, schematically indicated in **(Figure 5)**.

Figure 5 Components of Sectoral Intelligence

1.2 EVALUATION OF REPORT BENEFITS

Desk research which was carried out in both work packages for stationary and other industrial applications and mobile applications was extensive and has shown a significant volume of useful information. Benefits could be categorized as follows:

- **Industry and Market Perspective:** Original reports may serve as a substitute for consultant company market reports as well as for a general audience that is curious to learn about the battery industry. From the industry perspective, job offer analysis and statistics give an idea of what is needed by the industry and provide a good overview of the full value chain from raw material to final battery system integrated into an application.
- **Education Providers and EU Skills Agenda:** Original reports contain an analysis of job advertisements with their skills and knowledge and synthesized job roles as well as the overview of the battery sector with the geographical distribution which points out where educational programs may already exist.

2 Summary of the Sub-sectors

2.1 HIGHLIGHTS OF DRIVERS OF CHANGE AND ATTRACTIVENESS OF THE SECTOR

Drivers of Change are those factors which are key to transforming an industry. Specifically, a literature review of available reports was undertaken to create an overview of the current Drivers of Change and their relevance in the sector.

During the desk-research process 3 main areas subdivided into 9 specific Drivers of Change emerged:

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

  Batteries are one of the most important elements to achieve climate targets, and drivers to decarbonize road transportation and support the transition to a renewable power system.

  a. **Reducing CO_2 emissions from battery manufacturing:** since the production of batteries requires significant amounts of energy, an increase in the share of renewable energies and energy efficiency in the battery value chain would be a major step for decreasing CO_2 emissions from battery production.
  b. **Electrification and green energy:** batteries can fundamentally reduce greenhouse gas emissions in the transport and power sectors as they are a systemic enabler of a major shift to bring transportation and power to greenhouse gas neutrality playing an increasingly important role.
  c. **Widespread charging/refueling infrastructure:** demand for widespread charging infrastructure is a key driver to boost the production and commercialization of a technology based on batteries. The easier the access to a reliable and suitable charging infrastructure is, the quicker the development of such new technologies will be.

- **Globalization**

  Over the next years, production in global markets for EV batteries is expected to grow strongly and the EU production must completely change its position to create a competitive advantage.

d. **Access to raw materials:** with a rapid increase in numbers of EVs, strategic planning of the security of supply linked to raw materials becomes critical, especially considering that some critical resources (limited in terms of quantity or geographical presence) are necessary to produce key components.

e. **Global regulatory dialogue:** The Commission and in general, Governments and public administrations in Europe will need to play a fundamental role in the elaboration of policies and strategies, from which the battery sector could benefit

f. **Restructuring:** sectors related to the emerging battery sector are expected to undergo structural changes due to the development of zero-emission mobility and as a flexible facilitator of intermittent renewable energy sources.

- **New technologies**

The need for urgent and intense actions to mitigate climate change is widely recognized and batteries are an essential system for storing energy in electric vehicles and making renewable energy a reliable alternative source.

g. **Cybersecurity:** the exponential growth of IoT devices connected to a network, cloud infrastructures, and the navigation and location information can compromise customer privacy and security, requiring providers to keep communications and the integrated system secure, this threat landscape requires the industry to modify the security approach, aimed at guaranteeing the resilience of the infrastructures to cyber-attacks. This will affect various battery applications in the future.

h. **Global technical harmonization and standardizations:** the supply chain structure within the sector will need to meet the challenges posed by the introduction of new technology but also meet changing market conditions.

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

The desk research activity also focused on 3 main aspects for each Driver of Change:

- **Occurrence**: indicating whether a Driver of Change was cited in analyzed reports reviewed. “CLIMATE GOALS, REGULATION AND ENVIRONMENTAL CHALLENGES” is the most cited Driver of Change in terms of occurrence, with 40,28% followed by “GLOBALISATION” at 34,72%; the third one is “NEW TECHNOLOGIES” with 25,00%.
- **Importance**: an evaluation by the ALBATTS project partners, based on the context in which the specific Driver of Change is discussed, focused on its possible status in the future and on its direct implications on changes in the sector, using a ranking from 0 to 5 (0 = not possible to evaluate, 1= not important, 5 very important). All of them are similar and the difference between the first (“REDUCING CO_2 EMISSIONS FROM BATTERY MANUFACTURING“ at 4,50) and the last (“IMPROVED CHARGING/REFUELLING INFRASTRUCTURE“ and “CYBERSECURITY“ at 3,75) on a scale of 0-5 is only 0,75.
- **Urgency**: a specific time frame (year), which can be noticed from the text of the analyzed document, in which the Driver of Change will become particularly necessary or will make its consequences will be overwhelming. “ACCESS TO RAW MATERIALS“ has been outlined as the most urgent as in 2021 it will be particularly crucial (according to the adopted desk-research methodology to map the “urgency” of a Driver of Change); in 2025 the problems related to “CYBERSECURITY”, and in 2027 for the “REDUCING CO2 EMISSIONS FROM BATTERY MANUFACTURING” will be crucial too.

2.1.1 Gaps in Drivers of Change

The carried-out analysis and obtained results highlighted two gaps that will have to be filled in the project lifespan through subsequent iterations of the Desk Research and with targeted in-depth analyses with Stakeholders (Workshops and Online Survey).

The balance between mobile and stationary battery applications: the carried-out intelligence followed an analysis of the existing bibliography with a slight preponderance towards IMBA. Future activities will bridge this gap between ISIBA and IMBA by giving equal emphasis to both sub-sectors.

Featuring the “Importance” of the Driver of Change: the concept underlying the desk research aims to enhance the Drivers of Change mentioned in the existing literature. The fact that a Driver of Change itself is mentioned as a factor of **"importance"** and it is not easy to highlight the correct value to attribute to the parameter. In the continuation of the project, it will be necessary to use all possible direct interactions with Stakeholders to validate the information and, where possible, improve the analysis.

2.1.2 The Attractiveness of the Sector

From the results of the desk research (published papers, reports, and articles), there is no evidence yet about a proper and specific battery energy sector **"attraction effect"**. Therefore, to better understand the attractiveness of the battery sector, the ALBATTS project has taken a much broader perspective through the analysis and consideration of its main areas of application.

2.1.3 Gaps into Sector Attractiveness

The success of a sector depends on the success of the companies that operate there, which in turn depends on the skills of the workers. A strong attractiveness of the sector brings together **skilled** and **talented workers** within it, creating a virtuous process of success. Therefore, to **strengthen** the success of the sector it is first necessary to understand how it is **perceived** by **existing** and **potential workers**, as well as what their **preferences** and **priorities** are.

During the desk research, it was necessary to focus on the battery sector's main areas of application to indirectly analyze the attractiveness, but it will be necessary to deepen all possible interactions with **Stakeholders** to validate the information and, where possible, improve the analysis to have more specific and direct insights. This might be achieved through more targeted **surveys** covering aspects related to attractiveness – how it is perceived by stakeholders and what are the key areas to focus on to improve it.

2.2 HIGHLIGHTS OF STAKEHOLDERS

Stakeholders in the whole battery value chain, from raw materials to recycling, represent a wide-ranging group of entities. While this section describes some highlights, more details can be found in the respective parts of the original reports.[1]

2.2.1 Raw Materials and Processing

The activities of the stakeholders involved in the process of mining and processing of raw materials have an impact on the whole value chain since companies that are using batteries in their products consider this step as a reason for concern due to public scrutiny (environmental impacts, working conditions, political factors, etc.) and potential subsequent (negative) effects on the company's reputation. Not only are stakeholders active in **mining**, **mineral refining**, and **upstream sector** included, but also **public organizations** and **authorities** responsible for **ecological** and **economical sustainability,** and **human rights**.

2.2.2 Components and Cell Manufacturing

Concerning components and cell manufacturing, mass battery production in Europe is only starting to develop, as big battery players are progressively building and launching their battery production in Europe, the so-called **gigafactories**. Many of these manufacturers come from Asia, but other players, such as Tesla or emerging **European companies** come into play as seen in **(Figure 6)**. Some of them focus on "niche markets" and adapt batteries to sometimes very specific customer needs.

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[1] See ALBATTS deliverable 5.1 p. 32, 67-68, 86-90, 121-124, 133-134, 164, 181-183, 200-203 and ALBATTS deliverable 4.1 p. 116-118 for references

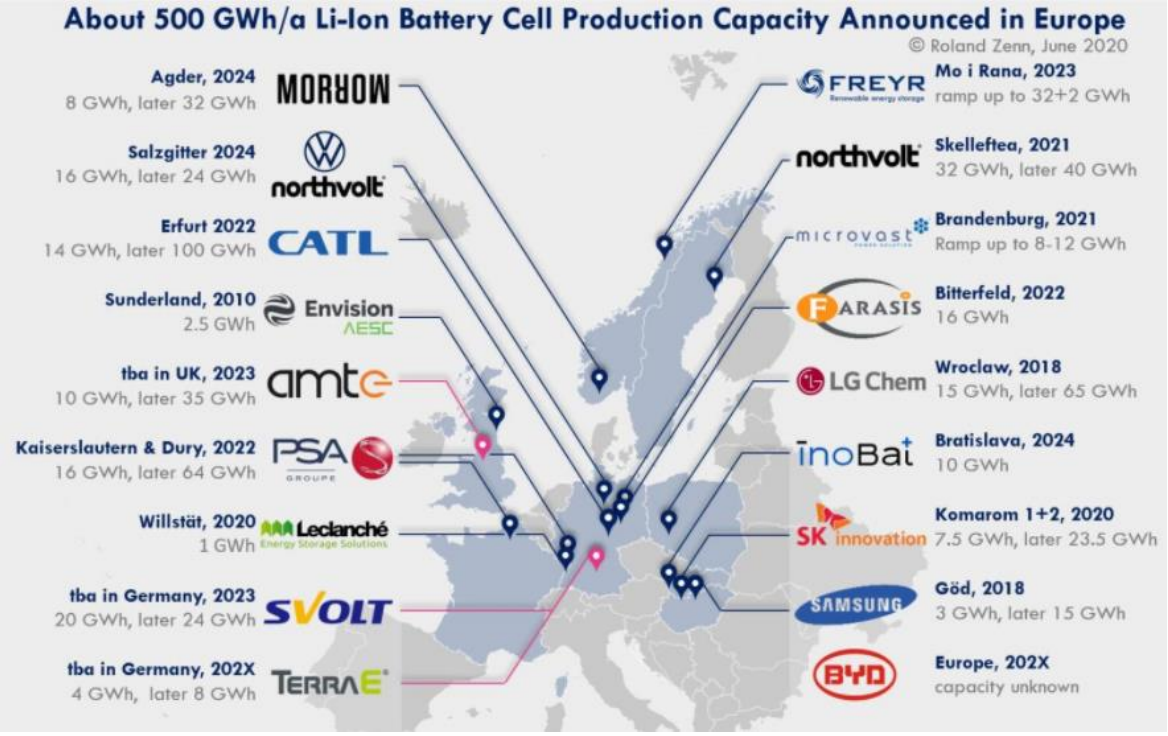

Figure 6 Major Stakeholders Active in Europe[2]

2.2.3 Module and Pack Manufacturing

In the case of the mobile applications/automotive industry, car manufacturers often opt for an in-house module and pack assembly trying to maximize the value they add to the vehicle. Modules and packs are critical to determining an **EV's** key performance indicator, such as **range** and **charging speed**. Control over the use of pack space and the battery optimal working temperature also has strong implications regarding the **safety** of the battery and the vehicle.

2.2.4 Battery Integration

Stakeholders active in battery integration specialize in the production of **battery embedded systems** like **battery management systems**, **battery thermal management systems**, and other components that are associated with **battery intelligence**. Since this is a crucial part of the whole battery system, many companies that produce energy storage solutions want to manufacture their systems and components. The car manufacturers in Europe are also a good example of this tendency. Many global players involved in this value chain come from **Europe**.

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[2] Zenn, R. (2020, June 09). Lion-battery-production-capacity-gigafactories-europe-june2020-electric-vehicle-ev-roland-zenn. Retrieved November 30, 2020, from https://www.orovel.net/insights/li-on-battery-gigafactories-in-europe-june-2020, **by Permission**

2.2.5 Operation, Repair, and Maintenance

Stakeholders in operation, repair, and maintenance of battery **electric passenger cars** include entities involved in type-approval of vehicles, standardization, vehicle manufacturing, and its supply chain, workers in dealerships, car repair shops, charging infrastructure providers, first-responders, or relevant bodies of public institutions. It also brings about opportunities to introduce brand new business concepts and services. Electrification of **vessels** creates new challenges to producers, owners, and operators of the vessels, including companies providing servicing and maintenance. Concerning **stationary use**, energy storage in the **grid** and **off-grid applications** have gained interest among various stakeholders from electric utility operators to policymakers. The telecom **base stations** form a large market that is accentuated by the **5G** network deployment. The stakeholders range from telecom technology and base station equipment providers to regulators and beyond.

2.2.6 Second Life

Entities involved in the second life of batteries range from battery and vehicle manufacturers, through repair and maintenance shops and recycling companies to stationary/storage application operators, such as industrial plant **operators**, **solar panel/wind farm developers**, **energy production** and **distribution companies**, **charging infrastructure operators** or **real estate owners** and **households**. In the future, refurbished batteries could be also used in **mobile applications**, for example, **non-road mobile machinery** or **micro-mobility vehicles** (e-scooters, e-bikes, etc.). As the second life of batteries is still in its infancy, there are huge opportunities for research and education institutions, standardization bodies, or different public bodies and authorities (providing incentives and altering the legislation).

2.2.7 Battery Recycling

The stakeholders in battery recycling involve all steps of the battery value chain since it is important for the **efficiency** and **sustainability** of the **battery ecosystem**, and the circular economy. There is a need for increased battery recycling capacity in Europe and new business models as well. Therefore, apart from battery and vehicle producers, new players completely focused on recycling are coming to the market. They differ in the applied processes and the level of the reclaimed material, but their main goal is to maximize the recovery of critical battery material from Li-ion batteries in a **sustainable**, **economically sound**, and **safe manner**.

2.3 HIGHLIGHTS OF TECHNOLOGIES[3] [4]

The Technologies section of the D4.1 and D5.1 report provides an overview of a battery value chain technological steps. The steps comprise the whole battery lifecycle elements for Lithium-ion Batteries (LIB) with NCA or NMC cathodes. According to the European Commission, Cobalt, Natural Graphite, and Silicon are considered to be essential for a LIBs manufacturing process, whereas Lithium, Nickel, and Manganese are also closely monitored.

2.3.1 Battery Raw Materials

Having a closer look at the battery elements, **Lithium** is a lightweight metal, Lithium Carbonate is mostly used in cathodes by the EV industry, whereas Lithium hydroxide production is expected to exceed that of Lithium Carbonate. **Cobalt** is supposed to provide LIBs chemical and thermal stability with high energy, though producers have been seeking cobalt substitutes not only due to its costly nature. **Nickel** enables heat and electricity conductivity along with low costs involved, so nickel can potentially be considered to be a good replacement for cobalt. **Manganese** can improve LIBs in a variety of ways and is also regarded as a cheap alternative to cobalt and nickel. **Graphite** is a safe and reliable anode material, which possesses sufficient energy density for mobile applications. **Silicon** is an anode material alternative to graphite.

2.3.2 Components and Cell Manufacturing

In battery manufacturing**, raw material processing** is followed by **components and cell manufacturing**. LIBs typology is derived based on a cathode material composition, which differs depending on parameters of voltage, operation life, capacity, etc. Needless to say, that now batteries account for up to **50%** of the total **cost of an EV** with a prevailing role of material costs**.** The manufacturing process includes the preparation of active materials, the production of electrodes, and the assembly of batteries. Battery shapes available are cylindrical, prismatic, and pouch cells. These variations define differences in terms of capacity, thermal management, and integration.

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[3] See ALBATTS deliverable 4.1 p. 42-47

[4] See ALBATTS deliverable 5.1 p. 54-59

2.3.3 Battery Packs and Integration

Component and cell manufacturing steps are followed with a **pack compilation,** where the pack usually consists of several blocks of battery modules**, battery management system (BMS) master,** and **thermal regulation system.** Design variations may involve series and parallel stacking of modules. One of the major LIBs **risks** is the possibility of **thermal runaway** and **explosion**, which are majorly prevented through an installation of BMS and a thermal regulation system. Together they occupy a significant volume of the pack and account for 24% of the total battery cost. The abovementioned activities are followed by a **battery integration** step, which varies mostly based on the application type: either stationary or mobile. The integration phase covers the configuration of cells and battery packs and its integration with embedded systems like battery management systems and thermal regulation systems.

2.3.4 Stationary Applications

Having been tested in line with compliance and safety standards, a battery goes into service. The following value chain step in a battery lifecycle after that is "operation, repair, and maintenance", which is defined application-wise. In the D4.1 report, there is a focus on **stationary battery** energy storage**,** which can be categorized as **grid** and **off-grid** applications, telecom base stations, and other heavy-duty energy storage. Grid and off-grid demand for energy storage both behind-the-meter (BTM) and front-of-the-meter (FTM) has increased due to the widening use of intermittent sources of energy production. Deployment of **5G** networks worldwide has boosted the usage of battery energy storage systems (ESS) for telecom base stations. Furthermore, lithium-ion batteries provide a higher energy density needed for a 5G base and a lower environmental impact. **Heavy-duty application** examples given in the report are offshore oil and gas applications, stadiums, hospitals, airports, and military applications, though heavy-duty sectoral applications are not limited with a scope of these examples. Large-scale stationary LIBs are designed to meet temperature and environmental extremes and can be utilized to decrease electricity costs, support in peak kW usage situations, help to meet environmental goals, support the use of renewables, and to provide power backup.

2.3.5 Mobile Applications

The D5.1 report focuses on **mobile battery** applications in passenger cars and vessels. The electric vehicle (EV) market is strongly being boosted by EU CO2 emission legislations. Reducing emissions such as CO2 and NOx is also important in the context of vessels in the maritime sector. With EVs, the battery technologies applied today are Lithium Nickel Manganese Cobalt Oxide (NMC) or Lithium Iron Phosphate (LFP), while NMC and solid-state technologies do have future potential. With vessels both **hybridization** and **electrification**, the fleet is the area of development. The dominant technology today is lead, both flooded and sealed, but Li-ion technologies (NMC) and LFP) are penetrating the vessel market. Solid-state electrolyte batteries do have the future potential with maritime applications.

2.3.6 Repair & Maintenance

It is important to take into consideration, that LIBs' **repair** involves **replacement** at the **end of their lifespan,** though maintenance procedures are performed to maximize that lifespan. The factors affecting LIBs' lifespan are, for example, **charge/discharge rate, depth of discharge,** and **ambient temperature procedures.**

In terms of repair and maintenance servicing, EVs are more simplified if compared to combustion engine vehicles. In the case of vessels servicing is done in docks and partly by the crew at sea. It is important to reduce or **eliminate risks** related to high-voltage batteries that apply to EVs and vessels with hybrid or electric propulsion systems.

2.3.7 Second life

Batteries can be repurposed and be subject to **second-life** applications**.** It enables the mitigation of CO2 emissions and reduction of the overall cost of electric vehicles (EV) through embedding the used batteries in stationary energy storage systems. Nowadays EV batteries are **re-used** for **stationary applications**, though in the future it may be possible to integrate used LIBs for mobile applications as well (e.g. in non-road machinery or micro-mobility devices). **Examples of second-life** stationary battery integration are the facilitation of renewable energy sources to the grid, off-grid stationary power back-up for remote consumers, etc. Even though battery repurposing for second-life usage is becoming more and more widespread, there are also potential challenges to overcome. Some sample problems are a lack of standardization for decommissioned batteries, technical barriers associated with the variations of battery cells, shapes, chemistries, etc., and a need for a proper residual energy capacity assessment.

2.3.8 Recycling

The last possible step in a battery value chain is the recycling stage. A sustainable vision of battery recycling needs to be present in the market to reduce LIBs' net production and leverage EoL (End of Life) batteries' materials. Recycling technologies' primary division is either **Direct or Indirect methods**, both include a variety of metal reclamation technique combinations to be applied, dependent on metals to be recovered (e.g. Co, Ni, Mn, Li, etc.), overall costs involved in operations and complexity of certain processes. In the D4.1 and D5.1 reports' 3.7 Recycling section is given an overview of both patented established recycling technologies (e.g. Retriev Technologies, Recupyl Valibat, Akkuser) and future ones (e.g. Accurec, "Closed Loop" process, Fortum's solution, etc.). According to 3.7 Recycling, there is a high potential behind the Akkuser process, which shows the lowest energy consumption and fire risks and brings a high level of recycling efficiency, though Akkuser has a certain amount of operational challenges.

2.4 HIGHLIGHTS OF JOB ROLES, SKILLS AND COMPETENCE[5]

As a basis for further Job Roles and Skills research, relevant battery sector job advertisements were collected from various companies. This led to the list of job roles and skills and competence which was further analyzed in original reports. These findings were mapped to the Battery Value Chain steps as well as a defined framework that normalizes the description and mapping of skills/competence to the job roles.

Based on this mapping, each step of the battery value chain contains the list of relevant job roles and analytical approach to the skills and knowledge listed by the occurrence. This analysis is a very good basis for further field research (online surveys and workshops) and shows that job advertisements are not unified by any of the well-known classification frameworks in the majority. Also, the ratio between the soft/transversal skills and sector-specific ones is not ideal with the first one to be in majority.

2.4.1 Job Roles

There are many job roles and skill that are relevant and needed throughout the **whole battery value chain**, from **general** Machine Operators, Handlers and Battery Assemblers led by Shift Leaders, to Safety and Quality Specialists, ISO Auditors, Process and Application Engineers who oversee the production with the support of Calibration Technicians, Metrologists and other professionals needed to maintain proper working environment.

Raw Materials and Processing specific job roles: Supply Chain Managers, Manufacturing Engineers, Production Engineers as well as Engineers with a focus on Anode, Cathode, and other Materials needed for battery production.

Components and Cell Manufacturing specific job roles: Electrical Engineers, Battery Specialists, Battery Design Engineers, and Production Engineers with a specific focus on battery components and cells.

Module and Pack Manufacturing specific job roles: Cell Module and Pack Engineers (Mechanical, Simulation, and Electrical) and Design Engineers with the same focus who work on development, design, and functionality of battery modules and packs.

Battery Integration specific job roles: Battery Management System Engineers, Thermal Engineers, and Embedded System Engineers who develop and adjust the software and overall

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[5] See ALBATTS deliverable 5.1 p. 61

integration with the hardware and specific use case either in stationary or mobile applications. This is assured by Battery System Consultants and Test Engineers and others.

The operation, Repair, and Maintenance specific job roles: Electrician Assemblers, Automotive Technicians, and Car Mechanics who are responsible for battery dismantling and Battery Test Technicians, Cell Inspection Technicians and Electric Battery Repairers and Engineers who are in charge of inspection and evaluation of dismantled batteries and possible repair. Day to day operation of vehicles requires jobs such as Towing/On-Road Services, Personnel, Fleet Management Experts, Insurance Personnel, Car Rental and Dealership Personnel, and Fire Brigades.

For the **Stationary Applications,** there are major differences in the expertise which cover the base stations, power grid, and many more. There is a need for Battery Storage Inspector, Field Service Engineers, and others.

Second Life specific job roles: Inspection Technicians, Service Technicians, Compliance Engineers, and End of Warranty Managers who determine the parameters of batteries that can be used as second-life batteries.

Recycling specific job roles: Recycling of batteries must follow strict rules and standards. Battery Dismantling and Recycling Engineers, as well as Warranty Managers, Recycling Auditors, and Safety Managers, and Specialists, are needed to ensure the fulfillment of these criteria.

2.4.2 Skills and Knowledge

Skills and knowledge demand obtained from the job advertisement analysis can be divided into two categories.

Soft and Transversal Skills and Knowledge were occurring in the majority compared to sector-specific skills and knowledge. The most commonly occurring elements were Communication, Teamwork and general Presentation, Analytical and Problem-Solving skills as well as Computer Literacy, and many more.

Sector Specific Skills were less commonly listed in comparison with the first category, but the analysis clearly showed that each battery value chain step has the right skills needed present ranging from Material Science (Battery Material), Chemistry (Electrochemistry), Battery Components, Manufacturing and Production, Development of a Product Design based on the

Requirements, Product Testing and Data Science and Analysis, Development of Models, Embedded Systems and Software Development, Quality Assurance, Auditing and Legislative, Battery Repair and Dismantle and other.

More detailed information can be observed in the reports **D4.1** and **D5.1**.

2.5 HIGHLIGHTS OF EDUCATION

All European countries will become involved in the batteries and electromobility value chain, and so will their national educational systems. The European **soft policy instruments** are used for stimulating national developments of education and creating transparency between systems and mobility of students, teachers, and working professionals at the European platform. A crucial task, from the ALBATTS perspective, is how the educational systems can follow and support the development of the battery and electromobility value chain. ALBATTS's task as a blueprint project is to help in this process, although we are not the only project, initiative, or organization at the EU level that views education and training for batteries and electromobility as a key issue. We have also Battery2030+, Batterieseurope.eu, EIT Raw Materials, EIT Innoenergy, and Fraunhofer Batterien Allianz, to mention just a few. ALBATTS works towards collaborating and not competing with these running initiatives.

2.5.1 Existing Education and Training[6]

At the mandatory primary, secondary schooling levels, orientation and experimentation modules may be needed to integrate into **STEM subjects** and similar contexts, as batteries and EVs are increasingly becoming a part of society. It is also important to create an attraction for the sector.

At the upper secondary and correspondent adult education level, more focused vocational education and training for machine operators, material handlers, maintenance personnel, etc. are growing up, but mostly in regions where the relevant jobs are available after education. The same applies to post-secondary technician-level of education, in vocational institutes, or at technical university colleges. The involved educational providers often react rather rapidly to emerging needs, but the trainers also need to be trained.

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[6] See ALBATTS deliverable 5.1 p. 233

For the bachelor level at universities and professional universities, existing educational profiles such as **mechanical-**, **mechatronics-**, **electronics-, computer-**, **chemical-**, etc **engineers** are often directly useful for careers in the battery and electromobility value chains, but elective courses and new exam profiles could be needed. For masters and Ph.D. education, profile and curricula are often created from the research perspectives on future industrial development, but increasingly also in communication with industry. In this sector, especially the master-level education shows promising diversity and cooperation between universities. This can be an effect of the Bologna process and its new mobility instruments at higher levels of university education.

Continuing education for working professionals and life-long learners seem to be able to grow in pace with demand, but not all courses offered by providers may be of the relevant quality.

2.5.2 Gaps in Education

Further cooperation with universities and Battery2030+ to understand diverse trends in the Ph.D. level of education better must be developed.

More information about vocational educational providers on ongoing projects in their national and regional environments must be researched.

Mapping of emerging labs that have LIB mini plants to enable skills practice opportunities must be done.

2.5.2.1 Next Steps

Through our Sectoral Intelligence work packages, we are trying to understand what is needed of new knowledge to learn, emerging new job roles, and skills. This process is ongoing.

We need to track where research specialization of different issues is to be found – as these also can help provide curricula on theoretical orientation areas.

We need to find ways to get educational providers, especially universities, to cooperate in education and training, instead of only competing or ignoring one another concerning educational provision.

3 Summary of Battery Value Chain

This section summarises desk research done for each battery value chain phase with specific current technologies, processes, and most importantly gap analysis and definition of future approach.

3.1 HIGHLIGHTS OF RAW MATERIALS AND PROCESSING

The small but growing Lithium-Ion battery production in Europe is presently dominated by the NCA (Nickel-Cobalt-Aluminium) and NMC (Nickel-Manganese-Cobalt) cell chemistries. These are the ones focussed on in table **Table 1**[7]. Other cell chemistries will emerge in European production. An example is the TESLA dry (solid-state) batteries without any cobalt, to be produced in the Grunheide plant near Berlin, presently under construction.

3.1.1 Import Dependence

From **Table 1**, building on the recently updated EU list of critical raw materials[8], it is clear that Europe is very dependent on non-European countries for the supply of critical raw materials for LiB cell production. To complicate it further, ore can be mined in one country, concentrated, and sent to another country with refining capacity, for ending up in a third country for cell production. EU is in its raw materials strategy working for the **free trade** of critical raw materials, but the producing or processing countries can have other interests. In 2020, because LIB production in Europe is small, dependence on imports is a smaller problem. The main worries have been concerning dependency on countries with largely unregulated mining practices (DNC for cobalt) and dependency on China. Now there is also the general **increased demand**.

LIB Giga factories can be built much faster than the raw materials sector can follow with the capacity to supply needed raw materials. This will mean increased competition for raw material delivery contracts, and since a lack of raw materials is likely, the cost for these contracts will increase. For EV and energy storage batteries, a calculation is that the EU would in 2030 need up to 18 times more lithium and 15 times more cobalt in comparison with the 2020 situation. The World Bank has pointed out that demand for minerals and metals can

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[7] See ALBATTS deliverable 4.1 p. 55-68 for references. Details have been updated by data from the updated EC Raw materials criticality list 2020, last visited 2020-10-28

[8] European Commission, Study on the EU's list of Critical Raw Materials – Final Report (2020)

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

increase rapidly with climate policy ambitions, with as much as 1000% for some materials to 2050 – and a big part of this is related to battery production.

3.1.2 Possible Solutions

There are however actions taken in Europe for addressing this situation. The EBA, European Battery Alliance, has been active in mobilizing private and public funding for supplying 80% of European lithium demand from European countries by 2025. Researchers and battery cell producers are also working intensively on new chemistries to make **raw material supply more European-sourced** and less critical. Interestingly, Europe may have a lot of the resources needed, although in smaller and sometimes complex deposits – but also, interestingly enough, often in countries with a history of carbon-mining, and sometimes close to planned battery cell factories. Together with the innovative **recycling of batteries**, these possibilities seem very critical to make the most of. It is also important to watch non-European stakeholders trying to contract the supply of European raw materials, including material for recycling.

Table 1 Essential Raw Materials in the EU

Raw Material (*critical)	**Use in LiB**	**Main EU Supply**	**EU import reliance**	**EU deposits**	**Recycling**	**Note**
Lithium* (Li)	Lithium oxide is the active cathode material. Li ions passes from cathode through elec-trolyte to the anode and back.	Chile, Bolivia and Argentina (from brine). Canada, Australia, China and USA (from hard rock mining).	100%	Portugal, Spain, Czechia, Finland.	Possible, but presently not so economically viable	Li is abun-dant, but production capacity and supply is limited
Cobalt* (Co)	Provides thermal and chemical stability to the cathode	DRC, Australia and as byproduct to copper and nickel mining globally.	86%	Co is byproduct of Cu- and Ni- mining and available as recycled metal.	Recycling is common (pyrometallurgy and biohydro-metallurgy)	Price and mining conditions in the DRC are drivers for Co-free batteries
Nickel (Ni)	Improves energy density and replaces Co.	Australia, New Caledonia, Canada, Russia.	59%	Finland. Exploration in Greece, Spain, Sweden.	About 98% of Ni is recycled, but not all to original state and quality.	Ni is abundant, but supply is limited.
Manganese (Mn)	Improve the cathode and is a cheap alt. to Co and Ni.	South Africa, Ukraine, Brazil, Australia, India	89%	In Czechia from tailings. Found in low concentration in soils globally	Mn can be recycled (37% 2005)	Mn is abundant, but supply is limited
Natural Graphite* (C)	Active anode material	China, India, Brazil, Turkey.	98%	Norway, Czechia and Austria have reserves.	Not often recycled, but methods are underway.	Synthetic graphite is an option.
Silicon* (Si)	Alternative to graphite in the anode	China, Russia, Norway, USA and Brazil.	63%	Norway, Bosnia, Spain, , France, Germany, N. Macedonia	Silicon for use in batteries is not presently recycled.	Abundant, but supply is limited.

3.1.3 Gaps into Raw Materials and Processing

We must know more about competitive cell chemistries, to alleviate criticality issues as well as possible. We must know more about ongoing raw materials exploration and processing projects in Europe for European sourcing, including recycling.

3.1.3.1 Next steps

There is a need to explore more about alternative cell chemistries and energy storage solutions and follow raw materials trade development in more detail.

3.2 HIGHLIGHTS OF COMPONENTS AND CELL MANUFACTURING[9]

In recent years, scientific and technological progress in batteries has been largely motivated by the automotive industry, as **Electric vehicles** (EVs) are becoming serious alternatives to internal combustion engine vehicles. According to the International Energy Agency, EVs account for 2.6% of global car sales in 2019, with an estimated increase to 3% in 2020. Lithium-ion batteries (LIBs) represent the only adopted solution for currently manufactured European EVs. Lithium's high electroactivity is the most suited to high voltage/power requirements, such as EVs' typical demand for 400-800 V. Therefore, LIBs, conversely to batteries based on different metals, allow fewer cells to be associated in series to match the latter voltages, consequently reducing the internal resistance of the batteries leading to lesser heat losses and smaller size components, thus reducing weight and cost.

According to the European Commission, **shipping** accounts for 2 - 3% of global greenhouse gas (GHG) emissions, with a forecasted increase of 50 – 250% by 2050. However, maritime applications have a market share of less than 1% of the total LIBs market, despite doubling the number of electric ships in the sea or ordered from 2018 to 2019 (314). Nonetheless, Li-based batteries are the most widely used battery type for maritime electric ship applications. The difficulty in implementing electric solutions on ships is mostly related to their higher power density, cycle, and calendar life demands, as well as safety requirements. Nevertheless, last year's market growth shows a potential successful leap for years to come.

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[9] See ALBATTS deliverable 5.1 p. 87-111

3.2.1 The Positive Electrode (Cathode)

Batteries using Lithium Cobalt oxide, Lithium-Nickel-Cobalt-Aluminium oxide (NCA), and Nickel-Manganese-Cobalt (NMC), still dominate the EV battery industry with an increasing market share of nearly 96% in 2019, and the same could be stated about LIB applications in Grid Storage Technologies (GSTs). These are the chemistries with the highest energy density. Besides these chemistries, Lithium-Iron-Phosphate (LFP) is also widely used in LIBs. Even though Cobalt seems to be the bottleneck of present-day LIBs, all passenger EVs sold in the European market use batteries with cathodes containing Cobalt. In the complete report, a table with the most relevant EV models currently manufactured is presented, identifying cell manufacturer, chemistry, and ratio (for NMC), as well as key performance characteristics.

It is noteworthy that since the cathode typically limits LIBs' performance, as it possesses a lower capacity than the graphitic anode and is the most expensive material of a LIB, it has been the target of intense research; the cathodes' enhancement has a significant impact on the overall battery performance.

Tesla installs in its EVs battery cells co-developed with Panasonic, Lithium nickel cobalt aluminum oxide, NCA, as a cathode. On the other hand, most car manufacturers incorporate batteries with Lithium nickel manganese cobalt oxide as the cathode type, with a clear tendency for the NMC622 ratio which reduces the Cobalt content.

Lithium-Iron-Phosphate (LFP) batteries provide higher cycle life and lower risk of thermal runaway, have no toxic components, are Cobalt-free, possess low internal resistance, and higher-load handling capability. These are the advantages that enable their application in mobile motorhomes and vehicles with low range and performance requirements, such as garbage trucks and electric road sweepers as well as in stationary applications, despite their lower energy density.

Chinese company CATL is the main company responsible for developing this type of cathode, supplying several car manufacturers from its native country. In 2015, LFP batteries were the most popular for hybrid vehicles, but over the last five years, NMC has surpassed this type of cathode, both in market share and research interest.

Two distinct groups of LIBs, based on their cathodes are, thus, clearly identified: **(1)** high voltage and energy density, but lower cycle life, batteries, using NMC/NCA. These batteries are tailored to high range and reduced weight, ideal for vehicles with shorter lifespans; **(2)** LFP batteries, tailored to longer cycle life demands, but exhibiting lower voltage and capacity, currently used in EVs sold in the Chinese market or stationary applications, for which weight saving is less critical, and a longer lifespan before the battery has to be replaced is desired. In the complete report, a comparison between different chemistries' electrical performance values is presented, including other chemistries that are less used in EVs.

3.2.2 The Negative Electrode (Anode)

Virtually every commercially available battery for mobile applications contains graphitic anodes, which remains to be the most compatible with Li-ion cathodes. The most relevant features for an ideal anode, which also explain the abundance of graphite anodes, are **(1)** a chemical potential that compares to Li-metal when the battery-cell is charged; **(2)** significant worldwide reserves; **(3)** good electrochemical stability; **(4)** increased safety in case of fire, concerning Li.

Anode **technology has been reasonably stable** throughout the years, but with the continuous development of Li-ion cathodes, new materials, coatings, and manufacturing processes are being studied and commercialized. Since anode degradation is accountable for much of full **battery-cell degradation**, improvements at the anode component level will be important for developing **long-lasting batteries** for mobile applications. Presently, **Li-metal**, **Carbon** (usually Carbon Black) coated graphite, and graphite-Silicon based anodes are widely regarded as the major alternatives to **replace plain graphite** as the most important anode for LIBs. Companies such as Tesla have already been producing a graphite/Silicon anode. The **issues concerning Silicon** anodes, responsible for its current absence from widely used commercial applications, are: **(1)** high volumetric expansion and contraction during charge/discharge (up to approximately 400%) continuously breaking/reforming the solid electrolyte interphase (SEI), and leading to high mechanical stress, and fracture; **(1)** unstable SEI film, a constituent responsible for consuming the cell's lithium leading to capacity fading; and **(3)** low electrical conductivity. The solution most widely investigated for eliminating/reducing these issues is to incorporate nano-Silicon into a composite structure, typically with graphite or some polymer as a structural element.

Pure graphite possesses the lowest voltage among the alternatives to lithium metal which results in a charged anode that almost does not lose in voltage to Li-metal. However, graphite anodes not only possess relatively low specific capacity (theoretically, 372 $mAh \cdot g^{-1}$), much lower than Silicon's theoretical capacity (4200 $mAh \cdot g^{-1}$ for pure Si anodes) but also have a typical cycle life of the same order as standard NMC cathodes, which means that graphite can limit the cycle life of the cell, contrary to Lithium-Titanium oxide LTO, which has the highest cycle life of the three anode types. LTO is usually combined with Lithium Iron Phosphate LFP cells, as LFP shows a lower plateau voltage. According to Toshiba, the manufacturing leader of cells containing LTO, their LFP/LTO based batteries are extremely safe, with little risk of thermal runaway, and long cycle life. These performance indicators render LFP/LTO batteries most suitable for grid applications, and information included in the original report indicates that several plants are using LIBs with this chemistry combination. LTO is the second most used anode commercially available.

3.2.3 Overview of Cell Manufacturing

Presently, batteries account for up to 50% of the total cost of an EV. Moreover, out of all cost associated with LIBs, material costs are the most significant; considering only separator (3%), electrolyte (1%), current collectors (3%), anode materials (8%), and cathode materials (26%), 41% of total battery cost is obtained, with the most significant contribution owing to the cathode material. The development of new manufacturing processes is paramount for reducing these costs and even more the elimination of expensive and non-sustainable materials such as Cobalt.

Current processes for manufacturing anode, cathode, and assembling a LIB cell are described in the original report.

For obtaining a battery cell, cathode and anode are prepared by a wet coating of current collectors (a costly and polluting process), insulated by a separator, and wetted by an electrolyte solution, while the current collectors assure the flow of electrons.

Nickel Manganese Cobalt oxides (NMC) cell manufacturers use cylindrical, prismatic, or pouch geometries for housing cells. Regardless of geometry, housings use tabs for connection with the system powered by the battery, thus assuring electron flow. Cell geometries give different complexity in cell assembly manufacturing. The cylindrical cell format is the most suitable way of producing high-energy cells since it is easier to produce the jellyroll efficiently. However, cylindrical cells are more complex when it comes to module design, wherefore the prismatic format is dominating in the automotive EV designs.

Liquid electrolytes, which are typically highly flammable, constitute one of the main safety concerns in LIBs. This has led to some major companies and research teams' efforts in developing all-solid-state batteries, for which manufacturing and successfully incorporating solid electrolytes are key steps.

3.2.4 Future Trends

Society and therefore the industry, is urging to develop of Cobalt-free cathodes. During its battery day, Tesla revealed plans to substitute Cobalt with Nickel in their batteries' cathodes. Without specifying the time necessary for shifting towards 0% Cobalt, it can be assumed that predictions identifying NMC as a dominant cathode technology in 2025 are still applicable.

LG Chem, a world leader in the number of NMC batteries sold, is focusing on developing NMC811 and NMC712, and NCA chemistries for the next generation of electric vehicles, thus reducing the amount of Cobalt oxide, while maintaining or enhancing electrical performance.

For more than a decade, Si anodes have been extensively researched without significant commercial success, associated with scarcity in low-cost design proposals. Nevertheless, it is regarded as the most serious alternative to graphite anodes, and Tesla's approach to manufacturing Si-based anodes seems to be the key strategy for finally unlocking next-generation LIBs for EVs, capable of withstanding combined ranges above 150-300 km.

The predicted increase in EVs (and, thus, LIBs) sales for the next decade will lead to larger production scales in the cell, module, and pack manufacturing, allowing for further investments and a reduction in overall costs. During battery day, Tesla hinted at key improvements: **(1)** eliminating tabs from housings which increases the conductive area allowing higher current rates and lower heat generation; **(2)** dry coating of cathodes. The dry coating reduces the environmental impact of materials used during fabrication and potentially reduces oven times and, therefore, manufacturing costs for cathodes; **(3)** opting for cell-to-pack designs.

3.3 HIGHLIGHTS OF BATTERY MODULE AND PACK MANUFACTURING[10]

Voltages and powers can be tailored by associating cells in series and parallel.

Two of the biggest challenges LIBs have endured since their commercialization are **(1)** their inherent risk of fire, attributed to graphite forming lithium-metal dendrites leading to short circuits and, therefore, thermal runaways aggravated by possible cathode's oxygen release; and **(2)** manage energy consumption from a relatively high number of cells in an EV/grid application. These facts forced the industry to combine cells with a battery management system (BMS) and a cooling system, thus obtaining modules, which are then combined, either in series or in parallel, into a pack, and placed in the vehicle. This necessity has a tremendous negative impact on energy density and the total volume of the component.

Cell stacking is mainly controlled by assuring **(1)** electrical insulation, **(2)** mechanical links, and **(3)** optimized cooling, or heat transfer, at the module level. Different manufacturing techniques are employed, based on cell geometry, for this step. After cell stacking, a BMS slave is usually welded (in many situations, an Aluminium plate with high conductivity), power and COM cables are connected, and the module housing is sealed.

3.3.1 Gaps in Energy Storage Technologies

In our first deliverable, we addressed technological developments from the last 5 years, exclusively for traditional LIBs. Furthermore, our focus in terms of mobile applications was the automotive and maritime industries, while for stationary applications, we have focussed on batteries for the grid in power plants.

In future works, we aim at exploring **emerging technologies**, such as all-solid-state, **LiS**, and **Lithium-metal** and **structural batteries**; as for components, we will focus our study on **Ni-rich cathodes**, **Si composite anodes**. Finally, we will benefit from market reports to understand how different technologies are being adopted in Europe and throughout the world.

Other competing and non-competing technologies should be addressed as well, such as **capacitors** and **fuel cells**.

The integration of energy storage with harvesting technologies like **photovoltaics**, **thermoelectric**, **triboelectric**, and others should be explored in future reports.

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[10] See ALBATTS deliverable 5.1 p. 111-115

A special insight will be given on technologies suitable for energy storage on the **Internet of Things (IoT)**, such as **antennas**, **wearables**, and **sensors**.

3.4 HIGHLIGHTS OF BATTERY INTEGRATION[11]

Battery integration is a very important step in the battery value chain. It is the last step before the battery goes into the working environment/applications and is installed with required intelligence systems like **battery management systems**, **thermal management systems,** and others so the correct functionality, safety, and longevity of the battery can be achieved. This installation accounts for 24% of the total battery cost (excluding manufacturing labor costs related to the components).

3.4.1 Battery Management System (BMS)

BMS may fulfill a variety of functions depending on the particular application as well as the type of battery but the overall goal is to keep the battery within the safety operation region in terms of voltage, current, and temperature during charge, discharge, and certain cases at open circuit. The most frequent topologies are **1)** centralized, **2)** modular and **3)** distributed. Other features like **monitoring of voltage**; **contactor control**; **isolation monitoring**; **temperature measurement** and **control**; **state of charge** and **state of health** calculation; and **communication** that the **BMS** offers are described in more detail in the original report.

3.4.2 Battery Thermal Management System (BTMS)

The battery thermal management system is an important and integral part of the BMS. The main goal is to **manage the temperature** of the battery and overcome all challenges that are coupled with thermal effects including (capacity/power fade, thermal runaway, electricity imbalance among multiple cells in a battery pack, and low-temperature performance). BTMS is comprised of a combination of hardware and software and while designing such a system certain requirements must be met.

In the original report, the most used configurations of BTMS were described such as types of mediums (liquid cooling, passive or active air thermal regulation) and materials needed for a certain type of configuration as well as the overall aspects of the BTMS were described.

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[11] See ALBATTS deliverable 5.1 p. 115

3.4.3 Drivers of Change, Attractiveness, and Stakeholders

BMS global market was evaluated based on existing reports. It is estimated that the BMS market will grow to USD 12.6 billion by 2024 at a Compound Annual Growth Rate of 19.5%. This growth is expected to be driven by the growing trend of electric vehicles, energy systems, battery monitoring, and effective electric grid management.

Various applications were described as well as the main global players in the BMS market such as Leclanche, LiTHIUM BALANCE, Saft, FIAMM, etc. One of the interesting findings was that Europe dominated the BMS market in 2018, this is mainly attributed to the presence of major automotive manufacturers in Europe.

3.4.4 Integration Processes

The generic integration process was described in the original reports as well as the processes that vary based on the application. The integration process for automotive, maritime, and stationary applications. The generic integration process consists of an **assembly of the battery module**, **integration of the modules with the BMS,** and **integration to the specific use case** follows.

3.4.5 Gaps in Battery Integration

Since BMS is a crucial part of every battery it is needed to establish a clear vision for the future about the need for competence, skills, and which job roles are going to be important in this fast-changing sector as well as for the specific application.

3.5 HIGHLIGHTS OF OPERATION, REPAIR, AND MAINTENANCE

This section summarizes the intelligence gathered for the operation, repair, and maintenance of batteries in specific use cases in stationary and mobile applications.

3.5.1 Stationary Applications

This section is focused on the summary of operation, repair, and maintenance of batteries in stationary applications with the main focus on telecom base stations and other heavy-duty applications.

3.5.1.1 Drivers of Change[12]

The areas highlighted in the report are grid and **off-grid applications, telecom base stations,** and other **heavy-duty energy storage variations.** Several factors are driving a battery storage market development, including massive integration of renewable energy sources (RES) to be complemented with BESS (Battery Energy Storage System), economic taxation incentives, decrease in consumer costs and an increased awareness shown by policymakers and regulators and to a higher sustainability level. Nevertheless, the battery energy storage defined markets are still about to be recalibrated in many European countries. The removal of barriers to the wide implementation of battery energy storage is still an ongoing process in many countries, which is governed by policymakers and regulators.

To start with, lithium-ion batteries have recently been widely integrated for the **grid and off-grid applications**, and there are multiple aspects involved to support this tendency, ranging from **environmental and economic factors to technical ones**. Without a doubt, the growing integration of renewable energy and its intermittent nature has opened wholesale electricity markets as well as ancillary services markets to battery energy storage systems. Batteries provide **grid support** by **regulating frequency, supporting voltage,** and **helping in electricity restoration in blackout situations.** As the integration of battery storage in electric grids is highly dependent on cost and performance, these factors have driven the application of LIBs in energy storage applications. Consequently, battery usage is implemented in three main areas: **residential, commercial, and industrial**; for the grid and operator utility needs and off-

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[12] See ALBATTS deliverable 4.1 p. 113-116, 125-128 and 133-137

grid. Due to the versatility of the battery storage perspectives, there is a broad range of both established players and newcomers in the market.

3.5.1.2 Front-of-the-meter and Behind-the-meter[13]

Batteries can be utilized by **integrating renewables, supporting smart grids, creating more dynamic electricity markets, and providing ancillary services.** An increased interest in lithium-ion battery deployment both behind-the-meter (BTM) and front-of-the-meter (FTM) levels of the grid and off-grid energy storage applications revolve around LIBs performance and reduced costs. One of the primary drivers of BTM battery application is the ability to **decrease electricity costs** when providing electricity residentially or for business purposes. As a result, the use of small-scale battery storage is expected to increase significantly, complementing utility-scale applications. Energy storage is also highly essential for utility-scale (FTM) usage in connection with distribution or transmission networks. It serves by shaving peaks and leveling loads of electricity demand, especially, in the case of wind and solar power (and other renewable energy sources).

3.5.1.3 Telecom Base Stations[14]

In the telecom sector, the recent **worldwide deployment of 5G network base stations** has initiated a demand for energy storage solutions, which is perfectly satisfied with LIBs. This trend is supported by the performance LIBs can provide for example as **backup power systems for telecom base stations**. In addition to the performance benefits, LIBs have, due to their construction much lower negative environmental impact, compared to their main energy storage market counterparts — for example, lead-acid batteries. In remote off-grid areas, the combination of diesel generators and lead-acid batteries has caused greenhouse gas emissions, which can be offset with **the combination of variable renewables and LIB based energy storages**. In the long run, these energy solutions can induce miscellaneous **benefits for telecom operators by bringing high capacity, improved safety, and mitigation of harmful environmental footprint**. Nevertheless, high costs of integrating LIBs into the operations are still considered as the main hurdle, even though there has been a decreasing trend with LIB

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[13] See ALBATTS deliverable 4.1 p. 120-124

[14] See ALBATTS deliverable 4.1 p. 125-133

prices. The major categories of the stakeholders can range from telecommunication operators, base station equipment manufacturers to regulators, and governmental agencies.

3.5.1.4 Other Heavy-duty Applications[15]

Large-scale battery systems of heavy-duty applications (as described in section **2.3.4**) are designed to meet **various temperature and environmental extremes and support renewable energy generation, decreasing electricity costs and peak-shaving in high usage situations**. Several financial and environmental forces drive energy storage proliferation. For example, costs can be reduced by moving the electricity grid use load to off-peak hours by storing cheaper and/or clean energy for later usage.

3.5.1.5 Stakeholders

There is a great variety of **stakeholders, who can be involved in the operations due to the specific complexity of the heavy-duty applications.** The sector involves several large and heavy equipment and complex processes, so it has always required efficient energy storage solutions. With the recent **developments** in the sphere of **renewable energy sources, the potential demand for a range of battery energy storage systems has noticeably increased.** Consequently, more and more active industrial and commercial players became involved in the process of BESS deployment in the following possible applicational directions discussed as examples in the desk research report (D4.1). For example, hospitals might experience several environmental and energy-saving advantages by upgrading their existing infrastructure (e.g. solar panels) with energy-intensive facilities. Airports can have their interest in combining energy storage solutions with photovoltaic systems, whereas the oil & gas industry may utilize batteries as load-levelers and peak-shavers. The military can benefit by storing renewables such as solar- and wind-generated energy, having LIBs providing a cost-effective and flexible power source for bases, and having a reduced carbon footprint by decreasing the need for diesel generators.

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[15] See ALBATTS deliverable 4.1 p. 133-145

3.5.1.6 Repair and Maintenance[16]

There are several concerns related to the technical nature of LIBs, and there are also **safety risks** involved in the operations. The major factors, which affect the LIBs lifespan, are **excessive charging and discharging activities as well as inadequate temperature levels exposure.** To extend a battery's lifespan regular maintenance activities are undertaken to check-up and control charge/discharge rate, depth of discharge, degradation rate, temperature level, etc., though safety procedures will differ battery type-wise**.** Furthermore, Battery Management Systems **(BMS)** are installed to control batteries' operations and **prevent overcharging**, **overheating**, and **short-circuiting**. When it comes to repairing procedures, the end of lifespan Li-ion batteries is subject to replacement.

3.5.2 Gaps in Operation, Repair, and Maintenance – Stationary Applications

The battery energy storage specific markets are still about to be recalibrated in many European countries. The **removal of barriers** to the wide implementation of battery energy storage is still an ongoing process. What kind of measures are and will be taken? Further study should be conducted to understand this process and its potential implications.

Are there other **factors** such as other **new technologies**, other than batteries, that act as **drivers of change**? In the coming research work, these new technologies such as **hydrogen-based** should be addressed.

There are other significant areas of application for stationary batteries such as **UPS systems** for datacentres etc. than those mentioned in the first release of WP4 desk research. These should be covered in future research work as well.

If a battery-related **disaster strikes**, e.g. battery fire, it should be studied what **procedures** should be undertaken in those situations and what implications does it have for related **planning, equipment, skills, and competences** of both the normal operative staff as well as the staffs of fire and **rescue services**. What **EU legislation** and **standards** are currently in place or planned regarding battery-related **emergencies** also remains an interesting question to be studied.

With regards to telecom base stations, are there **skills and competences** that are especially important for **maintenance teams**? What is the ideal mixture of **telecommunications** and

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[16] See ALBATTS deliverable 4.1 p. 145-152

battery skills vs. what are the most **common service-related challenges** with base stations? These remain potential gaps to be further analyzed in future research work.

3.5.3 Mobile Applications – Passenger Cars[17]

This section describes the mobile application of batteries and the operation, repairment, and maintenance.

3.5.3.1 Drivers of Change

The electrification of passenger cars is **driven mainly by EU CO_2 reduction regulation**, together with other pieces of climate or air pollutants related legislation. Among other drivers are low-emission mobility **incentives implemented by the Member States** or, on the other hand, **access restrictions** introduced by cities. **Technological improvements** increase in numbers of charging points and changing consumer behavior belongs to other encouraging factors.

3.5.3.2 Stakeholders

Stakeholders relevant to this value chain step who require some level of qualification related to battery topics are e. g. entities involved in type-approval of vehicles, standardization, workers in dealerships, car repair shops, charging infrastructure providers, first-responders, or relevant bodies of public institutions.

3.5.3.3 Technologies

There are passenger cars with **different degree of electrification and battery technology** in operation, ranging from full electrification in Battery Electric Vehicles (BEVs) to only partially electrified mild hybrids (vehicles with Internal Combustion Engine (ICE) combined with auxiliary electric propulsion) as seen in **(Figure 7)**. These vehicles also differ when it comes to the possibilities of charging their batteries; in the case of external charging, there is AC/DC with different charging speeds.

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[17] See ALBATTS deliverable 5.1 p. 132-158 for references

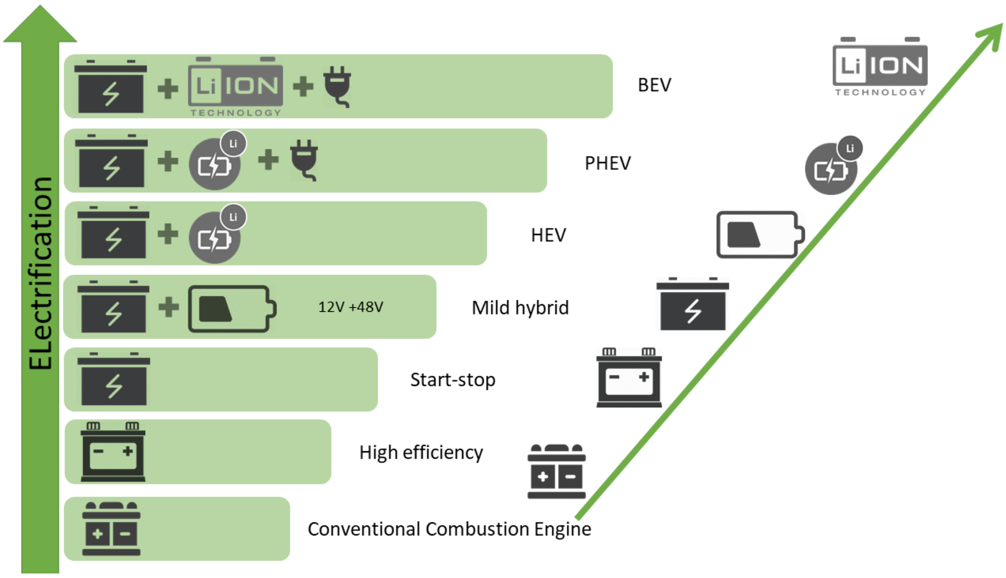

Figure 7 Degree of electrification of the vehicles

3.5.3.4 *Operation of Electric Vehicles and Safety Aspects*

Before electrified passenger cars can get to the road, they must be **tested** to ensure compliance with regulations addressing **safety**, **compatibility**, and **environmental issues**. From the testing and certification perspective, these vehicles bring together two previously separate worlds: the automotive industry (ISO standards) and the electrical industry (IEC standards).

BEVs and PHEVs (electric vehicles, EVs) operation provide opportunities for **new services and business models**, e.g. in charging, vehicle-to-grid applications, monitoring the state of charge, and health of batteries or fleet management.

At the same time, electrification of the vehicle fleet brings about challenges linked particularly to eliminating hazards that vehicles equipped with a large high-voltage battery could wreak on its environment while parked or in motion. The **primary safety concern** with lithium-ion batteries (LIBs) is a **risk of thermal runaway** (triggered by a chain of chemical reactions inside the battery resulting in an accelerated increase of internal temperature), where the outcome can be complete combustion of the LIB accompanied by the release of gas, flying projectiles, and jet flames. The LIB may also ignite after a significant amount of time after being damaged or reignite after having been extinguished. This matter not only concerns firefighters, but also those involved in handling damaged vehicles through towing, workshop, scrapyard, or recycling activities. There are many different types of LIBs, with different packaging and chemistries but also variations in how they are integrated into vehicles. These characteristics have implications for their safety. New technologies, like solid-state batteries having no liquid or flammable electrolytes, may reduce the risks of gassing/venting and fire in the future. An important role has the Battery Management System (BMS). First responders and post-crash handlers need to be aware of the possible risks posed by EVs and how to handle them.

3.5.3.5 Repair and Maintenance of Electric Vehicles

Under normal conditions, BEVs are **easier to maintain compared to vehicles with a combustion engine** as they do not require for example regular engine/gearbox oil change or oil/air/fuel filter replacement. However, **some works**, especially while repairing, **require extra skills and education, including a combination of car mechanics and high voltage qualifications**. It may require changes to the legislation in occupational safety; it would be useful to gather information on the situation in the different EU Member States and consider a common approach by the EU Member States. Now, **there seems to be a lack of experts qualified to repair EVs**.

As for battery replacement, due to a limited number of EVs at the end of life available, there is very limited information on this topic as well as a limited number of authorized / independent workshops providing this service.

3.5.9 Mobile Applications – Vessels[18]

This sub-section describes maritime applications of batteries.

3.5.3.6 Drivers of Change

The maritime sector also needs to **reduce its CO_2 and air pollutant emissions** such as NOx or PM. This, together with **technological development** and other drivers, leads to a progressive hybridization and electrification of the vessel fleet.

The **market introduction of maritime battery solutions** is **still in the early phase**. However, the maritime battery market is **fast-growing** and, according to Navigant, Western Europe stands out as a key market.

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[18] See ALBATTS deliverable 5.1 p. 161-174 for references

3.5.3.7 Stakeholders

The main purchasers of maritime battery systems are system integrators, but no orders are placed unless the end customers (like offshore supply vessel owners, ferry operators, cruise ship owners, tourist boat operators, fishing boat owners, workboat owners, bulk ship owners) want to install battery systems. Other important stakeholders include governments, including local authorities, and battery system manufacturers.

3.5.3.8 Technologies and Operation of Vessels

In the case of **large boats**, there are vessels with different degrees of electrification and battery technology used: mechanical propulsion with battery hybrid electric power plant, battery hybrid propulsion, battery hybrid propulsion with distributed batteries, electrical/mechanical hybrid with DC power distribution and all-electric propulsion. **Smaller battery-electric boats**, such as canal, river, and lake vessels, are boats propelled by mechanical systems consisting of an electric motor turning a propeller to reduce noise and operate with zero emissions. Battery electric boats are often integrated into a fleet of vessels which has an onshore charging infrastructure in place.

The **dominant technology today is lead**, both flooded and sealed, but **Li-ion technologies (NMC and LFP)** are **penetrating this market**. Solid-state electrolyte batteries are a new technology with great potential. Also, in the case of vessels, attention must be paid to **safety issues and potential negative thermal events**.

3.5.3.9 Repair and Maintenance of Vessels

Servicing of the electrified vessels by qualified personnel can be done in docks, by the crew at the sea, or, since vessels travel at distant locations, remotely.

3.5.4 Gaps in Operation, Repair, and Maintenance – Mobile Applications

In the first iteration, the focus was very much on current technologies. Emerging and **future technologies** concerning batteries (such as the chemistry of cathodes) and their implications for battery **safety, operation, repair and maintenance, and related job roles and skills need** to be researched and discussed in the next steps. Also, exploring other mobile battery applications will be among our future tasks.

As for specific job roles and skills, we will have a deeper look into the car mechanics tasks, education, training, and higher qualification requirements.

3.6 HIGHLIGHTS OF SECOND LIFE[19]

This section highlights the most important findings present in the research done about the second life of batteries.

3.6.1 Background

According to the European Commission vision[20] set in 2018 ("A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy"), **by 2050, the entire EU`s economy should become climate neutral**.

To achieve this tough objective, all stakeholders must commit themselves to serious efforts and investments. **The transport sector** must take the necessary steps towards **the phase-out of ICE vehicles (around 300 million units in 2018 in Europe)**[21].

As today`s most advanced propulsion technologies heavily rely on the electric motor, be it supplied with energy by a battery (the most common solution) or a fuel cell (still unreliable, complex, and expensive), it is quite obvious that the traction battery would become the most important option for onboard energy storage. As the pressure on the industry and the society towards electrification is mounting, the electric vehicle's proliferation is practically a given. The full decarbonization of the EU`s economy will probably not be achieved before 2050 but major steps towards that goal will certainly be made.

3.6.2 Used Battery Stream

The electrification trend, that has already begun in Europe and other regions of the world brings about another issue: the huge volumes of used traction batteries that must be properly handled once they get removed from the vehicle (be it because either the battery is no longer suitable or just the vehicle itself is not usable anymore), especially with ultra-long life batteries already announced recently that would completely redefine the second life concept and even

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[19] See ALBATTS deliverable 5.1 p. 176

[20] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0773 accessed on 06.10.2020

[21] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0773 accessed on 06.10.2020

introduce the third life concept[22]. According to the estimates, **more than 6 million battery packs will be retiring by 2030**[23].

Some of the resulting batteries ought to get straight to the recycling plant as they would not comply with the basic requirements for reuse but others (most of them, according to our estimates) could and would have to be repurposed. Batteries that reach 80% State of Health (SoH) or below are not spent, just unsuitable for their primary use (propulsion of vehicles) anymore.

3.6.3 Battery Reuse and Repurposing

Battery reuse and repurposing is an enterprise that, if approached and implemented properly, enables the achievement of several objectives set but also the solving of certain problems that may arise in the society in the foreseeable future.

First, battery second use dissemination enables **the mitigation of CO_2 emissions and decreases an overall demand for brand-new stationary application battery production**, thus decrease the impact on the environment by the extraction of minerals and the whole battery production chain. Repurposing retired electric vehicle (EV) batteries also provide a potential way to reduce EV cost. Embedded in stationary energy storage systems, second-life EV batteries could unlock the energy storage market and generate synergic value for the energy sector, thus contributing to the decarbonization of the economy.

EV batteries can be **reused in stationary applications** to facilitate the integration of renewable sources of energy to the grid, off-grid stationary to back-up power for remote consumers, etc., or for single households to manage demand peaks and regulate power flow. In the future, second-life batteries can be used also **in mobile applications**, for instance in non-road machinery or micro-mobility devices.

Capturing as much renewable energy is not only important towards achieving the climate neutrality of the European economy or reducing the burden on the grid, especially in the areas where the grid is either overwhelmed (as a result of the increase in electricity demand through either massive urbanization or electrification – the EV almost doubles the household consumption) or downright obsolete. It is also important as the **taxation on electricity**, in

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[22] https://www.reuters.com/article/us-autos-tesla-batteries-exclusive-idUSKBN22Q1WC accessed on 30.10.2020

[23] https://www.idtechex.com/en/research-article/post-vehicle-value-of-retired-electric-vehicle-batteries/18058, accessed on 07.10.2020

general, is **expected to increase** (to offset the drop in consumption of tax-dripping gasoline and Diesel[24] and discourage the production of black/grey energy – coal/gas/oil fuel burning or nuclear).

The reuse of the battery packs also needs to be heftily stimulated even if the recycling technology is not mature enough yet to provide an economically viable and technologically satisfactory solution. This needs to be accompanied by the implementation of circular concepts, procedures, and infrastructures, associated legislation, dedicated research, and technology development. Nowadays, the **recycling technology for traction batteries misses both EU legislative targets** applicable thereto: battery – 50% and vehicle – 95%. As future legislation is not expected to get softer, the recycling targets would either remain the same or increase to a new threshold.

3.6.4 Challenges

Currently, there are still **significant challenges in exploiting the expected volume of decommissioned batteries**. These include a **lack of standardization** generally, and specifically in communication protocols. There are also **technical barriers** associated with the variations of battery cells, shapes, chemistries, capacities, and sizes used by different vehicle manufacturers, in addition to data accessibility-related challenges.

Furthermore, the battery second life market is expected to absorb an important share of the workforce that could be laid off from the automotive industry and connected branches of the economy (repair shops, fuel extraction, and distribution, lubricants production, etc) once the EV sales volumes pick up consistently.

Another issue to be dealt with in the **management of the battery once is removed from the vehicle**, upon the decision of a technician from the manufacturer`s repair network. Before proceeding to the integration phase, a decision on either direct **redeployment or reconfiguration of batteries** must be made. Cell quality selection process is to be scrutinized, considering a battery’s SoH, the higher quality output is expected within the latter option. Overall, **a greater degree of certification** would help to allow a complete assessment of the residual energy capacity of a battery pack at the end of the first life; to allow a more **optimized**

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[24] https://www.uhy.com/european-companies-struggling-with-the-worlds-highest-fuel-costs/ accessed on 30.10.2020

design of the full battery system for a stationary application; to enable developers and integrators of second-life batteries to provide product **warranties** to their customers, etc. Challenges might also reside in the **final integration** of second-life batteries, the replacement, or the capacity expansion that prompt for cooling, safety, hence BMS perfect compliance.

Before the existence of the users/applications and the stream of functional second-life batteries, **a proper infrastructure** is needed to have a successful implementation. To this purpose, some **tools are required** to properly assess the overall state of the battery as well as the safe and efficient second life.

The tools needed to manage efficiently the second-life batteries are divided into two main categories: **software** and **hardware.**

The most important **software needed** is the protocol that can accommodate all common battery management systems (BMS). This can be used for either the **assessment** of the state of health of the battery (if not already done by the repair workshop with its tooling) or the **functioning** over its second life.

Further software solutions can be developed to deal with various function related phenomena a battery might encounter during its second life such as vibration monitoring, premises temperature measurement and regulation, core fluid thermal management, emergency connection cut-off, battery flooding, infrared thermal scanning.

The necessary **hardware** includes cradles, cooling ducts, and pipes, radiators, fans, connection cables, etc.

3.6.5 Gaps into Second Life of Batteries

The second life batteries will play an important role in the new paradigm of (green) energy production and power grid upgrade, the situation is already gloomy with less than **20% green energy share** in total consumption and a grid that is stretched to its limits and prone to **fail more often than acceptable**. This is where **second-life batteries** could act as a **game-changer**, as long as they benefit from a **proper regulatory framework**, **industry-wide, trustworthy standards,** and **maintain the operating cost at a reasonable level**.

For all the above-mentioned reasons, the society and the stakeholders must come up with a counteracting strategy with a series of measures meant to cushion the potential blows, to

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prevent serious negative effects that may severely impair various stakeholders, in the case of some of them, beyond the point of no return.

3.7 HIGHLIGHTS OF BATTERY RECYCLING

This section describes the most important findings throughout the research done on battery recycling.

3.7.1 Battery Lifecycle and EU Legislation

The whole battery lifecycle has recently been revised in line with **sustainability principles,** according to **Strategic Action Plan on Batteries,** recycling and re-use phases are still lacking some elements. The current and up-to-date recycling sector developments are compiled in the full version of the D4.1 report, whereas in this summary we would like to present the most essential highlights and provide **a systematic overview of existing recycling procedures for LIBs (Lithium-ion Battery)**. The major factors driving a need for reconsideration of a whole battery recycling market in Europe are, primarily, a global increase in the electric cars demand, the rising environmental concerns, and more stringent governmental regulations regarding the EoL (end-of-life) batteries. What is more, there are also some issues connected with **a** limited nature of raw material e.g. **Cobalt**, which is regarded to be one of the most widely used materials in lithium-ion batteries manufacturing. Consequently, **EU market Batteries Directive 2006/66/EC** has been put under revision to have the missing EoL batteries regulations incorporated.

New materials recovery targets are to be set (e.g. for Cobalt and Lithium) "second life" batteries handling is to be thoroughly addressed, and new battery chemistries and existing harmful substances are to be covered by the updated directive. Nevertheless, there are some other issues present, which impede smooth recycling activities from being implemented. For instance, lack of batteries standardization, diminishing quality of raw materials after recycling, absence of harmonization between recycling-related directive and other industrial directives, EV owners' inadequate analysis of batteries' SoH (State of Health), lack of solid legal and financial support from authorities, etc.

3.7.2 Stakeholders[25]

Talking about stakeholders involved in battery recycling activities, they are covering the whole battery value chain due to the importance of a battery economy's sustainability, which is

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[25] See ALBATTS deliverable 4.1 p. 182-186 and for deliverable 5.1 p. 200 - 203

possible to be achieved only with all current actors' engagement. Advantages in the recycling can only be taken in case different stakeholders are ready to share responsibilities and build brand-new business models to tackle the challenges of the battery recycling market (e.g. battery recycling capacity). One of the key benefits to be highlighted is an opportunity to lower the initial price of batteries if metals and rare minerals are properly recovered. For example, **operations of automakers and battery manufacturers are crucial to be aligned with circular economy principles**. That might be achieved through strategic partnerships and geographical shifts in favor of resource-abundant locations (e.g. BMW, Northvolt, and Umicore cases: BMW has signed a strategic partnership with Northvolt and Umicore to dismantle battery packs down to their cells and recycle them for new cells that are manufactured by Northvolt). Furthermore, telecom and energy utilities have their responsibilities for recycling as well as Engineering, Procurement, and Construction (EPC) companies and energy storage integrators do. The battery recycling capacity enhancement will induce new sectoral players, who will potentially provide recycled material to battery manufacturers and enhance the current technology and treatment processes. Last but not least stakeholders to be considered are citizens and battery end-users. They will initiate a shift towards electric vehicles and need to possess some expertise on Li-ion batteries in different phases of their lifecycle.

3.7.3 Recycling Processes and Technologies[26]

When it comes to a leading battery recycling technology, there are both state-of-the-art and future options present in the market, though supporting research is required to elaborate on the best opportunities. The European Union is currently lacking some regulations framework, which can guide e.g. dismantling specifications, residual capacity testing, etc. The major division of recycling technology types present on the market might be stated as follows: Direct and Indirect methods, where Direct recycling is supposed to be a more cost-effective and energy conservative method. Whether a cathode material is breaking or not defines the approach method, and several reclamation techniques in a combination with each other follow direct or indirect methods. Direct recycling is performed via the removal of anode and cathode material from the electrode, which is made with minimal changes to the crystal cathode morphology and guarantees a higher value generation. The Indirect method uses

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[26] See ALBATTS deliverable 4.1 p. 191-204 and for deliverable 5.1 p. 208-220

Pyrometallurgical and Hydrometallurgical techniques to recycle Co, Ni, Mn, and then achieve Li precipitation. The final lithium product is achieved by using the hydrometallurgical recycling method.

The major reclamation approaches are **Pyrometallurgical recovery, Hydrometallurgical metals reclamation, and Biological metals reclamation**. [27] The former approach is widely used for Nickel and Cobalt recovery and involves a range of physical separation processes, which bring out the end product called "black mass". Graphite and metal oxide removal is accomplished with a binder decomposition, whereas the production of toxic gases leaves a negative environmental footprint, which makes the method of Pyrometallurgical recovery rather complicated and less innovative. Hydrometallurgical treatments involve the use of aqueous solutions to leach away the desired metals from cathode material, followed by different precipitation reactions to recover metals, though the likelihood of cross-contamination of materials is rather high. Bioleaching is potentially complementary to both hydrometallurgical and pyrometallurgical processes; it uses microorganisms to selectively digest metal oxides from the cathode and is highly useful for difficultly separable metals. Also, recycling technique variations might be dependent on metals reclamation in question (e.g. Al, Cu, Co, Ni, etc.).

Moving on to the established recycling technologies overviewing, there are 4 major technologies currently integrated into the battery recycling market: Retriev technologies, Recupyl Valibat, Akkuser, and Umicore Valéas. The former process consists of shredding the LiBs, slurry processing, screening separation, which recover Cu-Co rich overflow, C, Li, and metallic oxides. The Recupyl process shows a clear advantage of using mechanical processing coupled with hydrometallurgical operations, consequently, Recupyl operational principles are more in line with the idea of the circular economy. Umicore Valéas process recovers Co and Ni, primarily from LIBs and Ni-MH batteries, and involves a combination of pyro- and hydrometallurgical steps. As a result, it presents the largest recovery capacity among the other methods. High levels of recycling efficiency and low energy consumption put the Akkuser process in a privileged position, compared to others. Though, the nature of this process is solely based on mechanical processing steps and requires a third-party intervention to obtain a "black mass".

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[27] See ALBATTS deliverable 4.1 p. 191-204 and for deliverable 5.1 p. 208-220

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Even though there is a great number of technological improvements in modern battery recycling processes, at the same time there are many **challenges** to overcome in the future, including further research for greener separation and higher efficiency in **recovering graphite** and **battery metal** oxides components. These challenges present concerns regarding low volumes of electric vehicle and storage used batteries, uncertainty in European recycling legislation, and standardization. Special attention should be drawn to considering the economic aspects of recycling and making a shift to a higher degree of automation. In other words, high capital might be required to perform metals reclamation (e.g. pyrometallurgical technology), whereas recycling alone cannot compensate by itself the shortage of minerals. As a consequence, to make **recycling more economically viable**, it should be perceived from a more holistic perspective, where a whole battery lifecycle is interconnected and well-designed; for example, it might be achieved through enabling collaboration between car manufacturers and recycling companies. Consequently, a battery lifecycle loop will be closed, as recovered materials might be used for further battery manufacturing or in other applicational contexts, adding value to the whole process.

3.7.4 Future Recycling Technologies[28]

The future recycling technologies are designed in a way to overcome some potential drawbacks present in the established ones. The D4.1 and D5.1 reports **cover 4 technologies** of that type: **Accurec, Battery recycling "Closed Loop" process, Laboratory process by Aalto University, and Fortum solution.** Accurec process presents a combination of mechanical, pyrometallurgical, and hydrometallurgical processes, aimed at recovering a Li2CO3 (90% recovery) cathode precursor and a Co-Ni–Mn alloy, though it does not allow an electrolyte to be recovered. The "Closed Loop" process recovers battery components suitable for further LIB production and is majorly based on mechanical and hydrometallurgical operations, but it involves the consumption of various chemical reagents. Aalto University process recovers 99% of the LIB materials and encompasses a mixture of mechanical pre-processing stages, pyrometallurgical, and hydrometallurgical treatments. Even though the aforementioned process provides a high recovery degree (99% of Al, 93% of Li, 89% of Co, 97% of Ni, 98%, etc.), a large number of reagents and extensive energy consumption is required, whereas some

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[28] See ALBATTS deliverable 4.1 p. 205-209 and for deliverable 5.1 p. 208-224

further elements processing is needed. The Fortum's technology is based on hydrometallurgical metals reclamation and provides an 80% recyclability of li-ion batteries (e.g. Co, Mn, Ni), which are applicable for producing new batteries.

3.7.5 Gaps in Battery Recycling

How **legislation standards** and their **harmonization** will soon be studied further. Additionally, regarding **legislation** overseas (**Asia** and the **USA**), is there something that we in **Europe** can **benchmark**?

Regarding recycling, we should gain a deeper understanding of how the **cooperation** between different **entities** involved in the battery **recycling processes** function; for example, between the automotive industry and recyclers of batteries, and with further analysis, we should identify areas of **improvement** and the implications on **needed skills and competences**.

Practices overseas should be studied: are there best practices overseas (Asia and USA) that could be applied in Europe to improve recycling-related mechanisms and avoid repeating downfalls?

There are several different recycling technologies already in use or being developed for near-future application. Which of these hold the best future potential in terms of recycling efficiency as well as financial viability?

4 Challenges

This section describes challenges based on the gap analysis done in each researched value chain step or topic of sectoral intelligence.

Each found gap is mapped to the corresponding topic of sectoral intelligence. This set of challenges will enable the partnership to better plan the next steps and ultimately come up with the sectoral intelligence roadmap and key actions for the whole battery sector.

Battery Sector

Balance between Mobile and Stationary Battery Applications

Importance of battery sub-sectors going hand in hand, benefiting from each other when it comes to technologies, stakeholders, job roles, skills, competence, education and identification of sector attractiveness as well drivers of change throughout the whole battery value chain.

Attractiveness

Attractiveness of the Battery Sector

Importance of the attractiveness of the battery sector, its connection to the drivers of change and newcomers to the battery sector seeking for an employment or new opportunities when it comes to re-skilling and up-skilling.

Job Roles, Skills and Competence

Categorisation of Job Roles, Skills and Competence

Importance of definition and categorization of important skills and competences that are needed to accommodate new and emerging job roles in the battery sector as well as further definition of education plans.

- Prioritization/identification of certain job roles and skills key for the future battery value chain in the EU
- Soft, Transversal and Sector Specific Skills

Intelligence

Reliable State-of-the-Art Information

Importance of workforce, companies and other entities that are active in the battery sector having access to relevant and up to date state-of-the-art information about the battery sector.

Technologies

Future Technologies and Processes

Importance of future technologies, processes and methodologies bridging the battery value chain and the many aspects for further attention and research:

- Prioritisation of Research and Development
- New battery chemistries and types
    - Solid-state, LiS, Lithium-metal and more
    - Hydrogen based and fuel cells
- Raw Materials and its Processing
- Production and Manufacturing Technologies
- IoT
- Relation to the Industry 4.0

Second Life of Batteries and Recycling

End of Life of Batteries

Importance of research on second life of batteries. This covers their usage in other applications and their recycling process.

- Harmonisation of legislation and standards
- Adoption of the circularity concept in Battery Recycling, Repair and Maintenance including innovative research and development

Battery Applications

New Mobile Battery Applications

To pursuit new possibilities and demand for mobile battery applications such as airplanes, vessels, e-bikes or other urban mobility platforms.

Battery Applications

New Stationary and Other Industrial Applications

Need to exploit new possibilities for implementing stationary and other industrial applications such as off-grid stationary applications in remote areas and other applications related to the IoT, 5G and more, alongside with related skills and competence, job roles of the maintenance teams and their up-skilling and re-skilling. Risk mitigation and proper legislation and standards should be taken into consideration.

Battery Sector

Transition of the Related Sectors

Importance of the transition into batteries and its influence on other sectors. Clear vision of a Roadmap on how to achieve full decarbonisation and usage of green energy and how to compensate in terms of expenses, unemployment, turnover, etc.

Stakeholders

Cooperation

Importance of cooperation between various EU initiatives, projects, universities, VET providers, companies and other entities active in battery sector. Strengthening interaction and exchange enables better R&D development as well as education.

5 Conclusions

This report summarises the desk research done on the state-of-the-art of stationary and other industrial and mobile applications of batteries, based on the detailed work done by correspondent work packages (WP4 and WP5).

The highlights of the different research areas are explained, covering topics of sectoral intelligence which were defined as key areas of interest such as drivers of change, sector attractiveness, job roles, skills and competence, education and technologies, mapped against the battery value chain.

Important to notice yet many stands of development and action in this emerging battery sector, globally and specifically in Europe. Aspects related to constantly evolving research and technology, battery production cycle and cost reduction, adoption by wide sectoral applications, battery lifecycle and legislation, circularity with recycling, and second use, require and ever increased and dedicated focus. Moreover, user acceptance, market trust, and democratization of batteries as an energy storage system for a sustainable green future, call for much further action. Skills, knowledge, and preparedness within the battery technology specificities and transversality with needs of other sectors, will need attention.

This report gives an overall view on the extensive research done, providing an additional gap analysis for the researched areas with the evaluation of the challenges that need to be taken into consideration when defining a roadmap for the battery sector in the future. This is the first iteration of one of the major goals of the ALBATTS project.