albatts

Alliance for Batteries Technology, Training and Skills

2019-2023

Intelligence in Stationary and Industrial Battery Applications

Desk Research Report

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Deliverable D4.1 Desk Research & Data Analysis ISIBA1

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INTRODUCTION

The first iteration of the report covers stationary battery use in energy storage systems in grid and off-grid applications, in telecom base stations and discusses the use of energy storages in other heavy-duty applications. The energy storage usage is increasing globally due to a number of drivers related to the above-mentioned areas. The increasing use of variable renewable energy sources to support grid and off-grid systems combined with the advances in telecommunication, moving to 5G cellular technology and consequent ongoing global deployment of 5G telecom base stations with integrated energy storage systems all add to the widening demand for energy storage systems. In terms of technology, in this report we mainly discuss about Lithium-ion batteries, the state-of-the-art battery technology at the moment. The primary purpose of the ALBATTS project being the identification of skills and competence, the findings we have done so far are discussed in this report.

In the following versions we aim to extend the coverage to include more applications of energy storages with paying attention to the rapidly developing battery technologies and consequent implications on the skills and competences required by the battery related industries, markets and areas where batteries will be used.

This report has limitations, when it comes to the content, and scope due to being the first study in the area of intelligence in stationary and industrial battery applications. The authors of this report are aware of these limitations. While a lot of information for certain topics can easily be found from various offline and online sources, certain information, possibly due to some being trade secrets, is more challenging to be found. Consequently, this report is a combination of detailed technical information and more general overviews.

This report will be fulfilled with workshops and surveys to support the identification of skills and competences needed in the future. Additionally, it will be followed by similar reports that will widen the scope of the studied areas and follow developments in the already studied areas.

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LIST OF ABBREVIATIONS

2G	...	Second Generation (mobile phone or mobile network)
3G	...	Third Generation (mobile phone or mobile network)
4G	...	Fourth generation (mobile phone or mobile network)
5G	...	Fifth Generation (mobile phone or mobile network)
AC	...	Alternating current
ACEA	...	European Automobile Manufacturers' Association
Ah/kg	...	Ampere-hour per kilogram
ALBATTS	...	Alliance for Batteries Technology, Training and Skills
Ar	...	Argon is a noble gas
B2G	...	Battery to Grid
BESS	...	Battery Energy Storage System
BEV	...	Battery electric vehicle
BMS	...	Battery management system
BRIDGE	...	European Commission initiative which unites Horizon 2020 Smart Grid, Energy Storage, Islands, and Digitalisation Projects to create a structured view of cross-cutting issues which are encountered in the demonstration projects and may constitute an obstacle to innovation.
BTM	...	behind-the-meter
C&I	...	commercial and industrial
CAGR	...	Compound annual growth rate
CAN	...	Controller area network
CNG	...	Compressed natural gas
CO	...	Carbon monoxide
CO2	...	Carbon Dioxide
COM	...	Completely
CSR	...	Corporate Social Responsibility
DC	...	Direct current
DEG	...	Digitally Enabled Grid
E-bikes	...	Electric bikes
E-buses	...	Electric buses
ECU	...	Electronic Control Unit
EEC	...	European Economic Community

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EGD	…	European Green Deal
EIB	…	European Investment Bank
ELIBAMA	…	European Li-ion Battery Advanced Manufacturing
ELV	…	End of Life Vehicles
EMS	…	Energy management system
EOL	…	End of Life
EOS	…	Energy Operating System
EPC	…	Engineering, Procurement and Construction
EPC	…	Engineering, Procurement and Construction
EPR	…	Extended Producer Responsibility
EPR	…	Extended Producers Responsibility
EQF	…	European Qualifications Framework
ESCO	…	European Skills/Competences, Qualifications and Occupations
E-scooters	…	Electric scooters
ESOI	…	European Society of Oncologic Imaging
ESS	…	Energy storage system
EU	…	The European Union
FCEV	…	Fuel cell electric vehicle
FFR	…	fast frequency response
FIT	…	Feed in Tariff
FTM	…	front-of-the-meter
GDP	…	Gross Domestic Product
GES	…	Grid Energy Storage
GHG	…	Greenhouse gas
GPS	…	Global positioning system
GST	…	Grid Storage Technologies
H2	…	H2, the chemical formula for hydrogen gas
HEV	…	Hybrid electric vehicle
HOV	…	High-occupancy vehicle lane
ICE	…	Internal combustion engine
ICT	…	Information and Communication Technologies
IMBA	…	Intelligence in Mobile Battery Applications
IoT	…	Internet of Things

ISCO	…	International Standard Classification of Occupations
ISIBA	…	Intelligence in Stationary and other Industrial Battery Applications
ISIC	…	International Standard Industrial Classification
JRC	…	Joint Research Center
kW	…	Kilowatt
KVAR	…	Kilo Volt Amperes Reactive
kWh	…	Kilowatt-hour
kWh	…	Kilowatt-hour per 100 kilometres
LCO	…	Lithium cobalt oxide
LFP	…	Lithium iron phosphate
LIB	…	Lithium-ion battery
$LiCoO_2$	…	Lithium Cobalt Oxide
LiFePO4	…	Lithium iron phosphate (LFP) is an inorganic compound with the formula LiFePO4
LiPF6	…	Lithium hexafluorophosphate is an inorganic compound with the formula LiPF6. It is a white crystalline powder.
LMO	…	Lithium ion manganese oxide
LTE	…	Long Term Evolution (standard for wireless data transmission - sometimes referred to as 4G LTE)
LTO	…	Lithium titanite oxide
MeO	…	Metal Oxid
MSDS	…	Material Safety Data Sheet
NACE	…	Nomenclature of Economic Activities
NCA	…	Lithium Nickel Cobalt Aluminium Oxide
NiMH	…	Nickel–metal hydride
NiMH	…	Nickel metal hydride battery is a rechargeable battery.
NMC	…	Lithium nickel manganese cobalt oxides
NMHC	…	Non-methane volatile organic compound
NMP	…	N-methyl-2-pyrrolidone
NOx	…	Nitrogen oxide
O&M	…	Operations and Maintenance
OEM	…	Original equipment manufacturer
PCR	…	primary control reserve
PCS	…	Power Conversion System

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PHEV	…	Plug-in hybrid electric vehicle
PM	…	Particulate matter
PV	…	photovoltaic
R&D	…	Research and Development
RES	…	Renewable Energy Sources
SEI	…	Solid-Electrolyte Interphase
SMEs	…	Small and medium-sized enterprises
SoC	…	State of Charge
SRM	…	Secondary Raw Materials
THC	…	Hydrocarbons
TOU	…	time-of-use
UPS	…	Uninterruptible Power Supply or Uninterruptible Power Source
USD	…	United States Dollar
V2G	…	Vehicle to Grid
Wh/kg	…	Watt-hour per kilogram

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1 Methodology

This section of the report describes role of the desk research in the ALBATTS project context, how it was executed and which methods and tools were used in order to gather all the necessary information about the sub-sectoral Intelligence in Stationary and Industrial Applications (ISIBA). After the methodology methods are declared it is important to define the goals of the report, these must be aligned with the defined scope, topics of the sub sectoral intelligence and overall approach to the execution of the desk research. Project **Deliverable 3.1 Methodology Methods for Sectoral Intelligence** is solely focused on the methodology

1.1 PREVIEW OF THE METHODOLOGY

This sub section describes the relation of the ISIBA to the overall battery sector and the defined scope and how the data about sub-sectoral intelligence are going to be gathered.

1.1.1 Work Package Structure and Relation

As defined in project application and **D3.1**, the overall battery sector was divided into 3 work packages in ALBATTS project as seen in Figure 1**.**

Work packages:

- **WP3 – Sectoral Intelligence**
  - Definition of methodology and overall approach.
  - Provision of summarisation for overall sector and comparison between application in sub-sectors.
- **WP4 – Intelligence in Stationary and other Industrial Battery Applications (ISIBA)**
  - Follows the same structure of work and methodology.
  - Provision of detailed insights and summarisation of ISIBA.
- **WP5 – Intelligence in Mobile Battery Applications (IMBA)**
  - Follows the same structure of work and methodology.
  - Provision of detailed insights and summarisation of IMBA.

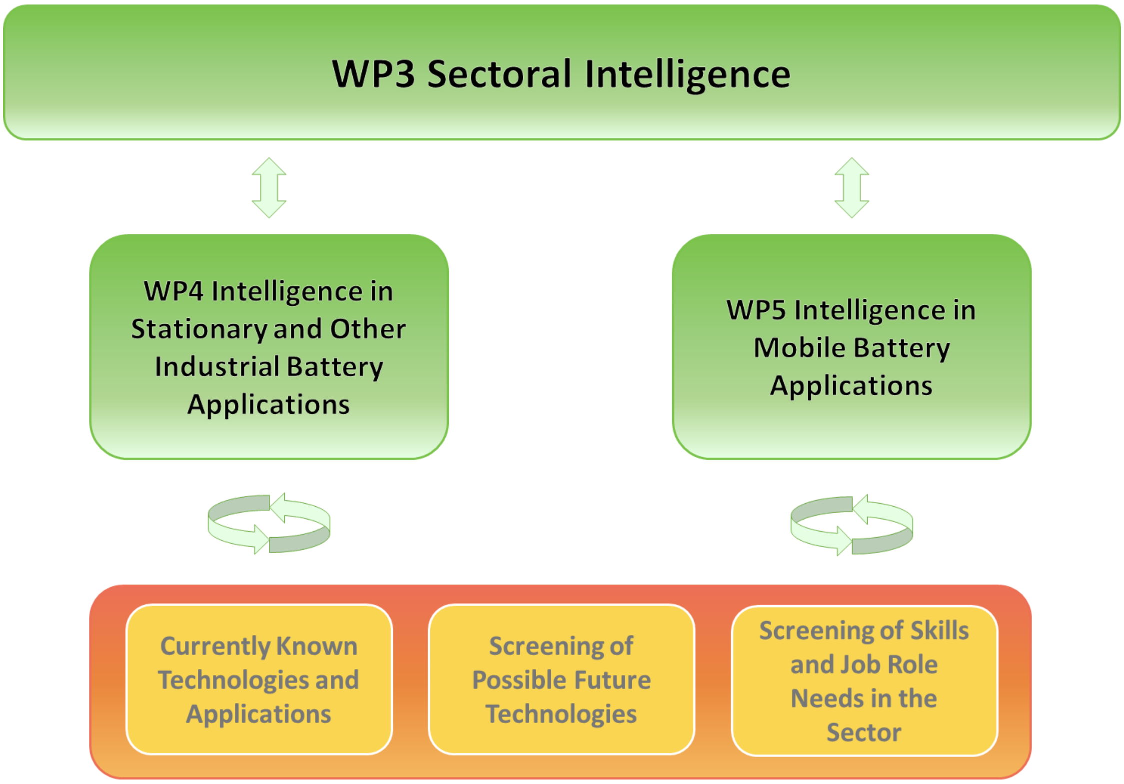

Figure 1. Depiction of WP3 and WP4-5 Relation

1.2 SCOPE

As mentioned above, whole sectoral intelligence will be composed from the findings of the WP4 and WP5. Therefore, the scope of the desk research needs to be defined for both sub-sectors.

1.2.1 Geographical Scope

The geographical scope of the sub-sector is focused on **Europe, especially in the EU** and the **EAA countries**. However, inputs to the project are not restricted by this geographical scope.

1.2.2 Educational Scope

Educational scope of the sub-sector was declared to be from EQF level 4 to 8. It also covers the reskilling and lifelong education for the workforce throughout the whole battery life cycle.

1.2.3 ISIBA Scope

The scope of the ISIBA:

- 1st iteration of the desk research report is mainly focused on Li-ion traction battery topics relevant to:
  - Energy Storage – grid and off-grid applications
  - Telecommunications – base stations
  - Heavy duty applications

1.2.4 Overlaps

Overlaps occurred between ISIBA and IMBA when executing the research since some of the battery **early and late value chain stages** are very similar for both stationary and mobile applications. That is why the following chapters were prepared in **close cooperation** between WP4 and WP5:

- Raw Materials and Processing
- Components and Cell Manufacturing
- Module and Pack Manufacturing
- Battery integration
- Second Use of Batteries
- Recycling
- Education

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1.3 DEFINED BATTERY VALUE CHAIN

The whole sectoral intelligence as well as each sub-sector follows the battery value chain structure which was defined in **D3.1**. This sub-section will briefly touch on the battery value chain steps with more detailed description to be found in **Chapter 3**. These steps of battery value chain, Figure 2, are important when it comes to categorisation of the information which is going to be researched throughout the project. Of course, there is always possibility of making changes to the battery value chain in the later stages of the ALBATTS project.

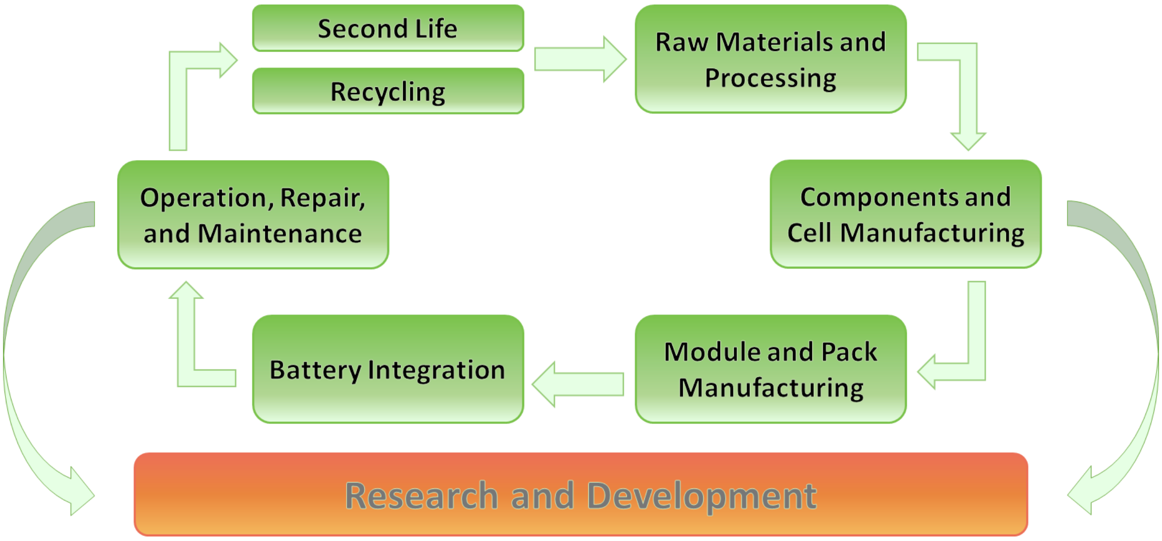

Figure 2. Battery Value Chain

Defined battery value chain:

- **Raw materials and processing**
  - Primary material sourcing with emphasis on rare earths and scarce metals. In the future, also integration of the recycled materials coming from end-of-life batteries into the production stream
- **Components and cell manufacturing**
  - Battery components, cell manufacturing methods
- **Module and pack manufacturing**
  - Creation of larger systems from battery cells and modules
- **Battery integration**
  - Integration of assembled battery modules together with Battery Management System into the specific energy storage use cases.

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- **Operation, repair, and maintenance**
  - Topics related to energy storages in various applications, operation, repair, and maintenance topics including safety issues.
- **Second life**
  - "Life after life" of the batteries used e. g. as an energy storage.
- **Recycling**
  - Re-use of the scarce materials taken from used batteries, in line with "circular economy" principles. Important to ensure compliance with current and upcoming legislation and to avoid harming the environment.

1.4 TOPICS OF SECTORAL INTELLIGENCE

Topics of sectoral intelligence which are going to be mapped within the battery value chain steps need to be defined to ensure systematic work and comparability of the results of both sub-sectors. This structure will also ensure adaptation of the field research and mapping its results to the same structure. This report covers adapted structure of topics of sectoral intelligence based on the **D3.1** as seen below.

Topics of the sectoral intelligence:

- Drivers of change
- Major stakeholders
- Technologies
- Sector Attractiveness
- Job roles and skills needs
- Existing training and education
- Training methods

1.4.1 Sectoral Intelligence Topics Association with the Battery Value Chain

The sectoral intelligence topics listed above are associated with the battery value chain in two different manners. Some topics have different associations with the battery value chain than others. This can be separated into two different categories:

- **Individual battery value chain step related topics** Figure 3
    - Major stakeholders
    - Technologies
    - Job roles and skills needs
    - Drivers of change

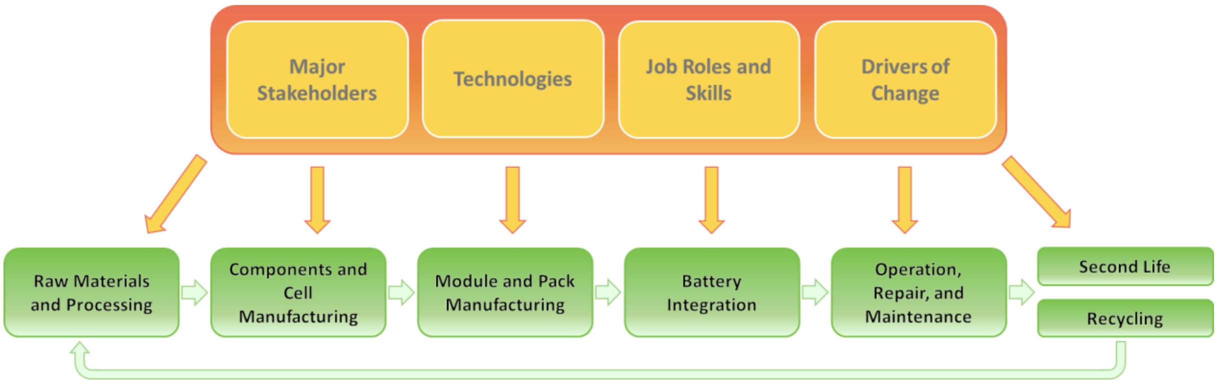

Figure 3. Individual Battery Chain Step Related Topics

- **Overall** battery value chain related topics Figure 4
    - Sector attractiveness
    - In some cases, this can be also mapped to the individual steps
    - Existing trainings, qualification, and education
    - Training methods and approaches

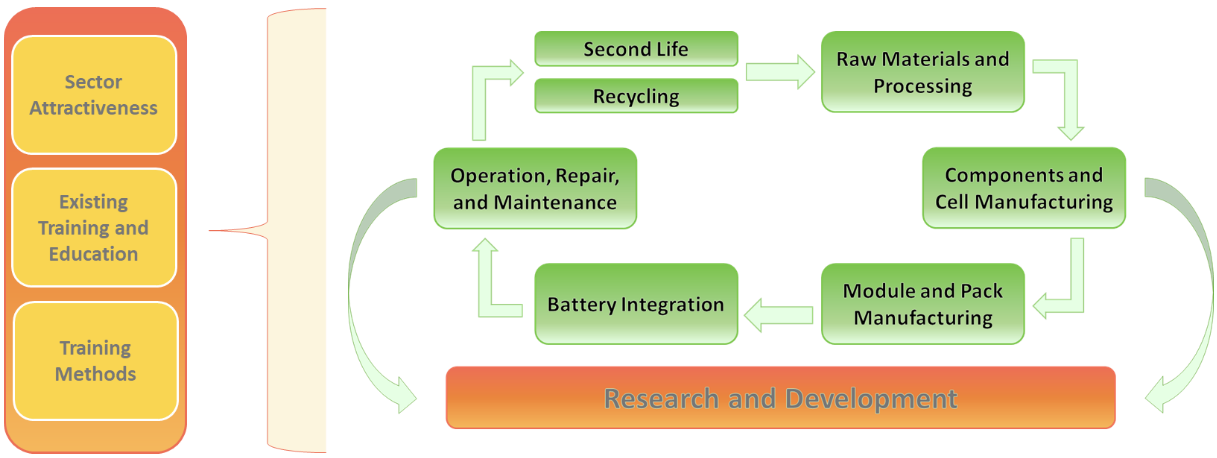

Figure 4. Overall Battery Chain Related Topics

1.5 DESK RESEARCH EXCEL FILE

An Excel file was created based on desk research methodology to classify and map information into the declared structure of the corresponding topics. This will allow the statistical analysis of the data, which will help with the choice of which data will be inputted into the final reports. This structured Excel file also allows data to be searched, sorted, and worked with collaboratively via the online NextCloud application, which is used to store and share materials between the project partners.

1.5.1 Desk Research File Structure

As mentioned previously, this Excel file is structured into worksheets based on the declared topics of sectoral intelligence. Each topic is represented by a separate worksheet with a unique structure.

1.5.2 Virtual Library

The desk research Excel file also includes Virtual Library, which is essentially one of the worksheets of the Excel file used to collect all the sources and material that might be used for analysis.

1.5.3 Competence List

A competence list was shared between the partners to classify their skills and competence. Based on their expertise and preference, they were assigned to the corresponding topics of the sectoral intelligence for further analysis. This allowed a very flexible division of work between the partners.

1.5.4 Desk Research Strategy

Strategy of execution of the desk research activity was defined to deliver good quality sectoral intelligence.

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Desk research process:

- Assessment of partners´ skills
- Population of the Virtual Library
- Declaration of index of the final report
- Division of the sections between the partners based on the assessed skills
- Research activity based on the defined methodology
  - Mapping selected information to the Desk Research Excel file
  - Writing the report
- Continuous report revision and finalisation
- Report delivery

1.6 GOALS

To have a clear vision and understanding where the project is heading, as well as the various reports, we need to define understandable goals to guide the work of the project partners.

1.6.1 Basis for Gap Analysis

As defined in **D3.1**, desk research is the opposite of field research. This does not mean that there will not be any interaction between those two. Field research is a key part of the research since it will enable us to close the gaps which will be encountered in the desk research. One of the goals of the desk research is to map the current state of the art of the sub-sector which will be then used for the gap analysis. This will further lead to declaration and creation of the online survey and workshop events which are going to close as many gaps as possible.

1.6.2 Understanding the State-of-the-Art

As mentioned previously, this first iteration of several desk research reports should serve as an overview of the state-of-the-art of the sub-sector. This will help partners and the public to understand the current situation and help us to establish next steps in the project and for the next iteration.

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2 Overview of the subsector

2.1 DRIVERS OF CHANGE

2.1.1 Methodology

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 current Drivers of Change and their relevance in the sector.

The process started from an internal project partners' analysis where 4 macro areas have been identified to concentrate the possible changing within: (i) the rise of new technologies, (ii) climate goals, (iii) societal and structural changes and (iv) globalisation and the rise of new players.

The literature review enabled the mapping of each initial macro area of the Drivers of Change against wider research evidence and following the desk-research process, the initial categories with several more specific Drivers of Change identified as relevant to be validated were:

- **New technologies and business models**
  - Cybersecurity
  - Global technical harmonisation, standardisation and Plug & Play
  - Smart Grid (B2X)
- **Climate goals, environmental and health challenges**
  - Circular value chain of the manufacturing process
  - Electrification and green energy
  - Improved charging/refuelling infrastructure
- **Structural changes**
  - Acquisition of new skills / Continuous training
  - Restructuring
- **Globalisation**
  - Access to raw materials
  - Global regulatory dialogue

During the desk-research process the 4 macro areas with the initial 10 Drivers of Change have been evaluated and compared with the analysed literature; this resulted in **3 main areas**:

(i) Climate goals, regulation and environmental challenges, (ii) Globalisation and (iii) New technologies with a total of 9 specific Drivers of Change (see next chapter for details).

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

- **Occurrence**: indicating whether a Driver of Change was cited in analysed reports reviewed (if a specific Driver of Change is cited multiple times in the same report, the occurrence is, in any case, 1; if in a report different Drivers of Change are cited, all of them are counted and the occurrence per each of them is 1).
- **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).
- **Urgency**: a specific time frame (year), which can be noticed from the text of the analysed document, in which the Driver of Change will become particularly necessary or will make its consequence felt overwhelmingly.

2.1.2 Introduction to the Drivers of Change

In the European Green Deal[1] (EGD), the European Commission stated that a 90% reduction in transport emissions is needed by 2050 (compared to 1990) and that road transport needs to move to zero emissions beyond 2025. In order to reach this objective, Europe will have to significantly increase the uptake of zero emission technologies with a strong emphasis on battery electric vehicles. Gradually, these will be accompanied by hydrogen powered vehicles.[2] According to the EGD, the power sector will be based much more on renewable sources of energy. Batteries can help with integrating renewables into the electricity grid. Development in other technological areas, such as 5G (5G base stations have higher energy consumption and require higher density than earlier generations[3]) also brings big

[1] European Green Deal, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en, 2019
[2] https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf
[3] https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/china-8217-s-5g-construction-turns-to-lithium-ion-batteries-for-energy-storage-58474880

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opportunities for (Li-ion) batteries. This will require large amounts of batteries on the European market. According to the 3 GHG scopes emissions[4;5]:

1. batteries could enable 30% of the required reductions in carbon emissions in the transport and power sectors, provide access to electricity to 600 million people who currently have no access, and create 10 million safe and sustainable jobs around the world.
2. a circular, responsible, and just battery value chain is one of the major near-term drivers to realize the 2°C Paris Agreement goal in the transport and power sectors, setting course.
3. batteries directly avoid 0.4 Gt CO_2 emissions in transport and contribute to enabling renewables as a reliable source of energy to displace carbon-based energy production, which will avoid 2.2 GtCO_2 emissions – together roughly 30% of required emission reductions in these sectors until 2030.

Based on a World Economic Forum report, the battery value chain will halve its GHG intensity by 2030 at a net economic gain, reducing 0.1 Gt emissions within the battery value chain itself and putting it on track to achieving net-zero emissions in 2050[6].

Within this context, the European Commission prioritises zero emission technologies also in the recently published EU Industrial Strategy and the Circular Economy Action Plan[7] to support the domestic production of sustainable batteries.

According to Bloomberg Electric Vehicle Outlook, EVs and fuel cell vehicles will reduce road CO_2 emissions by 2.57Gt a year by 2040 - and are set for much larger reductions thereafter. Lithium-ion battery pack prices fell 87% from 2010 to 2019, with the volume-weighted average hitting $156/kWh. Underlying material prices will play a larger role in the future, but the introduction of new chemistries, new manufacturing techniques and simplified pack designs will keep prices falling[8].

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[4] Greenhouse gas protocol, https://ghgprotocol.org/, 2020 and „Word Economic Forum" Report http://www3.weforum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf, 2019

[5] https://www.carbontrust.com/resources/briefing-what-are-scope-3-emissions

[6] A Vision for a Sustainable Battery Value Chain in 2030, Global Battery Alliance, WEF, 2019; accessed from: http://www3.weforum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf

[7] https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf, 2020

[8] Electric Vehicle Outlook 2020, Bloomberg, 2020 (https://about.bnef.com/electric-vehicle-outlook/) and EUROBAT „Battery Innovation Roadmap 2030", https://www.eurobat.org/news-publications/press-

In preparation for the upcoming EU Battery Strategy, the Commission is planning to revise still by the end of 2020 the Directive (2006/66/EC) on Batteries to prioritise a circular economy approach when it comes to addressing the recycling of batteries. This includes ensuring the security of supply of raw materials, the reuse (where adequate) and recycling of batteries, as well as the high environmental and social values in the manufacturing process as ways to promote a sustainable EU battery industry. Moreover, it will be extremely important to take note of the emerging new jobs related to the dismantling and recycling sector overall, as well as the processing and the reincorporation of used active materials within new batteries (i.e. when repurposing is economically proven to be better than recycling). The Commission is currently also evaluating the End of Life Vehicles Directive. As a follow up to this evaluation one can assume that a revision of the ELV Directive is likely to have an impact also on the batteries used for vehicles as it sets obligatory targets for reuse and recycling. This should, according to the Commission, be the path to build a sustainable battery industry in Europe.

The sourcing of certain raw materials such as cobalt and lithium that are crucial to the battery value chain is impaired by human rights abuses, environmental legislation infringement and business ethics violation. With a demand that is deemed to soar seven-fold by 2024 and in the absence of early and stringent countermeasures, the issues stated above need to be taken into consideration[9]. Moreover, the battery recycling process could lead to new economy and jobs in EU: it is important to distinguish the recycling of the whole battery pack and its critical components. Dismantling and recycling can be two separate business models where the dismantling might be handled at local level, creating new businesses opportunities, while it would be better if the active materials were shipped for recycling by high-tech industries.

The automotive sector is a major European employer[10] and the conversion to EVs production will have a strong impact on the workforce in the battery sector. The European Battery Alliance has paved the way for building a sustainable battery industry that could create up to 4 million

releases/442-eurobat-launches-the-battery-innovation-roadmap-2030-in-the-presence-of-european-commission-evp-frans-timmermans-and-mep-claudia-gamon

[9] https://www.greencarcongress.com/2020/07/20200704-un.html?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+greencarcongress%2FTrBK+%28Green+Car+Congress%29

[10] According to ACEA, 2.7 million direct manufacturing jobs and 14.6 million indirect jobs are provided by the EU automotive sector; https://www.acea.be/statistics/article/direct-automotive-manufacturing-jobs-in-eu-by-country, https://www.acea.be/uploads/publications/ACEA_Pocket_Guide_2020-2021.pdf

jobs in the EU[11]. While going through restructuring, European industry can benefit from an increased demand for the production, installation, operation & maintenance of charging points, public transport systems, batteries and other related infrastructure, resulting in a net increase in employment in the construction, electricity, services and most manufacturing sectors[12]. With the right enabling policies, e-mobility can also gradually replace the decreasing jobs in manufacturing of diesel and petrol engines with new jobs and new skills required in electric powertrain manufacturing and key supply chains such as batteries. Recent analysis by the Platform for Electro-mobility[13] (to update the existing job estimates in the e-mobility ecosystem) shows that an additional 1.1 million jobs will be created in Europe by 2030.

Overall, with a strong focus on e-mobility more than 200,000 net additional jobs by 2030 can be created in the European economy[14]. The demand for new skills and experience will equally result in a fall in demand for other more traditional skills. This implies a need for skills restructuring that balances out existing skills mismatches which in turn, will require significant investment in new technologies, production processes and in the reskilling and training of the workforce.

Apart from environmental concerns, also the aspect of novelty in mobility represents an important factor for the attractiveness of the sector. As social media plays an increasing role, the reason why a buyer of a car wants to have an electric vehicle may have more to do with the coolness factor, sleek looks, high performance, and innovative features in terms of user interface and experience etc. Other attractive elements might include easier operation and maintenance of EVs[15]. In a disruptive scenario[16] (the next years will bring such significant changes as electrification, shared mobility, vehicle connectivity, autonomous vehicles and the

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[11] EIT InnoEnergy assessed that the European Battery Alliance have a potential of 400GWh of battery production per year by 2025. EBA, InnoEnergy 2019 Battery Materials Europe (Amsterdam presentation) https://www.metalbulletin.com/events/presentations/E001854/battery-materials-europe-2019/a0I1t00000I5R1IEAV/day-2-0900-diego-pavia-kic-innovaenergy-fe.html

[12] EuropeOn, *Powering a new value chain in the automotive sector*, 2018 https://download.dalicloud.com/fis/download/66a8abe211271fa0ec3e2b07/c572c686-f52f-4c0d-88fc-51f9061126c5/Powering_a_new_value_chain_in_the_automotive_sector_-_the_job_potential_of_transport_electrification.pdf

[13] https://www.platformelectromobility.eu/2020/06/17/event-how-can-zero-emission-mobility-become-the-motor-of-european-green-recovery/, 2020

[14] Harrison P. 2018, Fueling Europe’s Future : How the transition from oil strengthens the economy

[15] https://newmotion.com/en/how-to-maintain-an-ev/

[16] Electric Vehicle Outlook 2020, Bloomberg, 2020 and EUROBAT „Battery Innovation Roadmap 2030“, https://www.eurobat.org/news-publications/press-releases/442-eurobat-launches-the-battery-innovation-roadmap-2030-in-the-presence-of-european-commission-evp-frans-timmermans-and-mep-claudia-gamon, 2020

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massive use of renewable energies) the changes and innovations create possible new markets and design new value chains and eventually disrupt an existing market and value network, displacing established market-leading firms, products, and alliances. It is necessary to analyse the Drivers of Change to support the market into this business transition[17].

Continuous education and training are part of lifelong learning and may encompass any kind of education (general, specialised, or vocational, formal or non-formal, etc.) and are important for the employability of individuals. During a disruptive period, continuous training becomes crucial not only as part of the regular lifelong learning process but also to align skills and competences to the new emerging needs. These activities also need to be supported by actions to improve mobility and transferability of skills, linked to the development of an efficient apprenticeship market and encouragement of informal learning. As batteries are a systemic enabler of a major shift to bring transportation and power to greenhouse gas neutrality, this transformation will have a significant impact on the industry's workforce and the acquisition of new skills will be a key factor enabling employees to be equipped to deal with these changes.

As previously mentioned, before the desk research analysis, the ALBATTS consortium identified 4 macro areas to concentrate on: (i) the rise of new technologies, (ii) climate goals, (iii) societal and structural changes and (iv) globalisation and the rise of new players. Later, during the analysis of the available literature sources, **3 macro areas** of Drivers of Change with an assessment on current availability intelligence[18] related to the Battery sector were identified and confirmed:

- Climate goals, regulation, and environmental challenges
- Globalisation
- New technologies

The following Figure 5 outlines the occurrence of the highlighted Drivers of Change (i.e. number of times they have been mentioned in the analysed reports). “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%; third one is “NEW TECHNOLOGIES” with 25,00%.

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[17] The innovator's solution : creating and sustaining successful growth, Christensen, Clayton M Raynor, Michael E, Harvard Business School Press, 2003

[18] See REFERENCE chapter

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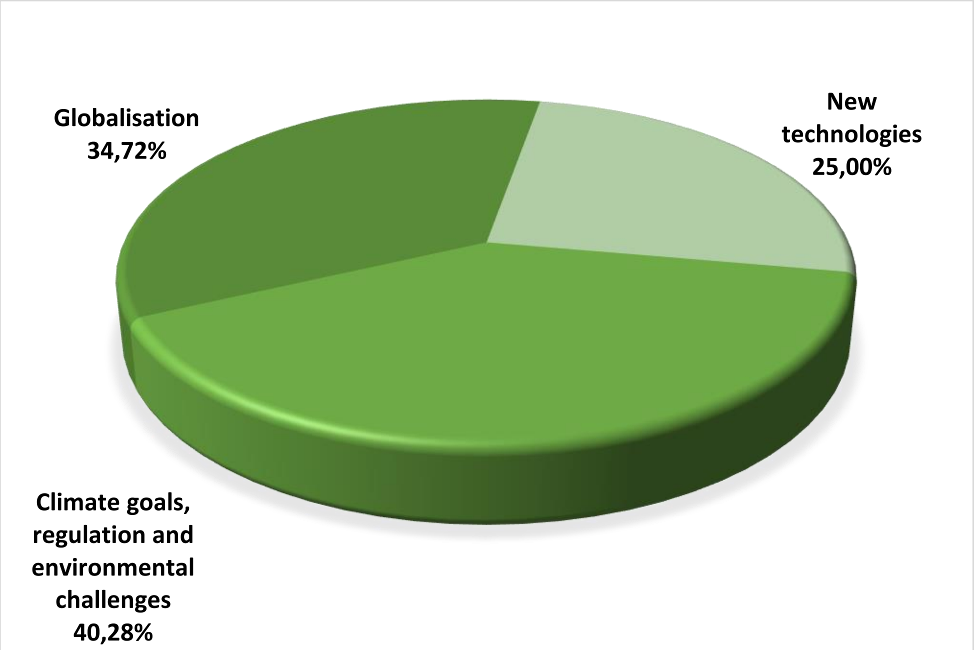

Figure 5. Occurrence- how much macro Drivers of Change are quoted related to all reports analysed

Each of the 3 macro areas then has different items for a total of 9 detailed Drivers of Change emerged and mapped:

- **Climate goals, regulation, and environmental challenges**
  - Reducing CO_2 emissions from battery manufacturing
  - Electrification and green energy
  - Widespread charging/refuelling infrastructure
- **Globalisation**
  - Access to raw materials
  - Global regulatory dialogue
  - Restructuring
- **New technologies**
  - Cybersecurity
  - Global technical harmonisation and standardisations
  - Smart Grid

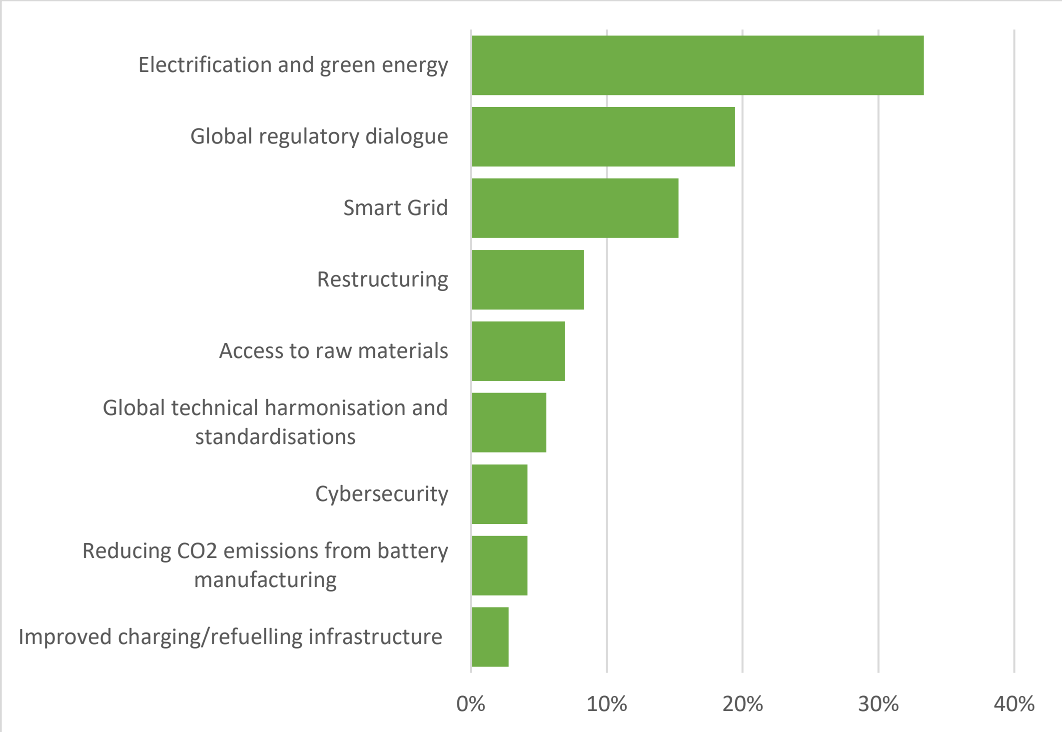

Figure 6. Occurrence - how much each Driver of Change is quoted related to all reports analysed

Figure 6 outlines the ranking of all 9 detailed Drivers of Change based on the occurrence point of view. „ELECTRIFICATION AND GREEN ENERGY" is the most cited Driver of Change, with 33%, followed by „GLOBAL REGULATORY DIALOGUE" WITH 19% and „SMART GRID" with 15%. These 3 Drivers of Change represent over 67% of the total.

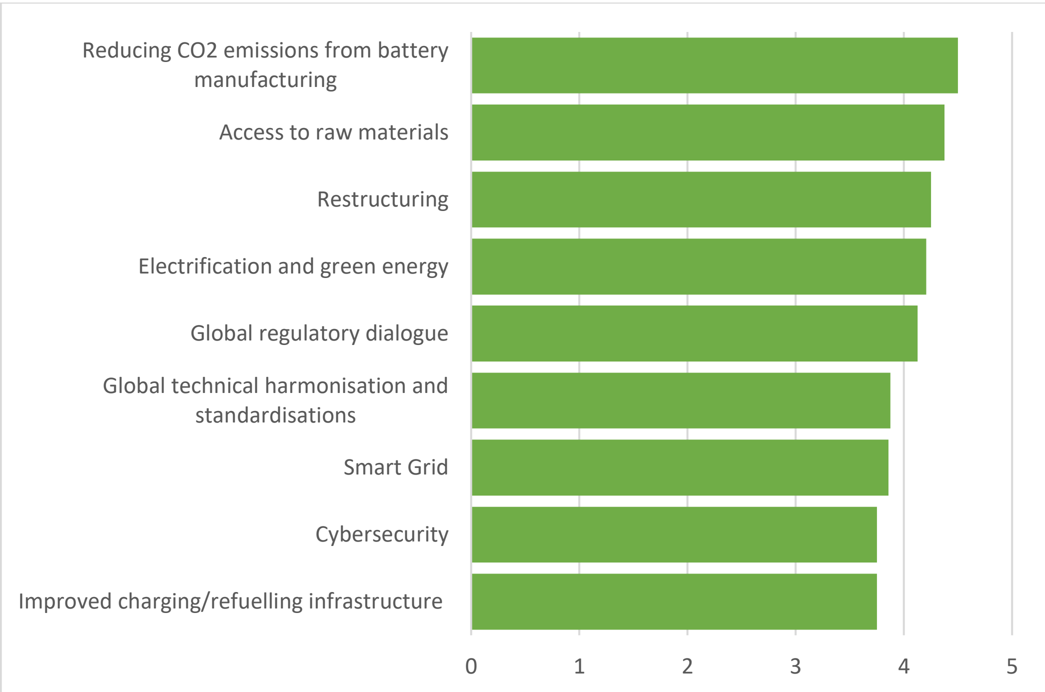

Figure 7. Importance - how much each Driver of Change is evaluated important related to all reports analysed

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The importance of point of view of the 9 detailed Drivers of Change is highlighted in Figure 7. All of them are similar and the difference between the first („REDUCING CO2 EMISSIONS FROM BATTERY MANUFACTURING“ at 4,50) and the last („IMPROVED CHARGING/REFUELLING INFRASTRUCTURE“ and „CYBERSECURITY“ at 3,75) on a scale 0-5 is only 0,75. Therefore, this aspect could be a suitable topic to be evaluated in direct interaction with stakeholders through a workshop and/or a survey.

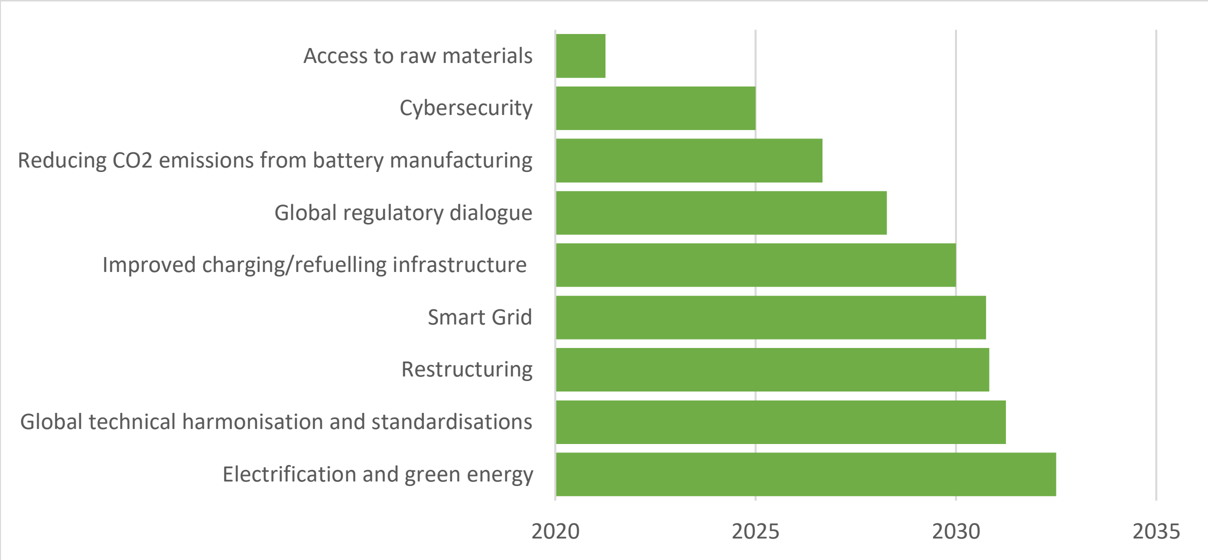

Figure 8. Urgency - how much each Driver of Change is evaluated urgent related to all reports analysed

The urgency of the analysed Drivers of Change is showed in Figure 8. „ACCESS TO RAW MATERIALS“ has been outlined as the most urgent as into 2021 it will be particularly crucial (according to the adopted desk-research methodology to map the “urgency” of a Driver of Change); into 2025 the problems related to “CYBERSECURITY” and 2027 for the “REDUCING CO2 EMISSIONS FROM BATTERY MANUFACTURING” will be crucial too.

2.1.3 Drivers of Change detailed description

Based on the methodology approach, this chapter presents the detailed description for each macro area and related Drivers of Change; the reports used for the wider literature review were selected through an expert group, comprising partners of the ALBATTS project involved in this task. Selection was based on practical experience and usage of particular reports by the partners. This approach was supplemented with manual searches, further iterative

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improvements in searches using keywords from selected papers, and further discussion to validate the final set of reports. The reports are, for the most part, those representing the whole battery value chain and compiled by respected consultancy organisation or projects; each Driver of Change title has a reference with the specific reports / documents where it has been mentioned in the desk-research analysis cited.

2.1.3.1 Climate goals, regulation, and environmental challenges

Global and EU level commitments to decrease GHG emissions, stricter EU CO_2 emissions regulation, legislation and standards concerning recharging infrastructure and incentives at EU, national, and regional level encourage EU industry to step-up efforts to find viable alternatives to current technologies that can reduce the CO_2 emissions in the run up to 2030 and beyond and facilitate the uptake of intermittent renewable energy sources by acting as a flexibility solution. Batteries are one of the most important climate targets driver to decarbonize road transportation and support the transition to a renewable power system. The process of managing the complete lifecycle of a product from concept to design, manufacture, service and disposal of manufactured products supports a reduction in waste and pollution, whilst at the same time providing opportunities for significant cost reductions and a need for new skills in different areas.

- **Reducing CO2 emissions from battery manufacturing**[19, 20,21]
  Since the production of batteries requires significant amounts of energy, 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. Also, moving from a linear to a circular value chain can improve both the environmental and the

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[19] UN report highlights urgent need to tackle impact of EV battery production boom, https://www.greencarcongress.com/2020/07/20200704-un.html?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+greencarcongress%2FTrBK+%28Green+Car+Congress%29, 2020

[20] Batteries and hydrogen technology: keys for a clean energy future, IEA, https://www.iea.org/articles/batteries-and-hydrogen-technology-keys-for-a-clean-energy-future, 2020

[21] A Vision for a Sustainable Battery Value Chain in 2030 (McKinsey World Economic Forum, 2019)

economic footprint of batteries by getting more out of batteries in use, and by harvesting end-of-life value from batteries. Carbon footprint criteria could be a useful tool to increase transparency and provide the relevant information about the battery's environmental impacts. It specifically should be based on where the battery and its key components such as cathodes are produced, as well as by CO_2 per kWh.

- **Electrification and green energy**[22,23,24,25,26,27,28,29,30,31, 32, 33, 34, 35, 36, 37, 38, 39, 40]
  Batteries can fundamentally reduce GHG 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 in three areas: (i)

[22] Transformation-in-energy-utilities-and-resources (PricewaterhouseCoopers, 2019)

[23] Three ways batteries could power change in the world (WEF 2019)

[24] Three surprising resource implications from the rise of electric vehicles (McKinsey, 2018)

[25] Second-life-EV-batteries-The-newest-value-pool-in-energy-storage (McKinsey, 2019)

[26] Renewable Energy and Jobs – Annual Review 2019 (IRENA 2019)

[27] Ready for inspection – the automotive aftermarket in 2030 (McKinsey, 2018)

[28] Powering an innovative battery value chain in Europe (EUROBAT 2018)

[29] Policy Recommendations German EU Presidency (EUROBAT 2020)

[30] New markets. New entrants. New challenges. Battery electric vehicles (Deloitte, 2019)

[31] Making the future of mobility work (Deloitte, 2017)

[32] Interactive map: Electric vehicle incentives per country in Europe, https://www.acea.be/statistics/article/interactive-map-electric-vehicle-incentives-per-country-in-europe, 2017

[33] Greenhouse gas protocol, https://ghgprotocol.org, 2020

[34] Five trends transforming the Automotive Industry (PwC, 2018)

[35] EBA, InnoEnergy 2019 Battery Materials Europe (Amsterdam presentation)

[36] Decarbonisation Pathways (Eurelectric, 2018)

[37] Carbon Neutrality in the Automotive Sector and its Effects for the Supply Chain (https://www.thinkstep.com/blog/carbon-neutrality-automotive-sector-and-its-effects-supply-chain, 2019)

[38] Battery storage: The next disruptive technology in the power sector (McKinsey, 2017)

[39] Battery innovation roadmap 2030 (EUROBAT, 2020)

[40] A Vision for a Sustainable Battery Value Chain in 2030 (McKinsey World Economic Forum, 2019)

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electrification (ii) renewables as a reliable source of energy and (iii) a circular, responsible and just battery value chain. For vehicle manufacturers, one of the most important drivers for electrification of their production fleet is EU regulation (particularly Regulation (EU) 2019/631 setting CO_2 emission performance standards for new passenger cars and for new light commercial vehicles for 2020/21 and 2025, 2030), as electrified vehicles can significantly help the car manufacturers to meet their respective CO_2 reduction targets.

- **Widespread charging/refuelling infrastructure**[41, 42]

  Demand for a widespread charging infrastructure is a key driver to boost the commercialisation of a technology based on batteries. The easier the access to a reliable and suitable (also in terms of charging speed needs) charging infrastructure is, the quicker will be the development of such new technologies. Regulation can play an important role here as well, for instance the planned revision of the Directive 2014/94/EU on the deployment of alternative fuels infrastructure. To increase the comfort for customers, innovative ways of vehicle charging (such as wireless charging or battery pack swapping) are being investigated as well.

2.1.3.2 Globalisation

In 2018, only approximately 1% of the total global demand for EV batteries was supplied by European companies. Over the next years, production in global markets is expected to grow strongly and the EU production must completely change its position to create a competitive advantage. This market represents a substantial—but so far untapped—potential opportunity for European battery makers and carmakers, as well as for the European economy in general. Currently, the EV-battery market is dominated by players from only three countries, all of them in Asia: China, Japan, and Korea. Stimulating the European mining and refining industry will be essential to provide the growing battery industry with sustainable raw materials[43].

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[41] EV charging infrastructure: a growing part of the electricity system (EBA250 2020)

[42] Automotive revolution – perspective towards 2030 (McKinsey, 2016)

[43] Platform for Electromobility, March 2020: https://www.platformelectromobility.eu/wp-content/uploads/2018/02/Platform-recommendations-on-European-Battery-Package.pdf (last accessed on 28.082020)

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- **Access to raw materials** [44,45,46,47,48]

  In a disruptive scenario (with rapid increase in numbers of EVs, the regulatory push across different European countries and the key role in complementing generation of renewable energy), activities linked to raw materials become critical, especially if some resources (limited in terms of quantity or geographical presence) are necessary to produce key components. From this point of view, the battery sector needs to come up with new chemistries of batteries (e. g. lithium-sulphur[49]), develop sourcing strategies to ensure a stable supply of critical and key raw material (e.g. lithium,

[44] UN report highlights urgent need to tackle impact of EV battery production boom, https://www.greencarcongress.com/2020/07/20200704-un.html?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+greencarcongress%2FTrBK+%28Green+Car+Congress%29, 2020

[45] Transformation-in-energy-utilities-and-resources (PricewaterhouseCoopers, 2019)

[46] Three surprising resource implications from the rise of electric vehicles (McKinsey, 2018)

[47] Policy Recommendations German EU Presidency (EUROBAT 2020)

[48] Lithium and cobalt: A tale of two commodities (McKinsey, 2018)

[49] Example of a project: https://www.vutbr.cz/en/rad/projects/detail/26436

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cobalt), also via recycling, to insulate them from the risk of shortages and potential price spikes.

- **Global regulatory dialogue** [50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62]
  [The EU Single Market is a key element for the maintenance and increase of the EU competitiveness and it is evident that such process cannot be put in place by social partners or industry alone; the Commission and in general, Governments and public administrations will need to play a fundamental role in the elaboration of policies and strategies, from which the battery sector could benefit. The process could be enabled

[50] Cleaner Cars from Cradle to Grave, https://www.ucsusa.org/sites/default/files/attach/2015/11/Cleaner-Cars-from-Cradle-to-Grave-full-report.pdf, 2015

[51] The future of distributed generation (PricewaterhouseCoopers, 2019)

[52] Second-life-EV-batteries-The-newest-value-pool-in-energy-storage (McKinsey, 2019)

[53] Ready for inspection – the automotive aftermarket in 2030 (McKinsey, 2018)

[54] Driving CO2 emissions to zero (and beyond) with carbon capture, use, and storage (McKinsey, 2020)

[55] Decarbonisation Pathways (Eurelectric, 2018)

[56] Battery storage: The next disruptive technology in the power sector (McKinsey, 2017)

[57] Battery innovation roadmap 2030 (EUROBAT, 2020)

[58] A Vision for a Sustainable Battery Value Chain in 2030 (McKinsey World Economic Forum, 2019)

[59] A new regulatory framework on batteries to reach Europe's sustainability goals (EBA 2020)

[60] EBA, InnoEnergy 2019 Battery Materials Europe (Amsterdam presentation)

[61] Policy Recommendations German EU Presidency (EUROBAT 2020)

[62] Powering an innovative battery value chain in Europe (EUROBAT 2018)

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by timely policies, including the review of the Alternative Fuels Infrastructure Directive, the Sustainable Battery package and the revision of the Energy Taxation Directive.

- **Restructuring** [63, 64, 65, 66]
  The European battery sector is expected to undergo structural changes due to the development of a zero-emission mobility and as a flexible facilitator of the intermittent renewable energy sources. The industry, in particular SMEs, will need to assess and, if necessary, redefine their position in the value chain as well as increase their capacity to integrate digital technologies and circular economy concepts in their production processes.

2.1.3.3 New technologies

The need for urgent and intense actions against climate change are widely recognized and batteries are an essential system for storing energy in electric vehicles and making renewable energy a reliable alternative source. Although batteries are therefore needed to help tackle climate change, this cannot be achieved without a fundamental change in the way materials are purchased and this technology is produced and used; these challenges can only be addressed through collaborative efforts throughout the value chain, with important investments in R&D[67] and with profound changes in the current business model.

[63] Transformation-in-energy-utilities-and-resources (PricewaterhouseCoopers, 2019)

[64] New markets. New entrants. New challenges. Battery electric vehicles (Deloitte, 2019)

[65] Motor vehicles generate €413 billion in taxes for EU-15, new data shows, https://www.acea.be/press-releases/article/motor-vehicles-generate-413-billion-in-taxes-for-eu-15-new-data-shows, 2018

[66] Automakers are cutting 80,000 jobs globally as EV shift upends industry, https://europe.autonews.com/automakers/automakers-are-cutting-80000-jobs-globally-ev-shift-upends-industry, 2019

[67] https://battery2030.eu/research/, 2020

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- **Cybersecurity** [68, 69, 70]
  By 2024, the number of connected devices will exceed 4 times that of the world population[71]. 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 secure. This threat landscape requires the industry to modify the security approach, aimed at guaranteeing the internal one linked to the resilience of the infrastructures to cyber-attacks. IoT are expected to advance the battery management systems (BMS) by fully utilizing wireless network and cloud support, resulting in providing significant value in cost reduction, extended scalability, and greater visibility in the lithium-ion battery energy storage systems[72].
- **Global technical harmonisation and standardisations** [73, 74, 75]
  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. Common online platforms might connect supply and demand globally to increase the efficiency of players across the supply chain; new standards and product harmonisations will also be necessary to create scale economies and to satisfy a possible increasing request of white label components and unbranded vehicles with also a standardisation of the dimension of the product. Future advantages are likely to be linked to increased standardisation between Member States and to achieving a leading role in regulation at the global level.

68 The future of the Automotive Value Chain – 2025 and beyond (Deloitte, 2017)

69 Securing the future of mobility: Addressing cyber risk in self-driving cars and beyond (Deloitte, 2017)

70 Forces of change: the future of mobility (Deloitte, 2017)

71 AgendaDigitale.eu, https://www.agendadigitale.eu/sicurezza/cybersecurity-per-iot-e-5g-il-ruolo-strategico-degli-standard/, 2020

72 S. Kumbhar, T. Faika, D. Makwana, T. Kim and Y. Lee, "Cybersecurity for Battery Management Systems in Cyber-Physical Environments", 2018

73 Second-life-EV-batteries-The-newest-value-pool-in-energy-storage (McKinsey, 2019)

74 Ready for inspection – the automotive aftermarket in 2030 (McKinsey, 2018)

75 EUROBAT proposal for a notification, verification and validation system of batteries that become waste (EUROBAT 2020)

- **Smart Grid** [76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87]

  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 smart grid, with its many advanced communications and control features, will make it possible to integrate the application of widely dispersed battery storage systems. Vehicles (vehicle-to-grid applications), houses and electrical devices will be connected, with digital technologies changing the way data is transferred and utilised. These new communication technologies have a key strategic importance in relation to changes in the sector.

2.2 STAKEHOLDERS

More details about stakeholders are provided in the respective chapters of the report in Section 3.

Raw materials and processing

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76 Transformation-in-energy-utilities-and-resources (PricewaterhouseCoopers, 2019)

77 The future of distributed generation (PricewaterhouseCoopers, 2019)

78 Powering an innovative battery value chain in Europe (EUROBAT 2018)

79 POV-Energy-Storage-DEG (Accenture, 2016)

80 Here's How Ionity Prices Stack Up Against Tesla's Supercharger in Europe, https://www.autoevolution.com/news/here-s-how-ionity-prices-stack-up-against-teslas-supercharger-in-europe-140457.html, 2020

81 Energy Storage - A key enabler of the Smart Grid (U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability by the National Energy Technology Laboratory, 2009)

82 Decarbonisation Pathways (Eurelectric, 2018)

83 Capturing-Value-Managing-Energy-Flexibility (Accenture, 2017)

84 Battery storage: The next disruptive technology in the power sector (McKinsey, 2017)

85 Battery innovation roadmap 2030 (EUROBAT, 2020)

86 Battery Energy Storage in the EU (EUROBAT 2020)

87 A Vision for a Sustainable Battery Value Chain in 2030 (McKinsey World Economic Forum, 2019)

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The activities of the stakeholders involved in the process of mining and processing of raw materials have an impact on the whole value chain and affect other stakeholders who need batteries for their own products. Companies who need batteries in their products consider mining and supply of raw materials as a reason for concern due to public scrutiny and potential subsequent negative impact on the company's reputation.

The environmental impact, the working conditions, as well as political factors related to mining and processing the materials needed in battery manufacturing, are often considered as challenges. This includes not only companies but also public organizations and authorities responsible for ecological and economical sustainability and human rights. Consequently, these challenges related to certain raw materials encourage companies to take a more active role in raw material extraction and affect their research and development on batteries and enhance the recycling.

Components and cell manufacturing

A mass battery production in Europe is only starting to develop. The driving force behind that is the need to satisfy rising demand from electric vehicles manufacturers combined with intensified efforts to store energy coming from conventional, but increasingly also renewable sources. Big battery players are starting to build their mass battery production facilities with outputs exceeding 1GWh in Europe, the so-called "Gigafactories." Many of these manufacturers currently come from Asia. There are also smaller companies starting to appear in Europe, which do not want to compete with large manufacturers, but focus instead on "niche markets" and adapt batteries to sometimes very specific customer needs. Battery factories can bring a large number of jobs, not only directly in the factories themselves, but also within subcontractors.

Module and pack manufacturing

As for the mobile applications/automotive industry, the car manufacturers often opt for in-house module and pack assembly trying to maximise 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. Vehicle manufacturers want to control the way in which the battery pack space is being used and also how the battery optimal working temperature is achieved, because it has strong implications regarding the safety of the battery and of the vehicle as such.

Battery integration

Stakeholders that are active at this stage of the value chain specialize in production of battery embedded systems like battery management system, battery thermal regulation systems and other components that are associated with battery intelligence which also cover the implementation of software needed. Since this is a crucial part of the whole battery system, many companies that produce energy storage solutions want to manufacture their own systems and components. The car manufacturers in Europe are a good example of this tendency.

Operation, repair and maintenance

Stationary battery systems, energy storages and related stakeholders are discussed in the following areas in this report: grid and off-grid applications, telecom base stations and other heavy-duty applications. In the coming reports, the scope of application areas will be widened. Energy storages in grid and off-grid applications have gained interest among various stakeholders from electric utilities operators to policy makers. The growing interest has led to new players entering the market. 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. Other heavy-duty applications need energy storage systems and with renewable energy sources, a demand for them has increased, further attracting more players to get involved.

Second life

The list of interested parties is quite long and diverse. It ranges from battery and vehicle manufacturers (alternative to direct recycling, also potential way to reduce electric vehicles´ cost, design of batteries with second life/use in mind), through repair and maintenance shops to entities involved in stationary applications and recycling companies. As for stationary/storage applications, second life of batteries could be an interesting area for 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 used in mobile applications, covering for example non-road mobile machinery or micro mobility vehicles (e-scooters, e-bikes etc.), thus important to manufacturers of these vehicles, repair shops or battery swapping services. As second life of batteries is still in its infancy, there are, therefore, huge opportunities for research and education institutions, standardisation bodies or different public bodies and authorities (providing incentives and altering the legislation).

Recycling

The stakeholders for battery recycling involve all elements of the battery value chain. This is important for the sustainability of the battery ecosystem but, also, for batteries to become part of the circular economy. Only through the engagement of all current actors and business newcomers, as well as through the creation of new business models, will such actors tackle the challenge and opportunity that recycling brings about.

As there is a need for increased battery recycling capacity and new business models, new players, completely focused on the recycling of the batteries, are coming to the market. Their main goal is to maximize the recovery of critical battery material from Li-ion batteries in a sustainable, economically sound and safe manner. Technologically, they may differ in the applied processes and the level of the reclaimed material, but their ultimate goal is to achieve the right balance between environmental performance and resource efficiency.

2.2.1 EUROSTAT statistics

The project **ALBATTS - Alliance for Batteries Technology, Training and Skills** - aims at enabling and guiding both industrial and educational stakeholders in the emerging European Batteries ecosystem, towards the future competence needs and supply.

As a result, the **ALBATTS project needs stakeholders' involvement** from a wide range of partners across the entire battery value chain (from raw materials to advanced materials, cells, packs, systems, and end-of-life management).

Who are the Stakeholders?

- **Battery cell manufacturing** sector will play a central role in the project, since cell manufacturing is at the core of the strategic battery value chain and major breakthroughs are necessary to curb current downsides.
- **End users in the automotive sector** will also have a very important role in the project given the fact that road transport will remain the largest battery market[88] by far in the foreseeable future. By 2030, passenger cars will account for the largest share (60 %) of global battery demand, followed by the commercial vehicle segment with 23 %.[89]

According to Deloitte study[90], total EV sales growing from 2.5 million in 2020 to 11.2 million in 2025, then reaching 31.1 million by 2030. EVs would secure approximately 32 per cent of the total market share for new car sales Figure 9.

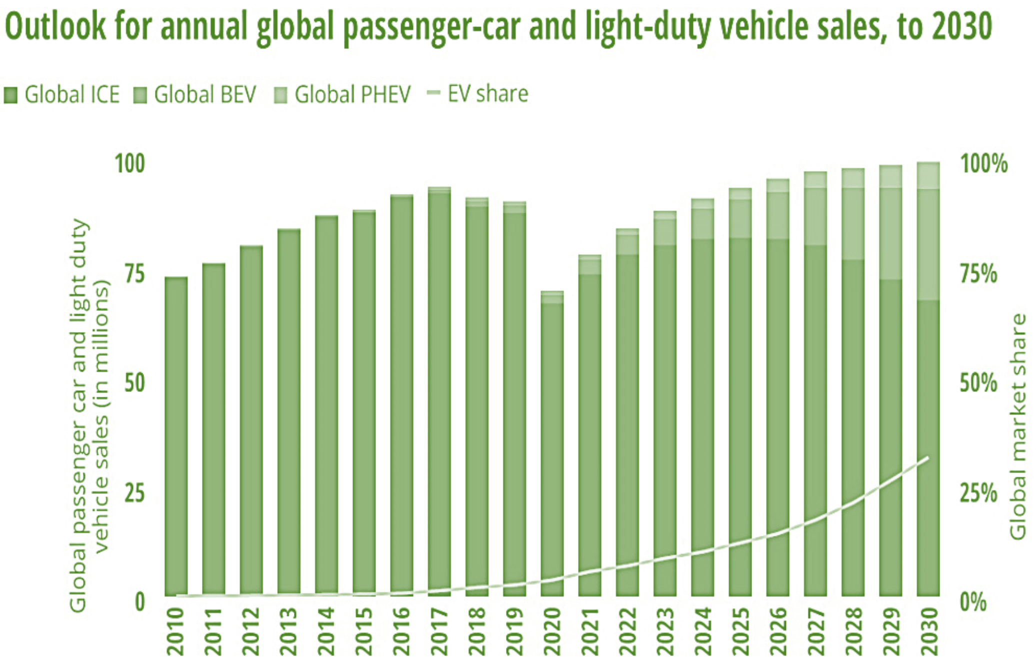

Figure 9. EV Projections by 2030

[88] https://about.bnef.com/electric-vehicle-outlook/, accessed on 07.08.2020 last accessed on 28.08.2020
[89] http://www3.weforum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf last accessed on 28.08.2020
[90] https://www2.deloitte.com/us/en/insights/focus/future-of-mobility/electric-vehicle-trends-2030.html, last accessed on 24.08.2020

- Other **relevant application sectors**: mobile road and non-road applications, other than automotive (sightseeing trackless trains[91], airport buses[92], forklifts, front loaders, Automatic Guided Vehicles-AGVs in automated container ports[93]), stationary applications, waterborne, airborne and rail transport.
- **Battery recycling sector** will help key players to establish a closed-loop and sustainable value chain.
- Finally, active involvement is needed from different sectors, backgrounds, and fields of expertise, including academic partners (**Universities and research organizations**).

The analysis of the sector has been compiled based on the most relevant EUROSTAT indicators relating to the economic structure, market dynamics and workforce within the 27 EU countries in terms of:

V11110 Enterprises – number

V12110 Turnover or gross premiums written - million Euro

V16110 Persons employed - number

The analysis uses **EUROSTAT data from 2017**, the last year with full data available.

NACE[94] (Nomenclature of Economic Activities) is the European statistical classification of economic activities. Statistics produced based on NACE are comparable at European level and, in general, at world level in line with the United Nations' International Standard Industrial Classification (ISIC).

The ALBATTS partners agreed to define the scope of the project based on the following NACE rev. 2 codes:

C2720 Manufacture of batteries and accumulators

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91 https://www.visiter-bordeaux.com/en/discovering-bordeaux/bordeaux-visit-electric-touristic-train.html , last accessed on 6.08.2020
92 https://www.buslife.de/en/2015/10/german-airport-electric-bus, last accessed on 6.08.2020
93 https://e.huawei.com/topic/leading-new-ict-en/yangshan-port-case.html , last accessed on 6.08.2020
94 https://ec.europa.eu/eurostat/web/nace-rev2/overview

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C2910 Manufacture of motor vehicles

C2920 Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers

C2931 Manufacture of electrical and electronic equipment for motor vehicles

C2932 Manufacture of other parts and accessories for motor vehicles

C3011 Building of ships and floating structures

C3012 Building of pleasure and sporting boats

C3091 Manufacture of motorcycles

E3812 Collection of hazardous waste (collection of hazardous waste, such as used batteries)

E3832 Recovery of sorted materials (recovery of materials from waste streams... or the separating and sorting of commingled recoverable materials.... shredding of metal waste, end-of-life vehicles)

G4511 Sale of cars and light motor vehicles

G4519 Sale of other motor vehicles

G4520 Maintenance and repair of motor vehicles (electrical repairs, repair of motor vehicle parts – battery)

G4531 Wholesale trade of motor vehicle parts and accessories

G4532 Retail trade of motor vehicle parts and accessories

G4540 Sale, maintenance and repair of motorcycles and related parts and accessories

G4764 Retail sale of sporting equipment in specialised stores (ships, boats…)

As some categories listed above have particular business-related specificities (large number of operators, low traceability of the business objects, insufficient policing), on top of the collected numbers, there are important additions that are not known but should somehow be accounted for. In the case of some of the NACE codes (**G4520**: Maintenance and repair of motor vehicles - electrical repairs, repair of motor vehicle parts – battery; **G4540**: Sale, maintenance and repair of motorcycles and related parts and accessories; **E3812**: Collection of hazardous waste and **E3832**: Recovery of sorted materials (recovery of materials from waste streams... or the separating and sorting of commonly recoverable materials....

shredding of metal waste, end-of-life vehicles), the figures presented are probably lower due to some unlawful activities, as suggested by several sources.[95;96;97;98]

Country	Enterprises - number	Persons employed - number	Turnover or gross premiums written - million euro
EU27	887,904	6,456,071	2,241,981

Figure 10. Sector Dimension

Based on EUROSTAT[99] data, the sector size is shown in(Figure 10)

2.3 TECHNOLOGIES

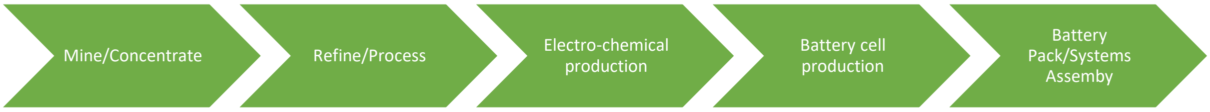

Figure 11. LIB value chain

2.3.1 Raw materials and processing

The chapter focuses on the raw materials needed for Lithium-ion Batteries (LIB) with NCA or NMC cathodes as these are the most important technologies currently being used Figure 11. Cobalt, Natural Graphite and Silicon are classified as critical by the European Commission. Lithium, Nickel and Manganese are essential as well, also considering the demand is increasing.

Lithium is the most electropositive element in nature; it is relatively lightweight compared to other metals such as Nickel and Cadmium. Lithium is extracted by mining from brine or

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95 https://www.autoactu.com/actualites/prison-ferme-et-fortes-amendes-pour-une-fraude-a-la-tva-sur-la-vente-de-voitures-d-occasion, last accessed on 6.08.2020

96 https://www.midilibre.fr/2019/10/10/nimes-fraude-a-la-tva-dans-le-milieu-automobile-suspects-deferes-a-marseille,8470759.php, last accessed on 6.08.2020

97 https://www.lecese.fr/sites/default/files/pdf/Avis/2016/2016_14_evitement_fiscal.pdfm last accessed on 6.08.2020

98 https://www.letelegramme.fr/morbihan/plumelec-operation-anti-fraude-dans-une-casse-auto-21-05-2015-10635922.php, last accessed on 6.08.2020

99 Source Eurostat, date of extraction 24.07.2020

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through hard rock Lithium processing. Lithium Carbonate is mostly used by the EV industry, mainly in cathodes. With NMC cathodes having higher Nickel proportions, the production of Lithium hydroxide is expected to exceed that of Lithium Carbonate.

Cobalt provides LIBs chemical and thermal stability with high energy density. It is recovered through different processes involving ore concentrate by roasting, solvent extraction, electrolysis or bioleaching. Producers seek to substitute Cobalt, as it is a costly mineral and is sourced mainly from conflict-ridden parts of the world.

Nickel conducts heat and electricity and delivers high energy density with low costs. This potential Cobalt replacement is mined as lateritic and Ni-sulfidic ores. Lateritic ores are processed in electric reduction furnaces followed by hydrometallurgical treatment. With sulfidic ores, flash smelting is common, followed by metallurgical processes.

Manganese can improve a cathode in LIBs in various ways and can be a cheap alternative to Cobalt and Nickel. Manganese is commonly found as oxide and hydroxide in soils. Its mining is frequently an open pit operation. Pure manganese is produced through hydrometallurgy and electrolysis.

Graphite, both natural and synthetic, is used for anodes due to being safe and reliable as an active material. It has sufficient energy density for mobile applications. Natural graphite is mined in open-cast quarries where it can exist as flakes, veins and crystal formations. When refined, graphite flakes are rounded to spherical units followed by thermal or acid purification.

Silicon is an alternative to graphite as an active material in an anode. It is preferably mined from pure quartz. After mining and sorting, reduction of quartz with carbon is conducted in a reduction furnace followed by oxidative refining, casting, crystallization and crushing.

2.3.2 Component and cell manufacturing

Several types of LIBs are used today. These are divided according to the composition of the cathode material. Each composition differs slightly in parameters such as voltage, operation life, capacity, etc.

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 the separator (3%), the electrolyte (1%), the current collectors (3%), the anode materials (8%) and the cathode materials (26%), 41% of total battery cost is reached already, with the most significant contribution owing to the cathode material.

The manufacturing process includes the preparation of active materials, the production of electrodes and the assembly of batteries. The positive electrode is formed by depositing a cathode material on an aluminium foil and the negative electrode is formed by depositing an anode material on a copper foil (for Graphite). A separator is inserted between these foils and also at the edges. The separator is a plastic, porous film that separates the anode from the cathode but allows electrolyte to flow. The structure is filled with electrolyte. Electrolyte is a solution of lithium salts and is used in a battery to enable the flow of electrons from the anode to the cathode. Then the battery is assembled into the desired shape.

Three shapes are used: cylindrical, prismatic and pouch cells. These variations in shape of the cells bring about differences in terms of capacity, thermal management, integration, etc.

2.3.3 Module and pack manufacturing

For stationary and mobile applications such as EVs, LIBs are used in the form of a pack. This pack consists of several blocks of battery modules, battery management system (BMS) master, and thermal regulation system. Design possibilities of the pack arrangement include series and parallel stacking of modules Figure 12.

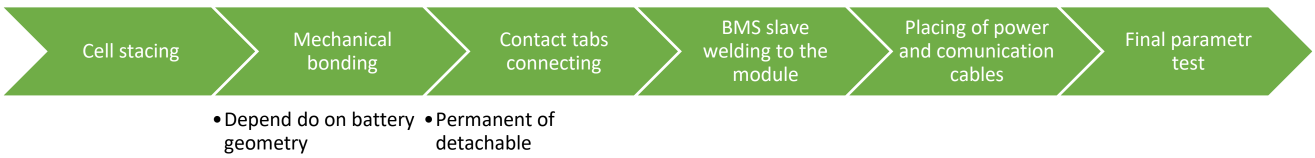

Figure 12. Battery module assembly process

One of the main concerns regarding the incorporation of LIBs is its inherent risk of thermal runaway and explosion. This leads to the important role the BMS and thermal regulation system have for the module and pack assembly, together accounting for 24% of the total battery cost. Each battery module requires the simultaneous installation of a BMS master and its thermal regulation system, significantly increasing the total volume occupied by the pack.

2.3.4 Battery integration

This step covers the stage between the module and pack manufacturing and operation, repair, and maintenance phases of the battery value chain. Integration process varies mostly based on the application type: either stationary (base stations, power grid, industrial applications, etc.) or mobile (cars, ships, etc.).

Generic integration process covers the configuration of cells and battery pack and its integration with embedded systems like battery management systems and thermal regulation system which prolong the battery life. This integration step also covers the hardware needed (wiring, sensors, etc.) and the proper enclosure. The last step, before the battery goes into service, is the check for compliance with the safety standards which requires proper testing.

2.3.5 Operation, Repair and Maintenance

The areas of application regarding stationary energy storages that are discussed in this report are grid and off-grid applications, telecom base stations and other heavy-duty energy storage.

2.3.5.1 Grid and off-grid applications

In the grid and off-grid applications the widening use of intermittent sources of energy production (wind, solar and tidal) in both behind-the-meter (BTM) residential consumer level applications and front-of-the-meter (FTM) with utility level applications has boosted the demand of energy storages. In utility-scale application battery energy storage systems (BESS) store excess generation, balance the grid and firm renewable energy output. One of the primary drivers of BTM application of batteries is the ability to decrease electricity costs.

2.3.5.2 Telecom base stations

The telecom base station application of energy storages has drawn attention during the last few years with the recent deployment of 5G networks worldwide. While lead-acid batteries were widely used with earlier generation base stations, the application of lithium-ion batteries is having increasingly significant share due to a lower environmental impact, an ability to support renewables and a greater performance. The power demands of a 5G base station is more than that of a 4G base station and the 5G base station density needs to be higher. Both factors increase the demand for energy storages.

2.3.5.3 Heavy-duty applications

Regarding other heavy-duty applications offshore oil and gas application, stadiums, hospitals, airports and military applications are discussed as examples in this report. Large-scale stationary LIBs can store energy in various backup and microgrid applications, and especially challenging operating environments require that they are designed to meet for example temperature and environmental extremes. Large-scale battery systems can be utilized for example 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.

2.3.5.4 Repairing and maintenance

To Repair Li-ion batteries, in their various applications, involves replacement at the end of their lifespan. Batteries are tested to verify their remaining capacity and when the threshold minimum capacity has been reached, replacement occurs. The purpose of maintenance is to ensure that the maximum lifespan of a battery can be reached. The factors affecting LIBs' lifespan are for example charge/discharge rate, depth of discharge, and ambient temperature, which need to be paid attention to. There are safety elements need to be taken into consideration such as overheating that may lead to combustion in extreme cases.

2.3.6 Second life

Battery second Use dissemination enables to mitigate CO_2 emissions and decrease an overall demand for brand-new batteries production, thus decrease the impact on environment by the extraction of minerals and the whole battery production chain. Repurposing retired electric vehicle (EV) batteries provides a potential way to also 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.

EV batteries can be re-used in stationary applications to facilitate integration of renewable sources of energy to 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.

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, before proceeding to the integration phase, a decision on either direct redeployment or reconfiguration of batteries is to be made. Cell quality selection process is to be scrutinized, considering a battery's SoH, a 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 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.

2.3.7 Recycling

According to the Strategic Action Plan on Batteries, the whole cycle of sustainable battery production has been revised, although recycling and re-use phases are still to be developed. Even though the EU has been lacking substantial regulations on sustainable battery recycling, a systematic vision is on the way to be integrated to reduce LIBs' (Lithium-ion Battery) net production and leverage EoL (End of Life) batteries' materials.

The recycling technologies of Li-ion batteries can be divided into two types, Direct and Indirect methods. Depending on whether a cathode is broken down to different elements, the former one appears to be more cost effective and energy conservative. There are different techniques to metals reclamation in the LIBs' recycling process for valuable metals (e.g. Co, Ni, Mn, Li etc.) recovery.

The most innovative recycling technologies have been elaborated in this report: Retriev Technologies, Recupyl Valibat, Akkuser and Umicore Valéas™. Significant leaps can be attained through bringing higher automation degree of the recycling processes and avoiding cathode/ anode materials mixing. There is a special attention drawn to Akkuser process, which shows the lowest energy consumption and fire risks with a high level of recycling efficiency, but a "black mass" is to be obtained by a third party. Furthermore, Recupyl Valibat also provides clear advantages, as it uses mechanical processing coupled with hydrometallurgical operations, which renders low losses and embraces strong circular economy principles.

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2.4 JOB ROLES AND SKILLS

As stated in the project application: "*partners will design roadmap or blueprint for the synchronization of the demand; the new needs for competence, on the enterprise side, with the supply of education and training services, customised to meet the demands.*"[100]

The desk research report is a first part of the basis for the above-mentioned roadmap/blueprint and it will deliver important data on which the other two parts (survey and workshops) will be based, as mentioned in the methodology **section 1**.

This section will further describe the focus and approach to this research topic along with the main findings.

2.4.1 Focus of the Topic

The focus of this topic of sectoral intelligence is to gather valuable data on current and future job roles, competencies, skills, and knowledge needs, and the so-called state-of-the-art, to better understand the current situation of the fast-emerging battery sector.

2.4.2 Attractiveness of the subsector

To better understand the current situation of the sector, the ALBATTS partnership carried out a desk research study analysing the attractiveness of the battery sector by focusing on target groups which include primarily **potential newcomers** to the sector (i.e. students or young people at the beginning of their professional career); but also workers from other sectors who are eventually **considering** entering this growing sector. Through this research, the aim was to answer the following questions:

a) Is the battery sector attractive for the above-mentioned target groups?
b) Are they aware of the battery sector's potential and its applications?

The numbers from the World Economic Forum, as reported by the Global Battery Alliance's 2019 Report, are encouraging. If the growing global battery demand is matched with sound

[100] Project application

collaborative actions, the battery sector could create 10 million safe and sustainable jobs and $150 billion of economic value in a fair value chain by 2030[101]. In the umbrella of such collaborative actions, the full exploiting the battery sector potential, increasing its attractiveness, and helping to create relevant competencies and training schemes that match new job roles and requirements are key.

As reported by the European Battery Alliance (EBA250), one of the top priority actions for the future is developing and strengthening a **skilled workforce** in all parts of the battery value chain and making Europe **attractive** for world class experts. To do this, it is imperative to attract talents with lighthouse projects for cell manufacturing and other relevant activities. Sufficient human capital with key skills are missing in Europe, especially in the field of applied process design[102].

From the results of the desk research (published papers, reports, and articles), there is no evidence about a proper and specific battery energy sector *"attraction effect"*. Therefore, in order 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 as per Figure 13.

Figure 13. The battery "ecosystem"

[101] WEF 2019 "Three ways batteries could power change in the world", https://www.weforum.org/agenda/2019/09/three-ways-batteries-could-power-the-world/
[102] EBA250 Priority Actions, https://www.eba250.com/actions-projects/priority-actions/

Electric vehicles are considered as an important step for clean energy transition, boosting innovation, digitalization and decarbonization. The general trend is year-on-year increase in first registrations, as shown for example by ACEA statistics.[103] Such interest in EVs requires a skilled workforce and ability to attract talents towards this growing sector. There is no doubt that electric vehicles and their potential are today an object of interest for many people, especially the youth. Young people are in fact attracted by the driving force behind the electrification of transport, namely, the concept of sustainability[104].

However, the shift to EV manufacturing[105] requires a substantial investment in new talents both from OEMs and new entrants (start-ups in particular). OEMs must look for a workforce that is broader and deeper in terms of knowledge. Multi-skilled engineers, who are as comfortable with **chemistry** as they are with **electrical and mechanical engineering** are required, but this is a challenge since now they are scarce (and they demand higher wages). In addition, another challenge in the difficulty to attract such multi-skilled engineers or graduates in science, technology, engineering, and mathematics altogether is the fact that such people are increasingly attracted to start-ups. To address this issue, OEMs invest in talents capable of designing, building and integrating battery cells. Various platforms and business models are being set up to find new ideas and talents, and not only in the production part of the value chain[106]. The demand for skilled workforce concerns not only university educated people, but also those with lower EQF level education. The ability to keep the current employees will be of great importance as well. Therefore, vast requalification programs are carried out by OEMs[107] and other stakeholders such as vehicle dealerships.

Another application of the battery sector representing an object of interest that is attracting many talents is “green energy,” where batteries represent a fundamental component in terms of green energy storage. **Young people** are increasingly concerned about environmental

[103] https://www.acea.be/uploads/publications/ACEA_Pocket_Guide_2020-2021.pdf
[104] PWC, 2017 “Five trends transforming the Automotive Industry”, https://eu-smartcities.eu/sites/default/files/2018-03/pwc-five-trends-transforming-the-automotive-industry.compressed.pdf
[105] Deloitte, 2019 “New markets. New entrants. New challenges. Battery electric vehicles”, https://www2.deloitte.com/content/dam/Deloitte/uk/Documents/manufacturing/deloitte-uk-battery-electric-vehicles.pdf
[106] For example https://skodaautodigilab.com/
[107] https://www.volkswagen-newsroom.com/en/press-releases/transformation-continuing-apace-zwickau-car-factory-to-produce-only-electric-models-in-future-6154

issues. Gen Z and Millennials see the industry's careers in oil and gas as unstable, blue-collar, difficult, dangerous and harmful to society, while considering jobs in green energy more appealing[108]. The green energy sector employed 11 million people at the end of 2018 (with solar photovoltaic panels being the top employer)[109]. Although many young people are interested in pursuing studies and making a career in the green energy sector, the main issue here is that, at EU level especially, more work should be done on providing a more systemic skills base. In fact, managing skills and technical job-specific skills are a greater concern than shortages of "new" green skills.

To conclude, when taken in isolation, it is still not possible to clearly outline if and to what extent the battery energy sector is attractive. However, findings from our desk research show that when taking a broader perspective by analysing its main areas of application, it is possible to measure as well as to boost the battery sector's attractiveness. People and especially the youth are increasingly attracted to new ways of generating and using energy in order to tackle the biggest climate challenges and contribute to achieving sustainability goals. Therefore, it is imperative to show that batteries are the key enablers and accelerators to achieve such goals, through their impact on areas such as smart mobility; secure, green and affordable energy; as well as circular economy. Therefore, young people should be aware that pursuing a career in such sector will allow them to contribute and make a direct impact on sustainability issues. Moreover, a more in-depth analysis of the sector attractiveness will be provided through the next steps of the project interactions with stakeholders.

2.4.3 Methodology and Classification Framework

All the job roles found were mapped to the battery value chain steps for further identification of the gaps. A spreadsheet template was used to achieve trackable work for all involved partners. This approach resulted in structured data collection.

- **Job Role** (current or future)
    - Name

[108] EY, 2017 "How do we regenerate this generation's view of oil and gas?", https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/oil-and-gas/ey-how-do-we-regenerate-this-generations-view-of-oil-and-gas.pdf
[109] IRENA, 2019 "Renewable Energy and Jobs – Annual Review 2019", https://www.irena.org/publications/2019/Jun/Renewable-Energy-and-Jobs-Annual-Review-2019

- Application (stationary or mobile)
- Category (corresponding with the ISCO classification level I & II[110])
- Description
- Mapping[111] to the battery value chain
  - Job role was assigned to the corresponding battery value chain.
- Responsibilities
- Qualification needed with EQF[112] mapping
- Actively offered or demanded
  - Information about demand or offer of the job role.
- Competences
  - Skills and knowledge required.
- Other relevant information
- ESCO mapping
- Information source

This generic template is very well suited for partners who can easily map the job advertisements, or any other data found in the various reports. It enables structured approach to the research and systematic work as well as backtracking to the source of information.

This structured data collection can then be easily mapped to the job role classification framework described below.

Job Role Classification Framework:

- **Name (Mandatory)**
- **Description (Mandatory)**
- **Work Context[113] (Optional)**

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[110] Glossary:International standard classification of occupations (ISCO). (n.d.). Retrieved August 04, 2020, from https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:International_standard_classification_of_occupations_(ISCO)
[111] An operation that associates each element of a given set (the domain) with one or more elements of a second set (the range).
[112] European qualifications framework (EQF). (2020, April 27). Retrieved August 04, 2020, from https://www.cedefop.europa.eu/en/events-and-projects/projects/european-qualifications-framework-eqf
[113] Work Context. (2020, March 07). Retrieved August 04, 2020, from https://ec.europa.eu/esco/portal/escopedia/Work_context

- **ESCO Mapping (Mandatory)**
  - Mapping to existing ESCO occupations
  - **M: N mapping[114]:** One job role to more occupations in ESCO and vice versa, one or more job roles to one occupation in ESCO.
- **ISCO Mapping (Optional)**
  - Level I ISCO Mapping
  - Level II ISCO Mapping
- **Competencies (Mandatory)**
  - List of competencies/skills on desired level
    - Mapped to ESCO existing competence/skill
  - List of knowledge necessary
    - Mapped to ESCO existing competence/skill
- **EQF Level (Mandatory)**
- **Other Parameters (Optional)**
  - Battery value chain mapping

Classification framework described above coheres well with the ESCO and enables identification among the different European skill agendas.

2.4.4 Main Findings

For this desk research report, project partners decided to look for various job advertisements available on the internet relevant to the battery sector. The deliverable 6.1 which was done in WP6 was also used as a reference to better understand what are the possible job roles that could be described in more detail. Some of the information also comes from the reports which are publicly available on the internet. Synthesis of this data leads to the list of job roles, skills, and knowledge for each value chain step. Occurrence of required skills and knowledge is depicted in charts.

114 https://en.wikipedia.org/wiki/Many-to-many_(data_model)

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Main findings are described in more detail in the sections that relate to the specific value chain steps. Each section contains list of the found job roles and statistics about the skills and knowledge that were found.

2.5 EDUCATION

Although the EU countries have national educations systems, the European Commission has high ambitions concerning their responsiveness to economic development needs, and continuously works with soft policy, such as the Bologna process, or in this case, the education blueprint for the development of education and training methods and approaches, for the fast development of the batteries and e-mobility sector in Europe.

The education and training methods and approaches used vary between the academic university sector and vocational education; methods also vary within these sectors. However, many of the same methods and approaches are used, but with varying blends, emphasis patterns and objectives. Universities work with advanced generalist education, and vocational institutes closer to actual application and work market. ICTs (Information and Communication Technologies) no longer constitute new methods by themselves, but they refresh the old and develop innovation in education, and training access and flexibility, so IT-integrated education has become the new normal. We present a time-based social perspective that can be used for analysis and classification when working further in desk research with analysing what is going on and what needs to be done.

ALBATTS deliverable 6.1 constituted a collection of European examples of existing education and training in the battery- and e-mobility sector, from EQF (European Qualification System) 4 (upper secondary school, gymnasium) to EQF 7 (master-level education), and found interesting examples all over, but with concentration on the masters level, which is important for development jobs in industry. For vocational education to start and thrive, job offers and opportunities in actual industries must be close in time. This work will continue with desktop research, surveys and workshops in WP3, 4 and 5, but also by networking with other initiatives (such as the European Battery Alliance, BatteriesEurope, Battery2030+, EITInnoEnergy, EIT Raw Materials.) and educational institutions.

3 Value chain

Introduction

Lithium-ion batteries (LIBs) currently dominate the battery market in mobile applications (mainly automotive) and are gaining increasing relevance in stationary (grid) applications. Lithium is relatively lightweight, compared to other metals such as Nickel and Cadmium. The couple Li^0/Li^+ (3.05 V) has the highest possible voltage among the known raw materials, as Lithium is the most electropositive element found in nature[115]. Since Sony started using this type of battery in 1991, LIBs have been under the spotlight as the main researched topic of the energy storage systems (ESS) which has led to several significant improvements.

Presently, the main challenges to overcome are:

(1) reducing or, if possible, eliminating the use of Cobalt, which has the most critical supply chain of all the main constituents of LIB`s positive electrode active materials, thus reducing cost and supply instability (Cobalt is $\geq 80\%$ mined in the Democratic Republic of Congo);

(2) increasing LIB's overall life cycle and energy density[116] ;

(3) decreasing the inherent safety risks such as thermal runaway that may lead to fire and explosions.

The first and second challenges are closely related to tailoring chemistries for positive electrodes' active materials. Hereinafter, the positive electrodes active material will be referred to as "cathode" for simplification, although in the secondary batteries (rechargeable), the positive electrodes are cathodes while discharging, and anodes while charging.

3.1 RAW MATERIALS AND PROCESSING

3.1.1 Stakeholders

Mining and supply of raw materials concern manufacturing companies, especially those involved in upstream battery cell. Furthermore, general consciousness about environmental impact, fair working conditions and political factors, associated with each raw material, create new avenues for developing new battery cell technologies, but also identifies current and future challenges such as recycling. These problems also concern public organizations and Global/European authorities, which are responsible for promoting ecological and economical sustainability, beside guaranteeing that working conditions in raw material supplying countries comply with fundamental human rights.

[115] Julien, C., et al., *Lithium Batteries: Science and Technology*. 2015: Springer International Publishing.
[116] Goodenough, J.B. and Y. Kim, *Challenges for Rechargeable Li Batteries.* Chemistry of Materials, 2010. **22**(3): p. 587-603.

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Major international companies selling end consumer products, such as well-known EVs manufacturers – Tesla, Nissan, and others – are subject of public scrutiny. This fact reinforces their active role in raw materials' extraction, since severe environmental consequences, as well as unfair working conditions, may arise from these activities.

Thus, a list of stakeholders taking part in raw material mining, supply and processing may be identified as follows:

- Mining and mineral refining companies
- Battery manufacturers
- Vehicle manufacturers
- Research institutions
- Education institutions
- Recycling companies
- Energy/Natural resources regulation and fiscal authorities
- Environmental non-profit organizations (NGOs)
- International organizations (UNESCO, UN, etc) and European Institutions
- Local authorities/municipalities

3.1.2 Drivers of Change

The European Commission (EC) list of Critical raw materials (CRM) from 2017 lists Cobalt, natural graphite and Silicon as critical for battery production.[117, 118] In this critical assessment, a balance between the economic importance and the supply risk is constantly analysed. The 2018 *Report on Raw Materials for Battery Applications* mentions Nickel and Lithium as "essential".[119] In the 2018 EC communication "Europe on the move", it is emphasized the need to increase the overview and knowledge on battery raw materials, which is the background of numerous reports, as the review of the 2017 list of CRMs[120] and JRC Science for policy report.[121] [122] Moreover, Nickel and Manganese are the most common metals employed to complement and decrease the amount of Cobalt which highlights both metals' importance for future cathode technologies.

[117] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52017DC0490
[118] Silicon metal is an interesting alternative to graphite as anode material. See https://www.globenewswire.com/news-release/2020/04/15/2016538/0/en/Silicon-Material-Produced-With-GEN2-PUREVAP-Offers-Promising-Potential-to-Replace-Graphite-in-Lithium-ion-Batteries.html
[119] https://ec.europa.eu/transport/sites/transport/files/3rd-mobility-pack/swd20180245.pdf
[120] https://op.europa.eu/en/publication-detail/-/publication/08fdab5f-9766-11e7-b92d-01aa75ed71a1
[121] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC112285/jrc112285_Cobalt.pdf
[122] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC105010/kj1a28534enn.pdf

3.1.3 Mining and supply

Limiting this study to the most important battery technologies currently being used, which are going to be identified in subsequent subchapters, the focus will be on critical raw materials needed for LIBs with NMC and NCA cathodes (lithiated compounds containing Nickel, Cobalt, Oxygen and Manganese or Aluminium, respectively. These compounds incorporate raw materials that are now in limited supply and extra demand due to the recent surge in battery production for EVs.

Based on *Drivers of Change* and the most relevant technologies, the short list for addressing raw materials includes: **Lithium**, **Cobalt**, **Nickel**, **Manganese**, **Graphite** and **Silicon**.

Lithium

Lithium is a highly reactive metal. It may ignite in the presence of moisture and/or air, and it is an electrical conductor (1.1×10^7 S/m). It is often transported in mineral oil to keep it protected from air and water. This metal's high reactivity leads to its absence in pure form. Instead, it is found in the composition of minerals, spodumene and petalite. There are two distinct techniques for extracting both minerals: mining from brine (salt lakes) and hard rock Lithium processing (pegmatite deposits).[123][124] The EU import reliance thereof is 86%.[125]

Deposits

The biggest known global deposits for brine mining are located in the South American Lithium Triangle (Chile, Argentina, Bolivia) and Canada. Australia, China and USA have the biggest hard-rock deposits in the world[126] and smaller deposits of both mining sources are to be found in many countries, often in combination with hard rock copper mining. Seawater also contains Lithium in small concentrations (0.17 parts per million)[127] but presently, its extraction is not economically viable. Lithium is a common component of sea-bottom polymetallic nodules as well, for which harvesting is highly controversial, due to damage caused by current mining methods being employed.[128] In all, global Lithium deposits

123 https://www.chemicool.com/elements/Lithium.html
124 https://www.sgs.com/~/media/Global/Documents/Flyers%20and%20Leaflets/SGS-MIN-WA109-Hard-Rock-Lithium-Processing-EN-11.pdf
125 https://op.europa.eu/en/publication-detail/-/publication/08fdab5f-9766-11e7-b92d-01aa75ed71a1 p 33f
126 https://www.statista.com/statistics/268790/countries-with-the-largest-Lithium-reserves-worldwide/
127 https://stockhead.com.au/resources/Lithium-from-seawater-its-possible-but-is-it-worth-pursuing/
128 https://www.nature.com/articles/d41586-019-00757-y

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are considered enough in supply for at least this century, especially if efficient recycling technologies develop. In Europe,

most of the additional prospecting for Lithium can be motivated by the lack of interest, therefore. In the recent past, Lithium has simply not been so much in focus during explorations. So far, only about 1% of the world's total deposits have been depleted, so there will be Lithium access for many years. The big Bolivian deposits at the world's biggest salt flat, Salar de Uyuni[129] are interesting for both European and Chinese companies[130] [131], but it is more expensive to exploit than the reserves in other parts of the Lithium triangle, since they are chemically more complex and the high altitude with lower temperatures makes drying processes slower.[132] China encountered similar problems with its big Lithium deposits in Tibet.[133]

Deposits in Europe

Portugal has the largest producing Lithium mines in Europe, in the Guarda area, Northern Portugal, near the border with Spain, run by Grupo Mota Felmica[134] and other deposits are under development.[135] Another promising deposit is located in the Krusne Hory mountains, Czech Republic, near the border with Germany.[136] Besides this, there are Lithium deposits in Mid-Finland (Ostrobothnia) which the company Keliber Oy plans to mine and then refine into Lithium hydroxide in Kokkola.[137] Lithium hydroxide is commonly found in LIBs electrolyte's composition, besides some more recently developed cathodes. These deposits, together with other smaller European deposits, are not considered enough for Europe's estimated needs of this metal.

Production

The brine exploitation is done by pumping up salt from underground, drying this in enormous ponds and harvesting Lithium Carbonate which can be sold directly. In hard rock mining[138], a Lithium concentrate is produced that must be refined into Lithium Carbonate or Lithium Hydroxide. Lithium Carbonate is the most widely used in the EV industry, mainly in cathodes, but recent market trends for Li- rich NMC cathodes containing higher proportions of Nickel is shifting Lithium's demand, with

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129 https://www.saltworkconsultants.com/salar-di-uyuni/
130 https://www.mining.com/web/bolivia-picks-chinese-partner-2-3b-Lithium-project/
131 https://www.dw.com/en/bolivia-scraps-joint-Lithium-project-with-german-company/a-51100873
132 https://dialogochino.net/en/extractive-industries/35423-bolivia-rethinks-how-to-industrialize-its-Lithium-amid-political-transition/
133 https://www.scmp.com/news/china/science/article/3010200/china-cracks-cheap-Lithium-production-electric-car-breakthrough
134 http://Lithium.today/Lithium-supply-by-countries/Lithium-supply-portugal/
135 https://blog.energybrainpool.com/en/is-there-enough-Lithium-to-feed-the-need-for-batteries/
136 https://www.mpo.cz/cz/rozcestnik/pro-media/tiskove-zpravy/tezba-lithia-na-cinovci-bude-v-ceskych-rukou--cez-ziska-51-procent-ve-spolecnosti-geomet--253714/ (last accessed on 30.08.2020)
137 https://www.keliber.fi/en/
138 https://www.sgs.com/~/media/Global/Documents/Flyers%20and%20Leaflets/SGS-MIN-WA109-Hard-Rock-Lithium-Processing-EN-11.pdf

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production of Lithium Hydroxide expected to overcome that of Lithium Carbonate by the second half of the 2020s decade.[139] The reason for this already observed increasing demand for Lithium Hydroxide is the need to enhance Nickel-rich active cathodes' chemical stability.

Refining

The recovery of Lithium from brine is more expensive than mining of Lithium from hard rock, while refining from brine is less expensive, as Lithium Carbonate from dried-up brine is directly sellable. It is the other way around for hard rock mining: expensive refining processes are needed turn the concentrate to Lithium Carbonate and further to Carbon Hydroxide. Considering total cost after refining, present day technologies render recovery of Lithium from brine the least expensive alternative.

Trade and logistics

The price of Lithium is considered low at the present[140] and demand is weak, due to Covid 19 pandemic, reported by Albemarle and Livent in a Roskill report.[141]. However, after the expected recovery from the pandemic, Lithium's cost will be on a steep rise as more battery factories resume (full capacity) production around 2022-2023. This will enable more investments – when the shortage becomes a fact. Nonetheless, a big problem for European battery value chain nowadays is that, although there are some deposits for mining in Europe`s soil, the refining processes are cheaper in China, leading to mass transportation of ore concentrates into this country, for refining – and increasing this country's attractiveness for manufacturing Li-Ion cells. A big part of Australian Lithium concentrates is also refined in China, where there are both cheap labour and innovative technology available. [142]

Politics and environment

The biggest three producers of Lithium are Albemarle[143](extracting from Chile and Nevada, US), Sociedad Quimica y Minera de Chile and FMC (now renamed Livent[144] and extracting from Argentina). China is very strong in the market with companies as Lithium Tiangji, Lithium Ganfeng. The strength comes both directly via own mining (fifth in the world), and via refining companies importing ores and

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139 Media, A. (2019). "Lithium hydroxide demand to overtake Carbonate: AABC." 2020, from https://www.argusmedia.com/en/news/1836977-Lithium-hydroxide-demand-to-overtake-Carbonate-aabc.
140 US$ 7,25 per kg Lithium Carbonate on London Stock Exchange Aug 6th, 2020 https://www.lme.com/Metals/Minor-metals/Lithium-prices#tabIndex=0
141 https://roskill.com/news/Lithium-albemarle-and-livent-highlight-continued-Lithium-market-weakness-in-q2-2020/
142 https://www.scmp.com/news/china/science/article/3010200/china-cracks-cheap-Lithium-production-electric-car-breakthrough
143 https://www.albemarle.com/businesses/Lithium
144 https://www.prnewswire.com/news-releases/fmc-s-Lithium-business-to-be-named-livent-corporation-888859582.html

concentrates. Chinese companies are important shareholders in big Australian Lithium producers as well (as in Talisman). [145]

Development and trends

Some new Lithium mining projects are located in Mexico, Australia and the US.[146] There are plans to exploit Lithium from clay as well.[147]

Recycling

Lithium is considered difficult and expensive to recycle and, at low market prices, it is not worthy to be done and that happens presently. Lithium from old batteries might end up as landfill in Europe while other parts of the batteries, that are more economically advantageous to recycle, would eventually re-join the value chain. It may be necessary to develop special processes for each cell chemistry in order to achieve viable recycling of Lithium. Northvolt intends to recycle substandard batteries from production directly at site and take the materials back in the process – besides using other recycled Lithium. The company American Manganese claims that their new ReCycLiCo process[148] "makes Lithium last forever".

Cobalt

Cobalt is a metal with high melting point but with low electrical and thermal conductivity. It is toxic by skin contact. [149] [150] This metal is mainly used for whitewares and technical applications, such as in the aircraft industry (superalloys), in tools (cemented carbides) and in electronics, as well as in cancer radioactive treatment. It is in high demand for high power and high-density batteries, namely LIBs, for which Cobalt enables chemical and thermal stability (so the cathode will not overheat or catch fire)[151]. The EC import reliance was 32%[152] in 2017, but has since then increased and will continue to do so with the boost of battery production.

Deposits

Cobalt findings are, to a high extent, geographically concentrated in the African Copper Belt and there, within the DRC, the Democratic Republic of Congo (Congo, capital city - Kinshasa) which owns about

[145] https://investingnews.com/daily/resource-investing/battery-metals-investing/Lithium-investing/top-Lithium-producers/
[146] https://www.mining-technology.com/features/top-ten-biggest-Lithium-mines/
[147] https://seekingalpha.com/article/4205681-look-Lithium-clay-projects
[148] https://americanmanganeseinc.com/
[149] https://www.chemicool.com/elements/Cobalt.html
[150] https://pubs.usgs.gov/of/2017/1155/ofr20171155.pdf
[151] Li, M., & Lu, J. (2020). Cobalt in Lithium-ion batteries. Science, 367(6481), 979-980. http://pibmub.com/pdf/979.full.pdf
[152] https://op.europa.eu/en/publication-detail/-/publication/08fdab5f-9766-11e7-b92d-01aa75ed71a1 p 33f

half of the world's known deposits.[153] Other big deposits are located in Australia, about 17% of all known deposits, with remaining sites shattered over the globe and often exploited as co-product of Copper and Nickel mining.[154]

Deposits in Europe

In Europe, there are deposits of Cobalt in Finland (with four working mines and a large deposit in Talvivaara, currently unexploited but restarting[155]) and some other (probably smaller[156]) deposits in an early stage of development or exploration in Poland, Germany, Italy, Cyprus, Slovakia, Austria and Czech Republic.[157] Other unquantified sources of Cobalt are old Copper and Nickel waste heaps that can be exploited by bioleaching processes like the one in Kasese, Uganda.

Production

Cobalt is mined from several ores: Cobalt arsenic-, Nickel Cobalt sulphide-, Copper Cobalt sulphide-, Copper Cobalt oxide- and Nickel Cobalt laterite ores. This is done both in ordinary mines following each country's mining codes and rules, but also under more makeshift conditions. An estimated 35.000 children work in privately owned artisanal Cobalt mines, often without any protection, which indicates another kind of mining.[158] The biggest Cobalt-producing companies often also produce Nickel and Copper. The five largest companies producing Cobalt are Glencore PLC, China Molybdenum, The Fleurette Group, NYSE VALE and Gecamines SA. Of these, all but VALE have their major operations or all operations, in the DRC. VALE also operates in Canada and New Caledonia. [159]

Refining

Cobalt is recovered from these ores by different processes for each concentrate, including roasting, solvent extraction, electrolysis, among others. In the DRC, this is done in many different ways that disregard environmental protection and health regulations. Cobalt can also be bioleached in a more environmentally friendly but slower way, as in the KCCL plant in Uganda, using copper mining waste heaps as resource.[160] [161] China is strong in the Cobalt refinery sector, but European projects are on the

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[153] https://www.statista.com/statistics/264930/global-Cobalt-reserves/
[154] https://pubs.usgs.gov/of/2017/1155/ofr20171155.pdf
[155] https://im-mining.com/2018/08/22/former-talvivaara-Nickel-mine-rebound-terrafame/
[156] It is only possible to clearly evaluate the dimensions after exploitation works have started.
[157] Alves Dias P., Blagoeva D., Pavel C., Arvanitidis N., Cobalt: demand-supply balances in the transition to electric mobility, EUR 29381 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-94311-9, doi:10.2760/97710, JRC112285. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC112285/jrc112285_Cobalt.pdf
[158] https://www.raconteur.net/business-innovation/responsible-business-2019/Cobalt-mining-human-rights
[159] http://www.centuryCobalt.com/Cobalt
[160] Brochot, S., Durance, M. V., Villeneuve, J., d'Hugues, P., & Mugabi, M. (2004). Modelling of the bioleaching of sulphide ores: application for the simulation of the bioleaching/gravity section of the Kasese Cobalt Company Ltd process plant. Minerals Engineering, 17(2), 253-260.
[161] https://youtu.be/CCzDIv38qAA a Youtube documentary from the FP6 Biomine research project, see from 22.30.

way. The Belgian metal recycler Umicore, with some Cobalt processing in Belgium, has bought the Kokkola plant in Finland from the Canadian Freeport Cobalt (who will continue to run the operations) and are about to start Cobalt processing and battery precursor production in Nysa, Poland, as well. [162]

Trade and logistics

The price of Cobalt has soared 180% in two years and development is steep and volatile[163]. The price of Cobalt on London Metal Exchange (presently at $33 per kilogram) was at a 10-month low in June 2020, due to pandemic-related factors. The supply of Cobalt is generally considered reliable than other metals. Shortages, together with reports of production conditions in the DRC stimulate innovation in cathodes' chemistry to limit the use or remove Cobalt from battery production altogether. A Roskill market report summary expresses hopes that "the Cobalt market is now entering a new phase of consolidation and rejuvenation". [164]

Politics and environment

Cobalt has been called "blood metal" and "conflict metal" and some production conditions in the DRC are unquestionably highly unsatisfactory. Companies selling Cobalt often guarantee child-free labour under fair conditions, but the Cobalt produced in artisanal mines finds reliable distribution channels anyway. Apple, Google, Dell, Microsoft and Tesla have become involved in a lawsuit against Congolese families and human rights advocates concerning child labour with many casualties and serious injuries when mining Cobalt for the supply chains of US corporations became precarious and fatal.[165] This is something companies buying Cobalt desperately try to avoid.

Development and trends

The version of Tesla's Model 3 to be produced in its Gigafactory in China (Shanghai) has no Cobalt in its batteries – using Lithium iron phosphate (LFP) batteries from CATL instead[166] and Tesla's new dry-electrode battery chemistry[167] (from Maxwell technologies) is expected to contain just a small quantity of Cobalt. In Li-Ion chemistries, the use of Cobalt has been reduced and limited to approximately 3% of a battery's weight. In existing cell chemistries, it can be substituted (but not totally replaced) by Nickel, which is less expensive and is integrated in stable supply chains.

Recycling

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162 https://www.umicore.com/en/media/press/umicore-to-acquire-Cobalt-refinery-and-cathode-precursor-operations-in-finland/
163 https://www.forbes.com/sites/greatspeculations/2018/02/27/the-worlds-Cobalt-supply-is-in-jeopardy/
164 https://roskill.com/market-report/Cobalt/
165 https://www.theguardian.com/global-development/2019/dec/16/apple-and-google-named-in-us-lawsuit-over-congolese-child-Cobalt-mining-deaths
166 https://www.futurecar.com/3972/Tesla-Wins-Approval-to-Use-Cobalt-Free-Batteries-in-its-China-made-Model-3
167 https://electrek.co/2020/05/05/tesla-million-mile-battery-less-Cobalt-higher-energy-density/

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Cobalt can be recycled to a high degree, but these processes, often involving acids, bring about environmental hurdles. There is much optimism, though; some stakeholders hope that Cobalt will prove itself to be an "infinitely recyclable metal".[168]

Nickel

Nickel has considerable strengths, does not corrode easily and conducts heat and electricity[169]. It has been used in batteries for a long time, as in NiCd and NiMH batteries, and now in Li-Ion batteries. It helps delivering higher energy density and lowering the cost as it can be successfully used as a partial replacement for Cobalt.[170] The EU import reliance for Nickel 2017 was listed at 59%[171], higher than for Cobalt.

Deposits

Some of the global Nickel deposits are believed to have their origin in meteorites, as in Canada (11% of world reserves). The biggest deposits are in Australia (30%), followed by New Caledonia (15%), Canada (11%) and Russia (7%). The world's core is believed to have a high Nickel content, which is, of course, unavailable.

Deposits in Europe

Finland, Greece, France (in New Caledonia, a French overseas territory) and Spain prospect for Nickel,[172] and exploration at scale is ongoing in Sweden. Europe's biggest deposit, in Talvivaara, Northern Finland, is a bioheapleaching plant using natural bacteria. It is now run by Finnish Terrafame, as the Talvivaara-Sotkamo corporation went bankrupt in 2013 after an environmental disaster, a bioleaching fluid leakage into a nearby lake system.[173] [174]

Production

Nickel is mined from lateritic ores as garnierite (in Australia and New Caledonia), and Ni-sulfidic ores as pentlandite (in Canada, Russia). [175] The biggest producers during 2018 were VALE (Headquarter in Brazil), Norilsk Nickel (Russia), Jinchuan Group Ltd (China-based), Glencore, BHP Billiton, Sumitomo Metal Mining (Japan), Sherrit International Corp (Canada), Framet (France), Anglo American and Minara Resources.[176]

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[168] https://globemetal.com/5-key-benefits-of-recycling-Cobalt/
[169] Habashi F. (2013) Nickel, Physical and Chemical Properties. In: Kretsinger R.H., Uversky V.N., Permyakov E.A. (eds) Encyclopedia of Metalloproteins. Springer, New York, NY. https://doi.org/10.1007/978-1-4614-1533-6_338
[170] https://www.Nickelinstitute.org/about-Nickel/Nickel-in-batteries
[171] https://op.europa.eu/en/publication-detail/-/publication/08fdab5f-9766-11e7-b92d-01aa75ed71a1 p 33f
[172] https://www.oma.on.ca/en/multimedialibrary/resources/NickelintheEuropeanUnionPDF.pdf
[173] https://www.mining.com/finland-inks-266-million-deal-revitalize-europes-largest-Nickel-mine/
[174] http://www.nuclear-heritage.net/index.php/Talvivaara_mine:_environmental_disaster_in_Finland
[175] https://mineralseducationcoalition.org/elements/Nickel/
[176] https://www.thebalance.com/the-10-biggest-Nickel-producers-2339731

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Refining

Lateric ores are processed in electric reduction furnaces (producing Nickel oxide), followed by hydrometallurgical treatment, often with ammonia. Sulfidic ores have a higher energy content and flash smelting from ore concentrates is common, producing Nickel matte (the principal metal extracted before a final pyrometallurgical reduction process). [177] Then different metallurgical processes follow to produce almost pure Nickel (with the Mond process) or to produce Nickel salts.[178]

Trade and logistics

In August of 2020, Nickel had a spot price on London Metal Exchange of $14,15 per kilogram. Roskill latest market report on Nickel forecasts that the use of this metal in batteries will grow from 3–4% of the total Nickel demand, to about 15–20% of the demand, which will affect prices.[179]

Politics

The trade has been irregular due to US-China trade wars, but the price is on the way up due to increased demand from China. According to Amnesty International, Nickel mines in some developing countries, such as Guatemala and the Philippines, have very unsatisfactory working conditions yet states and corporations try to capitalise on the Nickel demand without scruples. Nickel is sometimes discussed as a ‘conflict’ metal. However, it is less critical then Cobalt because most of the mining of this metal is being done in appropriate working conditions.

Development and trends

According to the Nickel Institute, Nickel is the 5th most common element on earth, with about 600 million-ton deposits available for land and sea mining. So far, about 60 million tons were depleted. However, production capacity will be critical. EV production is rising the demand for Nickel considerably.

Recycling

Nickel is recycled to a high extent; presently about 68% is recycled.[180]

Manganese

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177 https://www.ifc.org/wps/wcm/connect/5cb00df9-e2c1-4b92-a585-6bef08d8a5de/Nickel_PPAH.pdf?MOD=AJPERES&CVID=jqeDjcl
178 http://metalpedia.asianmetal.com/metal/Nickel/extraction.shtml
179 https://roskill.com/market-report/Nickel/
180 https://www.recyclingtoday.com/article/driving-Nickel-scrap-recovery/

Manganese is a metal, commonly found as oxide and hydroxide in soils. [181] In Li-Ion batteries, it can improve the cathode in different ways and can, at least to some extent, be a very cheap alternative to Cobalt and Nickel.[182] The EU import reliance in 2017 was listed at 89%.[183]

Deposits

South Africa holds the biggest known reserves of manganese, followed by Ukraine, Brazil, Australia and India.[184]

Deposits in Europe

In the Czech Republic, the Chvaletice Manganese Project, developed by European Manganese Inc, is aiming at taking advantage from tailing piles originated from earlier mining, which maintain high manganese content.[185]

Production

Manganese mining is often an open pit soil operation with heavy earth machines. In Ukraine and in South Africa, there are also underground mines, often explored through the room-and-pillar method.[186]

Refining

From a concentrate, the manganese in a pure form is retrieved by hydrometallurgy and electrolysis. Ferro- and silicomanganese are produced by smelting. [187]

Trade and logistics

Manganese is sold and delivered in many forms, from ores and concentrates to oxides or pure metal. The price is considered low and stable.

Regarding the politics and the environment, presently Manganese is not a ‘conflict’ metal. Its mining and refining processes can have environmental consequences and too much manganese exposure has its risks.

Recycling

Manganese is recycled from scrap and can also be bioleached.[188]

Graphite

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181 https://www.lenntech.com/periodic/elements/mn.htm#ixzz6Uz2fZR6F
182 https://www.chemistryworld.com/news/manganese-makeover-for-Lithium-ion-batteries/3008886.article
183 https://op.europa.eu/en/publication-detail/-/publication/08fdab5f-9766-11e7-b92d-01aa75ed71a1 p 33f
184 https://investingnews.com/daily/resource-investing/battery-metals-investing/manganese-investing/manganese-reserves/
185 https://www.mn25.ca/chvaletice-project
186 https://mineralseducationcoalition.org/minerals-database/manganese/
187 https://www.britannica.com/technology/manganese-processing
188 Ghosh, S., Mohanty, S., Akcil, A., Sukla, L. B., & Das, A. P. (2016). A greener approach for resource recycling: Manganese bioleaching. Chemosphere, 154, 628-639.

Carbon in the structural form of graphite is a mineral used in anodes in Li-Ion batteries, in its both natural and synthetic forms. It is safe and reliable as active material of anode, with sufficient energy density for high-density and mobile applications.[189] The EU import reliance for natural graphite was listed in 2017 as 99%.[190]

Deposits.

Turkey has the world's largest natural graphite reserves, followed by China, Brazil, Mozambique and Tanzania.[191] Turkey is increasing production, but owns, just as China does, a lot of the less attractive amorphous type of natural graphite.[192] Crystalline, vein and flake graphite has a higher price, but high-flake graphite can be too expensive for some applications. Battery producers seem to have different preferences.

Deposits in Europe

Norway, Czech Republic, and Austria have some natural graphite reserves and exploration reported to be of high quality. [193]

Production

Natural graphite is mostly mined in quarries where graphite in flakes, veins and crystal formations are found and less underground where lower quality amorphous lump graphite is common. China is, by far, the largest graphite producer in the world, with a reported production of 630 000 tons, in 2018, while the runner up, Brazil, produced 95 000 tons and Canada 40 000 tons. [194] The biggest companies are China Carbon Graphite Group in China and Syrah Resources in Brazil.

Refining

Graphite flakes are rounded into spherical units and then go through a thermal or acid purification. China producers often use the acid method, which is considered less environmentally friendly. [195]

Politics and environment

China is the biggest producing country and dominates the market. Reports suggest the country is also interested in increasing imports from Africa and other locations and stockpile graphite, probably to secure supply for battery cell production and as a preparation for higher price levels. [196]

Recycling

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[189] Lampe-Onnerud, C., Shi, J., Onnerud, P., Chamberlain, R., & Barnett, B. (2001). Benchmark study on high performing Carbon anode materials. Journal of power sources, 97, 133-136.

[190] https://op.europa.eu/en/publication-detail/-/publication/08fdab5f-9766-11e7-b92d-01aa75ed71a1 p 33f

[191] https://www.statista.com/statistics/267367/reserves-of-graphite-by-country/

[192] http://www.indmin.com/events/download.ashx/document/speaker/6517/a0ID000000X0jN5MAJ/Presentation

[193] http://www.indmin.com/downloads/IM%20MAPS/GraphiteWallchart2018980x650PRINThighres.pdf

[194] https://investingnews.com/daily/resource-investing/battery-metals-investing/graphite-investing/top-graphite-producing-countries-china-india-brazil-canada/

[195] https://www.batteryminerals.com/our-business/spherical-graphite-process/

[196] https://stockhead.com.au/resources/chinas-graphite-imports-are-now-up-2000-over-the-last-18-months/

Presently, graphite is not significantly recycled[197], but reliable methods seem to be under development.[198] [199]

Silicon

Silicon is a grey semi-conductive metalloid. Silicon is seldom found in the elementary form in nature, but is the second most abundant element in the earth's crust (behind oxygen). In batteries, it is an alternative to graphite as active material in the anode.[200] The EU import reliance is 64%.[201]

Deposits

Silicon is a widespread globally, but elementary silicon is very rare. It is preferably mined from very pure quartz. Additionally, silicon exists in minerals such as silica, feldspar and mica – major components of quartz and sandstone rocks.

Production

China stands presently for about 65% of global Silicon production, followed by Russia, Brazil and USA. In Europe, the Euroalliages Silicon-Metal Committee whose member companies are from Bosnia Hercegovina (B.S.I. d.o.o), Norway (Elkem), Spain (Ferroatlantica), Norway (Fesil), France (Ferropem), Germany (RW Silicium) and Northern Macedonia (Jugohrom),[202] declares a total production of about 330 000 tonnes/year. In Iceland, the PCC Bakki-Silicon company claims to have the world's most environmentally friendly silicon production.[203]

Refining

After mining and sorting, reduction of quartz with Carbon takes place at high temperatures in a reduction furnace. The metal is further processed by oxidative refining, casting, crystallization and crushing. The biggest five companies selling refined products are Dow Corning, Wacker, Shin Etsu and Blue Star.[204]

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[197] https://www.semcoCarbon.com/blog/3-reasons-graphite-recycling-is-better-than-disposal
[198] Moradi, B., & Botte, G. G. (2016). Recycling of graphite anodes for the next generation of Lithium ion batteries. Journal of Applied Electrochemistry, 46(2), 123-148.
[199] Rothermel, S., Evertz, M., Kasnatscheew, J., Qi, X., Grützke, M., Winter, M., & Nowak, S. (2016). Graphite recycling from spent Lithium-ion batteries. ChemSusChem, 9(24), 3473-3484.
[200] Ashuri, M., He, Q., & Shaw, L. L. (2016). Silicon as a potential anode material for Li-ion batteries: where size, geometry and structure matter. Nanoscale, 8(1), 74-103.
[201] https://op.europa.eu/en/publication-detail/-/publication/08fdab5f-9766-11e7-b92d-01aa75ed71a1 p 33f
[202] http://www.euroalliages.com/web/silicon_metal%20committee/1011306087/list1187970111/f1.html
[203] https://www.pcc.is/
[204] https://www.metalbulletin.com/events/download.ashx/document/speaker/7230/a0ID000000X0jzwMAB/Presentation

Politics and environment

According to sources, China has a history of increasing production and dumping prices of Silicon, making production in other countries more difficult.[205]

Recycling

Silicon is usually not recycled and no technologies for recycling Silicon used in batteries have been successfully implemented, but there are methods for recycling silicon wafers from scrapped solar panels.[206]

3.1.4 Job Roles and Skills

Very few relevant job advertisements were found in the desk research in comparison with other value chain steps. This must be compensated by workshops and surveys in the future. Listed job roles are not specific to mobile or stationary application but to the whole battery sector.

For materials preparation, handling, and management, advertisements concerning **Supply Chain Managers, Manufacturing Engineers, Production Engineers** and B**attery Materials Engineers, High Density Anodes** or **Cathodes Material Engineers, Material Planners** and **Handlers** were found. **Operator** and **Machine Operator** jobs are associated with this value chain step. They operate machines and do all the procedures (material combining, slurry mixing, coating, etc.) to produce materials needed for next value chain steps.

These processes are accompanied and supported by **Calibration Technicians, Controls Engineers, Equipment Engineers, Maintenance Engineers and Metrologists** who calibrate the equipment and assure that all the machines are performing as expected. **Shift Leaders** are also present. **Quality and Compliance Engineers** verify and manage the quality of products and **Process Engineers** seek continuous process improvement.

Safety Specialists and **Managers** as well as **ISO Internal Auditors** assure the safety standards and requirements are met.

Skills and knowledge required in relevant advertisements:

205 https://www.crmalliance.eu/silicon-metal
206 https://www.chemistryworld.com/news/a-bright-future-for-silicon-solar-cell-recycling/9160.article

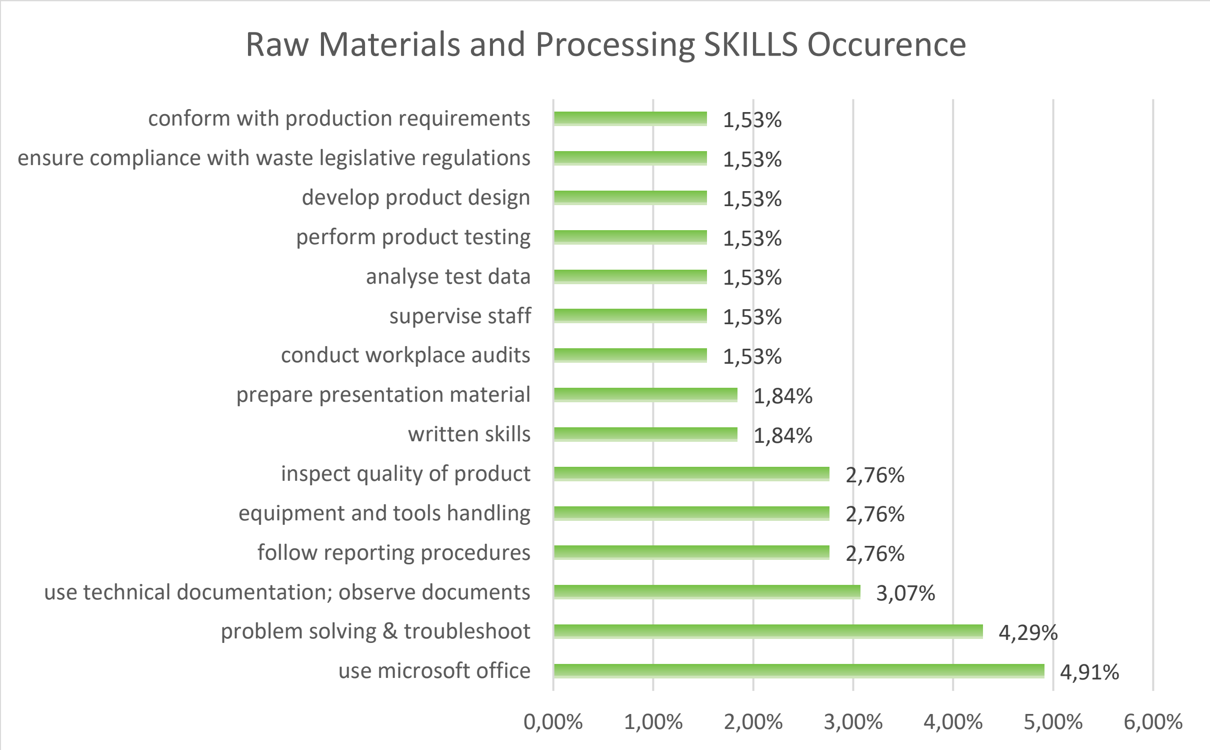

Figure 14 Raw Materials and Processing SKILLS Occurrences

Skills

Skills occurrences for raw materials and processing, which are based on the researched job advertisements, are shown in Figure 14**.** Usage of Microsoft Office was the most frequent skill in the researched offers as well as problem solving and troubleshooting, document management and observation and follow up of reporting procedures. Inspection of product quality and equipment and tools handling are also being requested.

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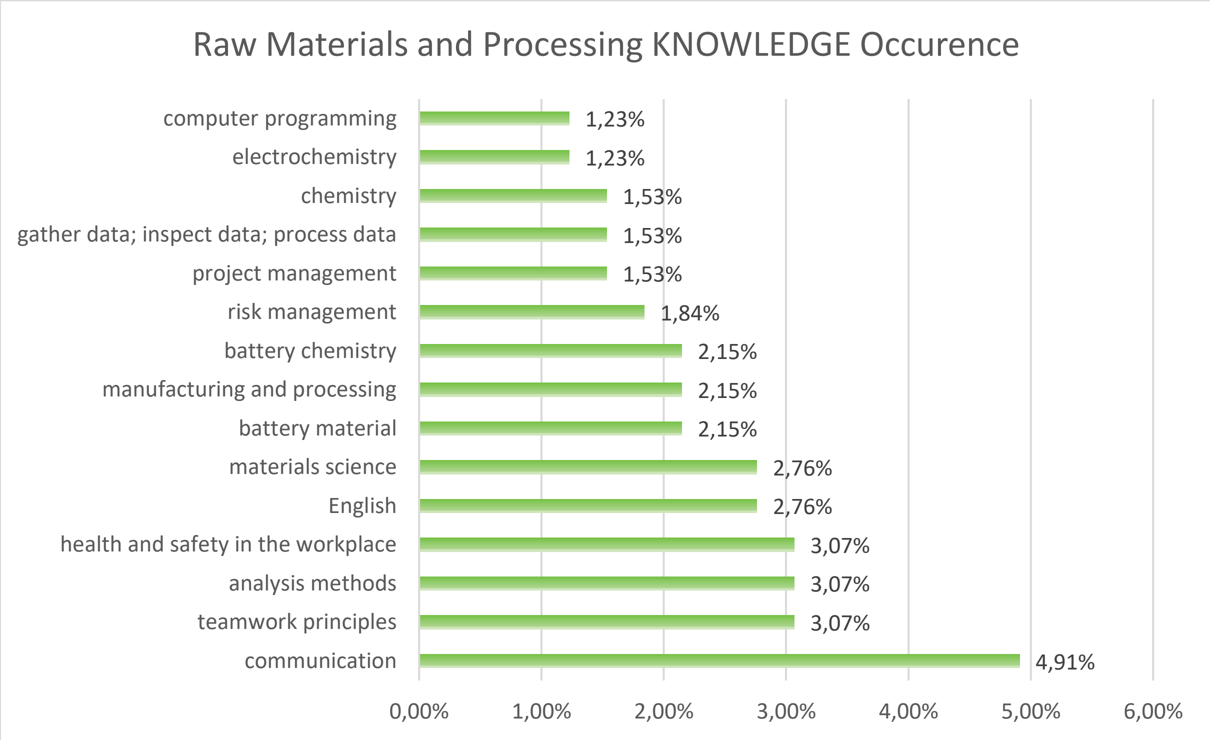

Figure 15 Raw Materials and Processing KNOWLEDGE Occurrence

Knowledge

Knowledge occurrences for raw materials and processing are shown in Figure 15. Communication and teamwork principles are on the top positions as well as health and safety in the workplace and analysis methods. Materials science and battery material are required in this stage of the production as well as battery chemistry associated with general chemistry and electrochemistry knowledge.

3.2 COMPONENTS AND CELL MANUFACTURING

3.2.1 Stakeholders

Due to the high pressure to reduce greenhouse gas emissions (GhG), fossil fuel combustion technology is slowly phased out. EVs and battery storage for storing green energy are beginning to expand. Consequently, big players in the field of batteries are building their Gigafactories in Europe. Most of these producers come from Asia, which means that Europe is dependent on their production. Most of these projects are sponsored by the EIB.[207][208]

[207] https://www.eib.org/en/press/all/2020-088-electric-vehicle-battery-production-in-europe-gets-boost-thanks-to-eib-loan-of-eur480-million-to-lg-chem-wroclaw-energy-in-poland

[208] https://www.eib.org/en/press/all/2020-208-european-backing-for-northvolt-s-battery-gigafactory-in-sweden

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Most European manufacturers tend to focus on specialized production on a smaller scale, because they cannot compete on price or production volume.[209] Figure 16.

LG Chem

LG Chem is planning to open their Gigafactory in Wroclaw by 2022. It will be one of the biggest factories in Europe with production reaching 70 GWh per year. The company wants to employ about 6.000 full-time workers by the end of 2022.[210][211]

CATL

CATL is building the first European factory in Germany. The factory should start manufacturing batteries in 2022 and the production capacity will be 14 GWh/year. It is planned to expand production up to 24 GWh/year in the future. The factory will offer about 2.000 jobs and will produce batteries for BMW, VW, Daimler and Volvo. [212]

Northvolt

Northvolt owns a Gigafactory in Skellefteå Sweden, which will be in operation as from 2022.The aim of the factory is to produce 32 GWh per year by 2024 and increase the capacity to 40 GWh/year in the future. The factory is set to provide about 2,500 jobs. Northvolt plans to build more LIB factories in the future. The condition for the location of each factory is the possibility of power supply from renewable energy sources. The factory produces batteries for BMW and VW. [213] [214]

AMTE

AMTE, in partnership with Britishvolt, plans to build a Gigafactory in Wales. The factory should be operational by the end of 2023. Total production should be between 30 and 35 GWh/year. The factory should hire about 3,500 employees. At the same time, another 10,000 to 15,000 jobs should be created by the suppliers.[215]

SAFT

SAFT is building its first Gigafactory in the Hauts-de-France region and its second in Kaiserslautern, Germany. The French factory should be in operation as of 2023 with a production of 8 GWh/year and an expansion to 24 GWh/year is foreseeable. The German factory will open in 2024 with the same

[209] https://www.reuters.com/article/us-climate-change-eu-batteries-insight/european-battery-makers-power-up-for-a-green-recovery-idUSKCN2590K3
[210] https://www.ebrd.com/news/2019/lg-chem-battery-gigafactory-in-poland-to-be-powered-by-ebrd.html
[211] https://www.electrive.com/2020/04/24/lg-chem-secures-ehalf-a-billion-for-polish-factory-expansion/
[212] https://www.electrive.com/2019/10/19/catl-starts-building-battery-plant-in-germany/
[213] https://www.electrive.com/2019/02/26/northvolt-to-build-32-gwh-battery-plant-in-sweden/
[214] https://northvolt.com/production
[215] https://www.electrive.com/2020/06/15/britishvolt-amte-planning-uk-battery-plant/

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production as the French factory. The overall goal is to reach 48 GWh/year as of 2030. The main battery production will be for the PSA Group.

Tesla

Tesla is building its newest Gigafactory near Berlin - Germany. The Gigafactory will include a giant line for the production of EVs (first will be Model Y), but also a large line for the production of new Tesla batteries. Giga Berlin should open by July 2021.[216]

VW

The VW Group plans to produce more than 50 EV models, so they want to be partially independent of battery suppliers. They want to open their own factory in Salzgitter at the turn of 2023/2024. Their target is a production of 16 GWh/year and then expand, within the next years up to 24 GWh/year. The factory is being built in cooperation with Northvolt. [217]

SK innovation

SK innovation is building two factories in Hungary. The first should be in operation this year (2020) and should produce 7,5 GWh/year of batteries. The second will be completed in 2022 and will produce 10 GWh/year. The factory produces batteries for Hyundai, Daimler and VW.[218]

Verkor

The French company Verkor plans to open its gigafactory in France. Their goal is to produce 16 GWh/year and then expand to 50 GWh/year in line with the foreseen market growth. The factory will directly provide more than 2,000 jobs and thousands more in the supply chain.[219]

Samsung SDI

Samsung built the first battery factory in 2018. It is located near Budapest in Hungary. Production is about 2,5 GWh/year. They are building the second Hungarian Gigafactory. The factory will be in operation in 2021 and will produce 7,5 GWh/year. The running factory produces batteries for BMW, VW and Volvo Trucks. [220]

InoBat

Slovak start-up, which has the support of CEZ Group, Wildcat Discovery Technology and etc., built a factory in Voderady, Slovakia. Production should start in 2021 with a volume of 100 MWh per year. The company deals with specialized batteries according to the needs of

[216] https://www.teslarati.com/tesla-gigafactory-berlin-2m-vehicles-per-year-media/
[217] https://www.electrive.com/2020/05/09/volkswagen-builds-battery-factory-in-salzgitter/
[218] https://insideevs.com/news/392140/sk-innovation-new-battery-plants-us-hungary/
[219] http://verkor.com/#partners
[220] https://www.automotive-iq.com/electrics-electronics/articles/top-five-ev-battery-factories-in-europe

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individual customers. They also plan to build a factory with a production of 10 GWh. The factory should open in 2024.[221]

FREYR

The Norwegian company FREYR is starting to build a fast track facility for LIB production in Mo Industrial Park in Northern Norway (Mo-i-Rana) in autumn of 2020 to produce 2GWh energy storage annually. Partners are the Norwegian Technical University (NTNU) and SINTEF, a large Norwegian research Institute. EIT Innoenergy supports the project. The pilot plant will be followed by a scaled-up facility for 32GWh energy storage per annum by 2025, also in Northern Norway.[222]

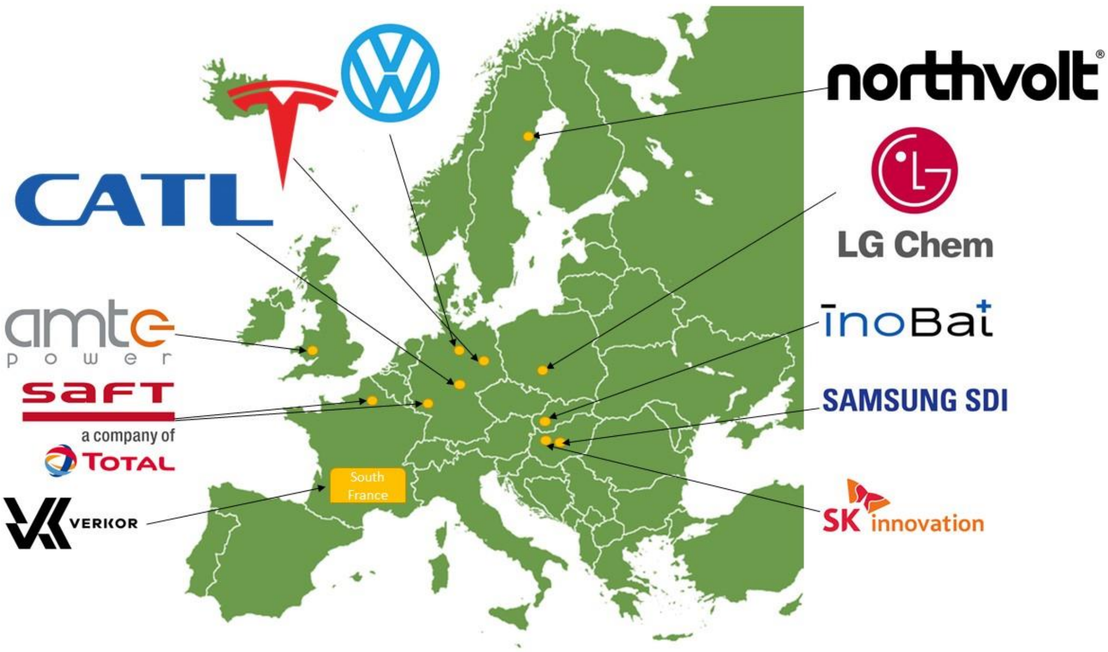

Figure 16.Location of stakeholders' factories

3.2.2 Cell Components

Drivers of Change for cathode and anode components

The different technologies that effectively allow for the full replacement of Cobalt without loss of performance are still to be adopted and batteries using Lithium Cobalt oxide (NMC,

[221] https://tech.eu/brief/inobat-funding/

222 https://news.cision.com/freyr/r/freyr-advances-the-development-of-its-initial-site-for-norway---s-first-battery-cell-facility,c3183404 (last accessed on 30.082020)

NCA) dominate the EV battery industry with an increasing market share of nearly 96% in 2019, according to Figure 17. The same could be stated about LIB applications in Grid Storage Technologies (GSTs).

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.

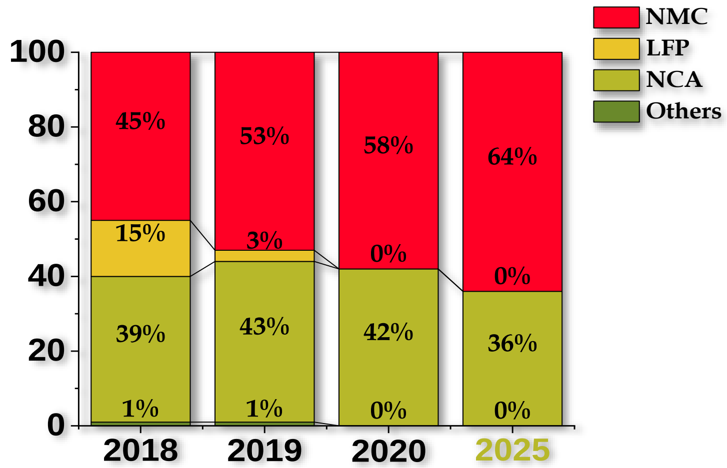

Figure 17. Adoption rate per Chemistry in EV battery Market. Adapted from the source[223,224]

In recent years, scientific and technological progress in batteries has been largely motivated by the automotive industry and, specifically, by small vehicles for urban transportation. Nevertheless, electric mobility is also associated with recent trends of aerial and maritime applications as well as e-Bikes, electric motorcycles, and others.

According to the European Commission[225], **shipping** accounts for 2 - 3% of global greenhouse gas (GHG) emissions, with a forecasted increase of 50 – 250% by 2050[226]. However, maritime applications have a market share of less than 1% of the total LIBs market, whereas Li-based

[223] Jurgens, J., *This is why NCm is the preferable cathode material for li-ion batteries*. 2019.
[224] KrannichSolarGermany (2020). *LG Chem ESS cell*. Available at: https://www.youtube.com/watch?v=CU0RGPnwYYA&feature=emb_title (accessed: 23 July 2020).
[225] Commission, E. *Commission publishes information on CO2 emissions from maritime transport*. 2019 [cited 2020; Available from: https://ec.europa.eu/clima/news/commission-publishes-information-co2-emissions-maritime-transport_en.
[226] Commission, E. *Reducing emissions from the shipping sector*. 2020 [cited 2020; Available from: https://ec.europa.eu/clima/policies/transport/shipping_en.

batteries are the most widely used battery type for maritime applications[227]. The difficulty in implementing electric solutions on ships is mainly related to their higher power density and cycle and calendar life demands, as well as safety requirements. Nevertheless, the number of ships with batteries installed, or contracted, more than doubled from 2018 (150 ships) to 2020 (314), which constitutes a major leap on the market, indicating that LIBs are reaching an interesting level of maturity[227].

Airbus, Boeing, and NASA have targeted **aircraft** electrification as a crucial research and development topic to address. One thing all current aircraft-level projects have in common, as is the case of maritime and automobile applications, is the choice of Li-ion batteries for energy storage due to their unmatchable energy density when compared with other batteries in the market.

Li-Ion Batteries (LIB) for stationary applications

The term *Grid Energy Storage* (GES) refers to any method used to store electrical energy that is being produced at a facility connected to an electrical grid.

Drivers of Change for Grid Energy Storage

Motivations for employing GES solutions include:[228,229]

- Peak shaving in low voltage (LV) grid;
- Load levelling in LV grid;
- Integration of renewable energy into the grid;
- Frequency regulation;
- Voltage control;
- Power management.

All the above-mentioned factors concern operators' responsibilities towards consumers. However, with the development of renewable energy technologies, such as solar panels and thermal solar collectors, end consumers with this type of equipment installed may also benefit from GES:[228]

[227] Helgesen, S.H., Sondre and A. Aarseth Langli, *Electrical Energy Storage for Ships*. 2020: Norway.
[228] Bussar, R., et al., *Battery Energy Storage for Smart Grid Applications*. 2013, Eurobat.
[229] Chen, T., et al., *Applications of Lithium-Ion Batteries in Grid-Scale Energy Storage Systems.* Transactions of Tianjin University, 2020. **26**(3): p. 208-217.

- Time-shift for self-consumption;
- Time-shift for feed-in;
- Smoothing of renewable energy sources (RES) feed-in:
- Uninterruptible Power Supply (UPS).

Presently, load levelling and integration of renewable energy into the grid constitute the main motivation and challenges for GES. In fact, the European Union aims to become the world's first climate-neutral continent by 2050, which translates into a target of 20% in the share of energy from renewable sources (concerning gross final energy consumption) by 2020[230]. Consequently, achieving proper load levelling is an increasingly critical challenge, given the inherent difficulty in adjusting electricity consumption and generation with renewable energy sources (RES). As such, GES will play a vital role in reaching climate neutrality[231]. Even though there are other alternatives for mitigating this problem, namely, demand-side management with load shifting and interconnection with external grids, GES can improve overall power quality and reliability.

The implementation of GES is obtained using a variety of different technologies with very distinct physical principles. Abdin and Khalilpour[232] enumerated solutions for electrical energy storage based on the following sources: **(1)** mechanical, using flywheels (kinetic energy), compressed air (pressure energy) and pumped hydro storage systems PHS (potential energy); **(2)** electrochemical, using solid-state batteries (SSBs) and flow batteries; **(3)** electrical; **(4)** thermal (latent, sensible and thermochemical heat); **(5)** chemical; and **(6)** hybrid energy storage.

Traditionally, large-scale PHS has provided almost 99% of worldwide storage capacity[228]. Although harvesting energy by using a fluid's potential energy is an ancient technique, it remains the dominant energy storage technology[237] e.g. water in dams). However, as LIBs and flow battery technology progresses, electrochemical energy storage is becoming more relevant, owing it to its clear advantages regarding complexity and flexibility requirements, as in the case of large-scale energy storage projects[17] and facilities located on sites where a large mass of water isn't readily available.

Electrochemical and electrical energy storage

[230] Eurostat. *Renewable energy statistics*. 2020 [cited 2020; Available from: renewable
[231] Gottke, V. *Energy storage and the EU: the push for carbon neutrality is underway*. 2020 [cited 2020; Available from: https://www.energy-storage.news/blogs/energy-storage-and-the-eu-the-push-for-carbon-neutrality-is-underway.
[232] Abdin, Z. and K.R. Khalilpour, Chapter 4 - Single and Polystorage Technologies for Renewable-Based Hybrid Energy Systems, in Polygeneration with Polystorage for Chemical and Energy Hubs, K.R. Khalilpour, Editor. 2019, Academic Press. p. 77-131.

Batteries developed for GES applications and those developed for mobile applications have some requirements in common. This can be seen by observing the similarities between chemistries in Table 2, Table 3 and Table 4, yet, high specific energy and power is a fundamental aspect of batteries for EVs, while for stationary the mass requirements are not so critical. Moreover, total output power and energy needed are substantially larger in GES. Battery life is also a major concern for both. In stationary projects, however, total life expectancy, in years, is typically far greater than that demanded for mobile applications, thus increasing calendar life issues associated with the former.

Besides LIBs, other types of SSBs are widely used in grid applications, namely, Nickel-based and Na-S batteries (which operate in the 300 - 350°C range, with molten liquid Na, leading to safety issues; Na and Li are alkali metals and there is no way to use various substances to extinguish an alkali metal fire besides allowing it to run out).

Nickel-Cadmium (Ni-Cd) SSBs, despite their absence from recent years' implementations, are still in use throughout several facilities, having been installed in some earlier energy-storage applications[233]. Despite having long life cycle, excellent calendar life and requiring low maintenance, their limited energy density, high toxicity (due to Cadmium) and memory effect render this technology inefficient except for a limited range of applications when compared to LIBs, especially due to recent technological advances for the latter[16,112].Having already reached a stage of technological maturity, current research topics related to Ni-Cd batteries are concerned with its recycling methods.

Solid-state batteries (SSBs) and particularly LIBs, are the most cost-effective solution for short storage durations[234].

[233] Association, E.S. *Nickel-Cadmium (Ni-Cd) Batteries*. Why Energy Storage 2020 [cited 2020; Available from: https://energystorage.org/why-energy-storage/technologies/nickel-cadmium-ni-cd-batteries/.

[234] McKay, C. *How three battery types work in grid-scale energy storage systems*. 2019 [cited 2020; Available from: https://www.windpowerengineering.com/how-three-battery-types-work-in-grid-scale-energy-storage-systems/.

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Redox-flow batteries (RFB) (liquid-state) have their energy capacity limited by the size of the electrolyte tanks and battery power by the size of the battery[17]. Consequently, adding more power and/or energy is simply done by adding more cells stacks[227] or increasing the dimensions of the tanks. Moreover, Vanadium Redox Flow Batteries (VRFBs), the most developed among flow RFBs[16], possesses very large life cycle[17] which, coupled with the advantages on design flexibility, renders VRFBs an interesting alternative for stationary applications.

Lithium batteries, flow batteries, and Zinc-hybrid batteries are regarded as the most significant GSTs for the near future[234].

Table 1. Capacity, thermal runaway temperature, and plateau voltage for different cathodes (reference values).[235]

Cathode type	Formula (general)	Experimental Capacity ($mAh.g^{-1}$) Cut off@2 V[236]	Plateau voltage (V vs Li^0/Li^+)	Thermal runaway (°C)	Cycle life (No. of cycles)[237]
Lithium Nickel-Cobalt-Aluminium oxide (NCA)	$LiNiCoAlO_2$	175	4.3-3.5	150	500
Lithium-Manganese-Oxide (LMO)	$LiMn_2O_4$	120-130	4.3-3.8	250	300 - 700
Lithium Nickel-Manganese-Cobalt oxide (NMC)	$LiNiMnCoO_2$	150	4.3-3.7	210	1000 - 2000
Lithium Cobalt Oxide (LCO)	$LiCoO_2$	150	4.3-3.8	150	500 - 1000
Lithium-Iron Phosphate (LFP)	$LiFePO_4$	160-170	3.3	270	>2000

Table 2. Different cathodes used in EVs and their main characteristics.

Cathode type	Ratios (R) or Cell designation (S)[238]	Manufacturer	No. of cells (series, parallel)	EV Model	Specific Energy (Wh/kg)	Energy (usable) (kWh)	Range, combined (WLTP values) (km)
Lithium Nickel-Cobalt-Aluminium oxide (NCA)	18650 (S)	Panasonic	8256 (s96p86)	Tesla Model S Tesla Model X	162	102.4 (98.4)	593, 487
	2170 (S)	Panasonic	4416 (s96p46)	Tesla Model 3	168	80.5 (76)	530

[235] City, S., The State Of Ev Batteries: Lg Chem, Sk Innovation, & Tesla–Panasonic Improvements. 2020.
[236] Voltage at which the capacity is determined.
[237] Significantly dependent on specific application and environment. Some cathodes reach cycle lives far greater than the displayed values (e.g. Yuasa's LEV50 battery's LMO cathode retains 80% capacity after 5500 charge/discharge cycles)
[238] Ratios – Metal proportions used for NMC, as explained above; Cell designation – refers to a cell's dimension, as will be explained in chapter 3.2.

Lithium-Manganese Oxide (LMO)		Yuasa	80	Citroen Zero (LEV50 battery)	107	14.5	150
Lithium Nickel-Manganese-Cobalt oxide (NMC)	532 (R)	Nissan	288	Nissan Leaf e+		62	385
		CATL	216 (s108p2)	Peugeot e-208 Opel Corsa-e	140	50 (46)	349, 336
		ENVISION AESC	192 (s96p2)	Nissan Leaf	130	39.5 (36)	270
	333 (R)	Samsung SDI	264 (s88p3)	Volkswagen e-Golf	103	35.8 (32)	232
	721 (R)	LG Chem	192 (s96p2)	Renault ZOE	168	54.7 (52)	394
	622 (R)	Samsung SDI	96 (s96p1)	BMWi3	152	42.2 (37.9)	293 - 303
		SK Innovation	294 (s98p3)	Kia e-Soul Kia e-Niro	148	67.5 (64)	451, 454
		LG Chem	168 (s84p2)	Volkswagen e-Up, Seat Mii Electric, Skoda CITIGOe iV	148	36.8 (32.3)	256 – 273
			176 (s88p2)	Hyundai Ioniq Electric	112.4	40.4 (38.3)	310
			294 (s98p3)	Hyundai Kona Electric	149	67.5 (64)	447
			384 (s96p4)	Mercedes-Benz EQC	130	85 (80)	417
			396 (s198p2)	Porsche Taycan	148	93.4 (83.7)	333 – 407
			432 (s108p4)	Jaguar I-Pace	149	90 (84.7)	470
				Audi e-tron 55 quattro	136	95 (86.5)	402
			288(s96p3)	Chevrolet Bolt	143	68	417
Lithium-Cobalt Oxide (LCO)		LG Chem	96	Smart Fortwo electric	150 - 200	17.6 (17.2)	120 – 135
Lithium-Iron Phosphate (LFP)		Elektrofahrzeuge Stuttgart		IRIDIUM E-MOBIL (electric mobile home)	90 – 120	106	400
		CATL		Tesla Model 3 (Chinese market)	125	106	400
		BYD Blade	102	BYD Han EV		65	506

Table 3. Commercially available anodes and their main features.

Anode type	Application	Voltage (V vs Li^0/Li^+)	Capacity ($mAh.g^{-1}$)	Specific Energy (Wh/kg)	Cycle life
Graphite (C)	Most of the commercially available batteries	0.15 – 0.25	375	100 – 156	2000
Lithium-Titanium Oxide $Li_4Ti_5O_{12}$ (LTO)	LFP batteries	2.40	175	50 - 80	3000 – 7000
Silicon	Nanowire (SiNW) Amprius Technologies: Airbus Zephyr S pseudo satellite HAPS Military vehicles	0.4	4200 (Silicon) 3579 (SiNW)	435 (Amprius)	>2000 (SiNW)

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Table 4. Commercially available GES batteries and their main features.

Cathode	Anode	Cell type	Plant	Power (kW)	Energy (kWh)	Operating Temperature (°C)	No. of cells (series, parallel)	Battery Manufacturer
NCA	Graphite	2170	Hornsdale powerplant (Tesla's Powerpacks)	150000	193500	-10 to 50		Tesla; Panasonic (Tesla's powerpack)
		2170	Strata Oxnard, California (Tesla's Megapacks)	100000	400000			Tesla; Panasonic (Tesla's megapack)
		2170	Tesla Moss Landing	182500	730000			
NMC	Graphite	Prismatic cells with Al exterior	Alamitos Energy Center, Long Beach, California (Fluence's Advancion 5 batteries)	100000	400000			Samsung SDI
LCO	LTO		Sendai Substation (Toshiba's SCiB)	40000	20000		24 (s12p2) per module	Toshiba
			Tohoku Minami-Soma (Toshiba's SCiB)	40000	40000			
LFP (BYD) LCO (Toshiba)	Graphite (BYD) LTO (Toshiba)		Zhangbei National Wind and Solar Energy Storage and Transmission Demo. Project	530000	36000			BYD; Toshiba
S	Na (liquid)		Abu Dhabi's main utility	108000	648000	300 to 350		NGK Insulators
			Transmission operator in Terna, Italy	35000	245000			
			Buzen Substation, Buzen, Fukuoka, Japan	50000	300000			
Ni-Cd			Golden valley Electric Association BESS	27000	25000	-52 to 32	13760	Saft Batteries
			Island of Bonaire	3000				

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3.2.3 Cell manufacturing

Due to LIBs dominant role in the battery segment, we will be focusing on manufacturing processes for this type of battery.

Drivers of Change for cell manufacturing

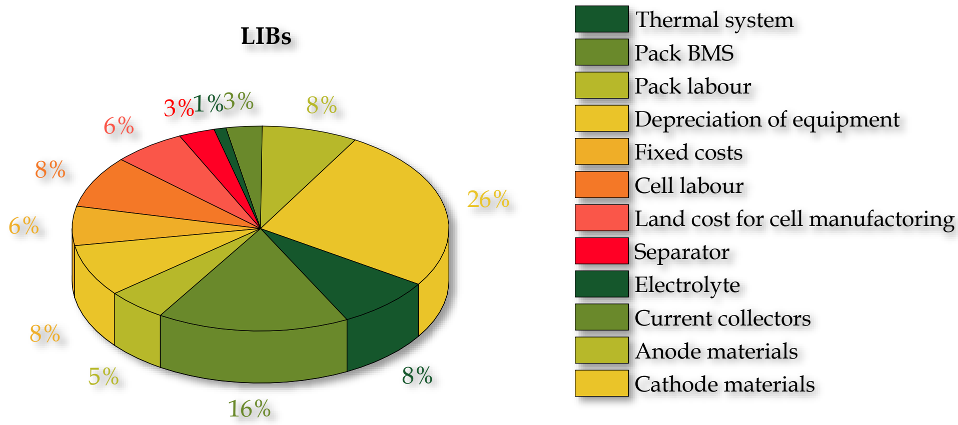

Figure 18. Relative costs for the fabrication of LIBs.

Presently, batteries account for up to 50% of the total cost of an EV[239]. Moreover, out of all costs associated with LIBs, **material costs** are the most significant; based on Figure 18, considering only separator (3%), electrolyte (1%), current collectors (3%), anode materials (8%) and cathode materials (26%), 41% of total battery cost is reached, with the most significant contribution owed to the **cathode material**. The development of new manufacturing processes is paramount for reducing these costs, and the predicted increase in EV (and, thus, LIBs) sales for the next decade, will pave the way for larger scale production capacities in cell manufacturing, allowing for further investments and a reduction of overall costs.

In order to obtain a liquid electrolyte battery cell, cathode and anode are insulated by a separator and wetted by an electrolyte solution, while the flow of electrons is assured by current collectors[239]. Liquid electrolytes, which are typically highly flammable, constitute one of the main safety concerns regarding 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.

[239] Heimes, H., et al., *Manufacturing of lithium-ion battery cell components*. 2019.

Manufacturing process for electrodes

Li-based cathodes and graphite anodes are manufactured according to the stages presented in Figure 19

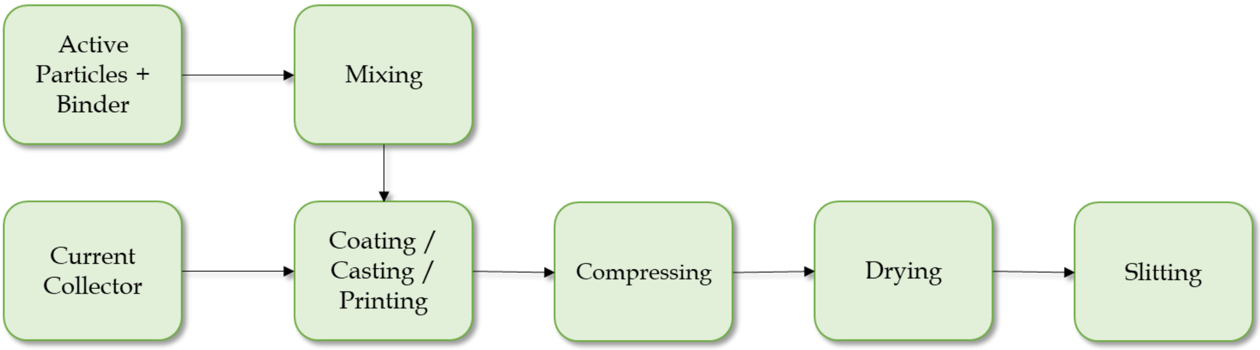

Figure 19. Electrode manufacturing [2]. Flowchart adapted from the source.

The active materials are mixed with a binder to form a slurry, achieved by mechanically mixing the base metals in a reactor tank, carefully added until the desired proportions are obtained. Heat is supplied to aid mixing and control precipitation reactions[1239]. After mixing, the electrode is plasticized, allowing to handle the material and its deposition on the current collector[115], typically as a continuous strip. Deposition can be achieved employing tape **casting, printing, and coating**, though the latteris the most used for LIBs current technologies. Coating speed is between 35 and 80 m/min.[239] Figure 20 depicts this type of manufacturing processes, often accompanied by a final measurement of total thickness. Next, the electrode is compressed by roll pressing. Thus, porosity is decreased, allowing for minimum electric contact resistance between the current collector and active particles. Finally, the strip is cut to the desired dimensions for cell assembly – ***slitting***.

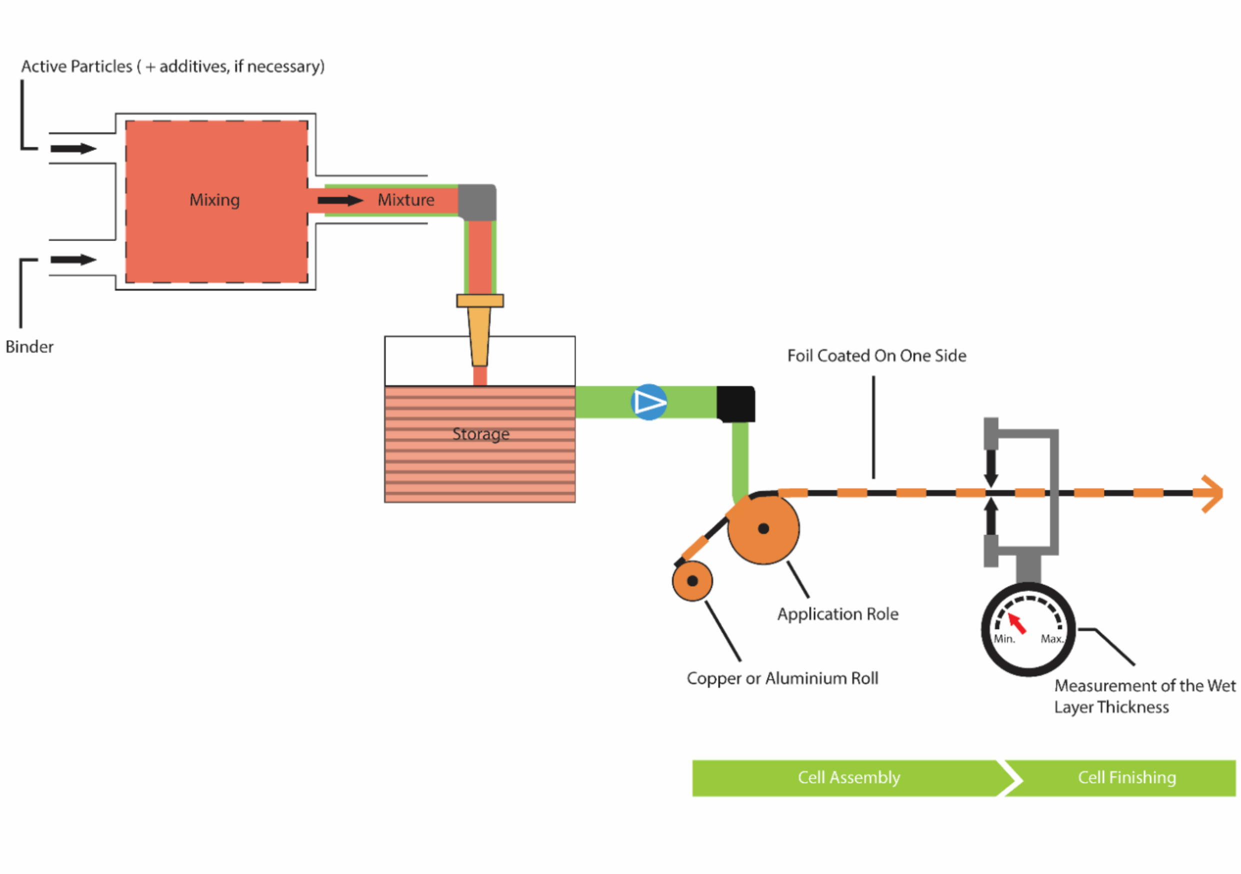

Figure 20. Main steps for electrode manufacturing using coating processes. Adapted from source[239]

Cathode manufacturing

For LIBs, the current collector used for cathodes is a 15 – 25 μm thick aluminium foil[239]. Active particles used are metal oxides which determine the cathode's designation as discussed previously. These compounds were mentioned and described in Table 1.

Anode manufacturing

Graphite anodes are obtained from **graphitization** of soft Carbon (pitch coke). This process requires high temperatures (in the 2400 to 2800°C range[240]), with the mixture of pitch and coke forming a graphite structure in the shape of graphite layers.[239] Copper is the material of choice for a graphitic anode's current collector.

LTO anodes are processed in a similar way to cathodes. Moreover, current collectors used for this type of anodes consist of Aluminium foil.

[240] Chung, D.D.L., *1 - Carbon Fibers, Nanofibers, and Nanotubes*, in *Carbon Composites (Second Edition)*, D.D.L. Chung, Editor. 2017, Butterworth-Heinemann. p. 1-87.

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Electrolyte solution

The fundamental requirements for electrolyte selection are good ionic conductivity and electrical resistivity, besides its inertia towards chemical reactions with the electrodes' materials. From ceramics, gels, solid polymers, ionic liquids, and liquids, the latter dominates commercial applications, especially for EVs. Liquid electrolytes are solutions usually consisting of carbonate solvents and lithium salts, namely Lithium Hexafluorophosphate ($LiPF_6$), the most used salt for liquid electrolytes. The salt provides the initial Li^+ content in the electrolyte.

Battery module manufacturing

Popular commercially available formats include cylindrical, prismatic, and pouch-shaped cells. These geometries are all depicted in Figure 21.

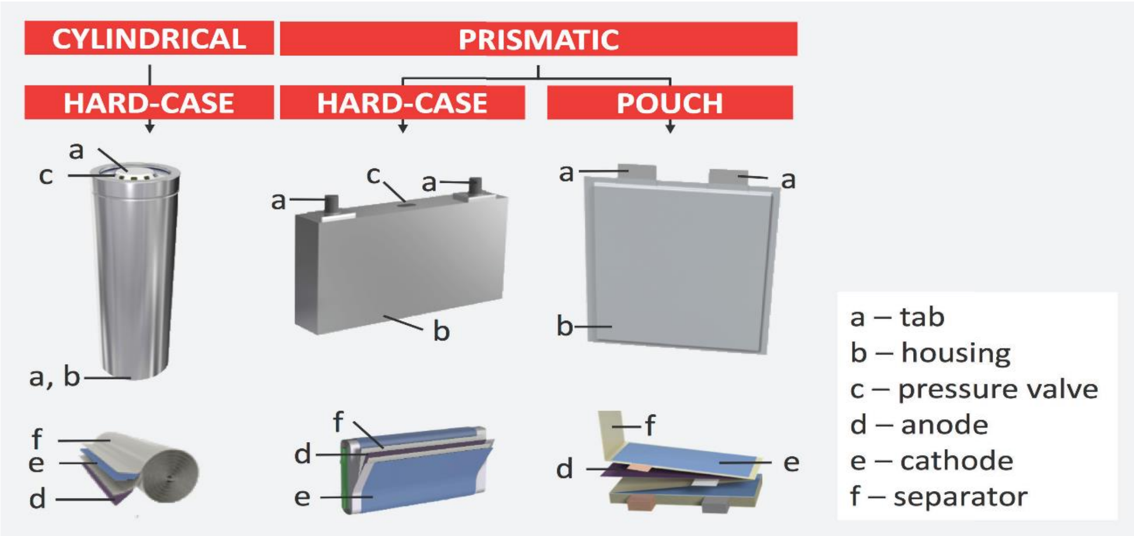

Figure 21. Different cell geometries for LIBs. According to the source.[241]

Cylindrical cells are among the earliest assembly designs for batteries. Nonetheless, they remain very popular on the market. The assembly is obtained by the cylindrical winding of three sheets: anode, separator, and cathode[115] originating a jellyroll. The jellyroll is bonded by tab welding, using ultrasonic or laser welding techniques[241]. A cylindrical **housing** is necessary for allocating the electrical components since it should be capable of withstanding mechanical loads and user handling. This housing is manufactured by deep drawing a metal sheet, a process that plastically deforms a metal sheet, typically made of Aluminium or stainless steel[242]. To establish an electric current during charge

[241] Schröder, R., M. Aydemir, and G. Seliger, *Comparatively Assessing different Shapes of Lithium-ion Battery Cells.* Procedia Manufacturing, 2017. **8**: p. 104-111.
[242] University, B. *BU-301a: Types of Battery Cells*. 2011 2019 [cited 2020; Available from: https://batteryuniversity.com/index.php/learn/article/types_of_battery_cells.

and discharge, **current connectors** are necessary. They make the contact between the cell and the device being powered. Connection is, thus, obtained via tabs, identified in Figure 22. Positive and negative terminals are connected to the respective electrodes.

After **packaging** (at cell level), cell activation is initiated with **electrolyte filling**, **sealing** the housing, formation, and aging of the cell.

During the **formation stage**, the solid electrolyte interphase (SEI) is formed in the initial charges, a very important step for assuring no premature degradation of the electrolyte.[115] Batteries that meet the required standards after SEI formation are fully charged and stabilized.

The final stage of cell manufacturing, the **aging**, consists of a month of storage under constant temperature and humidity. The objective is to detect short circuits and measure the performance – the battery is discharged to check for its capacity, which allows for its grading and commercialization.

Prismatic cells, very often installed in batteries for EVs, follow the same manufacturing procedure as cylindrical cells, except for the substitution of cylindrical winding by **flat winding and housing** shape. For prismatic geometry, the housing is also obtained by sheet metal stamping processes. However, both die and punch have rectangular geometries.

Pouch cells can be considered a type of prismatic cells. Their distinctive visual characteristic is the absence of a hard case. They are **sealed in a flexible foil** made of an Aluminium-Polymer electrical insulator compound, with raw materials being stacked, instead of using winding processes. **Stacking** is achieved either by single sheets of electrodes, or by z-folding the separator, and, then, insert the electrodes[241]. Figure 22 is a schematic illustration of both stacking options.

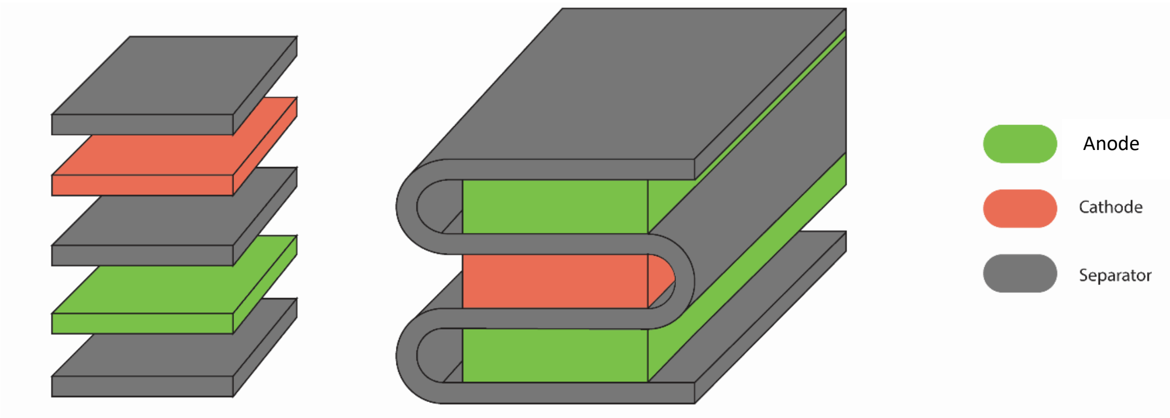

Figure 22. Stacking sequence of pouch cells, either by single sheets of electrode (to the left) or by z-folding the same component (to the right)

Electrolyte filling requires a vacuum, applied on the partially sealed cell, due to the stacked geometry. The final step before the formation is to complete the sealing of raw materials with flexible foil.

Once the formation process is completed, a pouch bag previously incorporated is filled with gas, which is absorbed during this step. The bag is removed, and the pouch cell permanently sealed. Aging of prismatic cells follows the same procedure as in the case of cylindrical cells.

Even though the dimensions of cells vary between manufacturers, all commercialized cells must comply with standards ISO/PAS 16898:2012 and DIN 91252 - 2016-11.

Market trends for cell geometry

The majority of NMC batteries installed in the EVs included in Table 2 are **prismatic and pouch cells.**

LG Chem's NMC622 cells are being sold with the latter geometry. The company appreciates that this geometry is slimmer and lighter than prismatic cells, which leads to utilization cost and space savings. Other advantages include superior thermal management and improved aging of the cells, a result of its manufacturing process (stacking).[1]

Nissan is using pouch cells for its Leaf and Leaf+ models. Samsung's technologies for EVs are based on prismatic cells.

NCA batteries follow a distinct trend, as Panasonic uses cylindrical cells. This explains why cell designation is included in this chemistry in Table 2. The 18650 cells have a diameter of 18 mm and a length of 65 mm, while 2170 cells have a diameter of 21 mm and a length of 70 mm.

3.2.4 Job Roles and Skills

Considering the job advertisements for the components and cell manufacturing there were very few found in comparison with other value chain steps. This must be compensated by workshops and online surveys in the future. Listed job roles are not specific to mobile or stationary application but to the whole battery sector.

For the manufacturing of components and cells **Material Engineers for Cathodes and Anodes**, **Electrical Engineers/Battery Specialists, Manufacturing Engineers, Mechanical Battery Design Engineers** are being searched for as well as **Production Engineers** for specific components of the batteries and cells like **Top Cap[243] Engineers**.

[243] Battery top cap assembly that closes an upper end of an opening of a cylindrical secondary battery.

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Operators and Machine Operators who operate machines and do all the necessary procedures are also associated with this value chain step.

These processes are accompanied and supported by **Calibration Technicians, Controls Engineers, Equipment Engineers, Maintenance Engineers and Metrologists** who calibrate the equipment and assure that all the machines are performing as expected. **Shift Leaders** are also required. **Quality and Compliance Engineers** verify and manage the quality of products and **Process Engineers** seek continuous process improvement.

Safety Specialists and **Managers** as well as **ISO Internal Auditors** assure the safety standards and requirements are met.

Skills and knowledge required in relevant advertisements:

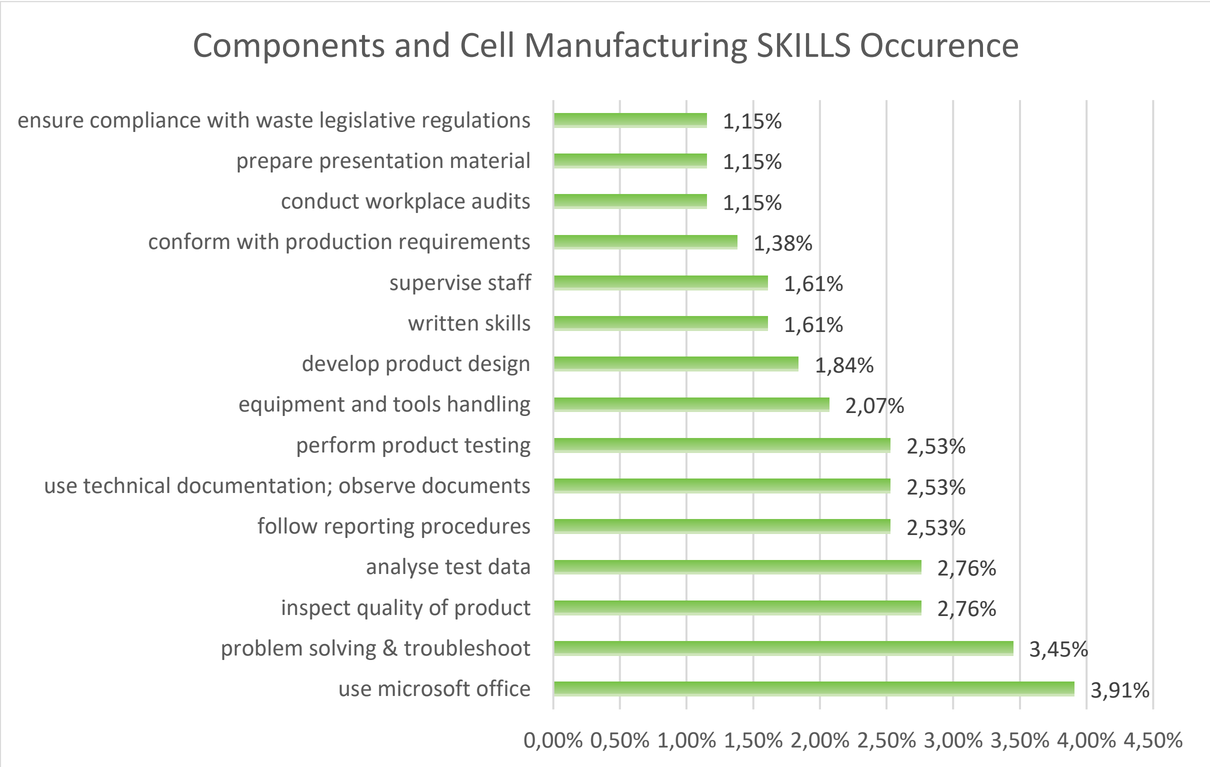

Figure 23. Components and Cell Manufacturing SKILLS Occurrence

Skills

Skills occurrence for components and cell manufacturing are shown in Figure 23 Usage of Microsoft Office was the most frequent skill in the researched offers as well as problem solving and troubleshooting, document management and observation, and following of reporting procedures. Inspection of product quality, design and testing of a cell is, as expected, in the first half of the list.

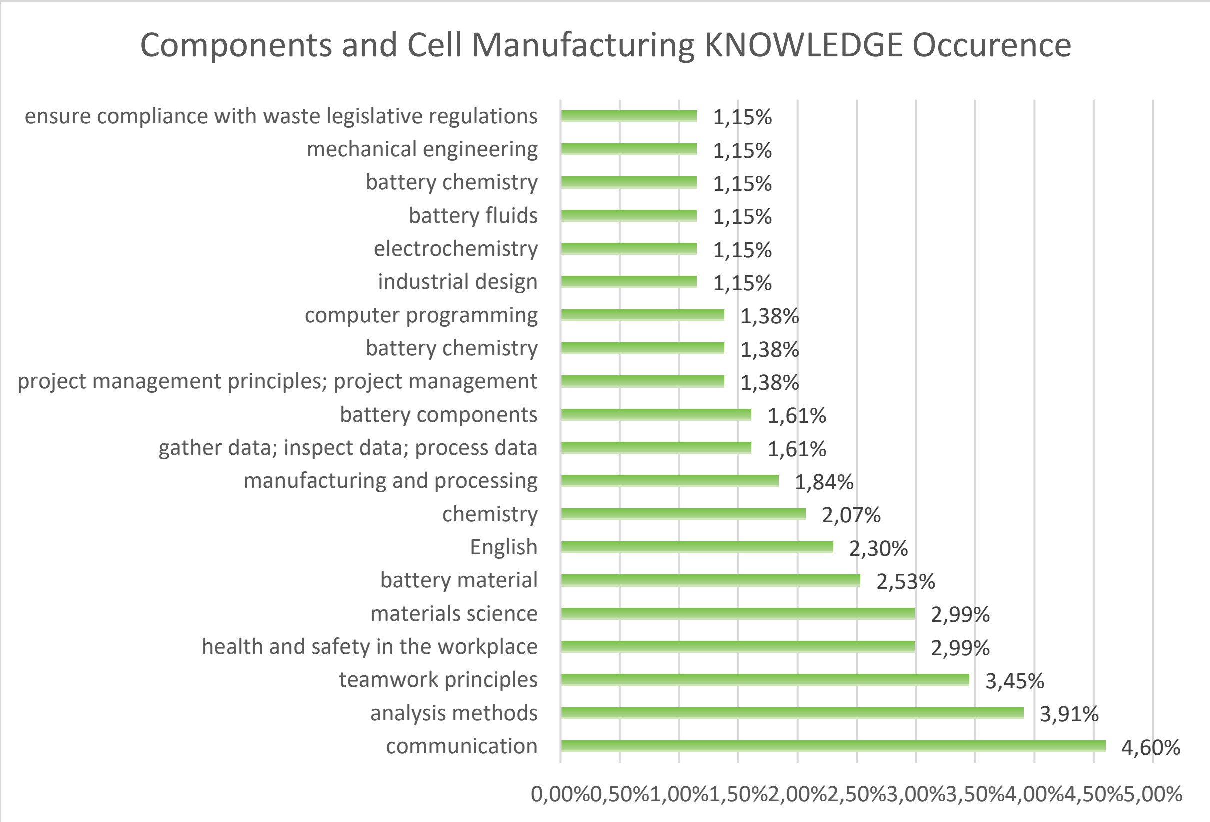

Figure 24. Components and Cell Manufacturing KNOWLEDGE Occurrence

Knowledge

Knowledge occurrence for raw materials and processing are shown in Figure 24. Communication and teamwork principles are on the top positions as well as health and safety in the workplace and analysis methods. Materials science and battery material and components knowledge are required in this stage of the production, as well as battery chemistry associated with general chemistry and electrochemistry knowledge.

3.3 MODULE AND PACK MANUFACTURING

For stationary and mobile applications such as EVs, LIBs are used in the form of a pack. This pack consists of several blocks of battery modules, battery management system (BMS) master, and battery thermal management system (BTMS). Design possibilities on the pack arrangement, include series and parallel stacking of modules, as previously mentioned, and highlighted in Table 2.

Regardless of the cell's chemistry, the way the cells are combined into a **module** and modules combined into a **pack** has total influence on the usable energy and the total range because the number of cells in series defines the total voltage while the number of cells in parallel and their shape/dimensions define(s) the capacity of the battery. Both voltage and capacity depend on the chemistry of each cell. Therefore, the same cell chemistry built by the same manufacturer leads to **very different values** due to the number of cells in series and parallel per module. This evidence can be easily comprehended by comparing values between EV models with NMC622 cells manufactured by LG Chem[244] in Table 2.

As for the mobile applications/automotive industry, the car manufacturers often perform module and pack assembly in-house. Modules and packs are critical in determining an EV's range and charging rate, vehicle manufacturers want to control the way the battery pack space is used and cooled. Going forward, battery packs might become an even more essential aspect of vehicle design.[245]

3.3.1 Module and Pack Assembly

A battery module is obtained when cells are packed together with a BMS slave and sensors. These components are insulated by the module's housing. Presently, the most important module types for EVs are prismatic and pouch-shaped cells, with the increasing popularity of the latter.

Cell stacking procedure depends on whether prismatic, pouch or cylindrical cells are used for the battery module. Prismatic cells require an adhesive layer between them. Besides assuring the mechanical link, this layer must be electrically insulating, thus preventing short circuits.[239] After being all glued together, the cells are pre-loaded to minimize swelling during charge and discharge, after which they are placed inside the insulation housing. As for pouch cells, each one is inserted into a

[244] Lithium and cobalt: A tale of two commodities (McKinsey, 2018)
[245] https://www.bcg.com/publications/2018/future-battery-production-electric-vehicles (last accessed on 28.08.2020)

frame, and the action of springs prevent high volumetric expansion/contraction, similarly to prismatic cells.

Following the mechanical bond, it is necessary to ensure the electrical functionality of the set. Contact tabs are electrically connected. This connection may either be **permanent** – guaranteed by welding processes - or **detachable**, using bolts and nuts. Although detachability is an advantage, connections with threaded fasteners typically bring about poorer electrical performance, with lower conductivity than permanent connections achieved by laser, ultrasonic or other welding techniques.

As a next step, the BMS slave is welded to the module, typically on top of the cells, with the temperature sensors.

Finally, power and COM cables are placed, and the lid fixed to the housing. In the end, a voltage test is performed, and the compliant module is ready to be inserted into a pack. Figure 25 shows a schematic of the assembly processes, clearly indicating that a module consists of a cluster of cells and a pack is a cluster of modules.

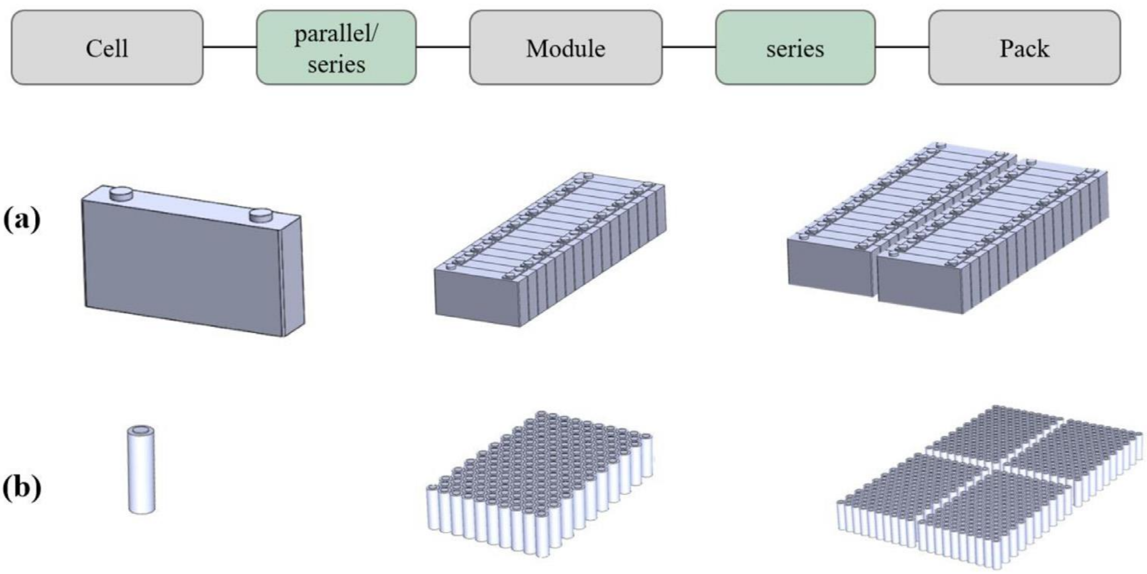

Figure 25. Overview of battery packs indicating two constructions with (a) cylindrical and (b) prismatic cells. Adapted from original source[246]

3.3.2 Job Roles and Skills

The differences based on the application are starting to be relevant at this stage.

[246] Zwicker, M.F.R., et al., *Automotive battery pack manufacturing – a review of battery to tab joining.* Journal of Advanced Joining Processes, 2020. **1**: p. 100017.

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As for the module and pack manufacturing, **Cell Module Engineers (Mechanical, Simulation, Electrical)** and **Manufacturing and Production Engineers** are working together with **Battery Design Engineers (Mechanical, Electrical)** on the development, design and functionality of a battery modules and packs. These are then assembled by Battery Assemblers as well as Machine Operators.

These processes are accompanied and supported by **Controls Engineers, Equipment Engineers, Maintenance Engineers and Metrologists** who calibrate the equipment and assure that all the machines are performing as expected. **Shift Leaders** are also present. **Quality and Compliance Engineers** verify and manage the quality of products and **Process Engineers** seek continuous process improvement.

Battery System Engineers and **Battery Test Engineers** and **Technicians** secure the preparation for further integration of the batteries into specific use cases (cars, vessels, etc. for mobile application and base stations, power grids, etc. for stationary applications).

Safety Specialists and **Managers** as well as **ISO Internal Auditors** assure the safety standards and requirements are met.

Skills and knowledge required in relevant advertisements:

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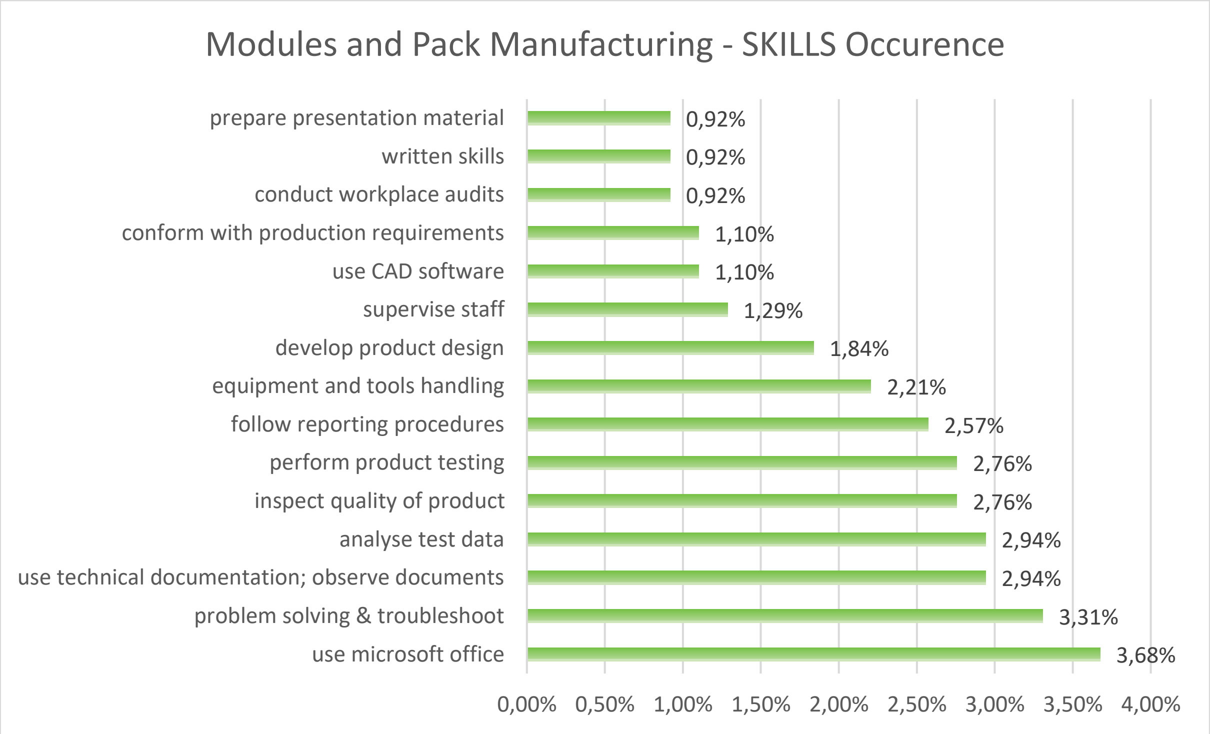

Figure 26. Module and Pack Manufacturing SKILLS Occurrence

Skills

Skills occurrence for module and pack manufacturing are shown in Figure 26. Usage of Microsoft Office was the most frequent skill in the researched offers as well as problem solving and troubleshooting, document management and observation and following of the reporting procedures. Testing is starting to be more frequent in this stage as well as development of product design with usage of Computer Aided Design (CAD) software and other related tools.

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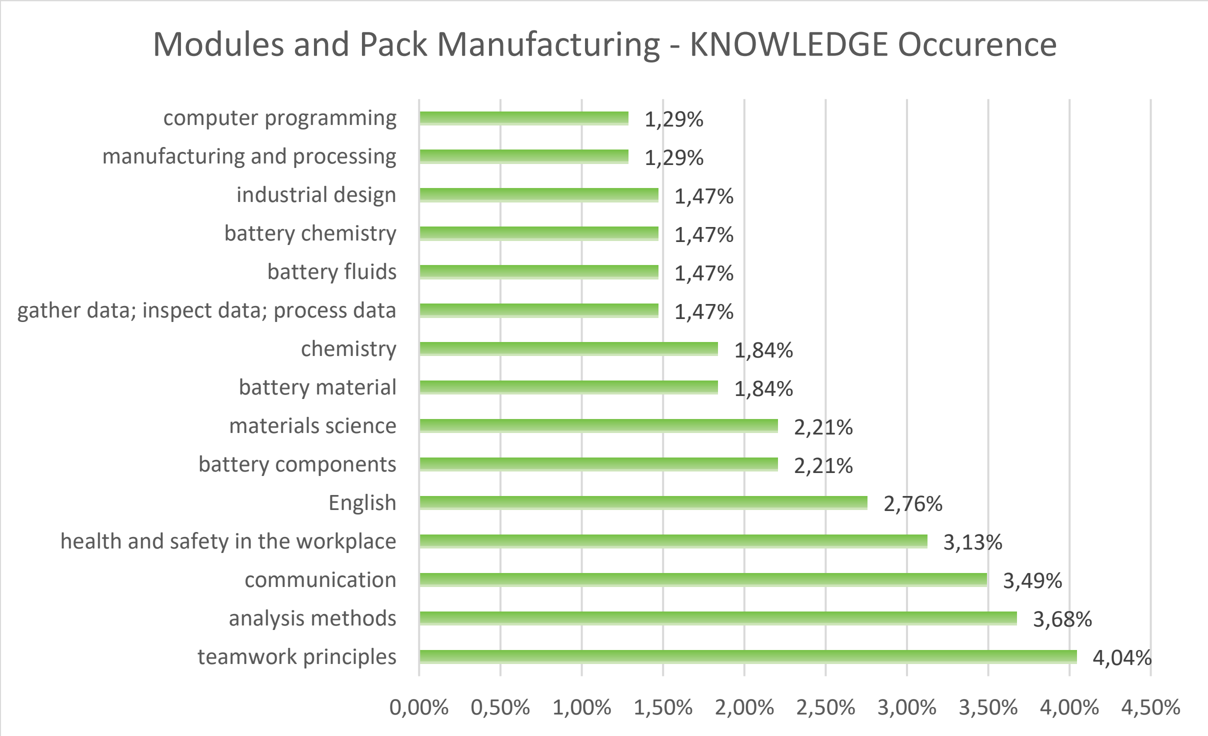

Figure 27. Module and Pack Manufacturing KNOWLEDGE Occurrence

Knowledge

Knowledge occurrences for module and pack manufacturing are shown in Figure 27. Communication and teamwork principles ranked on the top positions as well as health and safety in the workplace and analysis methods. Materials science and battery material and components knowledge is being required as well as competences in battery chemistry and fluids associated with general chemistry. Computer programming is starting to occur.

3.4 BATTERY INTEGRATION

This section describes the battery value chain step of the battery integration process. This is the last step before the battery goes into the working environment/applications. This step covers mainly integration of modules, Battery Management Systems (BMS), safety installations, electronic intelligence (algorithms needed).

3.4.1 Main Terminology

This section gives basic terminology and explanation of battery systems for the battery integration processes that are described further in 3.4.4 and 3.4.5.

Each battery pack requires simultaneous installation of a battery management system and battery thermal management system which together accounts for 24 % of total battery cost (excluding manufacturing labour costs related to the components).

3.4.1.1 Battery Management System (BTMS)

The BMS may fulfil a variety of functions depending on the particular application as well as the type and size of the battery, but the overall goal of the BMS is to keep the battery within the safety operation region in terms of voltage, current, and temperature during charge, the discharge, and certain cases at open circuit[247].

By achieving those goals, batteries will be efficient, with predictable behaviour and with no risk (inhabitants, staff, maintenance, etc.)[199].

Topology of BMS

Centralized: One central pack controller that monitors, balances, and controls all the cells**[248]**.

[247] Angel Kirchev, Chapter 20 - Battery Management and Battery Diagnostics, Electrochemical Energy Storage for Renewable Sources and Grid Balancing, Elsevier, 2015, Pages 411-435, ISBN 9780444626165, https://doi.org/10.1016/B978-0-444-62616-5.00020-6.

[248] Shanbhag, K. (2020, March 14). How to best select Battery Management Systems (BMS) for High Voltage Li-Ion Batteries. Retrieved August 04, 2020, from https://www.ionenergy.co/resources/blogs/hv-battery-management-systems/

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Modular: BMS is divided into multiple, identical modules, each with its bundle of wires going to one of the batteries in the pack. Typically, one module is a master that manages the entire pack and other modules are just remote measurement units[2].

Distributed: Distributed BMS uses few communication wires between the cell boards and a BMS controller, which handles computation and communications[2].

General functions of the BMS:[249, 250]

Cell voltage measurement and control

Monitoring of voltage across each series group of cells

Voltage excursions due to the overcharge, over discharge, or high-power pulses can lead to significantly reduced life and safety issues. Voltage is the critical input for the cell balancing algorithm, state of charge and state of health algorithms.

The main reason for the monitoring is to prevent overcharge which leads to the various chemical reaction and temperature rise which leads to the cell venting. Vented gases are highly flammable. The design of the battery must include a robust method for monitoring of the cells and for risk avoidance. The main response to this behaviour is that BMS request a change in power flow in/out of battery pack to bring voltage back within the limits; if some components might fail, the BMS has authority to open the contactors on the battery pack and stop all power flow.

Contactor control

BMS has the authority to control the contactors of the battery pack. This involves both the pre-charge contactor and main contactor(s). Contactors are managed by the contactor control algorithm which must confirm the state of the pre-charge process and the state of the

[249] Gianfranco Pistoia, Chapter 5 - Vehicle Applications: Traction and Control Systems, Battery Operated Devices and Systems, Elsevier, 2009, Pages 321-378, ISBN 9780444532145, https://doi.org/10.1016/B978-0-444-53214-5.00005-4.

[250] N.M. Johnson, 19 - Battery technology for CO2 reduction, Alternative Fuels and Advanced Vehicle Technologies for Improved Environmental Performance, Woodhead Publishing, 2014, Pages 582-631, ISBN 9780857095220, https://doi.org/10.1533/9780857097422.3.582.

different contactors. It must be assured that people do not get access to the high voltage system while it is energized.

Isolation monitoring

Isolation monitoring is another critical safety function which ensures that any fault of the system will not be exposed to the person in a dangerous way. It must be ensured that there is enough resistance between the high voltage system and the chassis (IEC 2007, ISO 2011). Monitoring and measurement are done by various methods and circuits.

Temperature measurement and control

BMS is responsible for battery pack and cell temperature control, strategy for monitoring and controlling is unique to each application. This data is needed to adjust heating, cooling, or pack power levels.

State of charge (SoC), state of health (SoH) calculation

Possibly the most complex algorithm within the BMS.

- **SoC** is the percentage of electrons available to do work compared to a fully charged battery.
    - This is useful for cell balancing, indication of electrical power limits including charge rate of the battery, operation modes and ranges in case of usage in vehicles, etc.
- **SoH** is broader measure of overall performance capability of the battery compared to its initial performance when new.
    - Does not require as urgent time accuracy as SOC. SOH estimates the battery's overall performance over time, loss of capacity, increase in resistance, etc.

Both calculations will continue to develop along with the chemistry of batteries.

Communications

BMS requires careful hardware and software design to assure maintenance of the safety goals of the system, as well as communication with the rest of the systems and the user interface if needed.

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Electronic Control Unit (ECU)

An ECU is a computer that performs a specific task, typically used in automotive and other branches of industry. Ultimately BMS as mentioned above could be considered an ECU since it is a separate computer system that performs a specific task; otherwise, the ECU could be considered as the logic part of the whole BMS.[251]

End of Line Testing

This term is related to the testing right after the battery modules are assembled. It includes quality and parameter control of the produced units with the related tests.[252]

- **Functional testing**
- **Performance testing**
- **Connection scanning**
- **Electrical testing including isolation tests**
- **Low voltages testing, sensor readings tests.**
- **Testing and calibration of BMS**
- **Parts checks**

3.4.1.2 Battery Thermal Management System (BTMS)[253]

The BTMS is an important and integral part of the BMS.

The main goal of the BTMS is to manage 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). While designing the battery and battery systems, the rate of heat dissipation must be fast enough so the battery does not reach the thermal runaway temperature which

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[251] Electronic Control Unit (ECU). (2015, September 22). Retrieved August 04, 2020, from https://www.orionbms.com/manuals/utility_jr/acc_ecu.html

[252] Quality Assurance within the Production. (n.d.). Retrieved August 04, 2020, from https://www.horiba-fuelcon.com/en/battery-end-of-line

[253] Khan, M.R.; Swierczynski, M.J.; Kær, S.K. Towards an Ultimate Battery Thermal Management System: A Review. *Batteries* **2017**, *3*, 9. Available from: https://www.mdpi.com/2313-0105/3/1/9/pdf

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would damage the electrolyte and electrodes and other battery components. The optimum range for most general batteries requires operating near room temperature (15-35 °C).
BTMS is comprised of a combination of hardware and software. It helps to enhance the lifetime of a battery while ensuring safe and secure operation of the battery pack. BTMS must be designed to suit application criteria either mobile or stationary (packing difficulty, costs, reliability, assembly difficulty, positioning, etc.).

BMTS Methods

Employed method inside of BTMS can be either for cooling, heating (electric), or insulating depending on the operating and ambient conditions. **Air** as the medium uses electric blowers or fans. **Liquid** BMTS include water, glycol, oil, acetone, **refrigerants**, and Phase Change Material (PCM) thermal management systems. Uniform and adequate cooling must be assured. Cooling or heating can be activated based on the rate of charge/discharge. This trigger is also dependent on altitude and geographical conditions. Proper insulation must be chosen based on these conditions as well. Figure 28.

Currently, most of LIBs are **liquid-cooled**, which brings complexity and potential leak issues related to the thermal regulation system. Some models use **passive or active air** thermal regulation, which is a much simpler and maintenance-friendly system. However, it requires a higher volumetric flow rate for equal cooling performance, owing to liquid's superior convective heat transfer coefficient, rendering its applications impractical for several EVs.

Figure 28. Battery Thermal Management System (BTMS)

Aspects of BTMS

- **Safety:** Proper insulation of heater system components and sealing of control devices with proper positioning of all components to minimize and prevent electrical damage, gas ignition and thermal gradients.
- **Physical or Mechanical Performance:** Proper design of all the system modules and physical components. Proper ventilation must be assured.
- **Durability:** Components must endure shock effects of the desired application.
- **Ripple Current:** Charging current frequency restrictions to avoid overheating.
- **Accuracy of Measuring Instruments:** In the available sensors, the overall accuracy of controlled or measured values must be assured with defined tolerance.
- **Materials for Fire Resistance:** Requirements for non-flammable or flammable-retardant materials to be used in accordance with applicable standards as well as

BTMS is associated with many existing standards.[254]

3.4.2 Drivers of Change and Attractiveness

This section is based on information taken from The Global Management System market report from November 2019[255].

Overview of drivers of change and attractiveness of the battery integration is mainly based on the BMS, overview of the BMS market is described in the following section.

The global BMS market size is estimated to grow from USD 5.2 billion in 2019 to USD 12.6 billion by 2024, at a Compound Annual Growth Rate (CAGR) of 19.5%.

[254] Khan, M.R.; Swierczynski, M.J.; Kær, S.K. Towards an Ultimate Battery Thermal Management System: A Review. *Batteries* **2017**, *3*. Available from: https://www.mdpi.com/2313-0105/3/1/9/pdf
[255] Battery Management System Market. (2019, November). Retrieved August 04, 2020, from https://www.marketsandmarkets.com/Market-Reports/battery-management-bms-market-234498189.html

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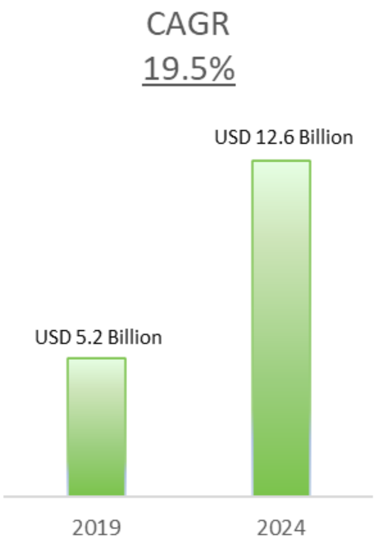

- The global battery management system market is estimated to grow from USD 5.2 billion in 2019 to USD 12.6 billion by 2024.
- The market in APAC is expected to grow at the highest CAGR from 2019 to 2024.
- The automotive industry is the most common application area for battery management systems.
- Potential markets such as South Korea and India offer several growth opportunities for the manufacturers and providers of battery management systems.

Figure 29. Attractive Opportunities in the Battery Management System Market

The growth of the global market, see Figure 29 is expected to be driven by the growing trend of electric vehicles, increased requirement of battery monitoring in renewable energy systems, and need for effective electric grid management.

Regarding the topology (architecture of the BMS), the modular topology of BMS is preferred by most of the manufacturers as it offers significant computational power and is also safe as it does not require extensive wire harnesses. It is present in a various application such as:

- **Energy Storage Systems**
- **Industrial Uninterruptible Power Supply**
- **Medical Mobility Vehicles**
- **Parts of Electric Vehicles**
- **Drones**

Demand for this topology is expected to drive the market at the highest rate from 2019-2024.

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3.4.3 Stakeholders

This section is based on the global management system market report from November 2019[256].

The main global players for the BMS market are as follows:

- **Leclanche (Switzerland)**
  Company largely involved in offering energy storage solutions, mainly dealing with lithium-ion cell technology aiming for cleaner energy. The company offers specialty battery systems, stationary solutions, e-transport solutions, battery, and BMS. The company offers BMS technologies and suites of BMS software. Covering low or high voltage systems.
- **LiTHIUM BALANCE (Denmark)**
  - Founded in 2006 as an ambitious start-up at the Danish Technological Institute. The company develops and manufactures BMS for lithium ion battery technologies[257].
- **Nuvation Engineering (US)**
  - Company founded in 1997 which provides hardware design, software development, and Field-Programmable Gate Array (FPGA) services for electronic product development[258].
- **Eberspaecher Vecture (Canada)**
  - Corporation launched in 2001 and has been focused on providing its customers with reliable, innovative, and cost-effective BMS for portable power applications[259].
- **Storage Battery Systems (US)**
  - Established in 1915, Storage Battery Systems LLC has become renowned for providing DC Power Solutions for stationary and mobile power applications.

[256] Battery Management System Market. (2019, November). Retrieved August 04, 2020, from https://www.marketsandmarkets.com/Market-Reports/battery-management-bms-market-234498189.html
[257] About us. (n.d.). Retrieved August 04, 2020, from https://lithiumbalance.com/about-us/
[258] About Us. (n.d.). Retrieved August 04, 2020, from https://www.nuvation.com/about-us
[259] About us. (2016, November 28). Retrieved August 04, 2020, from https://www.eberspaecher-vecture.com/about-us.html

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From flooded battery cells, to sealed VRLA strings, from Ni-Cd jars to Li-ion rechargeable battery packs[260].

- **STW Technic, LP (DE)**
  - STW Technic, LP is a worldwide leader in the design, manufacture, and implementation of mobile electronics solutions. Founded in 1985 in Germany, STW provides sophisticated, highly reliable solutions for connectivity, automation, and electrification in the agricultural, mining, construction, municipal, military and oil/gas industries.[261]
  - STW also specialises in development of battery management systems for HEV, BEV and for storage power plants.[262]
- **Johnson Matthey (UK)**
  - Johnson Matthey Battery Systems is one of Europe's largest Lithium-ion battery systems supplier, processing over 70 million cells a year and supplying volume production of batteries for global markets.[263]
- **Saft (France)**
  - Company which specialises in battery manufacturing and R&D[264].
- **FIAMM (Italy)**
  - Multinational company engaged in the production and distribution of batteries and accumulators for motor vehicles and for industrial use[265].

[260] About Us: Storage Battery Systems. (n.d.). Retrieved August 04, 2020, from https://www.sbsbattery.com/about-us
[261] About STW Technic. (n.d.). Retrieved August 24, 2020, from https://www.stw-technic.com/company/about-stw-technic/
[262] MBMS – Battery Management System. (n.d.). Retrieved August 24, 2020, from https://www.stw-technic.com/products/electrification-products/mbms-battery-management/
[263] About Us. Johnson Matthey Battery Systems. (n.d.). Retrieved August 09, 2020, from http://www.jmbatterysystems.com/company/about-us
[264] Who is Saft. (2020, August 04). Retrieved August 04, 2020, from https://www.saftbatteries.com/about-us/who-saft
[265] About Us. (2020, April 10). Retrieved August 04, 2020, from https://www.fiamm.com/en/north-america/company/about-us/

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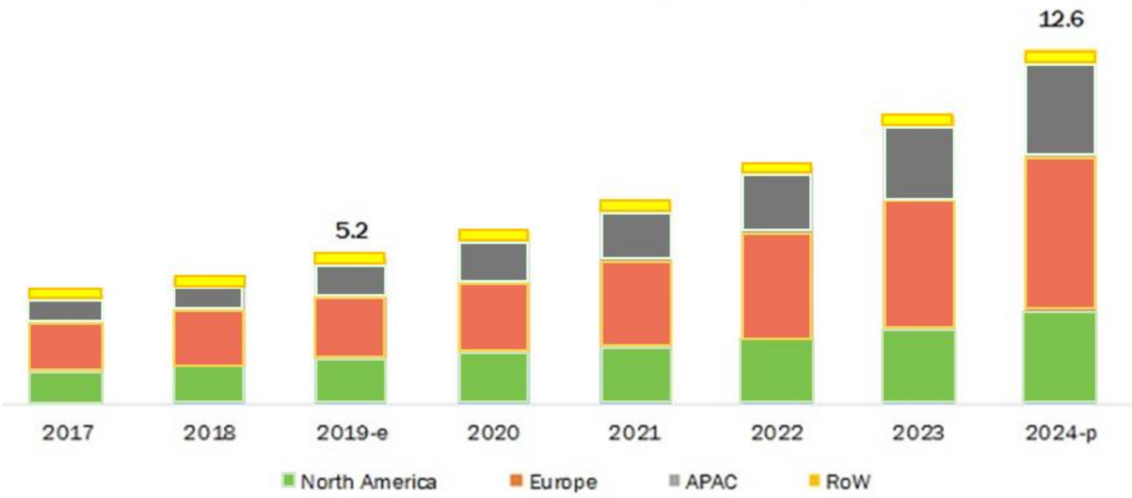

Source: Industry Expert, Secondary Research, and MarketsandMarkets Analysis

Figure 30. Battery Management System Market, by Region (USD Billion)

Europe dominated the battery management system market in 2018 as seen in Figure 30. This was especially the case about the automotive industry, which is very strong in Europe, with the leanest production processes where the use of water and energy is optimized. The demand for battery management systems is attributed mainly to the presence of major automotive manufacturers in Europe:

- **BMW Group (Germany)**
- **Daimler (Germany)**
- **Volkswagen Group (Germany)**
- **Scania AB (Sweden)**
- **Volvo Group (Sweden)**
- **MAN SE (Germany)**
- **Renault (France)**
- **Fiat Automobiles S.p.A. (France)**
- **Jaguar Land Rover (United Kingdom)**
- **Other**

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3.4.4 Generic Integration Process

This section provides a generic skeleton for the battery integration process which was made by scanning through the processes that are relevant in the mobile applications scope.

Generic battery integration process

- **Assembly of battery module**
  - In this step the battery module is created; it consists of several integrated battery cells, as well electronics and sensors which measure the temperature and voltage. It may also contain circuits, the purpose of which is to switch the battery off and prevent it from being damaged.
  - Cells are often between 2 – 4 volts each. Voltage for the whole module is dependent on the number of battery cells, and varies based on the application (car, vessel, stationary, etc.).
  - Cells could be of a different type (cylindrical, prismatic, pouch, etc.).
- **Integration of the battery modules with the BMS**
  - Integrated modules are tested and stacked together.
  - Modules are connected via bus to the pack controller which is essentially ECU to form the BMS.
  - Proper enclosure must be granted.
  - Test checks might be executed throughout this stage.
  - EoL testing.
- **Integration to the specific use case**
  - This means the integration of the BMS into the cars, vessels, etc.
  - Final integrated BMS must assure duplex communication between the battery and the rest of the system (information flow, commands, and error messages to be exchanged, state of health, state of charge).
  - Electrical connection within the BMS and the rest must be assured.

3.4.5 Battery Integration for ISIBA Scope

This section will provide description and flow of the battery integration process related to the stationary applications. It also considers and evaluated the differences and additions to the generic integration process described in 3.4.4.

Stationary Applications – Battery Integration Process[266]:

Assembly of battery modules[267]

A battery module is constituted by a series and/or parallel of battery cells and, typically, includes a Battery Control Unit (BCU) for the measurements and monitoring of voltage and temperature of cells. Depending on the battery technology and specific chemistry, each cell may have a nominal voltage between 2- 4 V with a few Ah of capacity. Battery cells may be cylindrical, pouch type or large-format prismatic, which influence module assembly and design. Therefore, the manufacturing process can be different depending on the type of cell and required voltage and capacity.

The configuration of battery cells at the module level typically results in voltages between 40 – 90 V with between 90 – 250 Ah of capacity.

Assembly of battery racks[268]

A battery rack is constituted by several battery modules, typically, in series to achieve higher levels of DC voltage and, thus, higher power. Also, this allows the connection to high power conversion systems with increased efficiency.

At the rack level there is also a rack BMS with several monitoring, control, and protection features. The information from each of the battery modules (voltage and temperature), and battery modules cells, are aggregated at the rack BMS level. This is crucial to identify and balance any voltage imbalances between battery cells and modules as well as to identify any overheating of battery cells. The electrical protection of the rack is normally achieved through

[266] S. Eckroad and I. Gyuk, "EPRI-DOE Handbook of Energy Storage for Transmission & Distribution Applications," Electric Power Research Institute - Department of Energy (EPRI-DOE), 2003.
[267] K. C. Divya and J. Østergaard, "Battery energy storage technology for power systems—An overview," *Electric Power Systems Research,* vol. 79, pp. 511-520, 2009.
[268] M. T. Lawder, B. Suthar, P. W. C. Northrop, S. De, C. M. Hoff, O. Leitermann*, et al.*, "Battery Energy Storage System (BESS) and Battery Management System (BMS) for Grid-Scale Applications," *Proceedings of the IEEE,* vol. 102, pp. 1014-1030, 2014.

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fuses in both poles, with contactors and switches that are controlled at the rack BMS level in a first instance.

In the battery rack design, also derived from the battery module design, there are challenges related with safety, the energy density, and the integration in the typical refrigerated enclosure (e.g. containerized solution).

Integration in proper enclosure[18]

The battery racks will have to be integrated in a proper enclosure that can have several designs and be based in different structures. For example, battery racks can be integrated in standard metallic containers, in prefabricated concrete buildings, specifics rooms or in metallic enclosures for outdoor exploitation.

The safety and useful life of a battery system are significantly influenced by the temperature to which they are subjected. Charging and discharging of the battery generates heat that should be taken from the enclosure. Outside temperature also impact the temperature inside the enclosure. Therefore, typically this enclosure is refrigerated by a Heat, Ventilation and Air Conditioning (HVAC) system to maintain a temperature, not only of the enclosure, but also at the battery cell level, between optimal values (e.g. 25ºC ± 5ºC) during battery operation.

Due to the nature of li-ion based batteries that can suffer from thermal runaway and are constituted by highly flammable material, a proper fire detection and suppression system must be in place. Depending on the specific battery technology and applicable regulation, such suppression systems may be based on several gases or aerosol.

Although the enclosure for battery racks can be the same as the power conversion system and grid interface, there is usually a physical separation due to the different requirements of batteries in relation to the remaining equipment of a stationary energy storage system.

Integration with Power Conversion System and grid interface[269]

The battery racks can be grouped in electrical parallel into battery banks, each connecting to a different battery inverter, part of the power conversion system (PCS). Each battery bank will have a BMS that will ensure several functionalities such as monitoring and balancing between

[269] G. Delille, B. Francois, G. Malarange, and J.-L. Fraisse, "Energy storage systems in distribution grids: new assets to upgrade distribution network abilities," in *Electricity Distribution-Part 1, 2009. CIRED 2009. 20th International Conference and Exhibition on*, 2009, pp. 1-4.

racks. The BMS will aggregate measurements from the voltage, current and temperature of the battery bank and ensure that no technical limits inherent to the battery system are surpassed during operation. Also, when voltage differences that can hurdle the operation of the battery system appear at the rack level, the BMS will be responsible for an adequate voltage passive or active balancing between them.

The PCS is required to convert the DC power input/output that the battery storage presents to AC. It is based on power electronics to allow bi-directional, 4-quadrant power flows. Beyond the AC/DC converter, additional converters may be needed (DC/DC converters) to match the output voltage level of the battery racks with the DC bus, or to control power flows in parallel multi-string configurations. Typically based in insulated gate bipolar transistors (IGBTs) controlled with a pulse-width modulation technique, the PCS can ensure a complete control over the active and reactive power of the battery system.

A step-up or decoupling power transformer is required to adequately connect the battery and PCS to the electrical grid at the point of Common Coupling (PCC), as there exist nominal voltage differences between the battery installation side and the grid side. Therefore, this transformer suits the output voltage of the PCS to adapt it to the voltage level of the electrical grid.

The complete integration of the battery energy storage system (BESS) is only achieved through an Energy Management System (EMS) that presents functionalities of monitoring, control, and communication. This component monitors the battery device, communicating with the BMS, and all other equipment including ancillary equipment, the PCS, and the transformer. In addition, the EMS can monitor electrical measurements at the PCC to achieve an adequate control of the BESS. The EMS is responsible for sending active and reactive power set-points to the PCS to perform different services. Moreover, by communicating with systems of other electric sector stakeholders (e.g. grid operators, electricity market operator) it is capable of optimizing the behaviour of the BESS both in technical and economic terms, as well as allowing the BESS to respond to external functional requests. The optimisation of the behaviour of the BESS consists of defining the schedule of the battery system i.e. the most adequate periods of time, considering the objectives of the integration, to charge and to discharge the BESS.

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3.4.6 Job Roles and Skills

This section provides an overview of the job roles and skills that have been found during the first iteration of the desk research and mapped according to a framework which is described in **section 2.4**.

Battery integration is heavily dependent on the BMS which is described and evaluated in the sections above. As for the first steps of the battery integration process the battery modules must be assembled. At this stage, the **Cell Module Engineers** are present, as well as **Battery Engineers** and **Battery Designers** who oversee the design of parts of the battery apart from the cells.

As for the second step of the integration process where assembled battery modules are integrated with the BMS, there is a need for **Battery Management System Engineers, Thermal Engineer (BTMS)** and **Embedded Software Engineers** who will develop and adjust the software needed, and its coherency with the system hardware, with expertise in energy storage for stationary applications like base stations and other. **Battery System Consultants** can be present when negotiating with the customers or third parties. Testing is performed by **Test Engineers**.

At the last step of the integration process the whole system is integrated into specific use cases where all job roles mentioned above might be present, as well as the **Application Engineers.** As for the specific use cases the **Application Engineers** for **PV Energy Storage, Base Stations** and other stationary applications are present.

During the whole integration process, i.e. before the battery goes into the operational environment, compliance with the standards and safety must be assured by **Compliance and Validation Engineers, Internal ISO Auditors, Safety Specialists,** and **Safety Managers** as well as the **Process Engineers** who actively seek the process improvement opportunities.

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Most notable skills and knowledge:

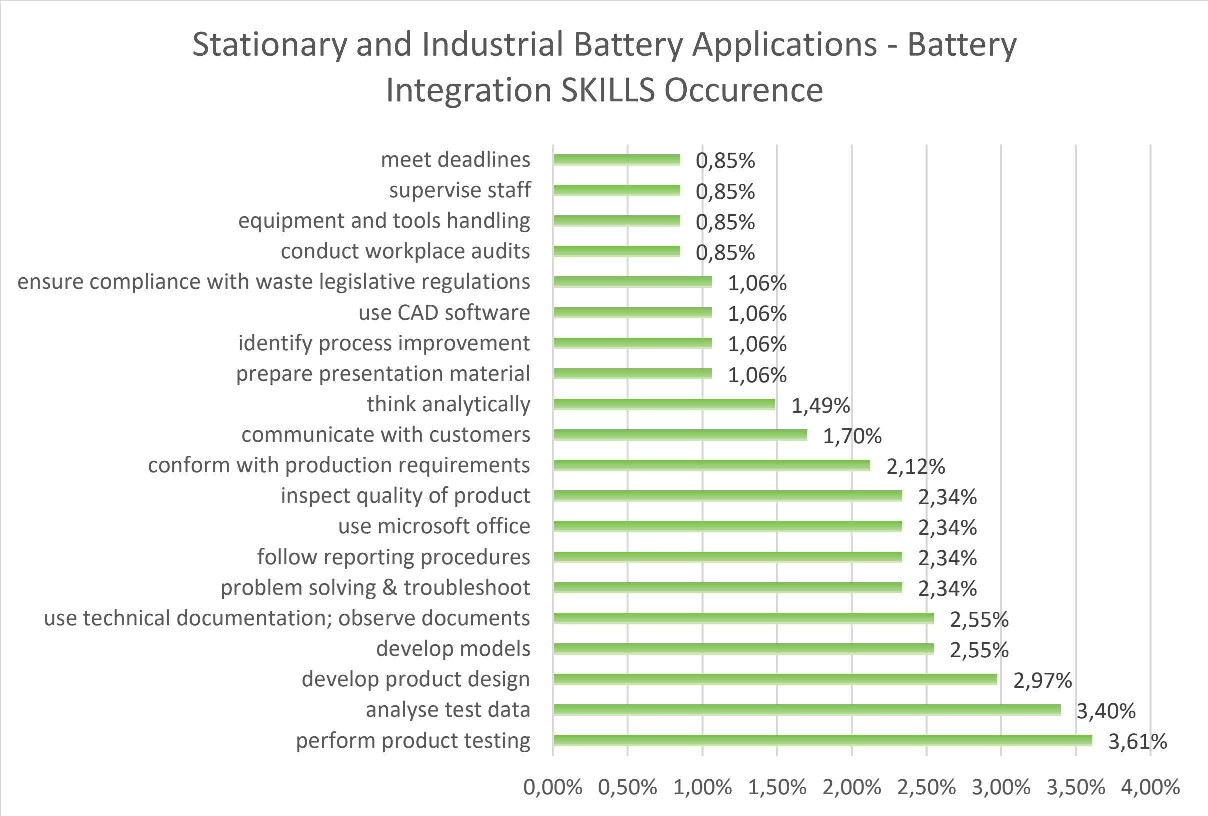

Figure 31. Skills Occurrence for Battery Integration

Skills

From the chart seen in Figure 31, which is based on the researched job advertisements, it is clearly visible that testing, in general, is a very important skill to have. Development of models and product design are also very important skills to have, as well as management and follow-up of documentation and reporting procedures. Communication with customers, conformation with production requirements, and inspection of product quality are also important.

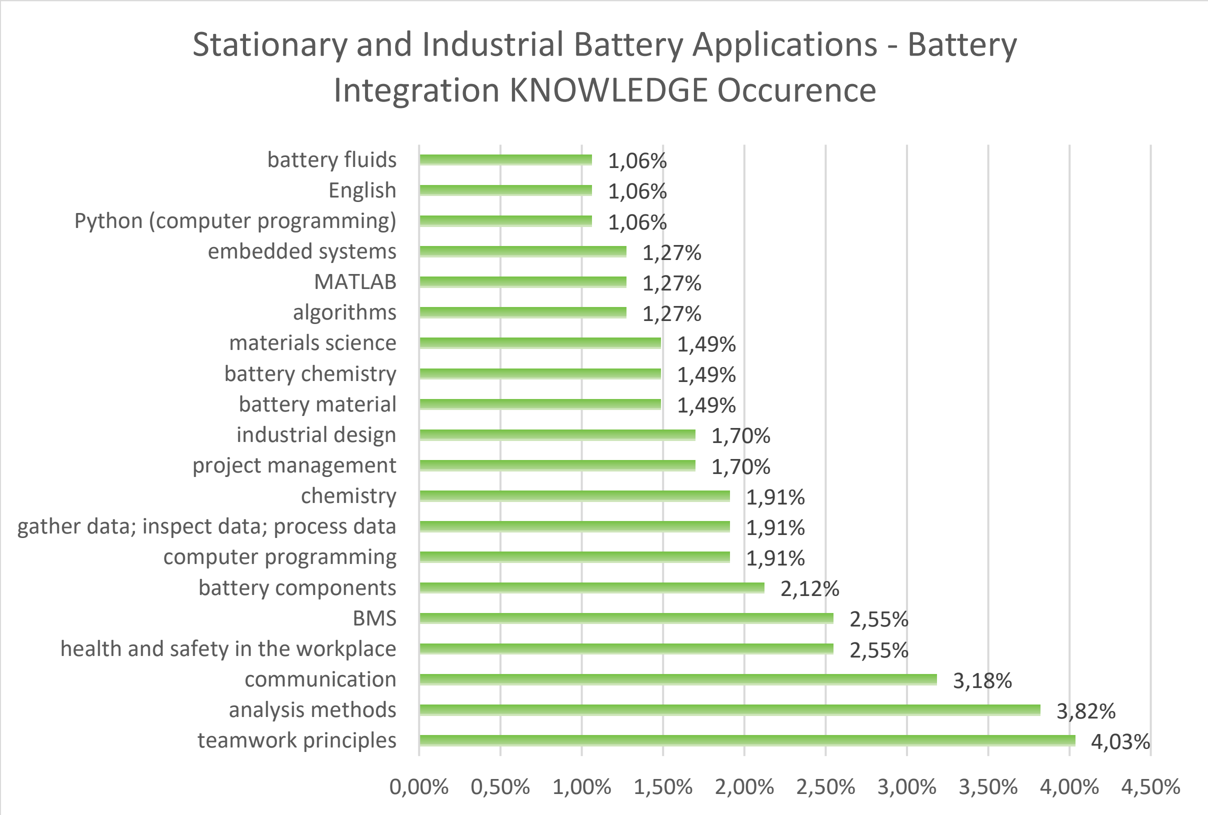

Figure 32. Knowledge Occurrence for Battery Integration

Knowledge Figure 32 Teamwork principles are the most demanded pieces of knowledge, as well as communication. English was frequently an in-demand language. As for technical knowledge, employees must have good knowledge about BMS and embedded systems, analysis methods needed for specific tasks, computer programming, and data science, as well as a background in batteries, as expected.

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3.5 OPERATION, REPAIR AND MAINTENANCE

3.5.1 ENERGY STORAGE – GRID AND OFF-GRID APPLICATIONS

3.5.1.1 DRIVERS OF CHANGE

The global market for energy storage is forecasted to grow fast, reaching more than 100 GW of installed capacity by 2030 Figure 33. The estimations on the pace of the growth differ, but according to the forecast of P&S Market Research, the storage market could reach 26 billion USD by 2022 which would mean a compound annual growth rate (CAGR) of 46.5 percent[270].

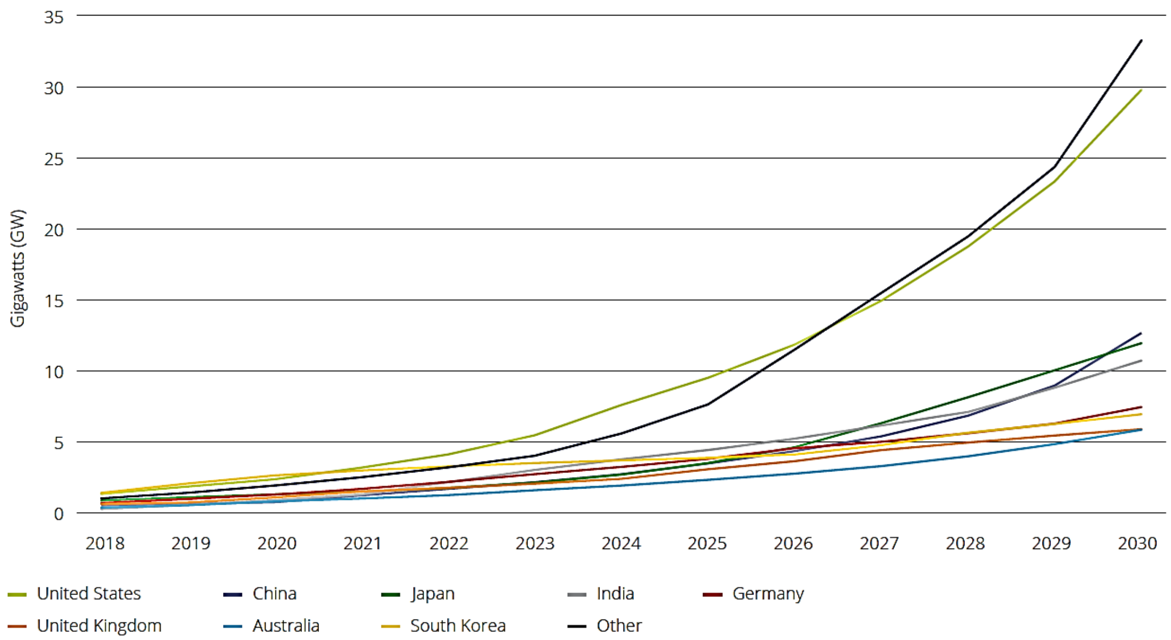

Figure 33. Projected global cumulative storage deployment by country 2018-2030[271]. Deloitte, Supercharged: Challenges and opportunities in global battery storage markets

The drivers for the growing interest in energy storage technologies for the energy sector have been multiple, ranging from environmental, economic, and technical aspects. The electric sector presents a consistent need for energy storage, significantly related to the integration

[270]Energy Storage Market to Reach $26,137 Million by 2022 (2017, July 7). Retrieved July 29, 2020, from https://www.globenewswire.com/news-release/2017/07/07/1041306/0/en/Energy-Storage-Market-to-Reach-26-137-Million-by-2022-P-S-Market-Research.html

[271] Bloomberg New Energy Finance. Deloitte. lobal energy storage Digitization and market innovation accelerate battery storage deployment. Retrieved July 22. 2020, from https://www2.deloitte.com/us/en/pages/energy-and-resources/articles/global-energy-storage-renewable-energy-storage.html

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of significant shares of renewable sources. In the last two decades, a massive integration of Renewable Energy Sources (RES) in the power/energy distribution systems has been prompted by the global increasing climate awareness and various economic incentives. The variable and intermittent nature of RES such as wind and photovoltaic (PV) presents new difficulties in planning and operation of power systems as they bring variability to the supply side which traditionally only occurs on the demand side[272]. Therefore, battery storage and the flexibility that it may offer is regarded as rather complementary to the further integration of variable RES. With the European Union (EU) committed to further integrate RES, aiming at reaching 50% of power generation in the EU from RES in 2050, as per its reference scenario[273], the need to accommodate such green generation will continue to grow. This means a great opportunity for a pursued deployment of battery storage, offsetting its intermittent character and avoiding curtailment, while contributing to a more technical and economic integration of such resources.

Besides the aforementioned drivers, an additional economic driver has been pushing for battery storage solutions. This is related to the phase-out of feed in tariffs (FITs) or net metering payments in several countries, particularly in Europe[274]. At the generation level, national programs for FIT in support of wind and solar generation are coming to an end in many countries, leading to a merchant, more risky operation of such assets. In these cases, energy storage may be used to provide a more stable revenue from energy sales by shifting generation to periods of higher value. At the consumer level, from residential to commercial and industrial, several stakeholders are now looking for ways to increase the return on investments made in renewable energy, namely photovoltaic (PV). This has been a particular driver for battery storage in regions that combine a mature solar market with high electricity prices, namely high prices for peak demand periods. Moreover, this has been reinforced by a growing desire by these stakeholders for energy self-sufficiency, which leverages the value of battery storage.

[272] European Association for Storage of Energy (EASE), European Energy Research Alliance (EERA), „European Energy Storage Technology Development Roadmap Towards 2030,“, 2013.Retrieved July 16, 2020
[273] European Commission DG ENER, 2013, pp. 42-43.“European energy and transport – trends to 2030 – update 2013,“, 2013
[274] Deloitte, „Supercharged: Challenges and opportunities in global battery storage markets“, 2018

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With the growing integration of renewable energy, together with the offset of some of the conventional electrical generation (coal-based generation, nuclear) the stability and balancing of the electrical grid needs to be ensured by different sources. This has opened wholesale electricity markets as well as ancillary services markets to the participation of battery storage. In fact, major electricity markets in the United States of America (USA), United Kingdom (UK), Germany and the Netherlands have adapted their structure not only to allow battery storage to participate, but also have redesigned them to reflect differentiating aspects of such technological solutions such as fast response. For example, this is the case of Germany's primary control reserve (PCR) market, and the fast frequency response (FFR) market in the UK. Such approaches have, for instance, shown that battery storage is already competitive with gas peaker plants. Although these types of markets are not yet widespread in many European countries, these nations have paved the way for others to follow and the trend will be for a throughout market recalibration prompt as well by policymakers and regulators. Moreover, the ability to participate in different markets allows battery storage owners to stack revenue streams offsetting the hurdles related to the still challenging investment cost.

In fact, the integration of battery storage in electric grids is highly dependent on cost and performance and the recent growth in installations has been driven by them. Particularly lithium-ion batteries have seen their costs significantly reduced in the last decade along with an improved performance. Figure 34 shows that in 2017 the cost of Lithium-ion batteries had already dropped 80% compared to the cost level in 2010. This has been mainly related to the expansion of electric vehicle markets that demanded more production and, thus, economies of scale have been achieved. With a growing capacity installation, other costs related to the balance of the battery storage system have also been diminished. These costs are related to battery inverters, control and monitoring devices, grid interconnection fees, Engineering, Procurement and Construction (EPC), etc. For example, from 2015 to 2020, the balance of system costs decreased by 41%[275].

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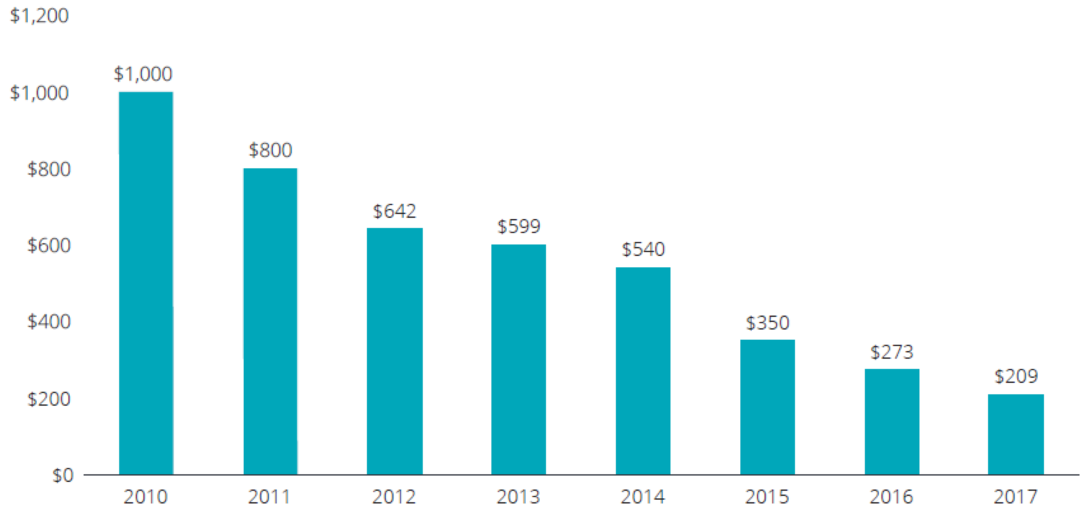
[275] GTM Research: US energy storage BOS costs to fall 41% by 2020 (2016, January 4). Retrieved August 5, 2020, from https://www.pv-magazine.com/2016/01/04/gtm-research-us-energy-storage-bos-costs-to-fall-41-by-2020_100022617/



Source: Bloomberg New Energy Finance, Lithium-ion Battery Price Survey

Figure 34. Declining costs of lithium-ion batteries from 2010 to 2017[2]

Other drivers for battery storage have been arising from a greater awareness and knowledge towards battery storage from policymakers and regulators. Particularly, the combination of clear national policies with fiscal incentives have been driving the integration of battery storage in many parts of the world[276]. Countries such as Italy and Japan where energy storage is a significant part of their strategic energy objectives have provided financial tools reflecting policymakers visions, that have led to a widespread adoption of these technologies from domestic users to investors in big projects. Such incentives are typically grants, subsidized financing, direct refunds or tax rebates[277]. Nevertheless, this brings battery storage in front of other broad impeding efforts to ensure energy independence and self-sufficiency of these countries in the future. This allows battery storage to show its potential in enhancing the reliability and resiliency of their power grids, in decarbonization and in providing the adequate flexibility to integrate renewables efficiently.

[276] Deloitte, „Supercharged: Challenges and opportunities in global battery storage markets“, 2018
[277] S. Ruester, X. He, L. Vasconcelos, and J.-M. Glachant, „Electricity storage: How to facilitate its deployment and operation in the EU,“ *Think Final Report, European University Institute,* 2012

3.5.1.2 STAKEHOLDERS

In recent years, energy storage regained the interest of various stakeholders along the electric sector value chain, from electric utilities to policy makers. The perspectives on battery storage are very diverse but the involvement of the entire value chain is important for leveraging the opportunity that energy storage brings about.

In what concerns a typical battery storage project to be connected to the power grid, several actors may be involved.

Therefore, the list of categories of stakeholders may be the following:

- Battery modules producers
- Battery manufacturers
- Environmental protection authorities / associations
- Citizens/battery users in general
- Commercial and industrial prosumers
- Electric utilities companies
- Engineering Procurement and Construction (EPC) companies
- Energy management system (EMS) providers
- Integrated storage technology vendors
- Local authorities/municipalities
- Market operators and aggregators
- Power Conversion System (PCS) manufacturers
- Project developers and investors
- Regulators
- Renewable energy promoters
- Research institutes
- Specialist battery storage integrators
- Transmission and distribution system operators

The growing interest in energy storage in recent years has also led to new players coming into the market in competition with very well-established players of the energy sector. These new players range from new battery manufacturers that put forward new battery chemistries or technologies that can have advantages in some applications. This is the case of: Blue Solutions that is developing a solid-state battery that can address safety and longevity challenges[278]; RedFlow that proposed a novel zinc-bromine flow battery particularly suited for the residential and telecom sector and with virtual power plant capabilities[279]; EOS energy storage that presents itself to the market with a zinc based solution for a safe, low-cost and long-duration operation. However, the market has been also very active in lithium-based batteries, with performance enhancements and new, cheaper manufacturing processes.

While several stakeholders derived as well from the renewable sector, from project developers to PCS manufacturers, other players focused on a differentiating feature of battery storage that is related to the EMS. Several players focused on the development of the EMS to allow a smooth and reliable integration of battery storage in different application contexts, from the co-location of battery storage with renewable plants, to industrial and residential self-consumption. Others focused on platforms that enabled the adequate integration of wholesale battery storage with ancillary market services in a single package, allowing the stacking of revenue streams.

The newcomers and traditional actors of the electric sector have a different positioning in the market and may address different segments, from the residential segment to the utility-scale segment. The following Figure 35 provides an overview of the energy storage technology value chain and their positioning in the market.

[278] Blue Solutions on why it's betting on solid-state batteries (2019, June 3). Retrieved August 5, 2020, from https://www.pv-magazine.com/2019/06/03/blue-solutions-on-why-its-betting-on-solid-state-batteries/
[279] Redflow batteries to add VPP capabilities (2020, July 24). Retrieved August 5, 2020, from https://www.pv-magazine-australia.com/2020/07/24/redflow-batteries-to-add-vpp-capabilities/

Figure 35. Overview of stakeholders in the energy storage technology value chain. GTM Research, 2016[280]

In the tumultuous energy storage business, policymakers and power sector regulators play a huge role in the healthy development of the market[281]. One of the key discussion topics is the removal of barriers for a widespread implementation of battery storage, namely removing hurdles to access the energy markets; to retool such markets so that they would be fairly treated compared to existing and alternative technologies; to recognize the inherent characteristics of such systems and valuing flexibility. While some countries have achieved significant progress, others need to follow quickly, having the grid operators engaged, and promoting innovation towards decarbonizing the power grid.

[280] Breaking Energy, „ Infrastructure, Solar, Wind, New Storage Technologies Open Doors for Wind and Solar by Enerknol Research on May 25, 2015.“ Retrieved July 22. 2020, from https://breakingenergy.com/2015/05/25/new-storage-technologies-open-doors-for-wind-and-solar/

[281] S. Ruester, X. He, L. Vasconcelos, and J.-M. Glachant, „Electricity storage: How to facilitate its deployment and operation in the EU,“ *Think Final Report, European University Institute,* 2012

3.5.1.3 TECHNOLOGIES AND OPERATION

General

There are “front-of-the-meter” (FTM) utility-scale technologies as well as “behind-the-meter” (BTM) solutions implemented by commercial and industrial (C&I) operators. Figure 36. Whether it is a question of a BTM or an FTM application, it is dictated by an energy system’s position in relation to an electric meter. A BTM system provides power that is used on-site and it does not pass through a meter. An FTM system provides power to off-site locations, injecting power in the distribution/transmission grid. When reaching an end-user, the power provided by an FTM system must pass through an electric meter. [282]

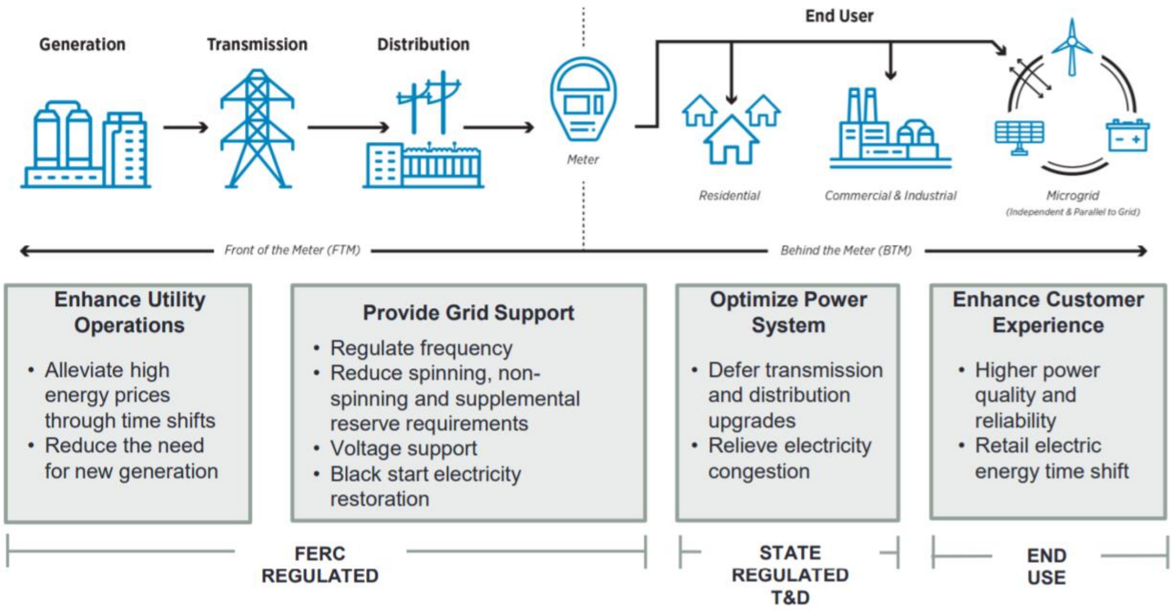


Figure 36. Front of the meter (FTM) vs Behind the meter (BTM) energy storage applications[283]. Adapted from DOE/EPRI Handbook, EEI (graphic)

[282] Behind-the-meter: what you need to know (2019, September 12). Retrieved July 29, 2020, from https://news.energysage.com/behind-the-meter-overview/

[283]Great River Energy, Minnesota Power, Otter Tail Power and Xcel Energy „Energy Storage Overview, Legislative Energy Commission Nov. 9, 2017.“ Retrieved July 22, 2020, from https://www.lec.leg.mn/2017/11092017/LEC%20Utility%20Presentation.pdf

There are also electric vehicle batteries and smaller scale battery-plus-solar panels combinations implemented by residential consumers, which could have not only BTM applications but also FTM uses if controlled by aggregators or utilities. There are applications for energy storage, which can be useful in integrating renewables, supporting smart grids, creating more dynamic electricity markets, providing ancillary services and bolstering both system resiliency and energy self-sufficiency[2]. In this context, we mainly focus on energy storages consisting of Li-ion batteries, the state-of-the-art battery technology today. Figure 37. Potential customers for energy storage are power generation unit owners, grid operators and residential consumers and prosumers, who are seeking ways to reduce the electricity costs and/or to find new value streams for their assets. In a nutshell, battery usage is driven by **consumers** (distributed residentially as well as commercially and industrially), **grid operator and utility needs** (dispersed and centralized storage systems), and **Off-grid applications of energy storage**, from individual energy systems for homes, telecom towers and microgrids.[284] The increasing application of renewables in the context of the abovementioned is a major influencer.

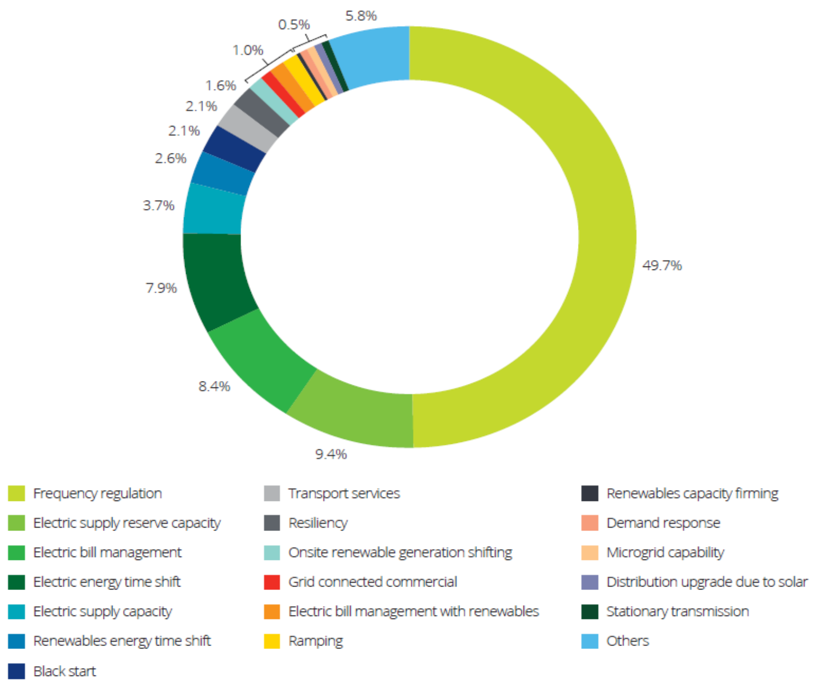


Figure 37. Global battery storage capacity by primary use case[2].

[284] BATSTORM project, "Battery Storage To Drive The Power System Transition", 2016-2018. Retrieved July 22. 2020, from https://ec.europa.eu/energy/topics/technology-and-innovation/energy-storage_es

Lithium-ion battery energy storage applied within renewables-generating grid (behind-the-meter)

According to International Renewable Energy Agency[285] while utility scale stationary batteries are the number one global energy storage now, by 2030, small-scale battery storage is expected to significantly increase, complementing utility scale applications. These so-called BTM (behind-the-meter) battery systems are connected behind the utility meter of commercial, industrial or residential customers. The main goal of the application of BTM systems is to generate energy bill savings. Figure 38.

Behind the meter (BTM) renewable systems include solar panel systems and small wind turbines that generate electricity that is used in a residence or a business. BTM renewable systems provide energy that can be accumulated in an energy storage. Excess generation can be re-routed through an electric meter to the power grid for credit on the invoicing for electricity (net metering). A more complex version of a BTM energy system is a microgrid. Microgrids are small versions of the larger power grid that supplies energy, for example, to a small number of buildings. Microgrids consist of generation, a distribution system and, when needed, battery storage.[286]

Additionally, there are mini-grids that are isolated (unlike microgrids that can operate in both grid-connected and island mode), small-scale distribution networks that provide power to a(n) isolated/stranded group of customers and produce electricity from small-size sources (conventional and renewable), potentially coupled with an energy storage system.[287]

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[285] Battery storage paves way for a renewable powered future (2020, March 26). Retrieved July 29, 2020, from https://www.irena.org/newsroom/articles/2020/Mar/Battery-storage-paves-way-for-a-renewable-powered-future

[286] Behind-the-meter: what you need to know (2019, September 12). Retrieved July 29, 2020, from https://news.energysage.com/behind-the-meter-overview/

[287] Microgrids, Mini-grids, and Nanogrids: An Emerging Energy Access Solution Ecosystem (2017, July 31). Retrieved July 29, 2020, from http://energyaccess.org/news/recent-news/microgrids-mini-grids-and-nanogrids-an-emerging-energy-access-solution-ecosystem/#:~:text=A%20microgrid%20can%20connect%20and,grid%2Dconnected%20or%20island%20mode.&text=The%20definition%20of%20a%20mini,in%20regulations%20in%20developing%20economies.

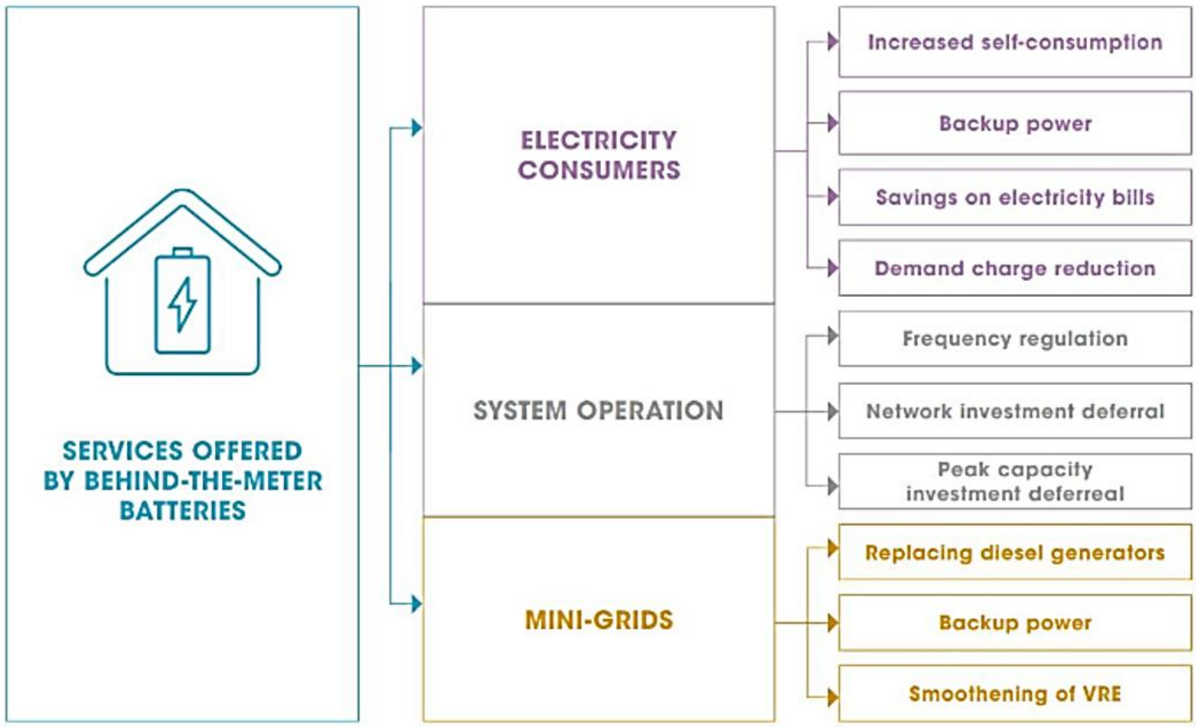

Figure 38. Services provided by BTM - battery storage systems[288]. Source: https://www.irena.org/newsroom/articles/2020/Mar/Battery-storage-paves-way-for-a-renewable-powered-future (July 29, 2020)

[288] Irena International Renewable Energy Agency, „Battery Storage Paves Way for a Renewable-powered Future, 26 March 2020." Retrieved July 22. 2020, from https://www.irena.org/newsroom/articles/2020/Mar/Battery-storage-paves-way-for-a-renewable-powered-future

Utility-scale battery storage (in-front of the meter) [289]

Utility-scale energy storage has a typical capacity ranging from a few megawatt-hours to hundreds of MWh. FTM (in-front of the meter) batteries are in connection with distribution or transmission networks or with a generation system.

The grid-level energy storage system plays an important role in the usage of electricity. The demand for electrical power varies daily and seasonally. Storing the generated energy and providing power to shave peaks and level loads are necessary since the demand for electricity can vary on the daily basis. Significant so-called peak-to-valley differences can occur if comparing daytime electricity demand to the overnight level.

Lithium-ion batteries come with advantages such as relatively high energy density, high Electrical Efficiency (more than 95%), and long life cycle (3000 cycles at depth of discharge of 80%) due to which their role in supporting grid devices is essential. Furthermore, LIBs in grid-level energy storage systems are an attractive choice for renewable energy source integration in order to provide generated power to end consumers with minimal cost. Storing energy from supporting renewable power systems into batteries, when needed ensures grid's stability and reliability.

Renewables such as wind and solar power suffer from significant intermittence as they are highly weather dependent. Storing the excess energy produced by wind and solar power systems to supply electrical energy when the power demand reaches its peak is an effective solution.

[289] Tianmei Chen, Yi Jin, Hanyu Lv, Antao Yang, Meiyi Liu, Bing Chen, Ying Xie, Qiang Chen, „Applications of Lithium-Ion Batteries in Grid-Scale Energy Storage Systems", Published online 8 February 2020. Retrieved July 22, 2020, from https://link.springer.com/content/pdf/10.1007/s12209-020-00236-w.pdf

3.5.2 TELECOMMUNICATIONS

3.5.2.1 DRIVERS OF CHANGE

Lithium-ion batteries are regarded as a very promising technological solution in the context of an ever-evolving telecom world of base stations. The drivers for this are threefold: the first is related to the evolution of the telecom technology of the base station itself; the second is related to the local off-grid Diesel generator used at the base station level; the third is related to the increase of performance and reduction of costs of lithium-ion batteries, which further stresses the other main drivers.

Deployment of base stations for 5G networks[290]

Mobile service customer volume has continuously risen and the advancements in technology have led to a significant energy consumption increase in the telecom industry. The total number of users surpassed 7 billion by 2017[291]. On one hand, the growth is expected to continue with an increasing number of people having access to it. On the other hand, several emerging technologies have surged ranging from smartphones, mobile TV to network of physical devices (internet of things) such as vehicles, home appliances, etc. This comes on top of the progress in radio access networks (2G, 3G, LTE, etc.).

This will be significantly aggravated by the recent widespread installations of base stations for 5G networks. This new technology presents two main challenges having to do with the designing or refurbishing of the base stations. First of all, 5G networks will demand more energy than previous technologies which means more local generation and battery storage. Figure 39 shows the typical power requirements of base stations for different communication technologies. Second, 5G networks need higher density of base stations than 4G networks meaning that new base stations need to be built, considering sustainability and environmental goals, nonetheless. This is a great opportunity for battery storage and, particularly, lithium-ion battery storage as it is deemed as a better technical and economical solution than

[290] China's 5G construction turns to lithium-ion batteries for energy storage (2020, May 17). Retrieved July 29, 2020, from https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/china-8217-s-5g-construction-turns-to-lithium-ion-batteries-for-energy-storage-58474880

[291] Asma M Aris, Bahman Shabani;"Sustainable Power Supply Solutions for Off-Grid Base Stations, September 2015, DOI: 10.3390/en81010904." Retrieved July 29, 2020, from https://www.researchgate.net/publication/282367344_Sustainable_Power_Supply_Solutions_for_Off-Grid_Base_Stations

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conventional lead-acid batteries. For example, in China, the demand for lithium-ion batteries for this purpose is expected to rise from 2.7 GWh in 2019, to 13.3 GWh in 2020, reaching 14.5 GWh in 2021[292].

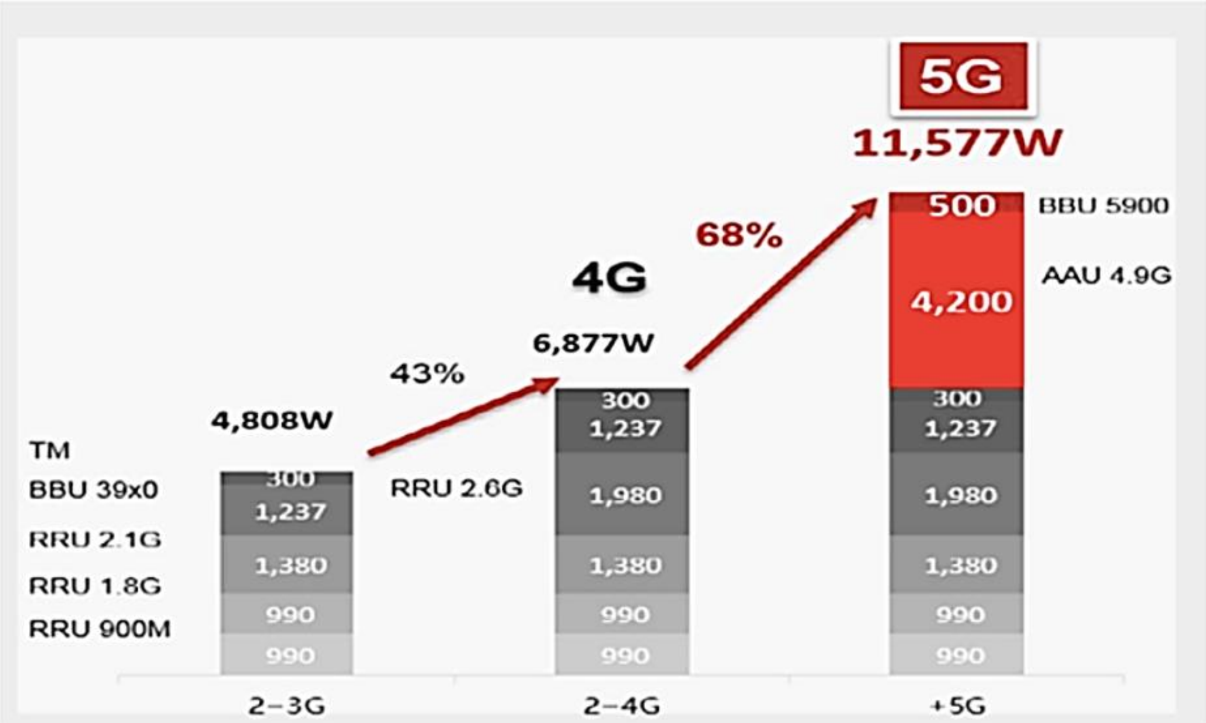

Figure 39. Base station power requirements 2G, 2-4G and 5G[293]. Source: Huawei / https://www.fiercewireless.com/tech/5g-base-stations-use-a-lot-more-energy-than-4g-base-stations-says-mtn (July 29, 2020)

The need for resilient and sustainable base stations [294, 295]

The challenge posed by 5G networks will further stress the fact that, in isolated off-grid areas, base stations are typically powered by small-scale Diesel generators. Even in areas where the

[292] Chinese 5G rollout lifts lithium battery demand (2020, March 19). Retrieved July 6, 2020, from https://www.argusmedia.com/en/news/2088490-chinese-5g-rollout-lifts-lithium-battery-demand

[293] Fierce Wireless, 5G base stations use a lot more energy than 4G base stations: MTN by Linda Hadestry, Apr 3, 2020. Huawei. Retrieved July 29, 2020 from https://www.fiercewireless.com/tech/5g-base-stations-use-a-lot-more-energy-than-4g-base-stations-says-mtn

[294] Luta, D. N., & Raji, A. K. (2019). Performance and Cost Analysis of Lithium-Ion Battery for Powering Off-Grid Telecoms Base Stations in Africa. International Journal of Engineering Research in Africa, 43, 101–111. doi:10.4028/www.scientific.net/jera.43.101.Retrieved July 29, 2020, from https://www.scientific.net/JERA.43.101

[295] Ferraro, M., Brunaccini, G., Sergi, F., Aloisio, D., Randazzo, N., & Antonucci, V. (2020). From Uninterruptible Power Supply to resilient smart micro grid: The case of a battery storage at telecommunication station. Journal of Energy Storage, 28, 101207.Retrieved July, 29 2020, from https://www.sciencedirect.com/science/article/abs/pii/S2352152X19302919

main electrical grid may be accessible, Diesel generators may be installed for backup power purposes in case of grid failure. Particularly in more remote areas, this means that an increase from the average 25 MWh of consumption per year per base station will automatically lead to an increase in greenhouse gas emissions, in a "business-as-usual" scenario. In fact, from the major parts of a telecom mobile network, base stations already account for 60 to 80% of the network energy consumption[26]. Although there is a clear trend to offset this pollution associated with the energy consumption by integrating local renewable generation (e.g. PV generation), this can only be achieved through a flexible, high performing battery system such as Li-ion based battery storage, which can accumulate the extra renewable energy and provide the backup power when needed. With a proper sizing and design, such batteries might even render the Diesel fuelled generators useless altogether.

Furthermore, the driver for battery storage is even more accelerated by the inherent characteristics of Diesel generators. Diesel generators showcase reliability issues, presenting a lower availability level than the one required for base station application, namely with the increasing dependence of people on telecommunications. These reliability issues may lead, on one hand, to the need to install extra generators for redundancy and, on the other hand, to increased operational and maintenance costs due to the need of maintaining and repairing through regular visits to a large number of base stations. Additionally, the fuel also needs to be made available at the site of the base station, which also increases operational and maintenance costs. This can be tackled by the combination of local renewable generation and battery storage, which can bring a significant reduction of the operational costs, reduce maintenance needs and mitigate greenhouse gas emissions.

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Increased performance and reduced costs of Lithium-ion batteries[296, 297, 26]

Whether the concern is off-grid or on-grid base stations, the fact of the matter is that Lithium-ion batteries are increasingly replacing Lead-acid batteries in telecom networks[298]. The rationale for this is threefold: first, the significantly decreasing costs of Lithium-ion batteries are making them competitive in terms of lifecycle compared to Lead-acid battery, which is still the most mature and cheapest type of battery; second, Lithium-ion batteries provide a higher energy density which means less footprint, a key challenge for the compactness required for a base station. This is achieved with greater electric efficiency and more usable energy, meaning that more back-up energy can be provided in base stations for systems with the same installed capacity. This is even more relevant in the transition to 5G networks; last, Lithium-ion batteries can perform more charge/discharge cycles and present a larger calendar life, which means that its needs for maintenance are lower and battery replacement can occur less frequently. This is a key driver in remote base stations, particularly the ones with local renewable generation, as the battery system cannot only provide backup-power but, also, maximize the usage of the available renewable energy.

[296] Telecom's 5G revolution triggers shakeup in base station market (2018, December 25). Retrieved August 7, 2020, from https://asia.nikkei.com/Business/Technology/Telecom-s-5G-revolution-triggers-shakeup-in-base-station-market

[297] Sawle, Yashwant, and S. C. Gupta. "A novel system optimization of a grid independent hybrid renewable energy system for telecom base station." International Journal of Soft Computing, Mathematics and Control 4: 49-57, 2015. Retrieved July 29, 2020, from https://www.wireilla.com/ns/maths/Papers/4215ijscmc04.pdf

[298] Chinese 5G rollout lifts lithium battery demand (2020, March 19). Retrieved August 7, 2020, from https://www.argusmedia.com/en/news/2088490-chinese-5g-rollout-lifts-lithium-battery-demand

3.5.2.2 STAKEHOLDERS

The telecom base station market is very large and has been in constant change and, due to its relevance in society, attracts a broad range of actors. This is accentuated by the ongoing revolution with the surging 5G networks[299].

The categories of stakeholders range from telecommunication technology providers, to base station equipment manufacturers, to regulators and governmental agencies. All stakeholders will play an important role in the transition to sustainable base stations, particularly in remote locations. With the number of base stations and, thus, their energy consumption expected to grow significantly, the adoption of lithium-ion based battery storage will largely depend on the strategies of the different stakeholders and the guidelines at national and international levels for the decarbonization of the sector.

Therefore, the list of categories of stakeholders may be the following:

- Battery manufacturers
- Citizens/telecom users in general
- Electric utilities providers
- Energy management system (EMS) providers
- Environmental protection agencies / associations
- 5G Telecom Base Station Equipment Providers
- Integrated base station providers
- Integrated storage technology vendors
- Local authorities/municipalities, governments
- Power Conversion System (PCS) manufacturers
- Research institutes
- Solar panels manufacturers
- Telecommunication technology providers
- Telecom operators
- Telecom regulators

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[299] Telecom's 5G revolution triggers shakeup in base station market (2018, December 25). Retrieved August 7, 2020, from https://asia.nikkei.com/Business/Technology/Telecom-s-5G-revolution-triggers-shakeup-in-base-station-market

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The landscape of the global market share in base station sales in 2017 is presented in Figure 40. The launch in several developed markets of the fifth-generation wireless networks is shaking up the market and will continue to create disruptions among stakeholders. On one hand, the typical group of companies that used to dominate the market for 3G and 4G networks are being challenged by new players that adapted very fast to this revolution period which threatens the relative stability of the market over the last decade. For example, Altiostar Networks, a 5G telecom base station equipment provider, will be building part of Rakuten's new mobile network in Japan[300]. In this project, more than 4000 base stations will be built over a period of 2 years at a reduced cost compared to other approaches. The reason for this is the industry shift to general purpose equipment instead of the dedicated equipment approach from Altiostar Networks. This commoditization of base stations is allowing a faster growth of 5G networks but, moreover, the apparition of new actors. This is also relevant for battery storage, particularly manufacturers and integrators, as it will need to follow this trend for standard products with large life cycle.

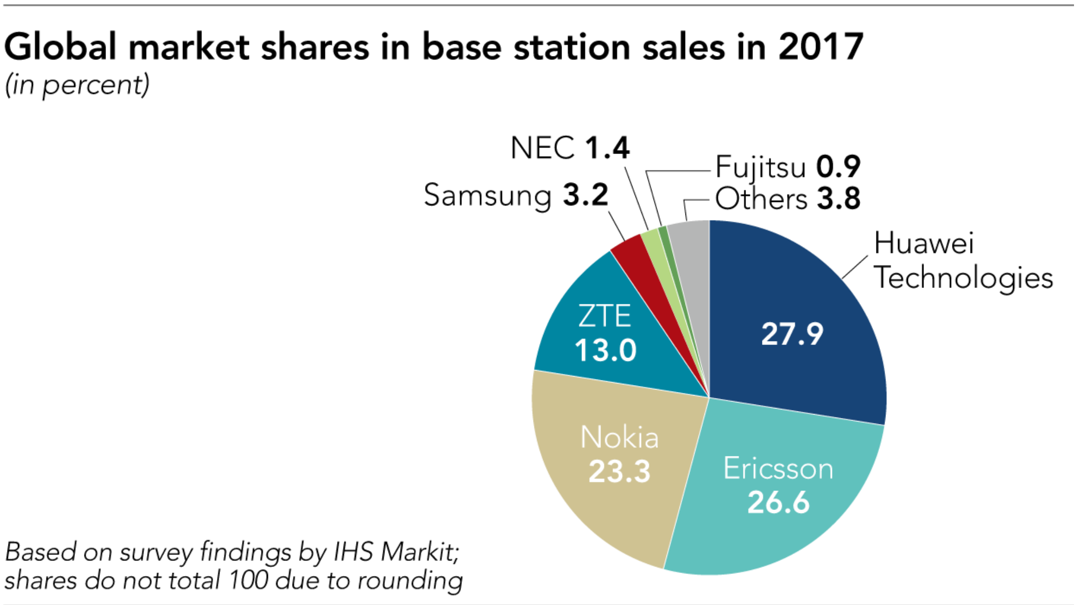

Figure 40. Base station sales share in 2017 according to HIS Market study.[301]

[300] Rakuten Network By the Numbers: Launching a New Era of Mobile Networking (2020). Retrieved August 7, 2020, from https://www.altiostar.com/rakuten-network-by-the-numbers-launching-a-new-era-of-mobile-networking/, last accessed in 07/08/2020.

[301] Telecom's 5G revolution triggers shakeup in base station market by I Horikoshi, T Kawakami, Nikkei staff writers. (December 25, 2018). Retrieved August 7, 2020, from https://asia.nikkei.com/Business/Technology/Telecom-s-5G-revolution-triggers-shakeup-in-base-station-market

The impact that telecom has in society and its national relevance have led to nationwide concerns, related to information independence, technology leadership, etc. This has caused a significant impact on the industry that has hurdled, for instance, the 5G deployment. Regulators and governments are the key stakeholders in these issues, directly influencing the market development. Although 5G networks are a challenge in developed countries, with new and refurbished base stations being a key driver for battery systems, similar aspects need to be considered by these stakeholders in developing countries. It is in developing countries where remote base stations will be mostly built, meaning that they represent the places where battery storage can have the most impact in mitigating greenhouse gas emissions.

3.5.2.3 TECHNOLOGIES AND OPERATION

Batteries are used as energy storages to provide backup power for telecommunication base stations. Additionally, batteries are used within off-grid base stations in remote locations together with Diesel generators and increasingly renewable energy sources such as solar panels and wind power turbines. Reliability and continuity of a power supply arrangement are critical elements when powering off-grid base stations to ensure that the mobile users and telecom operators would not suffer from service outages. Batteries are important to fill the supply gaps when utilizing intermittent renewables.

Lead-acid batteries have been widely used especially with earlier generation (4G) base stations, but recently, Li-ion batteries have become an interesting alternative with next generation stations due to their benefits. Figure 41. The ongoing deployment of 5G base stations will be the main driver of the increased demand for Li-ion (Lithium-iron-phosphate) batteries in the context of base station applications.

The main benefits for the application of Li-ion batteries with base stations are high capacity, high voltage and lack of pollution. Safety aspect is important as well as small size, light weight, temperature resistance and low susceptibility to seismic activity. Another important feature is a built-in diagnostic system that enables monitoring charging status and battery ageing speed. The weight and volume of a Li-ion battery, for example the one provided by the company ZRGB, are only one-third of the lead-acid battery[302]. Being fully replaceable with current batteries (Lead-Acid, Ni-Cd) is another important factor as is the case with, for example the Samsung SDI Li-ion battery solution[303]. **The main disadvantages** for the application of Li-ion batteries with base stations are the high cost (has been decreasing though) and the unfavourable impact of deep discharging on the battery lifetime[304].

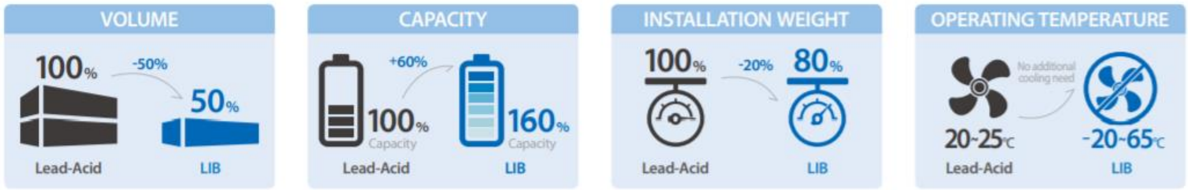

Figure 41.Comparing Li-ion battery solution (Samsung SDI battery system) to lead-acid batteries[35]. Source: http://samsungsdi.com/upload/ess_brochure/ESS%20for%20BTS.pdf (July 22, 2020)

In the context of off-grid base station solutions in remote areas, a variety of power source + energy storage combinations apply, from diesel generators to renewable energy sources and hybrid power supply systems that combine different energy sources[36]. Figure 42.

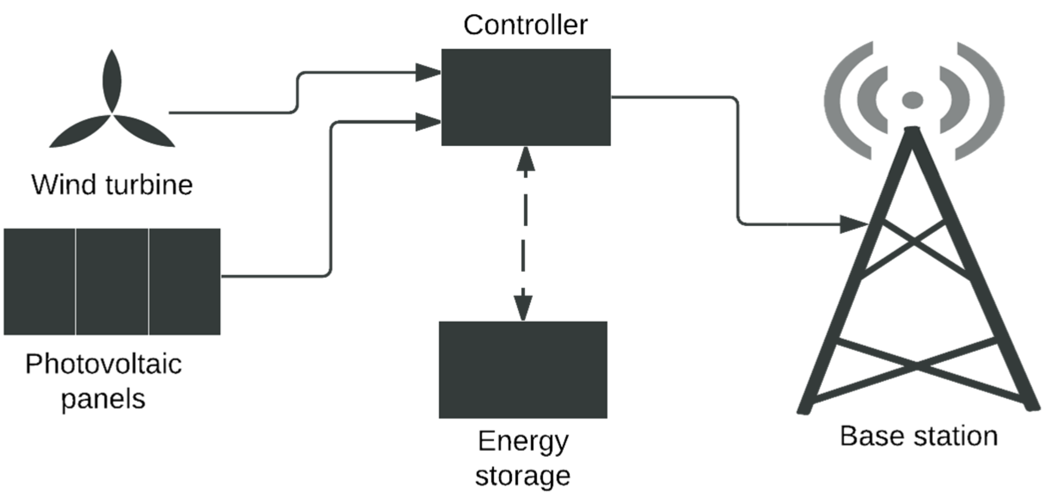

Figure 42. An example of a hybrid power supply system: a configuration of a hybrid PV-wind system in a base station site. Source: Sustainable Power Supply Solutions for Off-Grid Base Stations, 2015

[302] Base Station Battery Module – 48100 (2019). Retrieved July 22, 2020, from https://zruipower.com/products-item/48100-telecom/
[303] Samsung SDI, Li-Ion Battery Solution For Telecom Base Station (n. d.). Retrieved July 22, 2020, from http://samsungsdi.com/upload/ess_brochure/ESS%20for%20BTS.pdf
[304] Asma Mohamad Aris and Bahman Shabani, „Sustainable Power Supply Solutions for Off-Grid Base Stations“, 2015. Retrieved July 29, 2020 from

Opportunities and challenges for Li-ion batteries[305]

5G telecom base stations' use of electricity is 2-3 times higher than that of 4G stations. Backup power requirements are at least twice the size compared to 4G. High quality-to-price ratio second-life batteries have potential as a backup power supply source for 5G stations. However, safety issues regarding battery energy storages have become more important in the recent years. That is especially the case with second-life batteries for which safety is a priority. The safety of 5G energy storage must be emphasized in the industry. All safety issues must trigger indicators that are detectable by the Battery Management System (BMS) and can be reacted upon by immediately isolating any problematic battery before the possibility of fires or thermal runaway occurs.

Four requirements must be met when it comes to designing 5G base station power sources. **First**, application of multiple energy sources, that strengthens **the capabilities to produce stable electricity**. **Second**, **intelligence for operations and maintenance** to increase the efficiency of operations. **Third, digitalization of power for high density and efficiency**. **Fourth**, **developing smart batteries to achieve maximum value from the entire battery life cycle**.

3.5.3 HEAVY DUTY APPLICATIONS

3.5.3.1 DRIVERS OF CHANGE

Lithium-ion battery storage can also be regarded as a very promising technology, when it is coupled with a variety of heavy-duty applications. Some of the changes driving the market can be overlapped with the energy storage and telecom industries, which were specified earlier in this document. Without any doubt, environmental and economic aspects do have a significant weight, when it comes to LIBs deployment for the heavy-duty applications as well. Let us go deeper into the topic, by looking at some examples and consider some suitable industrial categories of interest for lithium-ion batteries heavy-duty integration.

[305] 5G: The Next Opportunity for Li-ion Energy Storage? (2019, December 30). Retrieved July 29, 2020, from http://en.cnesa.org/latest-news/2019/12/30/5g-the-next-opportunity-for-li-ion-energy-storage

Financial and environmental benefits to energy storage deployment for hospitals, stadiums, data centres etc.[306,307,308].

Originally, there is a great deal of directions, in which hospitals can potentially have their costs reduced after having LIB energy storage systems installed: Demand Charges reduction, Time-of-Use (TOU) Charges reduction and Demand Response Programs participation[3]. Consequently, financial benefits for hospitals will occur with a minimized peak kW usage, when laundries, kitchens, operating rooms, labs, and all other services are in full consumption mode. What is more, TOU cost rates can be regulated and cut by shifting the major electricity load to "off-peak" hours. Last point to consider is that hospitals can earn significant amount of money per year simply for participating in Demand Response (DR) programs, aimed at reducing electricity usage for a couple of hours ("negative demand") and getting paid by utilities companies[3].

The similar patterns of costs reduction can be achieved, if Battery Energy Storage System BESS are deployed for stadiums, by avoiding peak power prices, buying electricity when it is cheap and storing clean energy for later use when prices are high. Batteries instalment will become a step forward for creating cost-effective economy and promoting efficient energy usage, helping local government, authorities, and businesses to follow green trends. Furthermore, in the long run, the concept of BESS for stadiums can act in favour of supporting grids through selling generated access energy to them.

Except for the abovementioned economic benefits, BESS proliferation in hospitals, stadiums etc. can make its own contribution in reducing carbon footprint and making low-carbon economics transition smoother and faster.

It is possible to have second life EV batteries involved in the process of energy supporting for grids in the periods of low demands for stadiums. That would have a positive influence on the whole battery

[306] "Large-Scale Battery Storage for Hospitals" (January 22, 2018). Retrieved August 26, 2020 from https://www.engiemep.com/news/large-scale-battery-storage-for-hospitals/

[307] "Arsenal's new battery will store to run Emirates stadium from kick-off to full time" (2018). Retrieved August 26, 2020 from https://www.pivot-power.co.uk/arsenals-new-battery-will-store-enough-energy-to-run-emirates-stadium-from-kick-off-to-full-time/

[308] "The Dutch football stadium creates its own energy and stores it in electric car batteries" (July 6, 2018). Retrieved August 26, 2020 from https://www.weforum.org/agenda/2018/07/netherlands-football-johan-cruijff-stadium-electric-car-batteries/

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life cycle, contribute to green energy commitments and reduce the need for Diesel-generated energy power backup for outage periods.

Renewable Energy Sources RES increased generation supported by BESS[309,310]

Sustainable energy generation is vital to guaranteeing high living standards and green economy development. An important step forward down this way can be considered the grid-connected hospitals, airports, stadiums etc., which have their energy generated with photovoltaic (PV) panels or wind turbines[6]. Nevertheless, both energy sources suffer from intermittence, so this is the point when BESS step in. Consequently, with an increased demand for renewable energy generation, the subsequent demand for Lithium-ion batteries will go up in order to both store energy and provide a stable electricity supply.

PV and wind turbine energy are already widely used for hospitals around the world, as they naturally feature high energy consumption and have enough space, for example, for photovoltaic panels to be installed. In other words, similar projects aimed at PV energy generation and storage will enable the medical centres to better serve their patients by establishing a reliable source of clean energy that covers the centre's consumption of electricity and, as a result, bring access to a secure energy source that is a critical component to the hospital's ability to deliver sustainable and reliable health care[311].

What is more, LIBs can be also paired with the airport's existing photovoltaic solar system, the new energy storage system will reduce energy charges during peak demand which equate to approximately 40 percent. In other words, the airports can be compared to small or medium-sized cities, which may need enormous amounts of energy for consumption in order to support a variety of infrastructure elements. Unique requirements of airports' buildings and facilities (e.g. terminal air conditioning, pre-conditioned air and power at gates, powering of many appliances and other systems, baggage handling

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[309] "A review of sustainable energy access and technologies for healthcare facilities in the Global South" (August 2017). Retrieved August 26, 2020 from https://www.sciencedirect.com/science/article/pii/S2213138817301376

[310] "San Diego Airport announces 2 MW energy storage system" (June 25, 2019). Retrieved August 26, 2020 from https://www.smartenergydecisions.com/energy-management/2019/06/25/san-diego-airport-announces-2-mw-energy-storage-system

[311] "World's largest hospital solar PV project online now in Amman, Jordan" (August 27, 2019). Retrieved August 27, 2020 from https://www.renewableenergyworld.com/2019/08/27/worlds-largest-hospital-solar-pv-project-online-now-in-aman-jordan/#gref

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systems, etc.) can be strategic reasons for investing into energy efficient technologies. In this case, analysing the potential benefits that may be acquired in case of renewable energy sources installation, there is a number of advantages to be taken into consideration: greenhouse gas (GHG) emissions objectives support, Corporate Social Responsibility (CSR), strong environmental commitment, opportunities for additional revenue generation in case of energy access and risk mitigation concerning energy supply in case of on-site BESS installation[312].

The possibilities are really broad, though the whole spectre of their functionality and overall feasibility of deployment can be achieved only with a combination of proper energy storage systems. As a result, the overall RES increase in different institutions will require the energy to be efficiently stored to maximize renewable energy opportunities and have the benefits transferred for subsequent use.

Legislative and regulatory compliance and incentives

Policymakers and regulators have already shown interest in fostering a battery storage uptake in many industries and sectors, including heavy-duty one. For example, many airports may have legislative and regulatory compliance requirements that can be met or addressed with on-site renewable energy projects. By investing in a renewable energy supply, an airport may proactively address standards, policy requirements and other compliance elements, whilst being at the forefront of the operating environment. In addition, there may also be current regulatory incentives such as subsidies and tax-breaks for renewable energy that airport operators should consider. Needless to say, that all RES installations should be supported with BESS to be efficiently integrated into airports ecosystems.

Similar battery energy storage regulations are widely promoted by Dutch policymakers in Netherlands due to the increased attention to reducing CO_2 emissions. As a consequence, there will be specific funding for R&D in electric storage and batteries second life use is intensively promoted through projects aimed at advancing national football stadiums and providing sustainable energy back-up solutions[313]. These pilots are having good results and similar initiatives could be followed elsewhere in Europe.

[312] "A Focus on the production of renewable energy at the Airport site" (ICAO report). Retrieved August 27, 2020 from https://www.icao.int/environmental-protection/Documents/Energy%20at%20Airports.pdf
[313] "Battery Promoting Policies in Selected Member States" p. 19-21. Retrieved August 27, 2020 from https://ec.europa.eu/energy/sites/ener/files/policy_analysis_-_battery_promoting_policies_in_selected_member_states.pdf

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Deployment of lithium-ion energy storage for directed high-energy lasers[314,315].

There is a higher degree of flexibility needed, when it comes to directed energy weapon development and proliferation, to sustain the demand of changing load profiles and enhanced sensors capability. As a result, innovative characteristics of modern Lithium-ion battery storage systems can be successfully exploited in terms of naval power systems. A common use energy storage system could facilitate benefits such as reduced fuel consumption and prime mover running hours by decreasing the number of running generator sets. Based on the recent investigations, there is a great potential for Lithium-ion Nickel Manganese Cobalt (NMC) based energy storage system to power predicted laser directed energy weapons and show high rates of fire for extended periods subject to state of charge operating limitations.

In fact, energy storage systems deployed onboard of naval ships can serve miscellaneous purposes, such as: functioning as an uninterruptible power supply (UPS) for the ship's power system in case of temporary loss of any of the normal power sources or as a power ripple levelling device when sudden loads are switched on and off the ship's power grid. Furthermore, storage medias will allow a ship to fire multiple shots from a high-powered laser without overloading the ship's electrical system.

3.5.3.2 STAKEHOLDERS

Heavy Duty sector involves a number of large and heavy equipment and complex processes, so it has always been in need for efficient energy storage solutions. What is more, with recent developments in the sphere of renewable energy sources, a 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: maritime oil & gas rigs, airports, stadiums, hospitals, military bases etc. This is easily supported by the significance of electrification in the

[314] "Assessing battery energy storage for integration with hybrid propulsion and high energy weapons" (July 3, 2019). Retrieved August 26, 2020 from https://zenodo.org/record/3381138#.X0Z_Q_gza3I

[315] "Power systems and energy storage modeling for directed energy weapons" (June 2014). Retrieved August 26, 2020 from https://calhoun.nps.edu/bitstream/handle/10945/42734/14Jun_Sylvester_Jeremy.pdf?sequence=1&isAllowed=y

industries of the future, which helps to replace Diesel, reduce environmental impact, and carbon footprint and guarantee backup power supplies in outage periods.

Except for the large-scale aforementioned industrial applications, there is viability for a commercial utilization of BESS to backing up power supply in hospitals, stadiums, etc. In this case, there is supposed to be a high level of involvement from multiple potential stakeholders, including consumers and end-users. Nevertheless, efficient proliferation of battery energy storage commercially in public places is highly dependent on decisions made by regulators and decision-makers[316]. For instance, the V2G technology deployment for the Energy Arena in Amsterdam can serve as a brilliant example of a beneficial cooperation between a variety of players: network operators, car manufacturers, industrial companies, business units, private individuals, etc.

Another impressive example of promoting the ESS technologies of the 21st century is bringing renewable infrastructure upgrade to hospitals, as they are known to be energy-intensive facilities (e.g. New Jersey Hospital project in US), where there are roofs of relevant size for photovoltaic (PV) systems installation, coupled with battery ESS thus it becomes possible to grab both economic and environmental advantages[317]. It can be executed within a cooperation between Solar Panels Manufacturers, Battery Systems Integrators and other stakeholders to balance the peak hours energy consumption and reduce overall bills for hospitals.

As a potential interested party, the technology can also serve the aviation community and authorities, as energy storage solutions can be deployed at airports, e.g. San Diego Airport and ENGIE Storage case[318], where BESS is coupled with photovoltaic systems as well. It will enable energy usage to be balanced and demand patterns regulated. Furthermore, military

[316] Commercialization of Energy Storage in EU, p. 13: Key regulatory obstacles to energy storage can be lifted by fair consideration of the role of storage in the electric power value chain (March 21, 2015). Retrieved August 21, 2020, from https://www.fch.europa.eu/sites/default/files/CommercializationofEnergyStorageFinal_3.pdf
[317] The Economist & NRG Energy Case Study: Optimizing the 21st Century Hospital. Retrieved August 21, 2020, from https://www.economist.com/sites/default/files/uclaanderson_wattsupdoc_report.pdf
[318] ENGIE Storage 4MWh system lands at San Diego airport (2019, June 26). Retrieved August 21, 2020, from https://www.energy-storage.news/news/engie-storage-4mwh-system-lands-at-san-diego-airport

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community can also have its own interest in battery storage, which can provide cost-efficient uninterrupted power supply for military bases.

Talking about Offshore Oil & Gas applications, batteries can act as peak-shavers, load-levellers etc. and provide fuel costs savings along with low maintenance expenses. Let's take a look at some big industry players, for example, the company **MJR Power & Automation Services** (UK-based company, which delivers marine energy solutions) is able to execute the following marine electrical engineering services[319]: Marine Electrical Consultancy, Marine Electrical and Automation Design, Marine Electrical Power Engineering, Offshore Electrical Power Engineering, Marine Electrical Installation etc. Furthermore, **Corvus Energy** (Norway-based company, which provides engineering-oriented energy storage solutions for marine, oil & gas and port apps) supplies ESS for both offshore operations supporting vessels and the ones placed onboard the rigs[320]. In addition to battery storage installation to a drilling rig power plant itself, there is also potential scope to replace Diesel generators with batteries for offshore supply vessels, e.g. **SPBES** (Canada-based) company has the necessary expertise to provide the battery system solutions, as SPBES's battery systems are used to power offshore supply vessels, large hybrid yachts, industrial machinery and in land-based grid energy projects[321].

All things considered; the following stakeholder list can be compiled regarding heavy duty energy storage applications as follows:

- Airports
- Aviation authorities
- Battery manufacturers
- Battery management system (BMS) providers
- Citizens/ end-users in hospitals, stadiums etc.

[319] MJR Power & Automation, Marine Automation & Control Systems section (MJR official website, 2020). Retrieved August 21, 2020 from https://www.mjrcontrols.com/service/marine-automation-control-systems/
[320] Corvus Energy website, About Corvus Energy section; Offshore section (Corvus Energy official website, 2020). Retrieved August 21, 2020 from https://corvusenergy.com/about/
[321] SPBES official website, home page (Sterling PBES Energy Solution official website, 2020). Retrieved August 21, 2020 from https://spbes.com/

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- Commercial organizations
- Electric utilities companies
- Environmental protection agencies / associations
- Local authorities/municipalities, governments
- Marine electrical engineering servicing providers
- Maritime ESS suppliers
- Maritime industry advisors
- Military bases
- Oil drilling companies/ Oil groups
- Power management companies
- Project developers and investors
- Regulators
- Solar panels manufacturers
- Specialist battery storage integrators

3.5.3.3 TECHNOLOGIES AND OPERATION

General

Battery solutions can be used in many large scale energy storage applications, other than those primarily used in the utility/grid and off-grid applications as well as telecom applications explained earlier in chapters 3.5.1 and 3.5.2, for example as backup and supporting roles in industrial applications, stadiums, hospitals, airports, various military applications and so on. In this report some of these possible areas of applications are discussed.

Marine and offshore oil and gas application[322]

Li-ion batteries can be used in offshore/marine applications. This market is expected to grow in the future and there are clear benefits. The integration of energy storage with the power supply and distribution system of a drilling rig improves the environmental sustainability of the offshore oil and gas industry. The power consumption is very variable in drilling and dynamic positioning processes. With energy storages, it is possible to decrease the use of Diesel engines (runtime) and optimize combustion level when operating them decreasing the emissions consequently.

A good example is Northern Drilling Ltd.'s West Mira offshore drilling rig that will operate in the North Sea's Nova Field. It will be the world's first modern drilling rig to operate a low-emission hybrid (diesel-electric) power plant using **lithium-ion energy storage**. The installed system consists of four converter-battery systems with a total maximum power of 6 MWh. The use of the battery system will result in an estimated 42% reduction in the runtime of on-platform Diesel engines with a reduction of CO2 emissions by 15% and NOx emissions by 12%.

[322] Siemens targeting Li-ion energy storage for marine and offshore oil and gas applications; 6MW system to West Mira rig (2019, January 31). Retrieved July 29, 2020, from https://www.greencarcongress.com/2019/01/20190131-siemens.html (July 29, 2020)

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The charging of the batteries will be done with the rig's Diesel-electric generators. The batteries can be used for supplying power during peak load times and as a backup power system to prevent blackout situations and provide power to the thrusters if needed (a low probability scenario in which all running machinery would be out of service).

Stadiums

Stadium battery energy storage can be a combination of new and second-life batteries as is the case with Johan Cruijff ArenA in Amsterdam, Netherlands[323], for example:

In that example, a 3 MWh energy storage system is applied, with 2.8 MWh storage system that includes energy storage battery packs (of Nissan LEAF[324]), out of which 250 are second life vehicle batteries, and 340 first life batteries. The initial step of energy storage introduction is about complementing the Diesel generators, which provide the stadium's backup power. They will replace the generators when the regulation framework is in place.

The use of energy storage system for stadiums can be further monetized with the vehicle-to-grid capability. There will be additional charging infrastructure outside the stadium, which will be connected to the energy storage system and work in conjunction with the grid. The average stadium capacity is 50,000-60,000 people for just a few hours a week, other time it can be monetized by trading energy on the regulated market, on the spot market, and provide the local neighbourhood with usable backup power.

[323]Eaton talks business cases for energy storage systems in stadiums, hospitals and data centers (2018, July 16). Retrieved July 29, 2020, from https://www.pv-magazine.com/2018/07/16/eaton-talks-business-cases-for-energy-storage-systems-in-stadiums-hospitals-and-data-centers/

[324]The 3 megawatt energy storage system in Johan Cruijff ArenA is now live (2018, June 28). Retrieved July 29, 2020, from https://www.johancruijffarena.nl/nieuws/the-3-megawatt-energy-storage-system-in-johan-cruijff-arena-is-now-live/

Hospitals

It is important to store large amounts of electricity to power hospitals, though it might be challenging, yet new battery technologies are making large-scale electricity storage practical and affordable. Due to their extensive use in electric vehicles and other applications, Li-ion batteries are the most popular choice for many large-scale applications[325].

Using electricity stored in a large-scale battery system, a hospital can minimize its peak kW usage (Demand Charges) and correct poor power factor conditions (KVAR) to save significantly on its electric bill. Furthermore, if electricity generated by a renewable source such as photovoltaic panels is stored, a hospital may also be eligible for financial benefits beyond simply reducing its electric bill.

A hospital's highest electricity usage typically occurs between 8 AM and 8 PM when demand for electricity and time-of-use (TOU) charges are high. Large-scale battery storage can help a hospital reduce TOU costs by "shifting" all or part of its load to off-peak hours. By recharging a large-scale battery system during off-peak hours, the hospital pays the lowest rates for electricity. It then uses that stored electricity during the day to minimize the hospital's electricity bills when TOU rates are highest.

Hospitals and their patients are highly dependent on the presence of sufficient electricity supply. Though, double-conversion uninterruptible power supplies (UPS) with support from backup Diesel-generators appears to be a costly and complex system. On the other hand, large-scale battery systems can provide hospitals reliable and resilient, high quality, environmentally friendly and, potentially, the lowest electricity cost for the periods of power problems or outages.

[325] Large-Scale Battery Storage for Hospitals (2018, January 22). Retrieved July 29, 2020, from https://www.engiemep.com/news/large-scale-battery-storage-for-hospitals/

Airports

Battery energy storage systems can be combined for example with on-site solar panel power systems to reduce electricity costs of airports and to reduce carbon emissions. with the help of batteries, airports have the capability to produce, store and distribute power to a single terminal or an entire airport complex, either as its main source of power or as its auxiliary electricity supply in the event the grid fails. Energy storage can assist in decreasing electricity expenses by allowing airports to charge batteries during off-peak hours and to release power during peak times to reduce energy costs. Consequently, airports can avoid spikes in energy use and high demand charges and thus pay less for energy. [326]

Airport renewable energy microgrid enables any airport to store some of the energy generated from the PV arrays onsite, feed energy directly to the airport and decrease electricity costs. Some off the generated excess electricity can be sold on wholesale energy market. By storing power in the batteries, the microgrid can provide energy when the demand is the highest and the sun has set. In a power blackout situation, the microgrid's solar power system, combined with a battery storage system enable maintaining electricity supply for the airport steady.[327]

Military applications

There are potential military applications concerning stationary Li-ion batteries such as microgrid applications and integration of renewable energy systems[328]:

[326] ENGIE Storage 4MWh system lands at San Diego airport (2019, June 26). Retrieved July 29, 2020, from https://www.energy-storage.news/news/engie-storage-4mwh-system-lands-at-san-diego-airport
[327] The Redwood Coast Airport Renewable Energy Microgrid being installed at Humboldt County's Main Airport (n. d.). Retrieved July 29, 2020, from https://redwoodenergy.org/community-choice-energy/about-community-choice/power-sources/airport-solar-microgrid/
[328] Lithium-ion Battery Systems Ready for Military Use (2011, November 1). Retrieved July 29, 2020, from https://www.powerelectronics.com/news/article/21859820/lithiumion-battery-systems-ready-for-military-use

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Forward operating bases in remote locations can apply energy efficient technologies such as solar and wind and store that energy to battery storage systems. Li-ion battery enables storage of solar and/or wind energy in a system that is substantially lighter than a typical lead-acid battery. The Lithium-ion battery also features a life cycle that is over five times higher than the life cycle of lead-acid batteries. Consequently, lithium-ion batteries present a high potential for storing energy in military transportation and microgrid applications.

The batteries used in military applications should be designed to meet the weight, temperature and environmental extremes. A suitable option can be large-format Lithium Iron Phosphate (considered the safest form of Lithium-ion chemistry) cells combined with an advanced thermal management technology to deliver reliable energy as a compact solution.

Battery storage technologies have advanced enabling large-scale systems that can provide cost-effectively immediate and flexible power source for military bases, etc. At the same time, battery-based systems help reducing carbon footprint and bring down the fuel consumption and costs related to existing backup Diesel generators. [329]

The increasing demand for microgrids in military applications is also rising the need for energy storages[330], as militaries are interested in grid-independent systems to provide continuous power. Reliance on Diesel generators in remote locations is often found to be a security threat, as transporting fuel can be dangerous and costly, and the generators are loud in service.

3.5.4 REPAIR AND MAINTENANCE

3.5.4.1 REPAIR

Stationary Li-ion batteries, in their various applications, are replaced at the end of their lifespan which essentially means repairing in this context. There is a very limited amount of information available regarding the actual replacement processes of Li-ion batteries per area of application. It can be speculated that the areas of application and the related technologies differ significantly and thus each system has its own unique instructions regarding the battery replacement procedure. One example of instructions that are related to the battery replacement procedure is presented below[331]:

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Performing a battery rundown test is a suitable way of determining the battery's capacity. Taking a module offline, connecting it to a load bank for operating at rated power until the defined runtime elapses or, alternatively, low battery voltage causes the unit to shut down. In this case, the battery replacement should occur when less than 80% of the rated capacity has been reached, in order to avoid getting to a critical load. Maintaining batteries and replacing them eventually should include the following:

- Inspection of a battery and a rack/cabinet for signs of corrosion or leakage
- Measurement & recording
  - the float voltage and current of the entire bank
  - the terminal voltage of selected batteries
- Checking
  - electrolyte level in each cell, if possible, and visual inspection
  - voltage balance & internal temperature of cells
- Keeping record of the ambient temperature
- Comparison of the collected data with previous maintenance inspections data

[329] Commentary: The Military's Next Essential Tool: Battery Storage (2019, September 16). Retrieved July 29, 2020, from http://www.energystoragenews.org/category/26/military/
[330] Global Energy Storage Market for Microgrids 2017-2021 | Key Insights and Forecasts | Technavio (2018, September 7). Retrieved July 29, 2020, from https://www.businesswire.com/news/home/20180906006023/en/Global-Energy-Storage-Market-Microgrids-2017-2021-Key
[331] https://www.eaton.com/content/dam/eaton/products/backup-power-ups-surge-it-power-distribution/backup-power-ups/services-resources/Eaton-Battery-Handbook-BAT11LTA.pdf (July 29, 2020)

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3.5.4.2 MAINTENANCE

Installation of Li-ion batteries[332]

Lithium-ion battery systems are normally shipped assembled. However, sometimes assembly on site is required. Purchasing a packaged system may help to save installation costs and time. The delivered battery modules may not all be at the similar state of charge. Therefore, it is advisable to give the battery management system (BMS) time to balance the voltage of all cells before starting functional tests. It is required that the batteries are installed in a stable ambient temperature long enough to be thermally consistent as measured by the BMS before running a test discharge or charge cycle.

Maintenance of Li-ion batteries in UPS energy storage applications[333]

While Lithium-ion batteries are harmless during normal handling as they lack toxic substances, it is important that they are correctly maintained according to right safety requirements. Should a battery case be punctured or fractured, consulting the Material Safety Data Sheet (MSDS) provided by a vendor for appropriate action is necessary. Different lithium-ion battery models use a variety of different chemical components, and consequently safety procedures will differ between Li-ion batteries.

Batteries can lose charge or self-discharge due to slight differences in local areas of the plates that discharge the battery. Self-discharge of the battery occurs continuously whether the battery is standing open circuited or operating. In case of for example UPS (uninterruptible power supplies) battery, used as a backup power system, if it happened to have a significant charge without being in use, recharging might be necessary. Proper recharging within the stated shelf life will maintain the runtime to the level of a new battery. It is useful to apply "recharge by" labels with a date of the next recharge visibly marked. If it is not possible for batteries to be installed before a certain recharge date, it is possible to connect them to a

[332] Key Considerations for Evaluating Lithium-ion Batteries for Stationary Applications (2019). Retrieved July 29, 2020, from https://www.vertiv.com/globalassets/documents/white-papers/key-considerations-for-evaluating-lithium-ion-batteries-for-stationary-applications/vertiv-lib-keyconsiderations-wp-en-na-sl-70519-web_280471_0.pdf

[333] The large UPS battery handbook (2020, March). Retrieved July 29, 2020, from https://www.eaton.com/content/dam/eaton/products/backup-power-ups-surge-it-power-distribution/backup-power-ups/services-resources/Eaton-Battery-Handbook-BAT11LTA.pdf

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temporary feed to recharge them. In some cases, external battery charging systems can be brought in to perform a refreshing charge. Nevertheless, it is highly recommended to use OEM chargers for this purpose. Failure to put the battery system in service or failure to recharge before the “recharge by” date will result in a permanent loss of battery capacity. Figure 43.

There are four main factors which affect a battery life:

1. ambient temperature of 25°C (The rated capacity of a battery is based on an ambient temperature of 25°C),
2. battery chemistry naturally makes a power delivery process slower,
3. each discharge and subsequent recharge reduce a battery’s capacity, and
4. the final factor is a proper maintenance itself.

Cycle Parameter	Influence on Cycle Life	Description
Charge / Discharge Rate	Significant	Charging or discharging a battery at rates higher than it was designed for will shorten its cycle life considerably
Depth of Discharge	Moderate	Partially discharging a battery before recharging is less damaging than discharging it completely
Temperature	Moderate	While a warmer battery will have less resistance and lower self-heating rates, cooler operating temps are generally better for life. Many lithium-ion batteries are also sensitive to charging at cold temps (usually below freezing) but this is generally not a concern for data center applications
State of Charge (SOC) Window	Minor	When using a battery at partial depth of discharge, cycling it near completely full (100% SOC) or completely empty (0% SOC) is more damaging than specifying an operating window at partial states of charge

Figure 43. Key Considerations for Evaluating Lithium-ion Batteries for Stationary Applications. Source: www.vertiv.com

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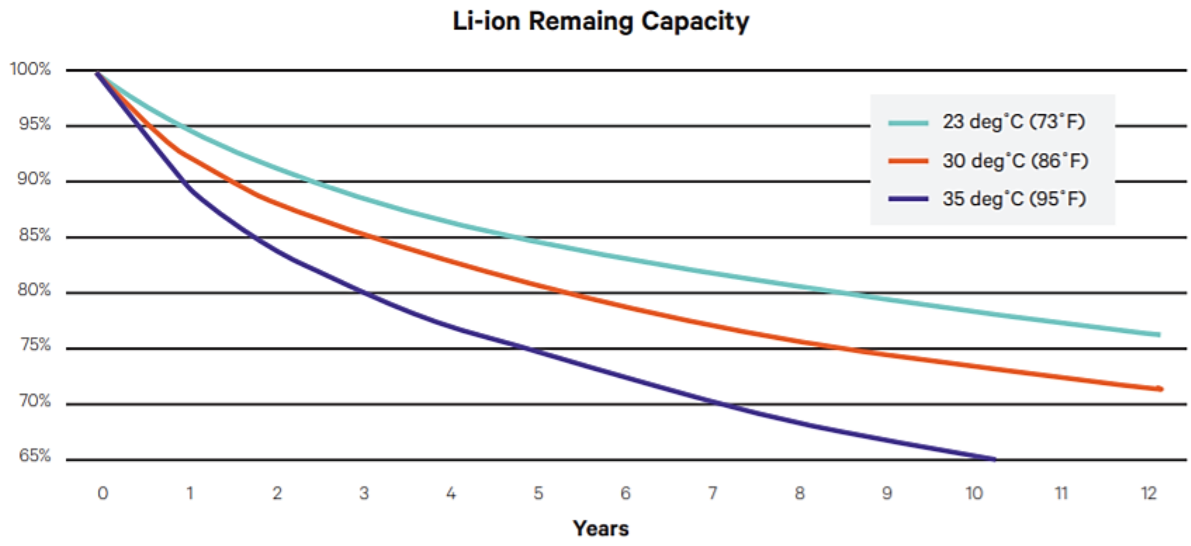

Figure 44. Figure 44The effect of ambient temperature on the lifespan of Li-ion batteries. Source: www.vertiv.com

A gradual decrease in battery life can be assessed and evaluated through voltage checks, load testing or monitoring. Periodic preventive maintenance extends battery string life by preventing loose connections, removing corrosion, and identifying weakened or damaged cells before they can affect the rest of the string. Even sealed batteries, despite their maintenance-free nature, require regular maintenance and servicing.

Even though determining the actual battery life can be difficult, it is usually dependent on both the battery design (taking into account the battery performs under perfect conditions) and the four factors mentioned above (temperature exposure, battery chemistry behaviour, charge/discharge cycling and maintenance procedures carried out). Figure 44.

Maintenance of Li-ion batteries with renewable energy systems[334]

The largest maintenance concern regarding lithium-ion batteries is their degradation rate. Just as with a cell phone, lithium batteries used in solar applications wear out after a certain number of charges and discharges. That degradation rate must be planned for. The two

[334] What regular maintenance is required of batteries used in solar systems? (2018, December 18). Retrieved July 29, 2020, from https://www.solarpowerworldonline.com/2018/12/what-regular-maintenance-is-required-of-batteries-used-in-solar-systems/#:~:text=LFP%20batteries%20require%20no%20maintenance,and%20more%20to%20maximize%20performance.

most common lithium-ion battery types used in solar-plus-storage are lithium iron phosphate (LFP) and lithium nickel manganese cobalt oxide (NMC).

LFP batteries are supposed to be a good choice, as cobalt is not used in them, so they do not risk thermal runaway (fire) concerns and do not require ventilation or cooling. These lithium batteries are ideal for use in stationary energy storage, especially if daily cycling of the batteries for solar self-consumption optimization and grid services is required.

LFP batteries:

Even though LFP batteries can originally require almost no maintenance, the installation location significantly affect the way they should be serviced. In other words, temperature ranges and altitudes should be considered. Usually battery management system (BMS) automatically monitors each battery cell for temperature, state of charge, life cycle and more to maximize performance. Though, batteries should be prepared for seasonal temperature fluctuations, stored, and installed in a location that meets the product specifications.

NMC batteries:

These battery type also shows great long-lasting performance, as nickel and manganese are providing additional density to the battery chemistry, though it`s vital to have a proper BMS (battery management system) to run these batteries smoothly. The BMS will monitor cell voltages, currents and temperatures to ensure safety and long life and is supposed to shut the system down, if there is potential for unsafe conditions. NMC batteries do not have special instructions for winter usage, as long as safe temperature ranges are complied with, but in case seasonal storage is required, they should be stored indoors, if winter conditions are considered harsh.

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Power Management of Li-ion batteries in grid energy storage systems [335]

With a variety of batteries packed in a stack, the power management must balance the electrical characteristics (e.g., voltage and current) of each battery in the stack. The power management system is a contributor to the capability of the battery to satisfy the requirements of grid-level energy storage applications, which have a considerable effect on the operation of the overall battery stack, its safety and cost.

Li-ion batteries need to be assembled in parallel to increase the current capability or in series to increase the voltage, which poses serious challenges to the stability, voltage operation, safety, and life cycle. For example, with just a few cells in series, the charge current and voltage are divided nearly equally among the cells. However, to achieve a high voltage, many cells need to be connected in series, which will result in unevenly divided voltage among these cells, leading to unbalanced cells with some cells fully charged and others overcharged. LIBs do not deal well with overcharging, resulting in potential safety issues and limited life cycle of the system. Therefore, establishing a monitoring system to prevent any cell from being overcharged and balance the batteries to maximize the performance of the entire system is important.

To ensure safety, the LIB monitoring system must function as follows: (1) balance the circuit and prevent the voltage or current of any cell from exceeding the limit by stopping the charging current, which should be considered to address the safety issues and ensure the stability of the system, and (2) monitor the temperature and prevent the temperature of any cell from exceeding the limit by requesting that the system be stopped and cooled.

Base station battery cooling management[336]

The lifespan of batteries applied for base stations is significantly reduced if exposed to temperatures that are outside the optimal range.

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[335]Tianmei Chen, Yi Jin, Hanyu Lv, Antao Yang, Meiyi Liu, Bing Chen, Ying Xie, Qiang Chen, „Applications of Lithium-Ion Batteries in Grid-Scale Energy Storage Systems“, 2020

[336] Cooling for Mobile Base Stations and Cell Towers (n. d.). Retrieved July 29, 2020, from https://www.lairdthermal.com/resources/application-notes/cooling-mobile-base-stations-and-cell-towers

While bigger compressor-based conditioners have traditionally been used, thermoelectric cooler assemblies are a newer system that can be used to cool or heat vital electronics, energy storage and battery backup cabinets. Battery back-up systems are prone to degradation under exposure to high temperatures or low temperatures. Cooling below ambient is necessary to extend the life of back-up batteries and temperature stabilization is required to maintain peak performance. Remote monitoring and control of the cooling system is vital to ensure the working condition of the machines distributed in different base stations.

Li-ion battery safety

For Li-ion batteries the riskiest conditions are overcharging, overheating, and short-circuiting of the battery cells.[337] Each of these conditions can cause the electrolyte in a lithium-ion battery to decompose into gases or, in extreme cases, to ignite. Lithium-ion battery failures usually begin in the electrolyte and nearly all today's commercially available cells use an electrolyte that is flammable.

Being aware of these risk conditions and controlling them is the purpose of the battery management system (BMS). Today's stationary battery applications benefit from the safety developments of the auto industry. Lithium-ion batteries do not contain toxic substances, and therefore do not pose a danger during normal handling.[338]

3.5.5 PROS AND CONS

3.5.5.1 PROS

Decreasing prices of Li-ion batteries is enabling continuously widening use and deployment thereof to various areas of stationary applications in which energy storages can provide significant support in terms of reliability by ensuring uninterruptable power supply, decreasing energy costs and lowering CO_2 emissions by facilitating the integration of renewable energy sources which are often intermittent due to their dependency on environmental conditions (e.g. solar and wind power).

[337] The large UPS battery handbook (2020). Retrieved July 29, 2020, from https://www.eaton.com/content/dam/eaton/products/backup-power-ups-surge-it-power-distribution/backup-power-ups/services-resources/Eaton-Battery-Handbook-BAT11LTA.pdf
[338] Key Considerations for Evaluating Lithium-ion Batteries for Stationary Applications (2019). Retrieved July 29, 2020, from https://www.vertiv.com/globalassets/documents/white-papers/key-considerations-for-evaluating-lithium-ion-batteries-for-stationary-applications/vertiv-lib-keyconsiderations-wp-en-na-sl-70519-web_280471_0.pdf

In terms of grid applications, energy storage helps enhancing utility operations by alleviating energy prices through time shifts and reduce the need for extra production. Additionally, batteries provide grid support by regulating frequency, supporting voltage and help in black starting electricity restoration. In terms of power optimizing, energy storages enable, for example, the relief in electricity congestion situations. For customers, energy storages can provide enhanced service through higher power quality and reliability. Energy storages such as UPS systems (uninterruptible power supplies) play a significant role in providing power in critical applications such as in hospitals and airports, should a blackout occur.

Integration of and facilitating the application of variable renewable energy sources is an important factor enabled by the deployment of energy storages. With the support of behind-the-meter energy storage applications, consumers can cut their energy related costs. It is possible to combine peak shaving and money saving with providing energy during peak hours from batteries that would have been stored at night-time prices. The energy may have been generated by solar panels or other renewables, stored in batteries, and used to cut the electricity costs and increase independency from front-of-the-meter grid.

Energy storages, when paired with, for example, renewable energy systems, enable generating power in off-grid circumstances. This helps the deployment of, for example, telecom base stations to provide the critical means of communications to remote areas as well as providing power to microgrids for remote community power applications.

3.5.5.2 CONS AND CHALLENGES

Despite the clear advantages of using Li-ion batteries in stationary applications, there are also challenges that are of technical nature. For example, deep recharging may affect the lifetime of a battery unfavourably. Additionally, the life cycle and performance of Li-ion batteries are often an issue in relation with the effects of ambient temperature and therefore temperature controlling may be needed in certain applications.

Another area of concern is safety. While the safety has been improving in the recent years thanks to the application of Li-ion batteries in electric vehicles, there are still safety concerns related to batteries. Abnormal use, such as disposing of in an unsafe environment with sparks

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or fire sources, excessive charging or discharging (e.g. overcharging and external short circuiting) and crushing, can result in spontaneous heat-evolving reactions[339].

The main safety risks involved with Li-ion batteries[340]:

Sensitivity to mechanical damage and electrical transients:

Li-ion batteries are prone to mechanical damage and electrical surges that may cause internal short circuits. The consequences may be internal heating, fire and explosion. Failure of a single battery may rapidly affect surrounding batteries escalating the problem.

Failure of control systems

For example, a BMS (Battery Management System) can fail and consequently lead to overcharging in a situation in which an operating parameter, for example the temperature or cell voltage of a battery, cannot be monitored.

Thermal runaway and potential fire

Thermal runaway is a significant risk with Li-ion battery technology. It is a cycle in which more heat continues to be generated by excessive heat. The process can result from internal cell defects, over voltage or mechanical failures/defects that lead to high temperatures, gas build-up and potential explosive rupture of the battery cell. Fire or an explosion can thus result. Thermal runaway can also spread from one cell to another generating more damage.

Battery fires are intense and difficult to extinguish. The extinguishing process may take days or even weeks and sometimes battery fires may seem to be put out when they continue burning. Generated toxic fumes, hazardous materials and consequent decontamination can be dangerous for firefighters. What adds to the challenge is that, due to a number of different kinds of batteries, firefighters should be aware of how to cope with the concerned battery type they are dealing with. This may lead to the previously explained situation in which firefighters think they have extinguished the fire which is not actually the case.

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[339] Tianmei Chen, Yi Jin, Hanyu Lv, Antao Yang, Meiyi Liu, Bing Chen, Ying Xie, Qiang Chen, „Applications of Lithium-Ion Batteries in Grid-Scale Energy Storage Systems“, 2020

[340] Lithium-ion Battery Energy Storage Systems The risks and how to manage them (n. d.). Retrieved August 3, 2020, from https://www.aig.co.uk/content/dam/aig/emea/united-kingdom/documents/Insights/battery-storage-systems-energy.pdf

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3.5.6 JOB ROLES AND SKILLS

At this value chain stage, the **Application Engineers, Battery System Engineers, Embedded Battery Systems Engineer** troubleshoot the system.

In a case of stationary applications **Application Engineers** are responsible for dismantling of batteries and other components. All processes must follow safety standards and procedures developed by **Quality Planners and Process Engineers.** Batteries are evaluated and tested by **Battery Test Technicians, Cell Inspection Technicians** under supervision of **Functional Safety Engineers and Managers, Validation and Compliance Engineers** and **ISO Auditors.**

For the battery repair and maintenance, the **Field Service Engineers (Stationary Applications), Electrical/Battery Storage Inspector** and **Electric Battery Repairers** or the above-mentioned **Test Engineers** and **Technicians** are relevant.

Skills and knowledge required in relevant advertisements:

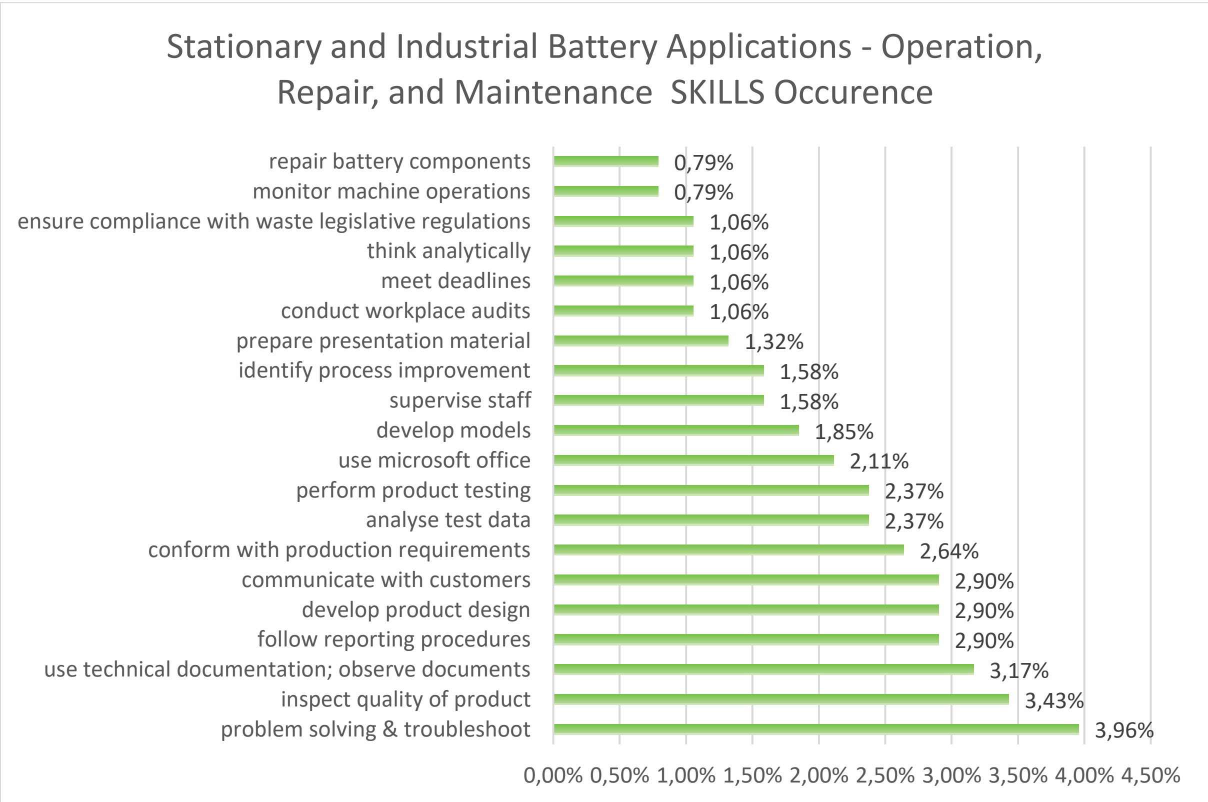

Figure 45 Operation, Repair, and Maintenance SKILLS Occurrence Stationary Applications

Skills

From the information shown in Figure 45, it is clearly visible that problem solving and troubleshooting is a very critical skill to have. Analysis of test data and product testing and quality as well as documentation management, observation and reporting are important. Development of models, conformation with production requirements, Microsoft Office usage and other follows.

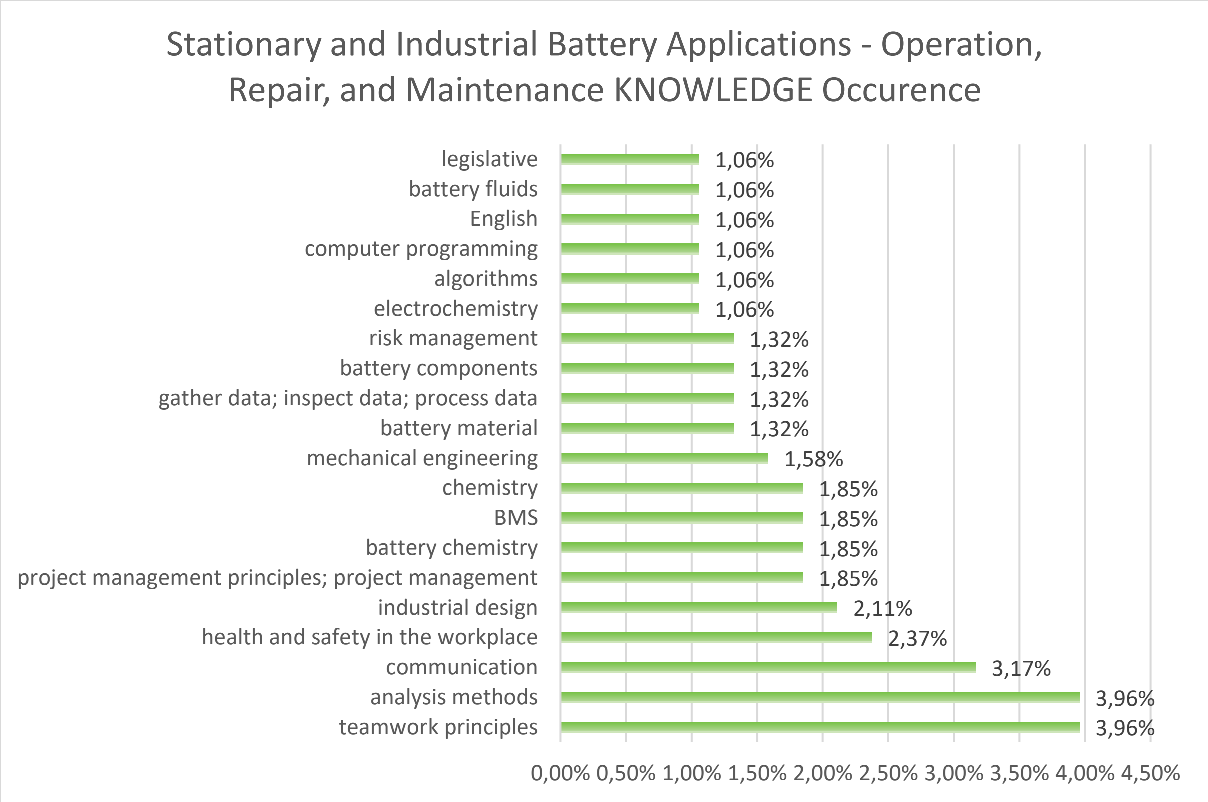

Figure 46 Operation, Repair, and Maintenance KNOWLEDGE Occurrence Stationary Applications

Knowledge Figure 46

Amongst the knowledge needed, the teamwork principles are most in demand, as well as communication. As for technical knowledge, employees must have a good knowledge of BMS, analysis methods needed for specific tasks, computer programming (Python, MATLAB) knowledge, be familiar with data science, and have background in batteries and material science.

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3.6 SECOND LIFE

3.6.1 Drivers of change

By 2030, up to half of the vehicles sold in Europe will be electric and will need batteries to power them[341]. At the same time, renewable energy sources will make up an increasing share of our electricity system. This increased demand will result in a need for batteries that are capable of efficiently storing power to smooth out peak demands.

3.6.1.1 Environmental impacts

The mobility of the future is tightly related to the electric propulsion, especially the electric vehicle (next to the Fuel Cell). These technologies imply the use of a propulsion battery whose life cycle is currently estimated between 10 and 20 years (best case scenario). If the donor EV is driven mostly in warm climate countries such as Portugal and Spain, the lifespan of the battery might reach 20 years whereas the batteries of cars driven mostly in temperate, cold climate countries (Belgium, Poland, Germany) is expected to go up to 10 years.[342] Future battery technologies promise longer lifespans and better resilience to frequent charging – discharging cycles, yet over the next couple of years, the most commonly used technology will remain the Li-ion.

Battery production is energy and resource intensive. To meet the growing demand, it is necessary to find solutions to make the entire battery life cycle more sustainable. To enable the transition to a circular economy, with emphasis on reuse and recycling, specific product designs and business models are required[343].

According to the company Watt4Ever[344], by reusing an electric vehicle battery for a stationary storage system one could avoid:

- Unnecessary CO_2 emissions:
    - To produce a battery with 1 kWh of energy, 70 to 110kg of CO_2-eq are released into the environment. This means that, for a small electric vehicle with a 41-kWh battery, the resulting emissions reach levels of up to 4,5 tons of CO_2-eq. Several additional tons of CO_2 by using the battery

[341] https://about.bnef.com/electric-vehicle-outlook/ (last accessed on 06.08.2020)
[342] https://pdfs.semanticscholar.org/49a1/d62cda83ed072ef77f169e71b8a0f0877f0a.pdf (last accessed on 06.08.2020)
[343] Bocken, N.M.P.; de Pauw, I.; Bakker, C.; van der Grinten, B. Product design and business model strategies for a circular economy. *J. Ind. Prod. Eng.* 2016, *33*, 308–320. [Google Scholar] [CrossRef].
[344] https://watt4ever.be/technology (last accessed on 30.07.2020)

to support renewable energy sources.

- Depleting rare minerals (Cobalt, Lithium, Nickel, and Yttrium), some of which have to be extracted using invasive and damaging mining techniques and must be imported from faraway countries, therefore carrying a massive carbon footprint.
- Up to 0,5 kg of Cobalt extraction per battery kWh.
- Avoid the impact of lithium extraction on local water resources.

These impacts will continue to grow along with the development of the electric vehicle and stationary battery markets. EU-based battery capacity is expected to jump from a mere dozen GWh today to several thousand GWh by 2049. This means that future battery production could be responsible for emitting hundreds of billions of tons of CO_2 into the atmosphere and for depleting rare mineral resources like Cobalt within a single generation.

There is a wave of investments in lithium-ion battery factories across Europe and the continent is expected to be the second largest battery producer after China. However, most investments are coming from Asian based companies such as LG Chem, Samsung, CATL, SK innovation or GS Yuasa. Majority of the lithium-ion battery factories that will be built in Europe will actually import battery cells from Asia and only the packing will be done in Europe Figure 47.

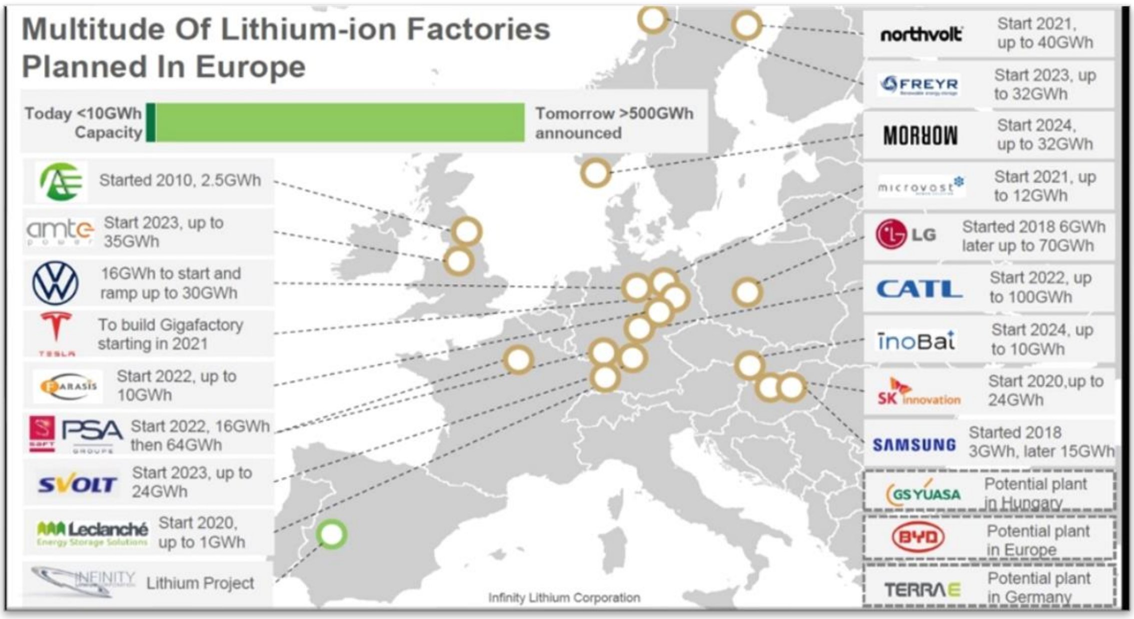

Figure 47: Factories planned in Europe (Source: www.infinitylithium.com)

Also, the raw materials needed for battery production, such as lithium, nickel, manganese and cobalt, are currently being extracted in limited quantities in Europe, though potential reserves are present. These European reserves will need to be exploited, although it currently seems that they will only be able to cover around 15 to 20% of the total demand[345]. The extension of the batteries lifetime through their second-use results in a decrease of quantity of secondary raw materials (SRM) available in the market. On the other hand, extending the lifetime also translates into an increase of materials productivity and a decrease of demand of batteries e.g. for stationary storage systems.

By 2025, 250,000 metric tons of EV lithium-ion batteries (LIBs) are expected to have reached end-of-life[346]. In this context, end-of-life means that the batteries are no longer considered useful in a vehicle, but they still retain 70–80% capacity. Being able to make use of that capacity, and only recycle the batteries, thereafter, might lead to big sustainability improvements. Capturing the value that is left in a product after the primary use is the cornerstone of circular economy. Through direct reuse, refurbishment, remanufacturing, and/or recycling, waste can be eliminated[347]. Remanufacturing and reuse slow down the resource cycle by extending products' life while recycling closes the resource loop[348;349].

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[345] OPINION European Economic and Social Committee, Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank on the Implementation of the Strategic Action Plan on Batteries: Building a Strategic Battery Value Chain in Europe, [COM(2019) 176 final], https://webapi2016.eesc.europa.eu/v1/documents/EESC-2019-01700-00-00-AC-TRA-EN.docx/content

[346] Winslow, K.M.; Laux, S.J.; Townsend, T.G. A review on the growing concern and potential management strategies of waste lithium-ion batteries. *Resour. Conserv. Recyc.* 2018, *129*, 263–277. [Google Scholar] [CrossRef]

[347] Ellen MacArthur Foundation. Towards a Circular Economy: Business Rationale for an Accelerated Transition. Available online: https://www.ellenmacarthurfoundation.org/assets/downloads/TCE_Ellen-MacArthur-Foundation_9-Dec-2015.pdf (last accessed on 6 August 2018)

[348] Bocken, N.M.P.; de Pauw, I.; Bakker, C.; van der Grinten, B. Product design and business model strategies for a circular economy. *J. Ind. Prod. Eng.* 2016, *33*, 308–320. [Google Scholar] [CrossRef]

[349] Stahel, W. The product-life factor. In *An Inquiry into the Nature of Sustainable Societies: The Role of the Private Sector*; Orr, S.G., Ed.; Houston Area Research Center: Houston, TX, USA, 1981; pp. 72–96. [Google Scholar]

Second life may bring more benefits than just economic revenue, such as environmental and social consciousness-raising or circular economy enhancement. In fact, circular economy by means of second life batteries eliminates the environmental impact caused by the manufacture of new batteries with an equivalent capacity, participating in the up/downstream circles of structural construction components.

The processes of reuse and recycling are complementary to each other, and the largest sustainability benefit can be reached if EV batteries are first reused and then recycled.

Globally, cumulative sales of fully electric and plug-in hybrid vehicles exceed five million units up to this date. As this market continues to grow and mature, the potential second-life battery storage capacity is huge. Several GWh of second-life batteries are expected to become available in the next 15 years Figure 48. The fact that the major EV automakers active in the European market cover their batteries with warranties over eight years essentially guarantees that they will retain 70-80% of their original rated capacity at end-of-life. Therefore, they can continue to provide services in stationary storage applications for up to 30 years.[350]

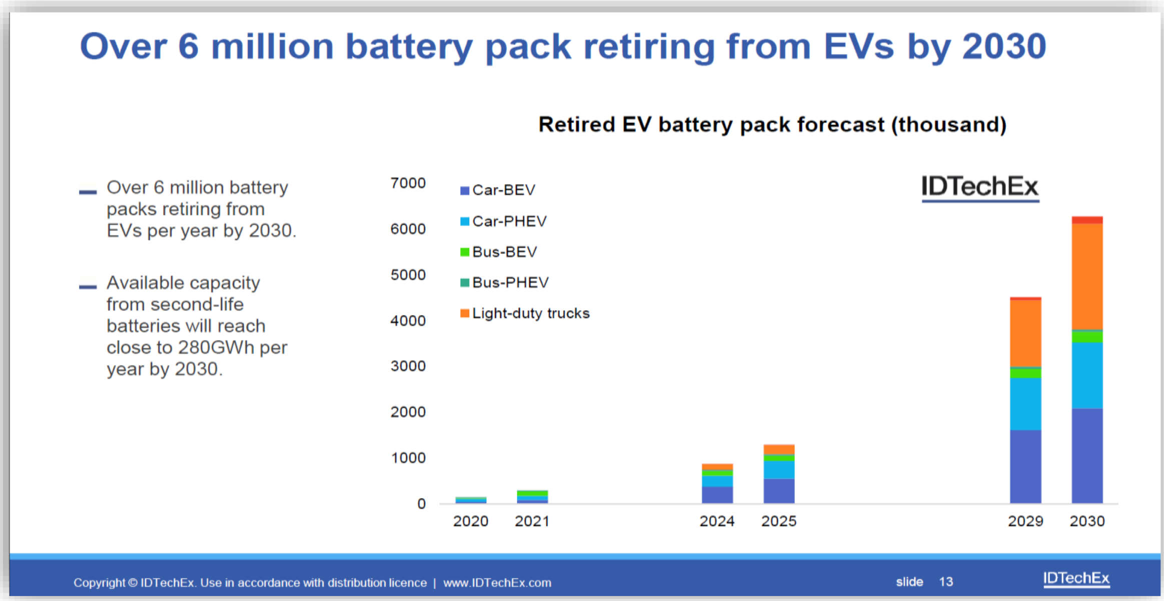

Figure 48: Retired EV battery pack forecast

[350] https://www.pv-magazine.com/2020/02/20/new-markets-for-old-batteries/ (last accessed on 05.07.2020)

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Second-life batteries can be used in various energy storage applications to facilitate renewable grid integration, thereby increasing the renewable mix of electricity; to provide grid ancillary services that improve the efficiency of power plant operation and potentially delay or even avoid grid infrastructure upgrade and the demand for new peaker-plants, which are often gas or coal-fired[351].

3.6.1.2 Financial and social aspects

The study performed by IDTechEx[352] shows that batteries are the most expensive component of an electric car. An electric vehicle (EV) battery is expected to last 8-10 years as with the battery warranties offered by most EV manufacturers, and the battery is retired from EVs when it cannot satisfy the requirements for use in EVs anymore, for example, when the loss of battery capacity limits the driving range of the electric car.

Repurposing retired electric vehicle (EV) batteries provides a potential way to also 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.[353]

Regarding the social perspective, the major step represented by the shift to electric mobility is expected to provide not only an environmentally-friendly, affordable means of transportation for the masses but also jobs for those who will most likely lose them in the automotive industry and the connected sectors (repair shops, fuel extraction and distribution, lubricants production, etc). The second life applications have a strong employment potential for both people being laid off from vehicle manufacturing and newcomers in the workforce.

Speaking about the financial aspects, there are also several issues that need to be dealt with in order to prevent the slump in GDP, fiscal revenues and local taxes. The strong employment potential and the business opportunities in the battery sector could

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[351] https://www.idtechex.com/users/action/dl.asp?documentid=22273 (last accessed on 06.08.2020)

[352] (https://www.idtechex.com/en/research-report/second-life-electric-vehicle-batteries-2020-2030/681 (last accessed on 30.07.2020)

[353] Jiao, Na & Evans, Steve. (2016). Market Diffusion of Second-life Electric Vehicle Batteries: Barriers and Enablers. World Electric Vehicle Journal. 8. 599-608. 10.3390/wevj8030599.

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compensate the fiscal revenue losses envisaged by the shift towards mass electric mobility.

3.6.1.3 Legislation compliance

As it is right now, the EU legislation on batteries and end-of-life vehicles might be a major drawback as it sets targets for recycling that are not yet technologically achievable: at least 50% by average weight of replaced batteries according to the directive 2006/66/EC and, considering the share of a battery in the overall vehicle´s weight, around 75% of the weight of the battery according to the provisions of directive 2000/53/EC[354].

The recyclability targets are not yet an issue as few EV have reached their end-of-life so far, except the crashed and damaged ones; that means the industry is enjoying some lead-time for research on performant recycling technologies, second-use applications and new battery technologies. Furthermore, most of the EVs that are approaching their end-of-life are prone to be exported to non-EU countries[355;356], thusly removing the legal compliance pressure away from the stakeholder's shoulders.

Also, the medium and long term decarbonization targets[357] call for a major switch from black and grey energy sources to green energy production; given that the green energy has some restrictive conditions and is mostly weather-dependent, it is absolutely necessary to develop performant storage technologies and solutions (e.g. accumulate energy during production peaks and shave off consumption peaks). One of the envisaged solutions, therefore, is the energy storage provided by second life batteries (e.g. in households equipped with solar panels) and even by the EVs themselves, through the smart charging and V2G applications, when the technology advances accordingly.

354 Directive 2000/53/EC https://eur-lex.europa.eu/resource.html?uri=cellar:02fa83cf-bf28-4afc-8f9f-eb201bd61813.0005.02/DOC_1&format=PDF and Directive 2006/66/EC https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006L0066&from=EN (last accessed on 14.08.2020), calculations by ALBATTS partners

355 https://news.africa-business.com/post/export-used-cars-to-africa-importers-of-used-cars (last accessed on 07.08.2020)

356 https://www.dw.com/en/world-in-progress-the-dirty-export-business-of-used-cars/av-44204306 (last accessed on 07.08.2020)

357 https://ec.europa.eu/clima/policies/strategies/2050_en (last accessed on 14.08.2020)

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Development of ultra-long life of EV propulsion batteries that outlive the vehicles they are installed in on the assembly line would pave the way for solid and extensive second-life applications.[358]

Refusal of some vehicle owners to replace the battery once it reaches SoH 80% might be a challenge[359]. As the SoH of a battery is not a safety concern, the diminution thereof resulting in the technical requirement to replace it cannot be enforced on owners of electric vehicles, thus unnaturally expanding the battery first life and depriving the second life market of the necessary stream. This phenomenon may be probably more intense in certain parts of the EU (e.g. Central and Eastern European countries) where many second-hand vehicles, including electric ones could end up.

3.6.2. Stakeholders

Vehicle manufacturers aren't the only companies paying attention to second-life batteries. A growing number of project developers are also starting to see second-life battery storage as a way to bring down the capital costs of commercial- and grid-scale battery installations. This marks a shift away from the smaller residential and off-grid battery applications where initially repurposed batteries were tested.[360]

Based on the perspective of potential operators, a broad range of second-life applications has been systemized. The resulting Figure 49 illustrates a variety of application scenarios which may be currently of particular interest from both the provider's and the user´s perspective[361].

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358 https://singularityhub.com/2020/06/11/road-trip-new-record-crushing-battery-lasts-1-2-million-miles-in-electric-cars/ (last accessed on 06.08.2020)

359 https://pdfs.semanticscholar.org/49a1/d62cda83ed072ef77f169e71b8a0f0877f0a.pdf, page 269 (last accessed on 06.08.2020)

360 https://www.greentechmedia.com/articles/read/car-makers-and-startups-get-serious-about-reusing-batteries (last accessed on 14.08.2020)

361 Rehme, Marco & Richter, Stefan & Temmler, Aniko & Götze, Uwe. (2016). CoFAT 2016 - Second-Life Battery Applications - Market potentials and contribution to the cost effectiveness of electric vehicles.

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Second-Life Applications						
Stationary application scenarios		*On-grid solutions* (network-connected)				
	Perspective of the operator	(Industrial) plant operators	Storage operators		Charging infrastructure operators	Residential and commercial real estate owners
	Applications	Short-term storage systems for renewable energy production plants (wind power and photovoltaics)	Stationary storage systems for participating in electricity balancing markets	Short-term storage systems for grid stabilization and regulation	Storage buffers for DC-quick charging stations	Storage systems for load shifting energy-intensive consumers (load management)
		Off-grid solutions (without network connection)				
	Perspective of the operator	(Small) plant operators/private households			Operators of critical infrastructure	Storage/charging infrastructure operators
	Applications	Storage systems for optimizing the own consumption of electrical energy from photovoltaics	Storage systems for uninterruptible power supply of private households		Emergency power systems for ensuring security of supply	Autarkic storage systems for micro mobility (e.g. charging e-bikes in non-grid-connected areas)
Quasi-stationary application scenarios		*Off-grid solutions* (without network connection)				
	Applications	Decentralized energy supply of major events			Decentralized energy supply of construction sites	
Mobile application scenarios		*Industrial solutions*				
	Applications	Re-use in industrial trucks (e.g. forklifts, lift trucks, tractors, transport trolleys), sweepers etc.			Re-use in driverless transport vehicles for the internal transport	
		Private and commercial solutions				
	Applications	Re-use in e-bikes, e-scooters, golf carts etc.	Battery swapping systems for e-bikes, e-scooters		Re-use in driverless transport vehicles	

Figure 49. Second life applications

The actors along the battery value chain should set up new collaborations with other actors to be able to benefit from creating new business opportunities and developing new business models together.

The list may refer to the following groups of stakeholders:

- Vehicle manufacturers
- Battery manufacturers
- Automotive repair and maintenance workshops
- Energy production companies with focus on green energy production
- Energy distribution companies including owners and operators of EV charging stations
- Solar panel manufacturers and distributors
- Electric component manufacturers
- Automation solutions developers and manufacturers
- High level and secondary level education institutions
- Research institutes
- Recycling companies
- Real estate developers
- Road construction and maintenance companies

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- Energy regulation and taxation authorities
- Local authorities/municipalities
- Regular citizens/flat owners associations

3.6.3. Technologies

3.6.3.1 Current technologies

The model of the value chain of EV batteries and the batteries flows in Europe according to the stakeholders' information and the performed literature review[362] is presented in Figure 50.

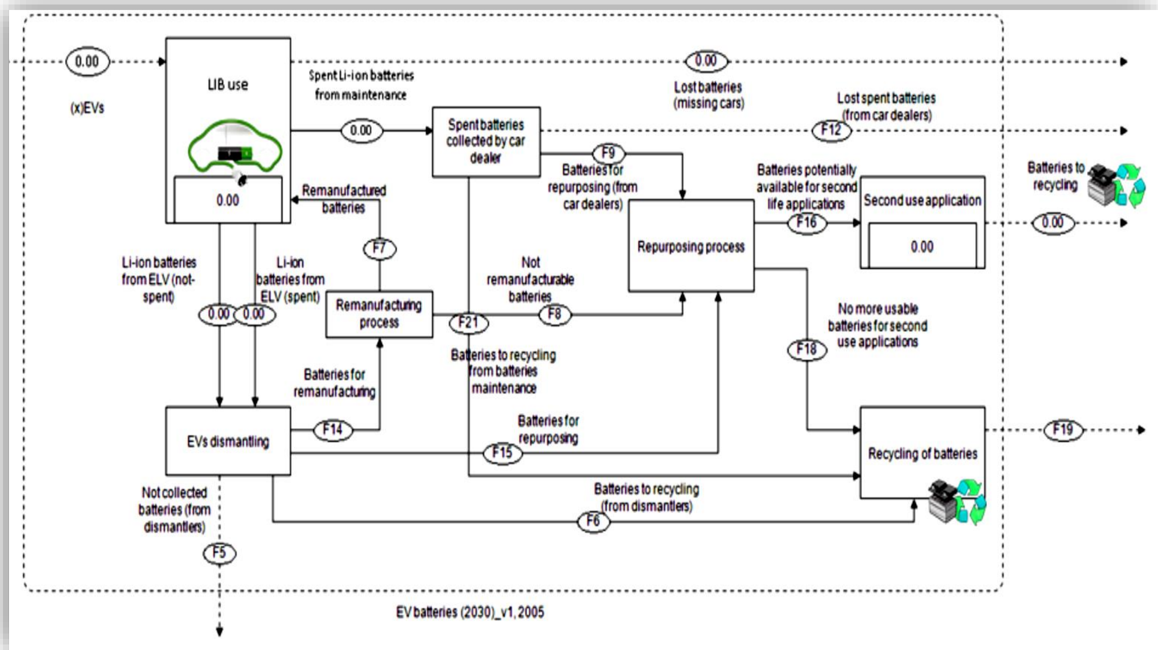

Figure 50. Value chain of EV batteries

[362] Bobba S., Podias A., Di Persio F., Messagie M., Tecchio P., Cusenza M.A., Eynard U., Mathieux F., Pfrang A.; Sustainability Assessment of Second Life Application of Automotive Batteries (SASLAB): JRC Exploratory Research (2016-2017): Final technical report: August 2018; EUR 29321 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-92835-2; doi:10.2760/53624, JRC112543

A simpler illustration of the value chain is provided in Figure 51. The value chain starts with design and manufacturing. After first life, the battery's health and capacity are checked to see if it can be used in a different vehicle or in a stationary application or if it needs to be recycled directly. If a second life is possible, the battery is refurbished according to the specific standards[363]. Depending on the battery and the application, refurbishment can include different processes[364].

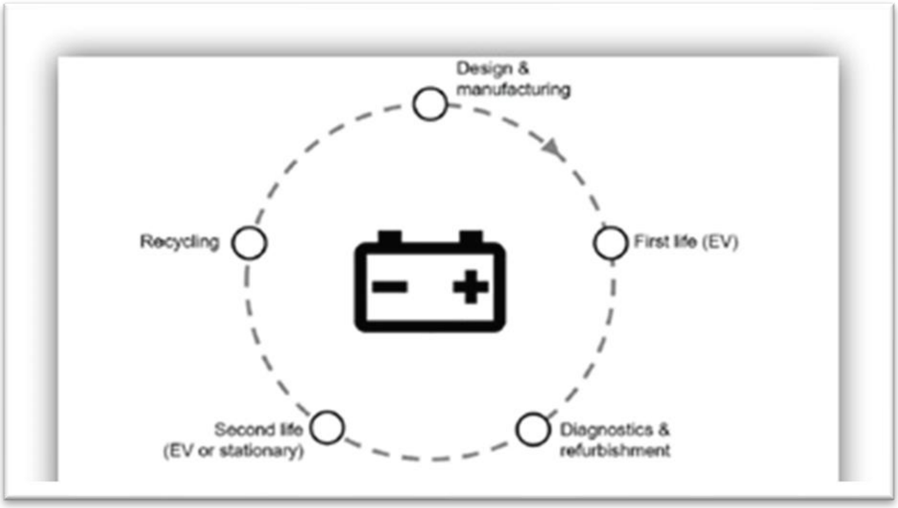

Figure 51. Value chain of EV batteries (simple form).

The main types of technology currently considered are divided into 2 main categories: mobile applications and stationary applications[365].

Although the second-hand batteries dealt with in this chapter come from road vehicles in general, the main "beneficiary" of this battery stream will be, at least in the beginning, a stationary application as mobile applications require more adjustment efforts[366].

[363] Standard for Evaluation for Repurposing Batteries, ANSI/CAN/UL 1974

[364] Olsson, L.; Fallahi, S.; Schnurr, M.; Diener, D.; Van Loon, P. Circular Business Models for Extended EV Battery Life. *Batteries* 2018, *4*, 57.

[365] https://www.idtechex.com/tw/research-report/second-life-electric-vehicle-batteries-2019-2029/626 (last accessed on 13.08.2020)

[366] https://pdfs.semanticscholar.org/49a1/d62cda83ed072ef77f169e71b8a0f0877f0a.pdf (last accessed on 06.08.2020)

For example, in the future, used batteries from BMW vehicles, can serve as stationary storage units for wind and solar power, which is currently the case on the premises of the BMW Leipzig plant[367].

Nissan formalized a partnership with Sumitomo Corporation to reuse battery packs from the Nissan Leaf for stationary distributed and utility-scale storage systems. In September 2018, Renault announced its Advanced Battery Storage Program[368].

In the near future, with a steep proliferation of the Electric Vehicle, the reuse of propulsion batteries is crucial for the sustainability of the grid. According to the calculations, a single average electric vehicle would double the energy consumption of a regular household[369]. Given the household consumption pattern and the vehicle charging particularity, this consumption could be also extremely intensive (without smart charging) if it takes place during a consumption peak which could result in severe production-consumption-grid stress[370].

Second life batteries (both stationary and mobile) will have a key role in storing the green energy (fundamentally weather dependent) and shaving the consumption peaks that may cripple the grid, especially in the countries where the infrastructure is still old/weak. For the beginning, the most accessible applications appear to be the stationary ones as the batteries used for such purposes are bulky and storage capacity impaired (e.g. 80% SoH in the best-case scenario).

A study[371] published in *Applied Energy* by MIT researcher Ian Mathews and five other current and former MIT researchers concluded that lithium-ion batteries could have a profitable second life as backup storage for grid-scale solar photovoltaic installations, where they could operate for a decade or more in this less-demanding role[372].

367 https://www.press.bmwgroup.com/global/article/detail/T0313566EN/more-than-seven-million-vehicles-with-all-electric-or-plug-in-hybrid-drive-systems-by-the-year-2030?language=en (last accessed on 14.08.2020)
368 https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/second-life-ev-batteries-the-newest-value-pool-in-energy-storage# (last accessed on 14.08.2020)
369 https://www.wall-street.ro/special/casa-ta-verde/201281/cata-electricitate-consuma-in-medie-o-locuinta-pe-ce-loc-se-situeaza-romania.html#gref (last accessed on 08.08.2020)
370 https://www.ofgem.gov.uk/ofgem-publications/136142, (last accessed on 06.08.2020)
371 https://news.mit.edu/2020/solar-energy-farms-electric-vehicle-batteries-life-0522 (last accessed on 14.08.2020)
372 https://www.greentechmedia.com/articles/read/car-makers-and-startups-get-serious-about-reusing-batteries (last accessed on 14.08.2020)

So, the first envisaged efficient application for the second life battery would be the (small scale) “battery farm” that could be conveniently located either near/in the big cities in order to store the conventional energy during the day for the subsequent use when the demand peaks or near the wind turbines/ solar panel farms in order to store the green energy and provide a constant stream around the clock[373]. Small scale battery farm solution is one of the best applications to jump start the trend as it is a pioneering enterprise. As an adaptation of a second-hand item to a different usage than the one it was initially designed for, there are many adjustments that need professional care and competent supervision. A battery farm is the only way this can be done in a cost-efficient manner. Even if the technology these days allows for efficient unmanned monitoring and intervention through automation, the associated costs are not to be belittled: all the required devices such as thermal cameras, regular cameras, remote control valves, sensors and so on (i.e. for safety reasons) add up to amounts that an average EV user or home owner might not afford.

Another possible type of stationary application for second life battery would be the power regulation hub for a small residential community such as a “cul-de-sac” or a group of homesteads that are within a small range away from one another, even though not all of them own energy production devices.

The third type of stationary application regards the single household with or without its own energy generation device.

The fourth type regards the stranded consumers such as off-grid homesteads or meteorological stations located in remote areas that only rely on the electricity generated by their own devices/sources. Even in the case of a consumer that relies mainly on the diesel generator, the battery provides a storage capability that comes in handy for the wellbeing of the generator (avoids the frequent on-and-off function thereof). Pairing up second-life batteries with solar panels and charging stations is also foreseeable for small communities or country roads.[374]

[373] https://www.sciencedirect.com/science/article/pii/S0301479718313124?via%3Dihub (last accessed on 14.08.2020)

[374] Example of a project: https://www.obnovitelne.cz/clanek/969/opravdu-cista-elektrina-pro-elektromobily-solarni-panely-a-baterie-nabiji-az-sedm-aut/ (last accessed on 20.08.2020)

Regarding the mobile applications considered up to this point, the most appropriate would be the following:

- Road applications: sightseeing trackless trains[375] and airport buses[376]
- Non-road applications: forklifts, front loaders and AGVs in automated container ports[377]

3.6.3.2 Challenges

Despite the benefits and potential for second-life batteries in energy storage applications, there are 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, in addition to challenges with the accessibility of data. Each battery is designed for a given EV model by its manufacturer and automotive OEM, which further fragments the volume of similar battery packs and increases the complexity of refurbishment. For example, more than 250 new EV models are planned by 2025 from more than 15 manufacturers further stressing this challenge[378]. On top of that, there is a lack of standardization for the battery management system (BMS) which leads to difficulties in guaranteeing second-life battery quality and performance.

Furthermore, decisions will need to be made about whether to invest in remanufacturing second-life batteries or opt for direct redeployment. While direct redeployment uses the original battery pack, remanufacturing (or reconfiguration) requires a cell quality selection process that results in enhanced battery pack quality. The cost difference between the two options can differ in favour of direct re-use, but remanufacturing has a higher quality output and overcomes several technical barriers. It is expected that remanufacturing, if it can be standardized, is likely to be the best way to create value from second-life applications and overcome some of the challenges.[379]

[375] https://www.visiter-bordeaux.com/en/discovering-bordeaux/bordeaux-visit-electric-touristic-train.html (last accessed on 06.08.2020)
[376] https://www.buslife.de/en/2015/10/german-airport-electric-bus (last accessed on 06.08.2020)
[377] https://e.huawei.com/topic/leading-new-ict-en/yangshan-port-case.html (last accessed on 06.08.2020)
[378] https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/second-life-ev-batteries-the-newest-value-pool-in-energy-storage (last accessed on 04.08.2020)
[379] https://www.pv-magazine.com/2020/02/20/new-markets-for-old-batteries/ (last accessed on 27.07.2020)

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In a presentation made by Na Jiao, PhD, Technology Analyst with IDTechEx[380], the challenges for second-life batteries are very well synthetized, as follows:

- Data availability and security
- Competition from new batteries
- Regulation and standards
- Uncertain raw material price
- Battery design for second life
- Battery collection

Regarding the professional decision on the reusability of a propulsion battery and the information that is necessary to have the right decision, the solution is a provision that exists in the legislation in force in the European Union. The End-of-Life Directive 2000/53/EC stipulates the obligation of manufacturers of components to supply appropriate information concerning dismantling, storage and testing of components which can be reused (Art.8, paragraph 4): "*4. Without prejudice to commercial and industrial confidentiality, Member States shall take the necessary measures to ensure that manufacturers of components used in vehicles make available to authorised treatment facilities, as far as it is requested by these facilities, appropriate information concerning dismantling, storage and testing of components which can be reused.*"

The only issue here is that the regulatory act is a directive (not a regulation) which has to be properly transposed in the national legislation and reasonably implemented in order to function as intended. The scheduled revision of this act might bring the clarifications needed (extension of the applicability of the requirement to "economic operators" (instead of "*authorised treatment facilities")* and the general applicability in all member states.

Once the regulatory framework is properly set, the certification mechanism can be adjusted to involve the operators that are already present in the economic environment: TÜV[381], SGS, etc. This certification is extremely important as: it can allow a complete assessment of the energy capacity remaining in a battery pack at the end of the first life; it may allow a more optimized design of the full battery system for a stationary

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[380] https://www.idtechex.com/users/action/dl.asp?documentid=22273 (last accessed on 27.07.2020)
[381] https://www.tuvsud.com/en/industries/energy, last accessed on 21.08.2020

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application since more balanced battery racks and battery banks can be achieved; enable developers and integrators of second-life batteries to provide product warranties to their customers, thus facilitating the widespread adoption of such solutions in the market.

Besides the legislative framework, there is another issue that must be dealt with as soon as possible, as practical applications are impossible without: the necessary tools to ship batteries across the country in a safe and expeditious manner as well as to ensure the right conditions for a proper and efficient second life.

The challenges also derive from the inherent technical and technological challenges related with this second-life opportunity, particularly when repurposing EV batteries to stationary electrical grid applications. There is still insufficient knowledge about the behaviour and performance of Li-ion battery systems beyond a certain SoH level, particularly upon the change of the type of usage of the system. This hinders not only the sizing of the system for a certain application but also leads to the lack of performance warranties that might lead to the lack of confidence and lower investments from the user.

For stationary applications, there are also challenges at the integration level with two main grounds: Li-ion based batteries have their internal resistance increased with age and utilisation, meaning that the design needs to consider that in terms of cooling and safety. Having a robust characterization of such behaviour will foster a more optimized design and further solution adoption; designing the solution for the stationary application may mean that a more regular replacement or capacity expansion in projects, which leads to the challenge of designing very flexible solutions, allowing such approach even in a changing EV battery pack design. This is an integration challenge as well as a challenge for the BMS.

3.6.3.3 Tools

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.

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The tools needed to deal with 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 own 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:

- Vibration monitoring system
- Premises temperature measuring and regulation
- Core fluid thermal management - for batteries cooled with (antifreeze) liquid or refrigerant fluid
- Emergency connection cut-off and, if necessary, battery flooding (stationary applications only)
- Infrared thermal scanning for defective cells[382]

In terms of hardware necessary to cope with the second life of the battery, there are also two main categories, beside the devices necessary to remove the battery from the vehicle which are stipulated by each manufacturer[383]:

- Storage and shipping hardware, mandatorily standardized regarding at least the following requirements: maximum length – 240cm, maximum width – 200cm, crane compliant, forklift compliant on both large sides, stackable on min 3 levels during shipping and min 6 levels when stowed, lockable between one another when stacked, vibration-proof and provided with detachable/foldable manoeuvring wheels on all bottom corners
- Final / working position hardware (especially in stationary applications) - cradle (with or without controller box, leak-proof and floodable), cooling ducts/pipes and radiators, with or without fans, connecting cables (both low and high voltage) from battery to consumer / generator, etc.

[382] https://www.aimspress.com/fileOther/PDF/energy/energy-07-05-646.pdf (last accessed on 14.08.2020)

[383] The service literature (spare parts catalogue, diagnosis software and repair manuals) is available on a fee/subscription basis. For example, the specific literature for Skoda vehicles is accessible under this link: https://erwin.skoda-auto.cz/erwin/showHome.do

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One item that can be found in both abovementioned categories is basically the "cradle" that could be used for either both tasks or just one of them[384].

3.6.3.4 Usage

According to a comprehensive study[385], second-life batteries can be employed for a wide range of applications (stationary and, to a lesser degree, mobile), based on:

- application area: residential, industrial, and commercial application
- usage: grid stationery, off-grid stationery, mobile applications

The Figure 52 shows the applications of ESS (energy storage system) using first life and second life of battery along with their usage pattern and potential.

Due to the requirements for a battery to be used in an EV, where it is required to provide a high C-rating[386] in charging and discharging, i.e. a high rate of charge/discharge due to acceleration and use of superchargers as well as the capacity to allow a significant driving range, such batteries can be used in the different applications shown below. However, the characteristics of each type of battery pack need to be studied to define the most appropriate operating regimes for such stationary applications. These batteries can be applied for frequency regulation, leveraging their capability of operating at up to 5C.

[384] information based on the ALBATTS partners experience

[385] Hossain, E., Murtaugh, D., Mody, J., Faruque, H.M., Sunny, M.S., & Mohammad, N. (2019). A Comprehensive Review on Second-Life Batteries: Current State, Manufacturing Considerations, Applications, Impacts, Barriers & Potential Solutions, Business Strategies, and Policies. *IEEE Access, 7*, 73215-73252. (pag 25-31)

[386] https://energsoft.com/blog/f/c-rate-of-batteries-and-fast-charging (last accessed on 26.08.2020)

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Also, they can be used to shift renewable energy in time, leading to a greater match between renewable production and consumption. However, the latter application is a more energy-oriented application, with a low c-rating, which can result in a less stressed usage of such batteries and can therefore contribute to a longer second-life.

Applications of ESS		1st life usage	2nd life usage
On-grid stationary	Renewable Farming	***	***
	Peak reduction	***	*
	Load levelling	***	**
	Area & frequency regulation	***	***
	Generation-side asset management	***	**
	Voltage or reactive power support	**	*
Off-grid stationary	Microgrid	***	***
	Smart grid	***	***
	Power quality & reliability	***	*
	Load following	***	**
	Spinning reserve	***	*
Mobile applications	EV charging station	***	**
	V2G for fast charging	***	*
	EV for long range trips	***	X
	EV for short range trips	***	**

*** Frequent, ** Occasional, * Rare, X Infeasible

Figure 52. Applications of ESS.

3.6.4. Future markets & projects

Reusing EV batteries in second-life applications extends their lifetime. Various sources show very different views and predictions regarding the share of batteries that will sustain a second life, emphasizing that the market is currently very uncertain. Second-life batteries can be employed for a wide range of applications[387]:

- stationary energy storage
- low-speed vehicles
- back-up storage systems
- mobile EV charger
- industrial forklifts

[387] https://www.idtechex.com/users/action/dl.asp?documentid=22273 (last accessed on 06.08.2020)

While portable lithium-ion batteries have been reused for a long time without much public attention, batteries from electric vehicles, which have become the dominant segment in the lithium-ion market, get more and more attention for their potential to be used in other applications. In Europe, several vehicle manufacturers, in particular companies that pioneered the electric car market, have installed used batteries primarily in different types of energy storage systems, ranging from small residential systems to larger containerised grid-scale solutions (see Figure 53)[388].

Car maker	Second life initiative
BJEV	EV-charging, backup power
BMW	Grid-scale energy storage, EV-charging
BYD	Grid-scale energy storage, backup power
Chengan	Backup power
Daimler	Grid-scale energy storage, C&I energy storage
General Motors	Remanufacturing,
Great Walll Motor	Backup power
Hyundai	Grid-scale energy storage, C&I energy storage
Nissan	Remanufacturing, C&I energy storage, EV-charging
Mitsubishi	C&I energy storage
PSA	C&I energy storage
Renault	EV-charging, residential energy storage, grid-scale energy storage
Tesla	Remanufacturing
Toyota	C&I energy storage, grid-scale energy storage (NiMH)
SAIC	Backup power
Volkswagen (Audi)	C&I energy storage
Volvo	Residential energy storage
Volvo Cars	Residential energy storage
Yin-Long	Backup power, C&I energy storage

Figure 53. Example of projects in use

3.6.2 Job Roles and Skills

Most notable jobs that could be classified under the second life of batteries stage are **Inspection Technicians, Service Technicians and Compliance Engineers, End of Warranty Managers** who can determine the parameter of battery to be used as a second life batteries. All of this could be done under supervision of **Safety Specialists and Managers**.

Skills and knowledge required in relevant advertisements:

388 http://www3.weforum.org/docs/GBA_EOL_baseline_Circular_Energy_Storage.pdf (last accessed on 14.08.2020)

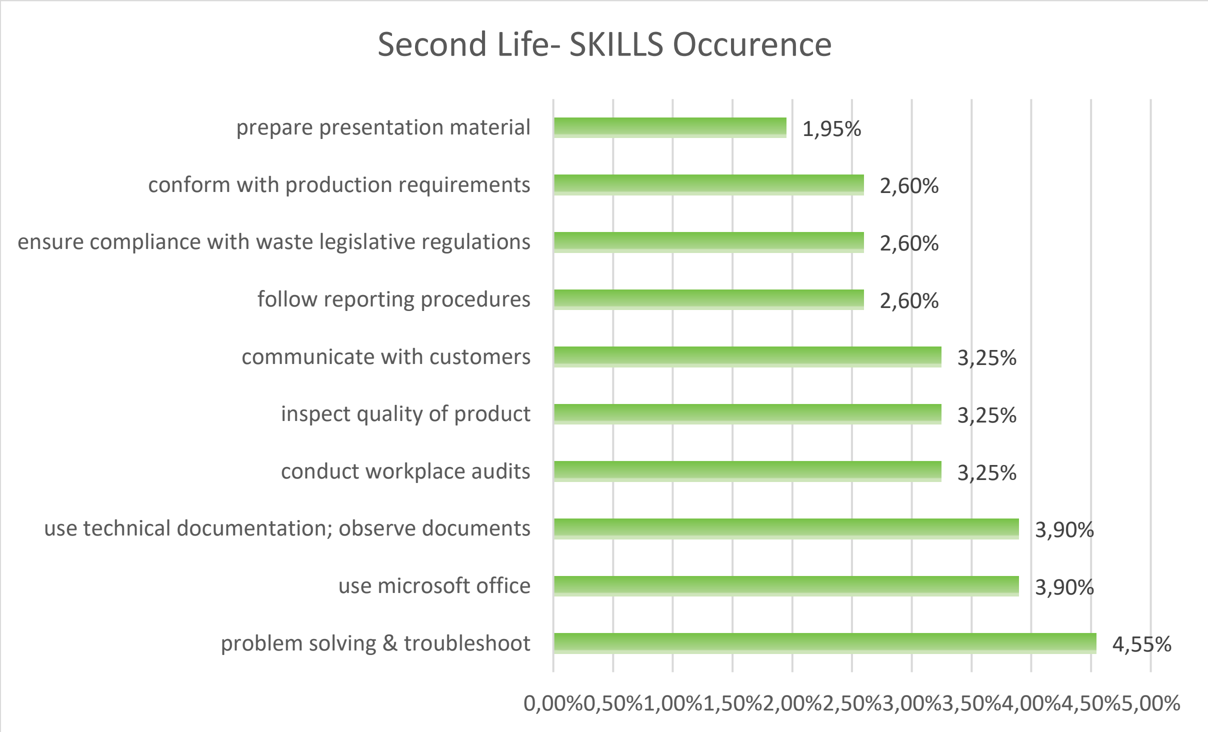

Figure 54. Second Life SKILLS Occurrence

Skills

Skills occurrence for battery second life is shown in Figure 54. Problem solving and troubleshooting, usage of Microsoft Office, documentation and quality inspections, audits and compliance with waste legislation are the most important.

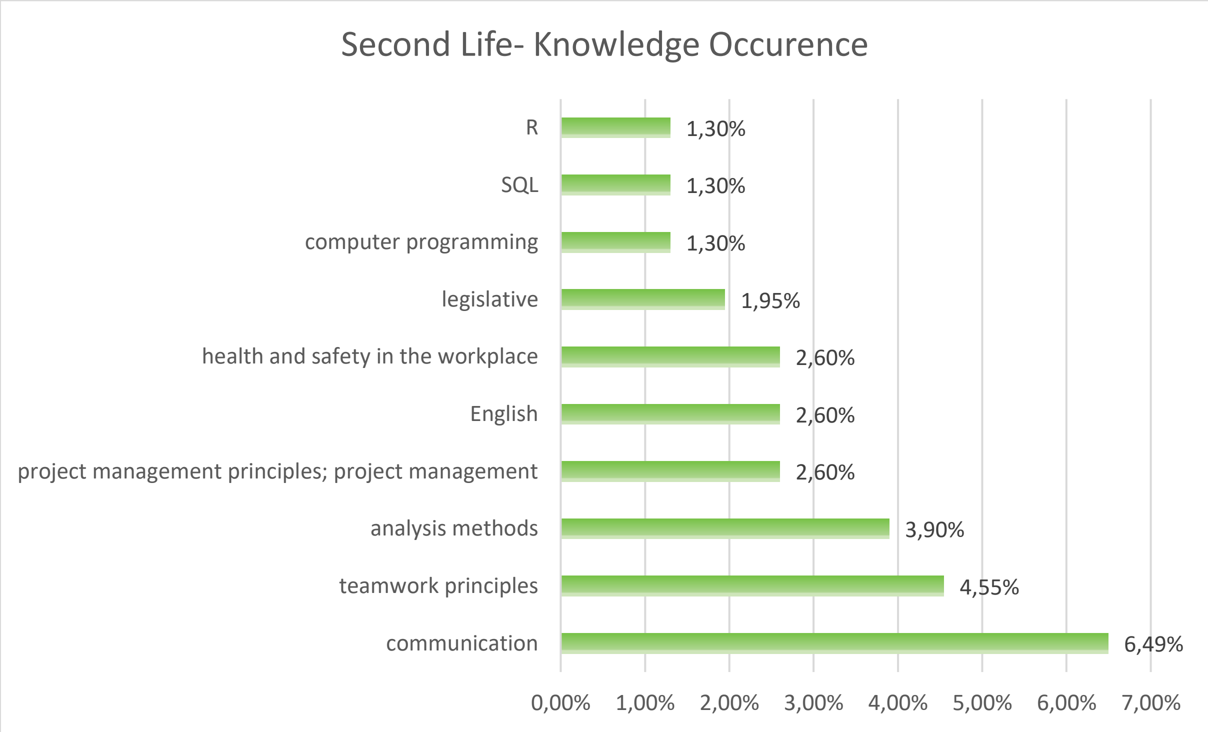

Figure 55. Second Life KNOWLEDGE Occurrence

Knowledge

Knowledge occurrence for battery second life are shown in Figure 55. Communication and teamwork are important knowledge outcomes from the analysis. The most relevant are legislative as well as health and safety knowledge.

3.7 RECYCLING

3.7.1 DRIVERS OF CHANGE

The major factors driving the change of the battery recycling market

The factors such as the increase in demand for electric vehicles globally, the rising environmental concerns, stringent government regulations regarding recycling of used batteries, and growing prices of rare earth metals such as Cobalt, which is used as a raw material for lithium-ion battery manufacturing, are considered as some of the major factors driving the growth of the battery recycling market.

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The lithium-ion battery recycling market is estimated at USD 1.5 billion in 2019 and projected to grow from USD 12.2 billion in 2025 to USD 18.1 billion by 2030, at a Compound annual growth rate (CAGR) of 8.2% from 2025 to 2030[389]

Rising investments in the development of electric vehicles are some of the key opportunities for the lithium-ion battery recycling market.

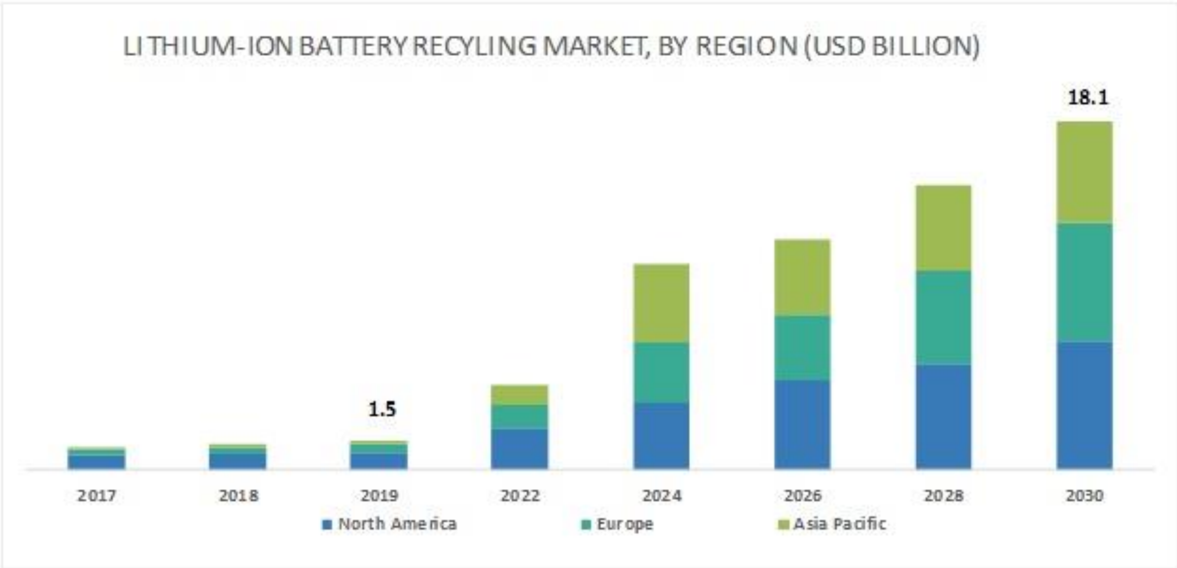

Figure 56. Lithium-ion Battery Recycling Market, by Region (USD Billion)

Automotive is the largest segment in the global Lithium-ion battery market, followed by the industrial and power segments. Lithium-ion batteries are being used in significant quantities for automotive propulsion. Since these batteries offer high energy and power density, there is an increasing demand for them, and this trend is expected to continue in the near future.

Batteries for EVs are expected to dominate the demand. The supply of Cobalt is a real concern, with batteries alone potentially using over 10% of the world reserves. Superalloys, which are used to make parts for gas turbine engines, are another major use for Cobalt[390]. Recycling

1 [389] Lithium-ion Battery Recycling Market. Retrieved August 03, 2020, from https://www.marketsandmarkets.com/Market-Reports/lithium-ion-battery-recycling-market-153488928.html

2 [390] National Minerals Information Center. Retrieved August, 12,. 2020, from https://www.usgs.gov/centers/nmic/cobalt-statistics-and-information

could reduce the severity of this potential shortage in the long term, and reserves may increase as the price rises.

The end of life of the batteries sold the EU market is regulated by the Batteries Directive 2006/66/EC[391]. It is the only piece of EU legislation dedicated to batteries and seeks to ensure that producers of batteries and products incorporating batteries are responsible for the management of the waste generated. As this directive is currently under revision, the EC has identified a need for:

- criteria to identify harmful substances which are not currently regulated (cobalt; organic electrolytes such as lithium hexafluorophosphate) and management measures prescribed.
- targets for battery collection (unsupported by the automotive industry) or provisions for national schemes, Extended Producer Responsibility (EPR), financing, labelling or reporting obligations with respect to industrial batteries (which include EV batteries).
- a mechanism to integrate new battery chemistries into the directive (e.g. solid-state, etc.).
- targets for the recovery of materials that constitute Lithium batteries such as Cobalt or Lithium – currently, the target for replaced batteries is 50%. According to the provisions of the ELV Directive (2000/53/EC[392] – also under revision) which applies to scrapped vehicles and affects the batteries indirectly, beyond the provisions of the Batteries Directive, the target for propulsion batteries removed from them is around 75%.

[391] EUR-Lex Aceess to European Union Law. Retrieved August, 12, 2020, from https://eur-lex.europa.eu/resource.html?uri=cellar:02fa83cf-bf28-4afc-8f9f-eb201bd61813.0005.02/DOC_1&format=PDF

[392] EUR-Lex Aceess to European Union Law. Retrieved August, 03, 2020, from https://eur-lex.europa.eu/resource.html?uri=cellar:02fa83cf-bf28-4afc-8f9f-eb201bd61813.0005.02/DOC_1&format=PDF

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- and the directive to address the "second life" of batteries. Producers currently remain responsible until the battery is eventually scrapped or recycled, independently of the number of intermediate lives it may have had.[393]

Further aspects that might create issues on the proper and efficient recycling and possible solutions:

- The decrease in quality of the core materials resulted from recycling, rendering them unfit for new batteries.
- Lack of standardization of the batteries, in many respects (shape, cooling solution, wiring, BMS, cell structure).
- Need for consideration of the broader context, complexity of vehicles and harmonisation of the different waste directives as a prerequisite for better recycling in the EU, as pointed out by the automotive industry representatives.[394].
- Recycling methods (mechanical and physical processing / pyro / hydro).
- The necessary investments in a high-capacity, complete recycling plant are considerable. A 1.200 tons/year processing plant would cost around 10 million dollars[395].
- Size of the waste stream – as in any other business / activity, the efficiency highly depends on the stream of batteries routed to the operator; frequent interruptions and / or scarcity of incoming stream of batteries might render the economic operator concerned unprofitable.

[393]Powering the future Commercial opportunities and legal developments across the EV batteries lifecycle. Retrieved, August, 03. 2020, from https://lpscdn.linklaters.com/-/media/files/thoughtleadership/electric-vehicle-batteries/powering_the_future_electric_vehicle_batteries_linklaters.ashx?rev=0921c08b-906a-48fd-b17e-45ff4063bd31&extension=pdf&hash=16DE5CE1C71E309E48836652B17D0AE4

[394] ACEA Position Paper Revision of the EU Batteries Directive (2006/66/EC) Retrieved, August, 03. 2020, from https://www.acea.be/publications/article/position-paper-revision-of-the-eu-batteries-directive-2006-66-ec

[395] Research Study on Reuse and Recycling of Batteries Employed in Electric Vehicles: The Technical, Environmental, Economic, Energy and Cost Implications of Reusing and Recycling EV Batteries. Retrieved August, 03, 2020, from https://www.api.org/~/media/Files/Oil-and-Natural-Gas/Fuels/Kelleher%20Final%20EV%20Battery%20Reuse%20and%20Recycling%20Report%20to%20API%2018Sept2019%20edits%2018Dec2019.pdf

- In line with the previous point, it is noteworthy the potential behaviour of some EV owners. More exactly their refusal to have the battery pack replaced once it reaches State of Health (SoH) 80% (or whatever threshold the manufacturer might set for the particular type of vehicle). As the SoH of a battery is not a safety concern, the degradation thereof resulting in the technical requirement to replace it cannot be enforced on owners of electric vehicles, thus unnaturally expanding the battery first life and depriving the second life market of the necessary stream. Furthermore, that particular battery, once it gets replaced, will probably be non-reusable for most of the second life envisaged applications and would have to be scrapped. This phenomenon will probably be more intense in low income countries where many second-hand vehicles including electric ones would end up once the original equipment (OE) battery`s SoH starts to diminish rapidly.
- The amount of recyclable batteries also depends on the discipline or lack thereof on the market. Even if the stream of unusable batteries is substantial, as long as it is possible to interfere effortlessly in the chain and cherry-pick the valuable, easy-to-remove materials, **the recycling industry will face either a shortage of batteries or the risk of inefficiency.**
- As it is a technology in its pioneering stage and the challenges are still high, besides the discipline, there is a need of constant and solid support from the authorities, including financial kind. The governments should support the establishment of automotive battery production value chains (from raw material extraction, sourcing and processing, battery materials, cell production and battery systems to reuse and recycling) by consulting key industry stakeholders to understand how to scale up capacity and investments to develop the value chain. Multilateral development agencies should strengthen funding for battery manufacturing, coupling it with requirements for sustainability (e.g. with respect to the transparency of supply chains).[396]
- Other options could be considered, for example an exclusive value chain for the spent batteries at least until the technology is mature enough and solid collection and

[396] Electric Vehicles On trac . Retrieved July, 15, 2020, from https://www.iea.org/reports/electric-vehicles

treatment systems are in place, possibly in conjunction with a “battery deposit” to be paid at purchase of the car and redeemed in full once the spent battery or the vehicle altogether is turned over to a certified collector/treatment facility.

The constant stream of spent batteries also depends on the proliferation of electric vehicles today. It is well known that most of the stimuli for the purchase of electric vehicles around Europe are incentives [rebate on the price, Value-added tax (VAT) exemption, registration tax exemption , ownership tax exemption, High-occupancy vehicle lane (HOV) privileges, free charging and parking, road/bridge/tunnel toll exemption, etc.) and the most stimulating ones are the financial kind. Unfortunately, not all countries can afford to grant these kind of stimuli[397] or not for a very important number of cars to be purchased[10],as it can be seen on the interactive map of Electric Vehicle incentives per country in Europe (2017) . The solution is to push for an EU-wide package of legislation to discourage the use of polluting, high CO_2-emitting cars that not only would be more efficient but would also be non-discriminatory. Not to mention that it would spare hefty funds that can be used on charging infrastructure or battery collection/recycling facilities.

3.7.2 STAKEHOLDERS

The stakeholders for battery recycling involve all elements of the battery value chain. This is important for the sustainability of the battery economy but, also, for batteries to become part of the circular economy. Only through the engagement of all current actors and business newcomers as well as through the creation of new business models will such actors tackle the challenge and take advantage of the opportunity that the recycling brings about.

The urgency to have current and new stakeholders involved in the recycling challenge derives from the very limited recycling capacity as in the past batteries have been treated only as hazardous waste. In Europe, battery recycling hosting capacity is only around 33.000 tons per year, not having an efficiency and effective process of recovering valuable metals

[397] Interactive map: Electric vehicle incentives per country in Europe (2017) 31/10/2017. Retrieved July 15, 2020, from https://www.acea.be/statistics/article/interactive-map-electric-vehicle-incentives-per-country-in-europe-2018

and rare minerals that can be found in Li-ion batteries. Also, there is not sufficient volume capacity for today's, and even less for tomorrow`s market, as electrification ramps-up[398]. The summary of the potential stakeholders in battery recycling are represented in the following Figure 57[399]:

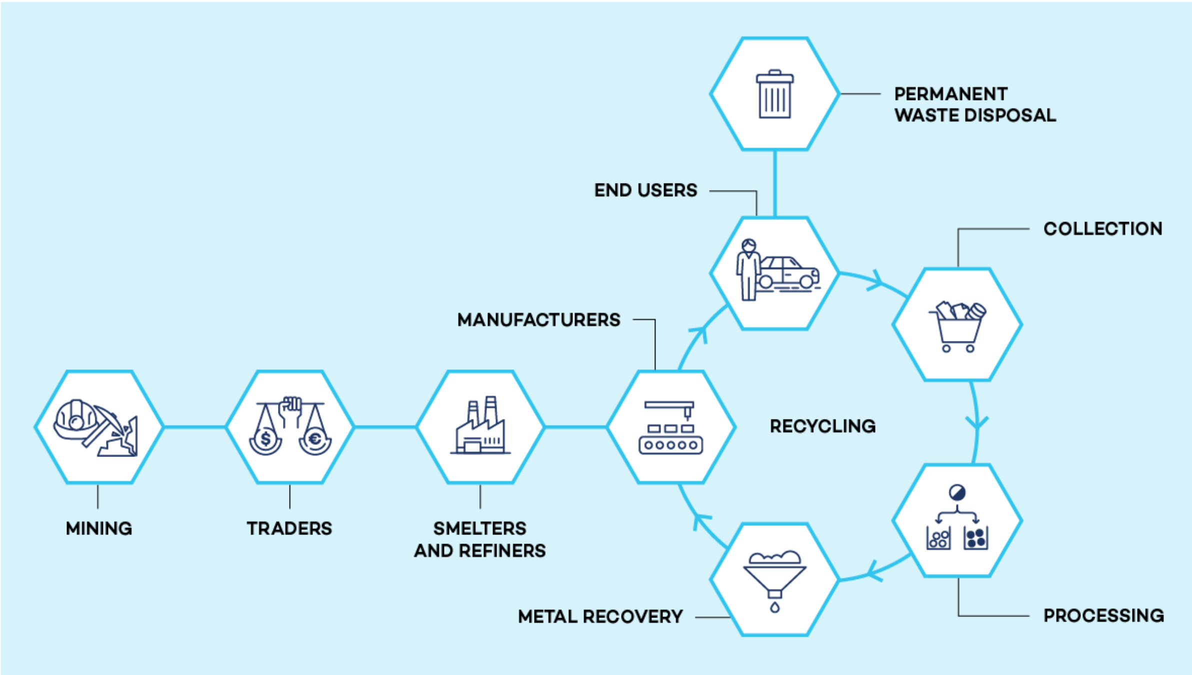

Figure 57. Summary of recycling stakeholders

The list of categories of stakeholders may be the following:

- Automobile manufacturers
- Automotive repair and maintenance workshops
- Battery manufacturers
- Citizens/ battery users in general
- Engineering, Procurement and Construction (EPC) companies with Operations and Maintenance (O&M) services
- Energy storage integrators
- Energy utilities
- Environmental protection agencies/ associations

[398] Northvolt. Retrieved August, 03, 2020, from https://northvolt.com/stories/RevoltTechnologies
[399]International Institute for Sustainable Development. Dead Batteries Deserve a Second Life by Claire Church on April 9, 2019. Retrieved August 03, 2020, from https://www.iisd.org/library/battery-recycling

- Local authorities/ municipalities
- Recycling companies
- Research institutes
- Telecom companies
- Waste, energy regulation and taxation authorities
- Waste management companies

On one hand, **stakeholders are not only focused on the sustainability of battery production** and, on the other hand, they are **changing actions due to new regulations** that increase the responsibility of different actors for battery recycling. Recycling may also foster other revenue streams and could lower the initial price of batteries as metals and rare minerals are recovered. European automakers are being made responsible for ensuring that their installed batteries are properly disposed of at the End of life (EoL). This has resulted in significant investments in recycling capacity, with recycling plants being owned by the automakers themselves or through partnerships. In these cases, recycling plants are responsible for battery manufacturers or materials processing companies while having continuous battery provision from automakers. The former, for example, includes the cases of the circular Gigafactory of Tesla[400] and the Volkswagen in-house Li-ion battery recycling plant[401]. The recycling plants are being planned or **located near automakers factories** to optimize logistics. An example of the latter is given by BMW[402], which has signed a strategic partnership with Northvolt and Umicore to dismantle battery packs down to their cells and recycle them for new cells, which will be manufactured by Northvolt. There is also the option to give a second life to disassembled packs if they meet the defined technical criteria. Another example is the

[400] Cooke, Philip, "Gigafactory logistics in space and time: Tesla's fourth Gigafactory and its rivals", 2020, MDPI Sustainability journal

[401] Volkswagen website. Retrieved July, 24, 2020, from https://www.volkswagenag.com/en/news/stories/2019/02/lithium-to-lithium-manganese-to-manganese.html#

[402] Digital Journal, BMW to partner with 2 firms to form battery supply recycle chain by Ken Hanly October 23, 2018. Retrieved July 27, 2020, from http://www.digitaljournal.com/tech-and-science/technology/bmw-to-partner-with-2-firms-to-form-battery-supply-recycle-chain/article/535272

joint venture between Nissan and Sumitomo[403], called “4R Energy”, that has built a factory in Japan focused on the reuse and recycling of Li-ion batteries from electric vehicles.

Battery manufacturers, the dominant players in the market, have already presented **circular strategies**, which are focused on recycling that is fundamental for a sustainable battery business and the continuous cost reduction. This is the case of Samsung SDI[404] and Farasis. One of the drivers is also a geographic shift in the location of availability of the resources, once mass recycling is achieved. In China there are regulations that assign responsibility to battery manufacturers for products placed on the domestic market. Figure 5. That structure will be leveraged for international battery sales as well. The same happens in Europe with Northvolt, as described previously, with a strong push and broad partnerships.

The same is applicable to providers and users of batteries to such fields as, for example, telecom and energy utilities. Therefore, the trend is that telecom and energy utilities as well as Engineering, Procurement and Construction (EPC) companies and energy storage integrators have a greater responsibility for recycling. Consequently, they can provide more opportunities to generate sustainable and circular products and services.

As there is a need for battery recycling capacity and new business models, new players, completely focused on the recycling or second use of the batteries, are coming to the market. Their main goal is to maximize the reuse potential and the recovery of critical material from Li-ion batteries in a sustainable and safe manner. These new players need to be capable of providing recycled material to battery manufacturers by enhancing the current technology and treatment processes and **challenging** existing mining and material processing companies in the value chain. Technologically, they may differ in the applied processes and how many percent of the material can be reclaimed. This is the case, for example, of Li-cycle[405], OnTo

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[403] Nisssan Motor Corporation, Global Newsroom, Nissan, sumito Corp. and 4R set up plant to recycle electric-car batteries. Retrieved July 27, 2020, from https://global.nissannews.com/en/releases/release-487297034c80023008bd9722aa069598-180326-01-e

[404] “Samsung SDI: Sustainability Report”, Samsung SDI, 2018. Retrieved July, 27, 2020, from https://www.samsungsdi.co.kr/upload/download/sustainable-management/2018_Samsung_SDI_Sustainability_Report_English.pdf

Technology[406], Anhua[407] and Duesenfeld[408].

Finally, the citizens and battery users need to be engaged and need to be aware of the challenge of recycling. Not only will they be shifting towards electric vehicles, but also, they need to know the differences and what to do with Li-ion batteries in different phases of their lifecycle. As the final users, they will be the key factor in the disposal process of batteries at the end of their lifecycles. In this process, local authorities, regulators as well as automotive repair and maintenance workshops will be crucial for the closing of the cycle

3.7.3 CURRENT TECHNOLOGIES AND STATE OF THE ART & TYPES

3.7.3.1 BACKGROUND

The waste management hierarchy was developed in 1975 from Council Directive 75/442/EEC[409] whose validity ended 2006. A Dutch politician, Ad Lansink, presented in 1979 a schematic picture, where waste is shown from the most to the least environmentally desirable option. In the Figure 58, the hierarchy is also considering battery recycling technologies.

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[405] Li-Cycle, Li-Cycle Technology, A unique and dependable approach to solving a pressing global issue. Retrieved July, 27, 2020, from
https://li-cycle.com/lithium-battery-recycling-technology/

[406] OnTo Technology Retrieved July 27, 2020, from
https://www.onto-technology.com/cathode-healing

[407] Anhua Tai-sem Recycling 2018. Retrieved July 27, 2020, from
http://www.tai-sen.cn/en/

[408] Duesenfeld, Ecofriendly recycling of lithium-ion batteries. Retrieved July 27.2020, from
https://www.duesenfeld.com/recycling_en.html

[409] EUR-Lex Acecess to European Union law, COUNCIL DIRECTIVE of 15 July 1975 on waste (75/442/EEC). Retrieved July 22, 2020, from
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31975L0442

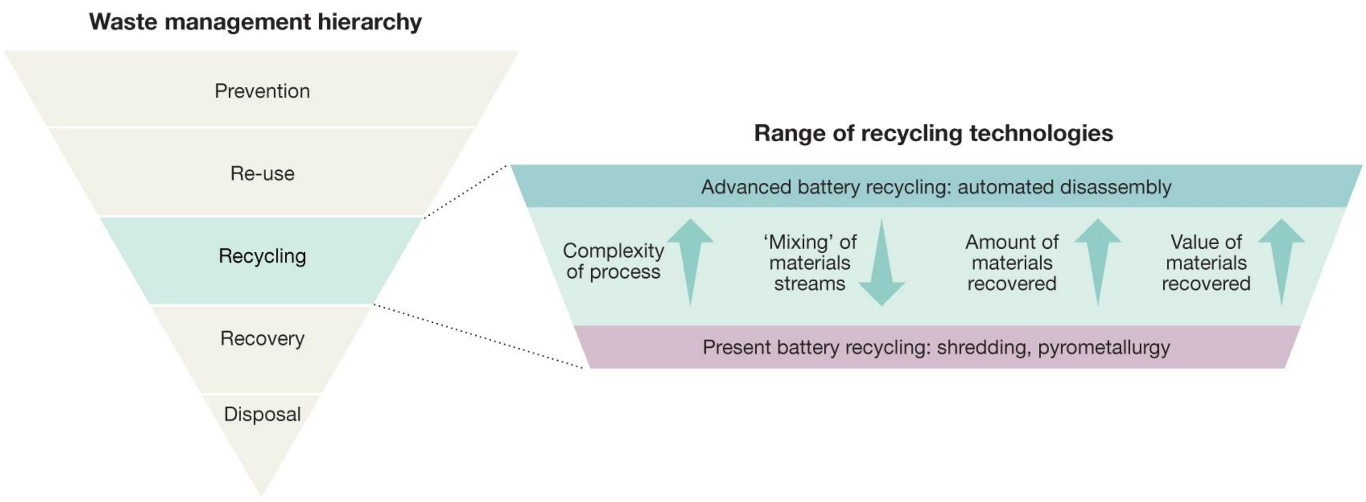

Figure 58. The waste management hierarchy and range of recycling options

The whole section below comes from a single source[410]:

- "Prevention" means that LIBs are designed to use less critical materials, which have high economic importance but are at risk of short supply. **It also means that EV's should be lighter and have smaller batteries.**
- "Reuse" means that EV's batteries **should have a second use as a stationary battery.**
- "Recovery" means that some **material is used as a fuel** for pyrometallurgy.
- "Disposal" means that **no value is recovered, and the waste goes to landfill.**

[410] Harper, G., Sommerville, R., Kendrick, E. et al. Recycling lithium-ion batteries from electric vehicles. Nature 575, 75–86 (2019). Retrieved July 22. 2020, from https://doi.org/10.1038/s41586-019-1682-5

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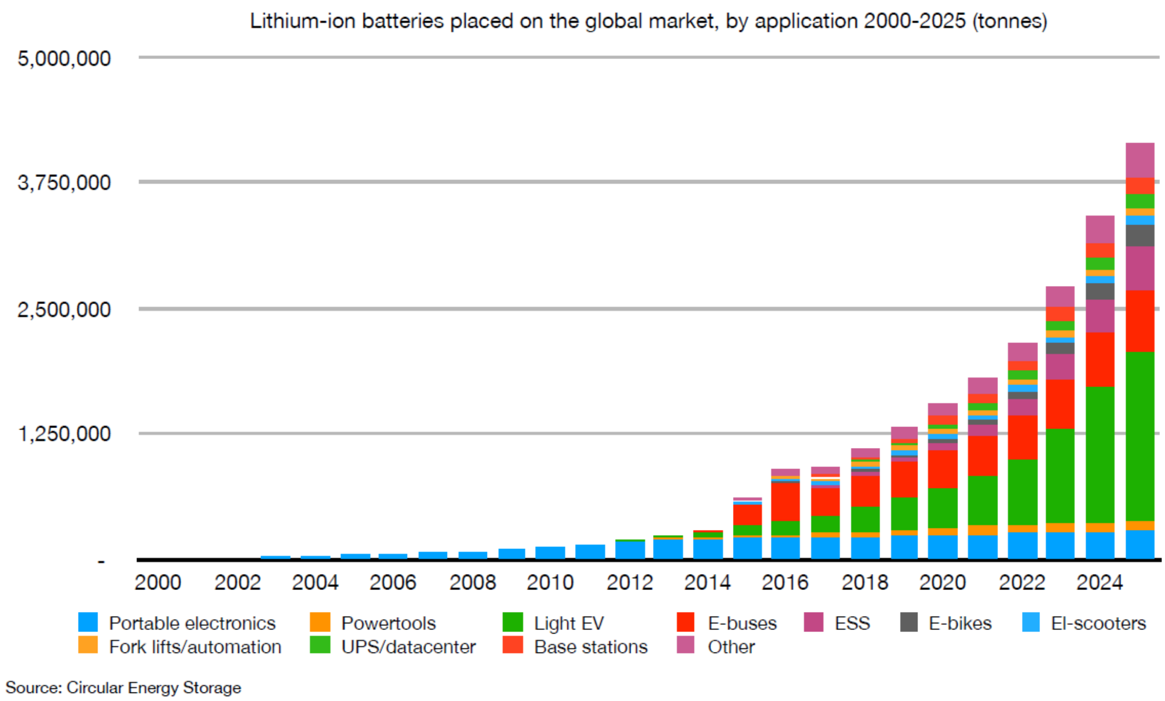

Figure 59. Lithium-ion batteries placed on the global market, by application 2000-2020 (tonnes)[411]

In the EU Legislation there are five important frameworks, where one is a Strategic Action Plan on Batteries: COM (2018) 293 final – Annex 2. In October 2017[412], the European Commission launched the 'European Battery Alliance'[413] cooperation platform with key industrial stakeholders, interested Member States and the European Investment Bank.

The Commission's Strategic Action Plan on Batteries has put forward actions covering the whole life cycle of battery production until re-use and recycling. Figure 59. Sustainable batteries – produced with responsible sourcing and ethical use of environment, the lowest carbon footprint and using the latest technology to promote second use and comply with the circular economy[414] principles.

[411] Circular Energy Storage Research and Consulting, ""The lithium-ion battery end-of-life market". Retrieved September, 2019, from https://circularenergystorage.com/reports

[412] European Commission „EUROPE ON THE MOVE Sustainable Mobility for Europe: safe, connected and clean. Brussels, 17.5.2018." Retrieved July 15, 2020, from https://ec.europa.eu/transport/sites/transport/files/3rd-mobility-pack/com20180293-annex2_en.pdf

[413] European Commission, Internal Market, Industry, Entrepreneurship and SMEs Industry, European Battery Alliance. Retrieved July 15, 2020, from https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en

[414] European Commission „EUROPE ON THE MOVE Sustainable Mobility for Europe: safe, connected and clean. Brussels, 17.5.2018." Retrieved July 15, 2020, from

A further opportunity represents the development of a world leading recycling technology by supporting research and innovation. Several battery-related research and innovation projects, which have been funded by EU are Horizon 2020, (approximately EUR 90 million per year) battery integration ,including also second use and vehicle to grid solutions, traditionally attract a non-negligible share of this financing, even if calls are technology neutral. The cluster of smart grid and storage projects (BRIDGE) goes beyond technical innovation aspects and looks into improvements of business models, regulatory issues, data management and consumer acceptance. There are also other initiatives such as "Horizon 2020 support of smart grids and energy storage projects", as announced in the Clean Energy for all European package [2018-2019] and "Smart Cities and Communities' projects"[415].

Several important issues have been studied and results have been published in the European research project **ELIBAMA**[416]. **The project strengthened European electric car battery industry and focused on a large-scale production LIBs. End-of-life comprehensive logistics chain was also studied in a work package.** Given that EU is lacking standardisation, the ELIBAMA project made proposals in three different areas: End-of-life logistics, recommendations for easy disassembly of batteries and standardised eco design for improved recycling[417].

https://eur-lex.europa.eu/resource.html?uri=cellar:0e8b694e-59b5-11e8-ab41-01aa75ed71a1.0003.02/DOC_3&format=PDF

[416] European Commission, TRIMIS Transport Research and Innovation Monitoring and Information System, ELIBAMA European Li-Ion Battery Advanced Manufacturing for Electric Vehicles. Retrieved August 03, 2020, from https://trimis.ec.europa.eu/project/european-li-ion-battery-advanced-manufacturing-electric-vehicles

[417] A Pdf document, Hans Eric Melin, State-of-the-art in reuse and recycling of Lithium-ion batteries, Swedish Energy Agency, June 07 2019.
Retrieved August 03, 2020 from Simona Tudor by email.

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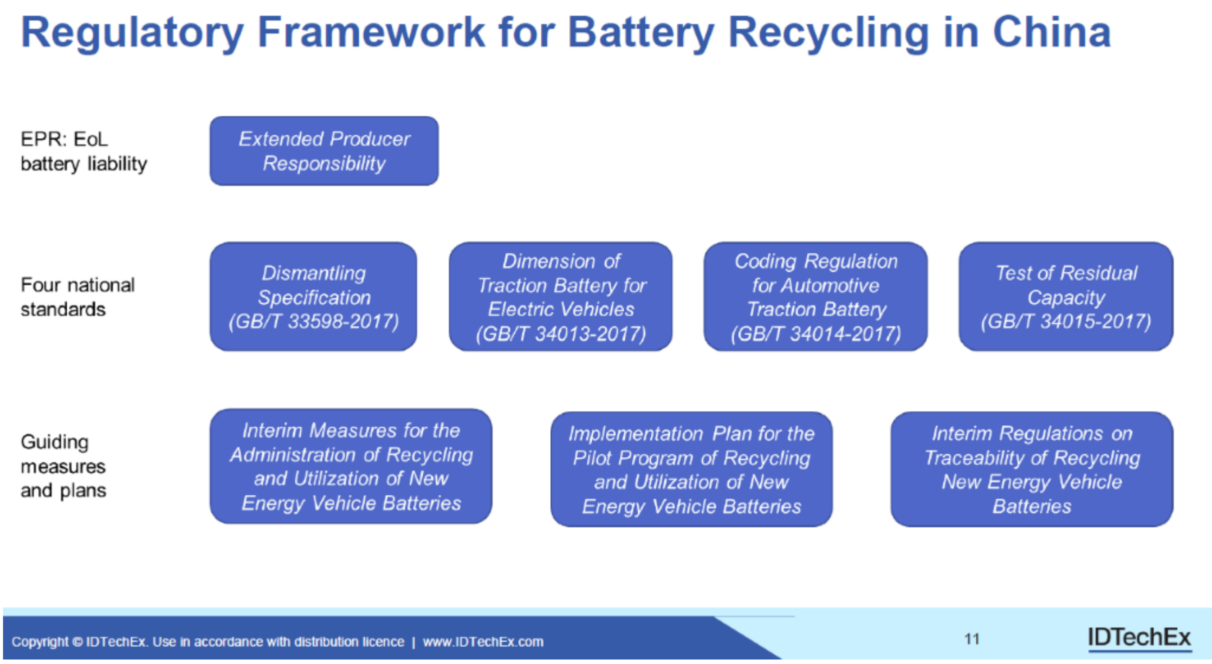

Figure 60. Regulatory Framework for Battery Recycling in China[418]

An introduction to Li-ion Battery Recycling – Where is the Value? Dr Alex Holland, ID TechEx

China, South-Korea, and Japan are countries which recycled most of the LIBs and **they are also paying for the battery waste**[419]. China has a regulatory framework for battery recycling, and manufacturers must apply the **Extended Producer Responsibility (EPR) principles** in the collection of end-of-life LIBs from the market. Figure 60. China also has four national standards for LIBs.

- 1 Dismantling specifications
- 2 Dimensions of Traction Battery for Electric Vehicles
- 3 Coding Regulation for Automotive Traction Battery
- 4 Test of Residual Capacity

[418] A Pdf document,
An introduction of to Li-ion Battery Recycling-Where's is the Value? Dr Alex Holland, ID TechEx, July 13 2020.
Retrieved August 03, 2020 from Simona Tudor APIAl.

[419] A Pdf document, Hans Eric Melin, State-of-the-art in reuse and recycling of Lithium-ion batteries, Swedish Energy Agency, June 07 2019.
Retrieved August 03, 2020 from Simona Tudor APIAl.

Furthermore, China applies Guiding measures and plans:

1. Interim Measures for the Administration of Recycling and Utilization of New Energy Vehicle Batteries
2. Implementation Plan for the Pilot Program of Recycling and Utilization of New Energy Vehicle Batteries
3. Interim Regulations on Traceability of Recycling New Energy Vehicle Batteries

European Union is lacking this type of regulatory in 2020, but the work has started. A systematic vision is necessary to design the framework for an integrated European industrial ecosystem, which allows horizontal cooperation between companies, while being supported financially, legislatively, and strategically by Member States and the EC[420].

Waste can be a renewable resource. **ESOI is an abbreviation of the Energy stored over energy invested** and the ratio between the energy that must be invested into producing the battery and the electrical energy that it will store during its useful life[421]. Based on the ESOI calculation results, it is easier to decide whether the EV used batteries can serve for stationary storage.

3.7.3.2 STATE OF THE ART

Current recycling methods

Current recycling of Li-ion batteries can be divided into two types, **direct and indirect methods**[422] as shown in the Figure 61. Several techniques follow the direct or indirect method, used in combination with each other:

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[420] Raphaël Danino-Perraud, „The Recycling of Lithium-Ion Batteries: A Strategic Pillar for the European Battery Alliance“, Études de i'Ifri, Ifri, March 2020. Retrieved August 3, 2020, from https://www.ifri.org/sites/default/files/atoms/files/danino_recycling_batteries_2020.pdf

[421] Harper, G., Sommerville, R., Kendrick, E. *et al.* Recycling lithium-ion batteries from electric vehicles. *Nature* **575,** 75–86 (2019). https://doi.org/10.1038/s41586-019-1682-5. Retrieved July 22, 2020, from https://www.nature.com/articles/s41586-019-1682-5#Fig5

[422] The Design and Optimization of a Lithium-ion Battery Direct Recycling Process by Panni Zheng, Li Cheng, Qiao Rui, Michael W Ellis, June 17, 2019. Retrieved August, 3, 2020, from https://vtechworks.lib.vt.edu/bitstream/handle/10919/93212/Zheng_P_T_2019.pdf

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- Physical material separation
- Pyrometallurgical separation (thermal treatment Celsius or Fahrenheit)
- Hydrometallurgical metals reclamation (with aqueous solution)
- Thermal pre-treatment followed by hydrometallurgical method, also often called a combination of pyrometallurgical and hydrometallurgical methods.

Li-ion batteries contain **an electrode**, which has **a positive charged anode (+)** and **a negatively charged cathode (-**), **metals** (Aluminium Al, Iron Fe, Copper Cu, Cobalt Co, Nickel Ni), and **polymeric material.** The way **the structure of the cathode material is breaking or not defines the approach method: direct or indirect.** During the recycling process, if cathode is breaking down to different elements, then the method to be applied is indirect. Figure 62.

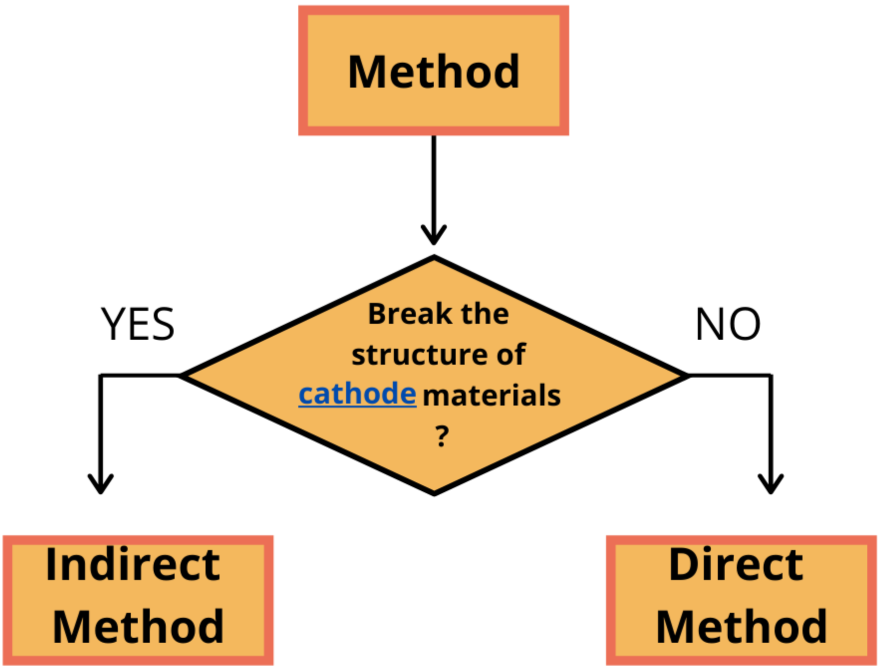

Figure 61. Direct and indirect method to recycle Li-ion batteries

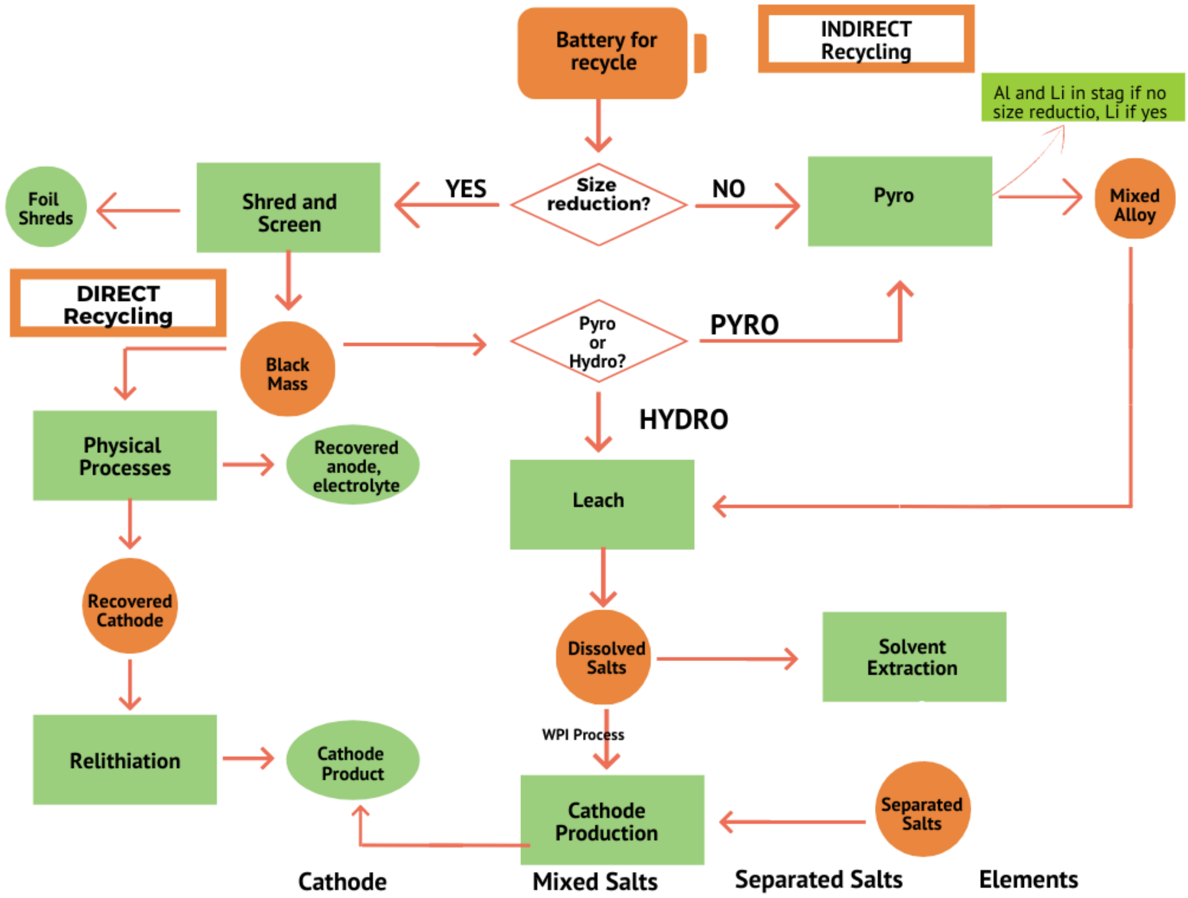

Figure 62. Possible recycling paths for lithium-ion batteries[423]

Direct recycling

In the Direct recycling, the removal of anode and cathode material from the electrode, is made with minimal changes to the crystal cathode morphology of the active material. The resulting mixed metal-oxide can be reincorporated into a new cathode electrode. The most valuable component on LIBs is the cathode material, like $LiCoO_2$ which contains Cobalt that is an expensive element. Thus, **recycling cathode material generates most value** and the direct method is the most cost effective and energy conservative[424].

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[423] ScienceDirect, Lithium-ion battery recycling processes: Research towards a sustainable course by Linda Gaines. Retrieved July 3, 2020, from redraw a figure to the ALBATTS report https://www.sciencedirect.com/science/article/pii/S2214993718300629

[424]Harper, G., Sommerville, R., Kendrick, E. *et al.* Recycling lithium-ion batteries from electric vehicles. *Nature* **575,** 75–86 (2019). https://doi.org/10.1038/s41586-019-1682-5. Retrieved July 03, 2020, from https://www.nature.com/articles/s41586-019-1682-5

The Figure 63. below shows a Direct recycling process performed by Farasis Energy. First, they discharge the cell and remove the electrolyte, then the cell is shredded by a milling machine and the result is “black mass” powder. Then active materials are separated from “black mass” powder by density differences between the anode and much denser metal oxide cathode materials. In the end, the active materials are purified and re-lithiated.

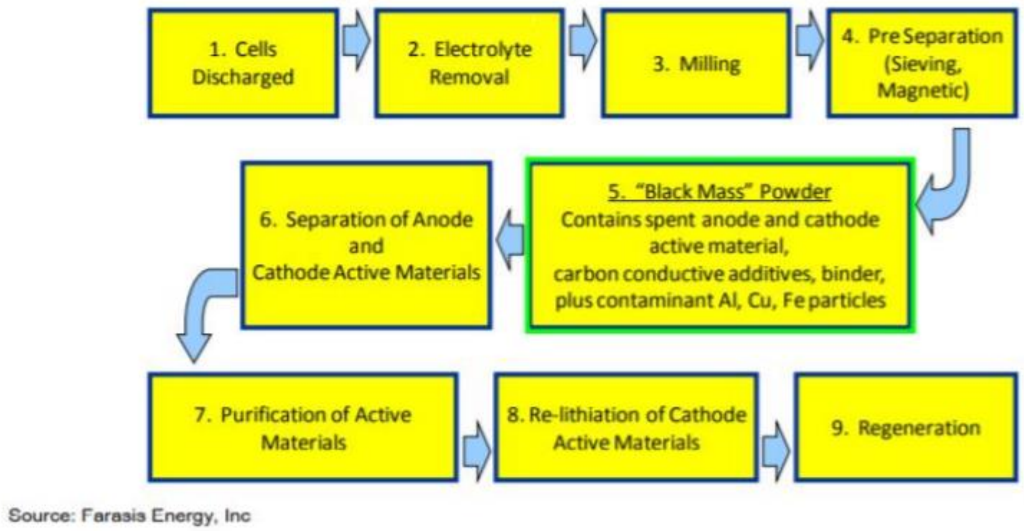

Figure 63. Direct recycling technology from Farasis energy[425]

Indirect recycling

The Indirect method uses Pyrometallurgical and Hydrometallurgical technics to recycle Co, Ni, Mn and then achieve Li precipitation. The leaching process consists of dissolving valuable metals from a raw material by solution purification. In the solution purification step, copper and aluminium are removed first by hydroxide precipitation.

[425] Larouche F., Demopoulos G.P., Amouzegar K., Bouchard P., Zaghib K. (2018) Recycling of Li-Ion and Li-Solid State Batteries: The Role of Hydrometallurgy. In: Davis B. et al. (eds) Extraction 2018. The Minerals, Metals & Materials Series. Springer, Cham. https://doi.org/10.1007/978-3-319-95022-8_214. Retrieved July 03, 2020, from https://rd.springer.com/chapter/10.1007/978-3-319-95022-8_214

The challenge is to avoid as much as possible the co-precipitation and the absorption of Co and Ni. With a suitable temperature and reaction time, the equilibrium can be completely reached. Equilibrium is the state in which the reactants in a chemical reaction and products do not change because the rate of forward reaction is equal to the rate of reverse reaction.

The Cu and Al particles can grow and aggregate in**to the right size**. Afterwards, the solution can be filtered, and the residue is supplied to copper and aluminium production. At this moment, the Al and Cu are precipitated together, there will be attempts to remove them from the solution separately in future[426]. Precipitated means that solid material is separated from the liquid by gravity. By using the hydrometallurgical recycling method, the final lithium product is reached, and the raw material can be used for synthesis. Further processes are needed in order to get purified Lithium.

3.7.3.3 PYROMETALLURGICAL RECOVERY

The whole section is sourced from this reference[427].

For reclamation after commotion, recovered materials can be subjected to a range of physical separation processes, which include sieves, filters, magnets, shaking tables and heavy medium, used to separate a mixture of lithium-rich solution, low-density plastics and papers, magnetic casings, coated electrodes and electrode powders. The result is generally a concentration of electrode coatings in the fine fractions of material, and a concentration of plastics, casing materials, and metal foils in the coarse fractions[428].

The end product is called "black mass" and consists of electrode coatings (metal oxides and carbon).

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[426] Wang, H., Vest, M. & Friedrich, B. Hydrometallurgical processing of Li-Ion battery scrap from electric vehicles. 16 (2011). Retrieved 22, July, 2020, from http://www.metallurgie.rwth-aachen.de/new/images/pages/publikationen/waeng_emc2011_id_2906.pdf

[427] Harper, G., Sommerville, R., Kendrick, E. *et al.* Recycling lithium-ion batteries from electric vehicles. *Nature* 575, 75–86 (2019). https://doi.org/10.1038/s41586-019-1682-5. Retrieved July, 03, 2020, from https://www.nature.com/articles/s41586-019-1682-5#Fig5

[428] Wang, X., Gaustad, G. & Babbitt, C. W. Targeting high value metals in lithium-ion battery recycling via shredding and size-based separation. Waste Manag. 51, 204–213 (2016). Retrieved from an artical, July 5, 2020.

To recover graphite and metal oxides from the copper, polymeric binders should be removed from the “black mass”. There are several possible technologies for this purpose, such as: solvents N-methyl-2-pyrrolidone (NMP) or dimethylformamide (DMF) to be applied, thermal heat to decompose the binder or dissolution of the aluminium collector. Unfortunately, all the aforementioned technologies **are not fast and innovative enough to be commercialized in the near future.** In the next ALBATTS report, this recycling method will be closely explained.

Nevertheless, there are some recent transitions in battery manufacturing i.e. moving away from fluorinated binders. Innovative batteries are moving towards alternative binders on the anode, which are water-soluble and easier to remove at end-of-life. There is also some work performed on similar cathode transitions, though, it appears to be more complicated[429].

3.7.3.4 HYDROMETALLURGICAL METALS RECLAMATION

This whole section extracted from the reference 42.

Hydrometallurgical treatments involve the use of aqueous solutions to leach away the desired metals from cathode material. By far the most common combination of reagents reported is H_2SO_4/H_2O_2. Based on studies performed, it is understood that H_2O_2 acts as a reducing agent to convert insoluble Co (III) materials into soluble Co (II). [Ferreira, D. A., Prados, L. M. Z., Majuste, D. & Mansur, M. B. Hydrometallurgical separation of aluminium, cobalt, copper and lithium from spent Li-ion batteries. J. Power Sources 187, 238–246 (2009).].

Other possible alternative leaching acids have been explored, with findings of organic solvents to be able to perform a solvent based extraction. After leaching, the metals may be recovered through a number of precipitation reactions controlled by manipulating the pH of the solution. [Granata, G., Moscardini, E., Pagnanelli, F., Trabucco, F. & Toro, L. Product recovery

[429] Nirmale, T. C., Kale, B. B. & Varma, A. J. A review on cellulose and lignin based binders and electrodes: small steps towards a sustainable lithium ion battery. Int. J. Biol. Macromol. 103, 1032–1043 (2017)
Recycling lithium-ion batteries from electric vehicles, Recycling methods. Retrieved July,03, 2020, from https://www.nature.com/articles/s41586-019-1682-5

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from Li-ion battery wastes coming from an industrial pre-treatment plant: lab scale tests and process simulations. J. Power Sources 206, 393–401 (2012).].

3.7.3.5 BIOLOGICAL METALS RECLAMATION

This whole section extracted from the reference[430].

Bioleaching is an emerging technology for LIB recycling and metal reclamation and is potentially complementary to the hydrometallurgical and pyrometallurgical processes currently used for metal extraction. It is highly useful for metals, which are particularly difficult to separate and which require additional solvent-extraction steps, e.g. cobalt and nickel. [Horeh, N. B., Mousavi, S. M. & Shojaosadati, S. A. Bioleaching of valuable metals from spent lithium-ion mobile phone batteries using Aspergillus niger. J. Power Sources 320, 257–266 (2016).]

Biological reclamation process uses microorganisms to selectively digest metal oxides from the cathode and to reduce these oxides to produce metal nanoparticles, though there are still extensive scopes for further research of this method. [Pollmann, K., Raff, J., Merroun, M., Fahmy, K. & Selenska-Pobell, S. Metal binding by bacteria from uranium mining waste piles and its technological applications. Biotechnol. Adv. 24, 58–68 (2006).]

3.7.4 ESTABLISHED TECHNOLOGIES

3.7.4.1 RETRIEV TECHNOLOGIES

Retriev Technologies (initially known as The Toxco). Large LIB packs undergo preliminary manual disassembly, while small batteries and cells may be processed “as-is”. Process begins

[430] Harper, G., Sommerville, R., Kendrick, E. *et al.* Recycling lithium-ion batteries from electric vehicles. *Nature* 575, 75–86 (2019). https://doi.org/10.1038/s41586-019-1682-5. Retrieved July 03, 2020, from https://www.nature.com/articles/s41586-019-1682-5#Fig5

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by shredding LIBs submerged in a brine solution to deactivate the cells and prevent fire due to Li oxidation[431].

The Retriev process consists of shredding the LiBs and the resulting slurry is processed with a hammer mill whereas larger metallic components are separated by screening. The resulting Cu-CO rich overflow is treated with a shaking table to remove Al and plastic particles. The small cathode-rich particles are filtered to get a cake rich in C and metallic oxides. The filtered liquid is also rich in Lithium. The metallic oxide and Li cakes are used in metal industry and considered downcycled.

3.7.4.2 RECUPYL VALIBAT

This whole section is extracted from: “A Critical Review of Lithium-Ion Battery Recycling Processes from a Circular Economy Perspective”[432].

The Recupyl process was developed as a low-temperature LIB recycling technology, directly addressing the gas emissions resulting from pyrometallurgy in the abovementioned processes. First, LIBs are fragmented in a low-speed rotary shear, in Argon Ar or CO_2 –rich atmosphere to expose the internal compounds. The consequence of using CO_2 is the formation of a surface to LIB whose role is to reduce fire risk. Secondary grinding is carried out in an impact mill on higher speed which reduces particles to the size of 3 mm or smaller.

Then a high-induction magnetic separator removes ferrous metals. The non-magnetic fraction is then processed with a densimetric table, which separates light and heavy particles. There, most of the remaining Cu particles are removed which is an important step, as metal impurity

[431] Vezzini, A. Manufacturers, Materials and Recycling Technologies. In Lithium-Ion Batteries; Elsevier BV: Rome, Italy, 2014; pp. 529–551. [Google Scholar]]. Retrieved August, 03, 2020, from https://www.sciencedirect.com/science/article/pii/B9780444595133000236?via%3Dihub

[432] Omar Velázquez-Martínez, Johanna Valio, Annukka Santasalo-Aarnio, M. Reuter, Rodrigo Serna-Guerrero, MDPI, A Critical Review of Lithium-Ion Battery Recycling Processes from a Circular Economy Perspective, https://doi.org/10.3390/batteries5040068, Publisher November, 5, 2019. Retrieved July, 03, 2020, from https://www.mdpi.com/2313-0105/5/4/68/html

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would later affect hydrometallurgical process. The electrode-rich fine fraction is mixed with water, and its pH is adjusted, which releases H_2 due to hydrolysis. In the aqueous phase, Li salts are then dissolved, leaving MeO and graphite suspended in the solution, to be separated by a filtration process. A series of leaching steps will continue, by processing it through several chemical stages. The Recupyl process can recover Co-containing cathode powder and $LiFePO_4$ whenever it is present in the feed. In addition, processing of the electrolyte $LiPF_6$ is possible, recovering PF_6 and an ammonium salt during a hydrolysis phase[433].

The losses in Recupyl Valibat process are considerably lower in comparison with Umicore Valeas™. The Recupyl process shows a clear advantage of using the mechanical processing coupled with hydrometallurgical operations. Consequently, Recupyl operational principles are more in line with the idea of circular economy, in comparison to the rest of the processes, as the cathode precursor is recovered[434].

3.7.4.3 AKKUSER

The Akkuser process employs low-temperature stages aimed at obtaining a metal-enriched fraction suitable for subsequent refining. This process involves only a mechanical pre-processing treatment and does not include hydro-or pyrometallurgical steps. Then the mixed feed will be sorted, and LIBs are sheared by two cutting mills. The first mill operates at a temperature between 40 °C and 50 °C and reduces the battery to small-sized pieces. During the shearing step, there is a low fire risk. The filtration of residues is done by a cyclonic system and most plastic–metal particles are then processed to recover Ni and Co by leaching. Upon reaching a pristine quality, the associated exhaust gases are then harmlessly released into the atmosphere[435].

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[433] Vadenbo, C.O. Prospective Environmental Assessment of Lithium Recovery in Battery Recycling; Institute of Environmental Decisions: Zurich, Switzerland, 2009. [[Google Scholar]]. Retrieved July 22, 2020.

[434] Tedjar, F.; Foudraz, J.C. Method for the Mixed Recycling of Lithium-Based Anode Batteries and Cells. U.S. Patent 7,820,317 B2, 26 October 2010. Retrieved July, 22, 2020, from https://patents.justia.com/patent/7820317

[435] Pudas, J.; Erkkila, A.; Viljamaa, J. Battery Recycling Method. U.S. Patent 8,979,006 B2, 17 March 2015. [[Google Scholar]]. Retrieved July 03, 2020.

The shredded material is transferred through an air-tight cooling tube into a secondary mill, which further reduces the size of the material. Ferrous metals are recovered employing a magnetic separator. The resulting non-volatile fraction rich in Co and Cu is ready to be refined by either hydro-or pyrometallurgy. The final recovery composition is not detailed in the literature but is likely a mixture of electrode materials and traces of Al[436].

3.7.4.4 UMICORE VALÉAS™ (BRUXELLES, BELGIUM)

The Umicore process recovers Co and Ni, primarily from LIBs and Ni-MH batteries, and it presents the largest capacity among the discussed processes, as it involves a combination of pyro- and hydrometallurgical steps.

The batteries are first dismantled, and the unnecessary metallic or plastic casing material removed in order to expose the cells. The process begins in a shaft of furnace, where three different temperatures are consecutively applied, low = 300 °C (evaporation of electrolyte); medium = 700 °C (plastics pyrolysis); and high = 1200–1450 °C (smelting and reduction)[437].

3.7.5 PROS

An advantage of direct recycling is that it avoids long, and expensive purification steps and it is particularly advantageous for lower value cathodes such as LiMn204 and $LiFePO_4$[438]

The direct recycling is a cost effective and energy conservative method which can be divided into two steps: retrieving the cathode materials from End of Life LIBs and regenerating the cathode materials.

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[436] Zhang, T.; He, Y.; Wang, F.; Ge, L.; Zhu, X.; Li, H. Chemical and process mineralogical characterizations of spent lithium-ion batteries: An approach by multi-analytical techniques. Waste Manag. 2014, 34, 1051–1058. [Google Scholar] [CrossRef]]. Retrieved July 03, 2020.

[437] Georgi-Maschler, T.; Friedrich, B.; Weyhe, R.; Heegn, H.; Rutz, M. Development of a recycling process for Li-ion batteries. J. Power Sources 2012, 207, 173–182. [Google Scholar] [CrossRef]]. Retrieved July 03, 2020.

[438] *Environ. Sci. Technol.* 2012, 46, 22, 12704–12710
Publication Date: October 17, 2012
https://doi.org/10.1021/es302420z
Copyright © 2012 American Chemical Society
Dunn, J. B., Gaines, L., Sullivan, J. & Wang, M. Q. Impact of recycling on cradle-to-gate energy consumption and greenhouse gas emissions of automotive lithium-ion batteries. Environ. Sci. Technol. 46, 12704–12710 (2012). Retrieved July 03, 2020.

One positive thing about the use of Pyrometallurgical process is that exothermic reactions of burning electrolytes and plastics reduce energy consumption. Exothermic reactions are a chemical reaction in which heat is generated.

Unfortunately, the Pyrometallurgical recovery has a negative environmental footprint, including production of toxic gases, in addition to that costs of processing that are high, while the quantities of materials recovered are limited. Nevertheless, it is a frequently used process for the extraction of high-value transition metals such as Cobalt and Nickel[439].

By using hydrometallurgical metals reclamation, the major issues to be addressed with regard to all solvometallurgical processes are the volumes of solvents required, the speed of delamination, the costs of neutralization and the likelihood of cross-contamination of materials. Significant improvements in the field of material segregation can be brought through avoiding cathode and anode materials mixing before a mechanical or a solvent-based separation occurs. The current design of cells makes recycling extremely complex and neither hydro- nor pyrometallurgy currently provide methods that would lead to pure streams of materials that could easily be fed into a closed-loop system for batteries.

The high levels of recycling efficiency of the Akkuser process (i.e., >90%) and its low energy consumption (0.3 kWh/kg material) set this process in a privileged position compared to the rest. However, it is only possible to reach this high cost/efficiency rating because the process involved is based solely on mechanical processing steps and aims at obtaining a black mass for cathode precursor manufacturing by a third party[440].

Hans Eric Melin found in his studies, " State-of-the-art in reuse and recycling of Lithium-ion batteries" that economic potential of recycling applications has been identified in over 30

[439] Lv, W. et al. A critical review and analysis on the recycling of spent lithium-ion batteries. ACS Sustain. Chem. Eng. 6, 1504–1521 (2018).] Recycling lithium-ion batteries from electric vehicles, Recycling methods. Retrieved July 22, 2020, from https://www.nature.com/articles/s41586-019-1682-5

[440] Martin, G.; Rentsch, L.; Höck, M.; Bertau, M. Lithium market research—Global supply, future demand and price development. Energy Storage Mater. 2017, 6, 171–179. Retrieved July 15, 2020, from [Google Scholar] [CrossRef]

studies, based on modelling, mainly with regard to the degradation and longevity of the battery. Most of the recycling studies have been carried out at a laboratory scale and they entail excellent control of the processes. Separation of cells has often been done by hand which is not the economical way in an industrial scale application. There are still patents covering similar methods, which are based on industrial principles[441]

3.7.6 CONS AND CHALLENGES

Nowadays, there are low volumes of electric-vehicle batteries and even fewer used storage batteries, that need to be recycled. It is still a little bit unsure but we strongly believe the EU recycling legislation and standardisation will have been updated and completed by the time **the LIBs powering today`s EVs reach the end-of-life stage (EOL), .** Also, the economic aspects of recycling operations must be carefully reflected, and automation is the key to lower the processing costs. Especially better sorting technologies, a method for separating electrode materials, wider standardization of the manufactured cells and packs, and better recycling design are also crucial for the success of the activity.

High capital is needed when pyrometallurgical technology is required especially if the demand is a fully recyclable Li-ion battery. Ideally, the whole battery should be recycled and not only the most economically valuable components, like Cobalt.

When recycling method is **a water-intensive technology, it involves environmental risk**, because some hazardous battery components are water-soluble[442].

In 2017, the best available technology would allow **Al and Cu to precipitate together**, but in the near future, **there will be attempts to separate them independently from the solution.** The net LIB production can be reduced if more materials are recovered from end-of-life LIBs and the recycled material has better quality. Unfortunately, **recycling alone cannot compensate by itself the shortage of minerals, especially with an EV market that is rapidly**

[441] From a Power Point presentation made by Hans Eric Melin: „State-of-the-art in reuse and recycling of Lithium-ion batteries“. Swedish Energy Agent. June 2019. Retrieved July 21, 2020 from Simona Tudor APIA.
[442] Sloop, S.E.; Bend, M.A. Recycling and Reconditioning of Battery Electrode Materials. U.S. Patent 9,484,606 B1, 1 November 2016. Retrieved July, 22, 2020 from [Google Scholar]

growing. LIBs last in their first life at least 15-20 years, based on the calendar ageing and their lifespan is three times longer than lead-acid batteries[443]

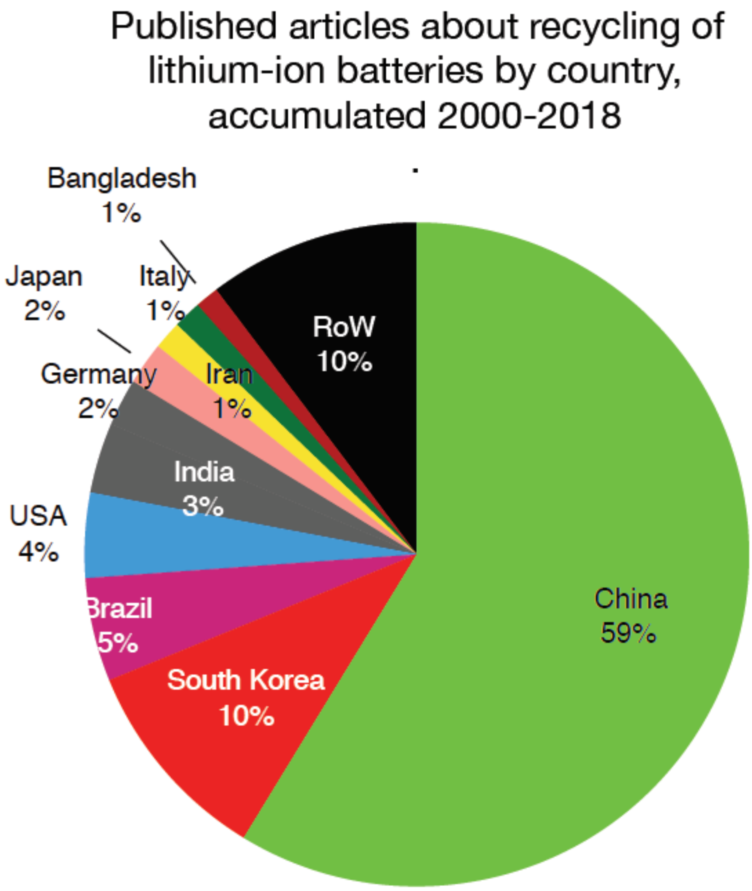

Figure 64. Published articles about recycling of lithium-ion batteries by country, accumulated 2000-2018[444]

To make recycling and reuse economical in Europe, the battery design should be planned for the whole life cycle, before manufacturing a single cell. Standardisation of materials, cells, packing and marking, could make it easier to disassemble, repair and recycle used LIB's. There was no article found in 2019 on research about design with recycling in mind. Only one piece of information was retrieved describing a British project, Amplifill 117, which is a collaboration between car manufacturers and recycling companies that has got more funds to continue

[443] Turcheniuk, K., Bondarev, D., Singhal, V. & Yushin, G. Ten years left to redesign lithium-ion batteries. *Nature* **559**, 467–470 (2018). Retrieved July, 22, 2020 from https://www.nature.com/articles/s41586-019-1682-5

[444] From a Power Point presentation made by Hans Eric Melin: „State-of-the-art in reuse and recycling of Lithium-ion batteries". Swedish Energy Agent. June 2019. Retrieved July 21, 2020 from Simona Tudor APIA.

manufacturing modular battery for various uses, vehicles and applications. Source, the same as earlier nr 54. Hans Eric Melin: „State-of-the-art in reuse and recycling of Lithium-ion batteries“. Swedish Energy Agent. June 2019. Figure 64.

The recycling process should be evaluated from different point of views:

- Cost and efficiency to environmental impact ratio
- Effects on transport
- Work environment
- The consequences for each material pre-treatment solution
- Material sorting solutions
- What will/can be the end product

There is a lack of evaluations with more holistic perspective. One important question hasn't been researched: why batteries take other paths than the ones both companies and legislators previously intended?

It is challenging to choose the right pre-treatment for a LIB.

- In LIBs, there are many different chemistry types used, which makes it difficult for recyclers to correctly classify and sort the EoL batteries.
- When using hydrometallurgical processes, the disintegration time of the modules and cell state of health assessment is also difficult.
- LIB's can easily catch fire or even explode when exposed to mechanical stress / impact.

Research on sorting, disassembly and discharge of batteries is highly uncommon as 2019 published Hans Eric Mellins report shows.

3.7.7 FUTURE TECHNOLOGIES

3.7.7.1 ACCUREC

The Accurec process is designed by the German company Accurec GmbH® (Krefeld, Germany)
for LIBs recycling and is supposed to present a combination of mechanical, pyrometallurgical and hydrometallurgical processes aimed at recovering a Li2CO3 cathode precursor and a Co–Ni–Mn alloy. The process begins with the sorting, cleaning, and manual dismantling of spent LIBs from consumer goods and EVs. The dismantled feed is transported to the company's proprietary vacuum thermal treatment, where it is heated at 250 °C under a vacuum to remove electrolytes, solvents, and volatile hydrocarbons. The produced fraction is then transported to milling and grinding operations to expose the enclosed constituents. Ground material undergoes a series of mechanical separation steps consisting of a vibrating screen, magnetic separator, and a zig-zag classifier[445].

The fractions of Fe–Ni, Al, and Al–Cu are retrieved after the mechanical separation step, from which base metals can be extracted. The remaining fraction is sent to agglomeration and a two-step pyrometallurgical process. In the end of the second step of the pyrometallurgical operation, commercially viable Co and Mn are released. Though, as the current market value of Co is higher than that of Mn, the purification of the former is favoured, while the latter is mostly lost in the slag phase[446].

Needless to highlight, that the Accurec process is able to provide a 90% recovery of Li2CO3, which can then be used either as a cathode precursor or as a raw material for glass manufacturing. On the other hand, the technology does not allow an electrolyte to be

[445] Accurec Recycling GmbH, "Accurec," (official website 2019). Retrieved August 25, 2020 from https://accurec.de/lithium

[446] Gratz, E.; Sa, Q.; Apelian, D.; Wang, Y. A closed loop process for recycling spent lithium ion batteries (September 15, 2014). Retrieved August 25, 2020 from https://www.sciencedirect.com/science/article/abs/pii/S0378775314004571

recovered, which can, without any doubt, be regarded as a drawback to these recycling operations[2].

3.7.7.2 BATTERY RESOURCES "CLOSED LOOP" PROCESS

The Battery Resources process, according to its developers, is considered to be a "closed loop" one, as it recovers battery components suitable for a further LIB production. The Battery Resources process is majorly based on mechanical and hydrometallurgical operations, with a single sintering step at the end for product refining. The Battery Resources process is designed to treat LIBs with LiNixMnyCozO2 cathode chemistry.

Analysing the sequence of technological treatments in a closer way, the first step for the whole recycling process is discharging, which is necessarily undertaken so as to reduce the risk of spontaneous ignition / explosion during shredding. Then the spent LIBs are shredded with a hammer mill to break down the particles, and shredded mixed material is treated by magnetic separation, producing a magnetic fraction with high content of steel and a cathode-containing non-magnetic fraction. The next steps involve different fractions to be treated in separate manners. Consequently, the non-magnetic fraction is mixed with NaOH in order to extract Al and then is filtered and dried at 60 °C. On the other hand, Cu-rich fraction is obtained through having a coarser fraction treated by dense media separation (DMS). Finally, the fine fraction is sent to a four-step hydrometallurgical process. The first stage of it includes removing of C, LiFePO4, and the remaining plastics under high temperature levels, whereas the remaining solution is supposed to contain ionic forms of Co, Ni, Mn, Li, Al, and Cu, which is later treated at a temperature of 40 °C to precipitate Li2CO3[447].

In the long-run, the aforementioned processes enable to have previously extracted Co(OH)2, Mn(OH)2, and Ni(OH)2 mixed with the precipitated Li2CO3 and some additional virgin

[447] Porvali, A.; Aaltonen, M.; Ojanen, S.; Velazquez-Martinez, O.; Eronen, E.; Liu, F.; Wilson, B.P.; Serna-Guerrero, R.; Lundström, M. Mechanical and hydrometallurgical processes in HCl media for the recycling of valuable metals from Li-ion battery waste (March 2019). Retrieved August 25, 2020 from https://www.sciencedirect.com/science/article/abs/pii/S0378775315002694

Li_2CO_3 and be forwarded to synthesizing battery-grade cathode material through compression into pellets and sintering at 900 °C. This way, the Battery Resources process allows to achieve "closed loop" results and obtains the most suitable product for use as a cathode material, although the consumption of various chemical reagents (e.g., $MnSO_4$, $NiSO_4$, and $CoSO_4$) is required[448].

3.7.7.3 *LABORATORY PROCESS BY AALTO UNIVERSITY*

The process encompasses a mixture of mechanical pre-processing stages followed by a pyrometallurgical step and a thorough hydrometallurgical treatment to recover 99% of the LIB materials. It begins with crushing and sieving, resulting in two distinctive fractions: one formed mostly of the electric peripherals, current collectors and foils, and a second one formed mostly of the electrode materials. As a next step, the mechanically obtained fractions are processed via two parallel paths: a hydrometallurgical and a pyrometallurgical process designed to treat the electrode material and metallic fraction, respectively[449].

The hydrometallurgical treatment consists of a series of 11 steps specifically designed to obtain cobalt oxalate, CoC_2O_4, while recovering other elements found in the electrode material fraction, including Li, Ni, Fe, and Co. On the other hand, a pyrometallurgical treatment in a rotary kiln has been proposed to recover Al and Cu. As a result of the aforementioned processing and treatments, it is claimed that Aalto University process recovers the vast majority of elements contained in LIBs with a high efficiency. That is, the hydrometallurgical stage recovers 99% of Al, 93% of Li, 89% of Co, 97% of Ni, 98% of Cu, 98%

[448] Martinez, V.; Porvali, A.; Boogaart, V.D.; Aarnio, S.; Lundström, M.; Reuter, M.; Guerrero, S.; Velázquez-Martinez, O.; Boogaart, K.G.V.D.; Santasalo-Aarnio, A.; et al. On the Use of Statistical Entropy Analysis as Assessment Parameter for the Comparison of Lithium-Ion Battery Recycling Processes (January 31, 2019). Retrieved August 25, 2020 from https://www.mdpi.com/2313-0105/5/2/41

[449] A Critical Review of Lithium-Ion Battery Recycling Processes from a Circular Economy Perspective (August 23, 2019). Retrieved August 25, 2020 from https://www.mdpi.com/2313-0105/5/4/68/htm

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of Mn, and 99% of Fe, whereas the pyrometallurgical path produces a molten phase with 74% of Al and 26% of Cu[450].

Even though the Aalto University process is supposed to provide a high degree of element recoverability, the recovered forms still require further processing to be considered usable raw materials. What is more, it presents a high quality of products, but at the same time demands a large number of reagents in the hydrometallurgical stages and high energy in the pyrometallurgical step, in addition to efficient mechanical pre-processing stages[451].

3.7.7.4 FORTUM LIB RECYCLING SOLUTION

This whole section extracted: Fortum's hydrometallurgical recycling technology[452].

This innovative Fortum's technology enables 80% of li-ion batteries materials to be recycled and it makes it possible that cobalt, manganese and nickel be utilized in producing new batteries. In order to achieve a high recycling rate, the process the company applies is a low-CO2 one and uses a hydrometallurgical recycling process. The hydrometallurgical recycling process involves a chemical precipitation methodology that allows scarce minerals to be recovered and delivered to battery manufacturers for reuse in the production of new batteries. Originally, this technology was developed by the Finnish growth company Crisolteq that was acquired by Fortum in January 2020.

A closer look at the stages of LIBs recycling reveals that the initial step in this process involves plastics, Aluminium, and Copper to be separated and directed to their own recycling processes, which makes lithium-ion safe for mechanical treatment. The remaining elements after the abovementioned treatments are the chemical, mineral components and the 'black

[450] Fortum's official website (2020), Lithium-ion Battery Recycling Technology. Retrieved August 25, 2020 from https://www.fortum.com/products-and-services/fortum-battery-solutions/recycling/lithium-ion-battery-recycling-solution

[451] A Critical Review of Lithium-Ion Battery Recycling Processes from a Circular Economy Perspective (August 23, 2019). Retrieved August 25, 2020 from https://www.mdpi.com/2313-0105/5/4/68/htm

[452] Fortum's official website (2020), Lithium-ion Battery Recycling Technology. Retrieved August 25, 2020 from https://www.fortum.com/products-and-services/fortum-battery-solutions/recycling/lithium-ion-battery-recycling-solution

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mass', which is further exposed to industrial-scale processing in Fortum's facility in Harjavalta. Furthermore, Fortum's recycling plant in Harjavalta is specialized in hydrometallurgical processing, which helps to initiate a sustainable production of high-grade chemical compounds from various industrial waste and side-streams. This recovered 'black mass' typically consists of a mixture of lithium, manganese, cobalt and nickel in different ratios. Of these, nickel – and especially cobalt – are the most valuable and most difficult to recover. As a consequence, most of today's recycling solutions for EV batteries are not able to recover these valuable minerals, while Fortum's solution is applicable, therefore.

3.7.8 JOB ROLES AND SKILLS

Recycling procedures must follow strict rules and standards. **Process Engineers for Battery Dismantling and Battery Recycling** improve the processes and align with the technicians. **End of Warranty Managers, Waste Recycling Auditors** and **Compliance Engineers** as well as **Safety Managers and Specialists** ensure the compliance with the legislation and standards; batteries are processed by **Processors** and **Recycling Technicians**, and various **Operators** might be involved.

Skills and knowledge required in relevant advertisements:

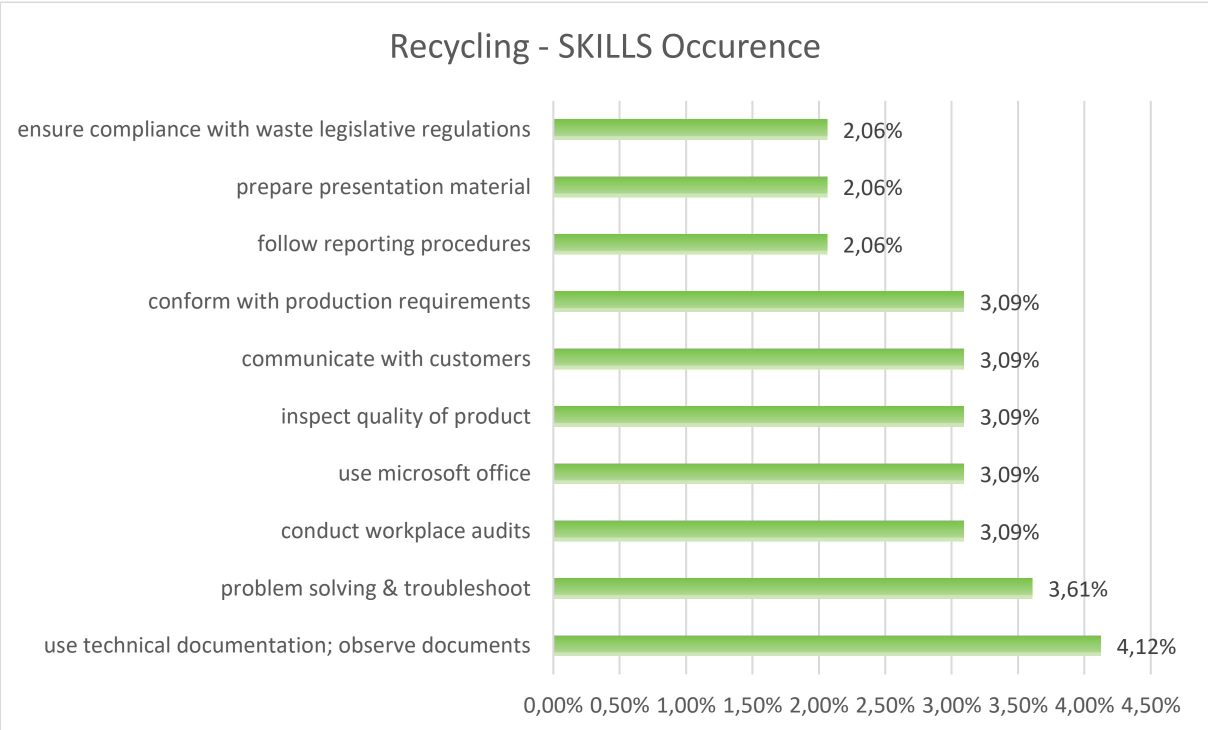

Figure 65 Recycling SKILLS Occurrence

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Skills

Skills occurrence for recycling are shown in Figure 65. Problem solving and technical documentation usage, Microsoft Office, quality inspection, reporting procedures and compliance with regulations are the most required skills.

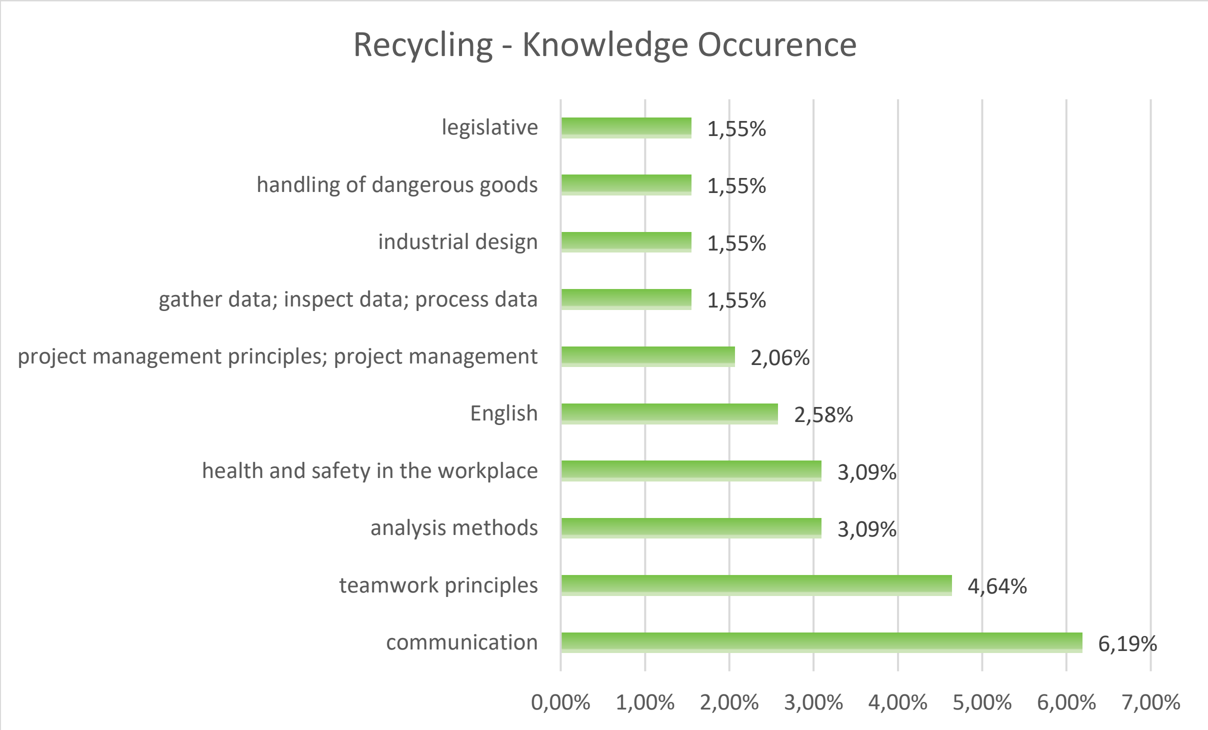

Figure 66 Recycling KNOWLEDGE Occurrence

Knowledge

Knowledge occurrences relevant to recycling are shown in Figure 66. Communication and teamwork principles are in the top positions, as well as knowledge of health and safety in the workplace and experience with analysis methods. Handling of dangerous goods and knowledge of the legislation are also required.

4 Training & Education Methods and Approaches

The ALBATTS project aims at making a blueprint for education and training development to support the emerging battery and electromobility sector in Europe. A first makeshift inventory of existing education and training in the sector has been done in D 6.1: Report on state of the art and job roles in the sector (only chosen examples of education and training on different levels are presented here below).

Analysis of desktop research (like this report), surveys and workshops in WP3, 4 and 5 will show what education and training is needed for the emerging new jobs, while other positions may partly vanish. As the education systems in European countries are national, the project must find ways to design learning objectives, job roles descriptions, learning materials and teaching structures in a way that is, on the one hand, modern and innovative but on the other hand, can connect well to existing and varying European education and training systems and practises. Below is a first characterisation attempt on educational providers, prevailing education and training methods and approaches, use of ICTs for education design to address learner access and flexibility, and some examples of training and education at different educational levels in Europe.

There are many ways of teaching and training people for jobs in a sector of the labour market. We have the classical university with full-time co-located offerings on a campus, including *lectures*, *planned readings*, *group discussions and assignments*, *lab work*, *learning projects*, and possibly *case studies* and *simulations*. The educational institution typically wants full control over the offering and communicates, usually not in detail, with industry and the target groups of potential students, since it views education as generalist education within one or two disciplines primarily. A research university is not expected to teach anything that is not being researched at the same institution.[453;454] The students receive a long and broad education and pass an exam, but will often need skills training after exam. The learning theory

[453] Elen, J., Lindblom-Ylänne, S., & Clement, M. (2007). Faculty development in research-intensive universities: The role of academics' conceptions on the relationship between research and teaching. International Journal for Academic Development, 12(2), 123-139.
[454] Hattie, J., & Marsh, H. W. (1996). The relationship between research and teaching: A meta-analysis. Review of educational research, 66(4), 507-542.

in universities is nowadays often declared to be constructivism – to make the individual create a personal, deep, and broad understanding.[455] A problem is that this understanding can stay theoretical.

The vocational school or institute typically works closer to industry (like the university college but with minimal or no research ability). In comparison with an academic university, vocational educational providers often reduce *lectures* - and *planned reading* in favour of more *internship* periods and *on-the-job training* in workplaces, use of *simulators*, *role-playing*, *management games*, *peer tutoring*, *coaching and mentoring* by industry professionals, etc. The emphasis is more on skills-training; a good theoretical understanding is also needed, but is developed through a combination of learning methods.[456] The learning theory behind this is often some kind of constructionism, meaning that the student learns best when trying to construct something, or attempting to solve real problems. Constructionism emphasises demonstrable understanding and skills, developed by personal trial- and-error in a context of mentoring. This also makes validation of previous learning easier than in a university context. The employer or work place is a training stakeholder and sometimes actor or provider as well, working both with specialised introduction at time of employment, so called on-boarding, but continuously also with various on-the-job training, simulators and learning games, coaching and mentoring, peer tutoring, etc. [457] This learning at the workplace is also *situated learning*; it has a clear context, and there is research showing that learners have the optimal conditions to learn in the environment where the learned knowledge and skills will be practised.[458]

Another distinction between training methods often used in a description like this is *"traditional methods"* versus *"e-learnin*g". This might be a shallow and not so useful description. Both concepts are moving targets, and there is no accepted definition of "traditional learning", for example, nor is there any unified definition of "e-learning". But

[455] Mueller, S. (2020). The mature learner: understanding entrepreneurial learning processes of university students from a social constructivist perspective (Doctoral dissertation). (p 11 ff)
[456] Backes-Gellner, U., Wolter, S. C., & Tuor, S. N. (2010). Risk-return trade-offs to different educational paths: vocational, academic and mixed. International journal of Manpower.
[457] Elkjaer, B., & Wahlgren, B. (2005). Organizational learning and workplace learning—similarities and differences. In Learning, working and living (pp. 15-32). Palgrave Macmillan, London.
[458] Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. Cambridge university press.

where do digital tools come in? A reasonable answer can be "everywhere", as we live in an "onlife"[459] world where all from lectures to on-the-job-mentoring can be done by using a mix of classical and digital tools.[460] The imagined border between digital and not digital is blurring, to say the least. What Internet-based ICTs have done for education and training recently is to reduce the friction of information flows even more than with print and mass media, postal service, TV and telephone. Digital ICTs do not, however, automatically guarantee modern training methods –behaviouristic setups and purely information-transmission-based lectures also make use of today's digital technology. What digital technologies excel in, however, is not only lowering information friction, but processing information outside human brains for the first time in history.[461] Such ICTs as learning analytics, adaptive learning, etc., are developing right now – using digital algorithms to adapt a learning track after the individual user/student. We will work with that in the ALBATTS project as well (WP6/Work Package 6 - Training and Education).

Students' *access to* and *flexibility in* studies can be much improved already with digital technology's reduced information friction. This is understood in various ways by stakeholders. Universities can call a course "distance course" just by using some digital technology, but still demand a lot of physical presence for exams, lab work, discussions, etc. – while the individual had expected a very flexible course and almost never visit a campus. The terms *"distance learning", "e-learning", "online learning", "blended learning", "flipped learning"* and so on have no agreed-upon definitions that describes level of access or flexibility or even course design.[462] However, the recent Covid-19 crisis has meant a lot of improvement in work with these practical questions, and we are in a period of change where "the normal" after the crisis has changed, especially concerning access to and flexibility in education and training.[463]

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[459] The term "onlife" comes from the Oxford Information philosophy Luciano Floridi, and simply says that digital ICTs (information and Communication technologies) are already an integrated part of people's lives – thereby recommending us to stop thinking in terms of being online or offline and moving between these modalities. See "The Onlife Manifesto" https://link.springer.com/book/10.1007/978-3-319-04093-6
[460] Dziuban, C., Graham, C. R., Moskal, P. D., Norberg, A., & Sicilia, N. (2018). Blended learning: the new normal and emerging technologies. International Journal of Educational Technology in Higher Education, 15(1), 3.
[461] Floridi, L. (2013) The Fourth Revolution – How the infosphere is transforming human
[462] Norberg, A. (2017). From blended learning to learning onlife: ICTs, time and access in higher education (Doctoral dissertation, Umeå University).
[463] Burgess, S., & Sievertsen, H. H. (2020). Schools, skills, and learning: The impact of COVID-19 on education. VoxEu. org, 1.

A practical way of analysing the level of access to and flexibility in an education package or course is to use *a time- and process perspective*, to clarify how the course design uses the student's time by the blend and shifts of synchronous and asynchronous events. The key is to see how synchronous events and asynchronous events shift in a course and how they are constructed. Here we do not make any distinction if something is digital or not, but it is the digital ICTs that makes considerable difference to new more inclusive course designs. As *synchronous* events we classify all events that happen at a scheduled time the same for all participants, *classroom lectures, video conferenced lectures and meetings, interactive discussions or chats, social simulation games*, etc. These synchronous events can be co-located (as in a classroom or lab) or not (using distance-spanning ICTs). As *asynchronous* events we think of doing *assignments*, *working in a learning management system*, *readings*, *watching recorded lecture videos or tutorials*, *communicating* with peers in forums, etc. – activities which the individual can plan during a period.[464;465;466]However, in the ALBATTS project, we must first and foremost take the educational provider's own description of a course, course package or programme at face value. If they say it is a distance course, it is. Next step, if we can get closer into the design of an individual learning expedition (course, programme, etc), is to try to classify after the following[467]:

SYNC – COLOC.

A synchronous course delivered in a room only – no asynchronous assignment, homework, etc. This kind of course is almost exclusively used in the corporate training world.

SYNC.

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[464] Norberg, A., Dziuban, C. D., & Moskal, P. D. (2011). A time-based blended learning model. On the Horizon.
[465] Power, M. (2008). The emergence of a blended online learning environment. MERLOT Journal of online Learning and Teaching, 4(4), 503-514.
[466] Bradford, G., Kehrwald, B., & Dinmore, S. (2011). A framework for evaluating online learning in an ecology of sustainable innovation (Doctoral dissertation, University of Tasmania).
[467] Norberg, A. (2017) From blended learning to learning onlife – ICTs and access to higher education. Doctoral dissertation, Umeå University, p. 53-58.
https://www.researchgate.net/publication/312922241_From_blended_learning_to_learning_onlife_-_ICTs_time_and_access_to_higher_education

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Similar but without a room for participants in common as the ICT - a video transmitted course with no asynchronous components as assignment or text readings or preparations for exam. Not so common.

ASYNC.

A web- or print-based course with no times or places, but possibly a deadline. Very flexible but demand a lot of design work to function and are usually expensive to develop. This kind of course is very flexible but also very demanding for a new learner.[468] The continuous feedback from teacher and peers is often missing. MOOC courses (Massive Open Online Courses[469]) are examples of ASYNC courses.

SYNC-ASYNC.

The usual university or school course or program. People meet at lessons, labs, and lectures, and have assignments, reading and flexible projects to work with between meetings. We do not distinguish whether the asynchronous modality/component is digital (web-based) or not (as book readings and assignments on paper). A risk here is that the synchronous and asynchronous tracks run in parallel instead of becoming driving forces for student development in a learning process, a so called "course-and-a half"[470]. For example, ASYNC MOOC courses can be made blended SYNC-ASYNC courses just by organising interactive learner meetings.[471] Then the question is if these SYNC-ASYNC courses are flexible or not, accessible or not from a distance, for students with time difficulties because of work, etc. Often just slight changes in courses can change flexibility a lot, by for example using the Hy-

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[468] Guri-Rosenblit, S. (2006). Eight paradoxes in the implementation process of e-learning in higher education. Distances et savoirs, 4(2), 155-179. https://www.cairn.info/revue-distances-et-savoirs-2006-2-page-155.htm#pa37

[469] MOOC courses are globally accessible orientation courses from universities, often in their specialisation subjects. They do not formally demand previous studies for participation, and can be studied without cost, or with a smaller cost for obtaining a course verification document.

[470] Kenney, J., & Newcombe, E. (2011). Adopting a blended learning approach: Challenges encountered and lessons learned in an action research study. Journal of Asynchronous Learning Networks, 15(1), 45-57.

[471] Norberg, A., Händel, Å., & Ödling, P. (2015). Using MOOCs at learning centers in Northern Sweden. International Review of Research in Open and Distributed Learning, 16(6), 137-151.

Flex or similar concept[472;473], creating an accessible course and a campus course within the same frame.

ASYNC-COLOC.

A course or training can be composed of flexible web components for theory understanding, and an open training lab for the student to visit, train in and finally use to demonstrate his or her skill for an instructor in a lab when ready.

The ALBATTS project can in WP6 possibly assist in improving course design not only concerning content and training methods, but also concerning accessible and flexible design of courses.

4.1 EDUCATION OFFERINGS

WP6 made a first draft overview of what educational offerings could be found on the themes of batteries and electromobility (Deliverable 6.1)[474]. This was made fast and early in the project just to lay first foundations. This work will continue within the WP3, 4 and 5 Sectoral Intelligence Work packages.

This first overview of education and training offerings (Deliverable 6.1) only claims to show *examples* of education and training on EQF levels 3-7 in Europe, and online global solutions as these are accessible and used in Europe.

EQF7

On the master level[475] we found many education programmes with occurrences in most EU member countries, following the Bologna declaration[476] model that has developed throughout Europe and surrounding countries since 1999. The Bologna process is a part of the

[472] Beatty, B. (2014). Hybrid courses with flexible participation: The HyFlex course design. In Practical applications and experiences in K-20 blended learning environments (pp. 153-177). IGI Global.

[473] Irvine, V., Code, J., & Richards, L. (2013). Realigning higher education for the 21st-century learner through multi-access learning. MERLOT Journal of Online Learning and Teaching, 9(2), 172-186.

[474] Deliverable 6.1 Report on state-of-art of job roles and education in the sector. Will be publicly availabe on http://www.project-albatts.eu

[475] Se page 27ff in ALBATTS Deliverable 6.1 Report on state-of-art of job roles and education in the sector, soon available via http://project-albatts.eu

[476] http://www.ehea.info/page-ministerial-conference-bologna-1999

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EHEA, the European Higher Education Area.[477] One EU ambition with the EHEA is to promote student mobility within Europe in both phases of education. The Bologna process is a shared ambition among now 48 countries concerning enabling easier student mobility. It should become normal that a student can have a first cycle of education in his home country and continue with a specialised master education in another country.

The master programmes relevant in the ALBATTS context are mainly to be found at research universities that have batteries or electromobility as one of their priorities. These master programmes are usually 2-year programmes (1 year in the UK) that demand an EQF6 exam (bachelor exam or similar) for entry. They prepare both for research but also for qualified work in industry. They sometimes appear in multi-university setups, where a student can study one semester here, next there, etc. and get a joint-degree exam.

Examples of such families of cooperating universities working together are the EIT InnoEnergy-supported master programmes in energy storage[478], the MESC[479] (Erasmus Mundus Joint Master) and the Nordic Joint Degree Master in Innovative Sustainable Energy Engineering.[480]

EQF 6

At the first Bologna cycle level, commonly called bachelor's level, we have not found so many education programmes[481], but some interesting ones, such as the Norwegian engineering program *Renewable Energy for the Marine Environment*.[482]

Not only technical educations are to be found – we also find, for example, business educations relating to this new developing energy sector in Germany[483].

EQF 5[484]

[477] http://www.ehea.info/
[478] https://www.innoenergy.com/for-students-learners/master-school/
[479] https://mesc-plus.eu/ a 2-year programme in Materials Science and Electrochemistry, fully taught in English, involving 5 Universities in 4 European countries (France, Poland, Slovenia and Spain), 2 Universities in USA and Australia, a European Research Institute (ALISTORE), the French Network on Energy Storage (RS2E), the Slovenian National Institute of Chemistry (NIC) and a leading Research Center in Spain (CIC Energigune).
[480] https://www.ntnu.edu/studies/msisee
[481] Se page 26ff in ALBATTS Deliverable 6.1
[482] https://www.ntnu.edu/studies/allstudies?admissions=1&search=enewable
[483] https://www.rwth-aachen.de/cms/root/Studium/Vor-dem-Studium/Studiengaenge/Liste-Aktuelle-Studiengaenge/Studiengangbeschreibung/~bmmx/Wirtschaftsingenieurwesen-B-Sc-Fachric/?lidx=1
[484] See page 24ff in ALBATTS Deliverable 6.1

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The EQF5 level includes longer vocational post-secondary education programmes, 2-4 years, at a professional university or school. We have found more such programmes related to electromobility than to battery production so far; just one example is the *CTeSP in Electric and Hybrid Vehicles* course in Portugal[485]. For a vocational school to be attractive, jobs must be available – and battery cell factories are still mostly planned or under construction, while electric and hybrid vehicles are already in use.

EQF 4

In secondary education (high school, gymnasium) and same-level adult education, we found rather few education and training programmes, but some in Sweden, in the Netherlands, in Portugal and in the Czech Republic.[486] This level is in many countries standardised with few possibilities to profiling education. Adult education, however, at this same level is often less standardised or easier to make customised educational solutions within. In Skellefteå, Sweden, an 18-week introductory training programme, *Automation operator* starts in the autumn of 2020 for entering jobs as machine operator or material handler in the Northvolt Li-Ion cell factory, beginning production in 2021.[487]

We have also found a lot of examples of training offers for working professionals[488], for example for electricians or mechanic technicians that want to develop their competence. These are usually short and intense, come with a cost, and seem to easily grow to fulfil demand. Online asynchronous courses such as MOOC courses have also been found and listed, and presently during the pandemic, some of them are recommended via the special ALBATTS/DRIVES site https://www.skills4automotive.eu/

Besides using desktop research to gather information about training and education, including providers, we hope to detect more with the help of networking within the sector and cooperation with stakeholders and partnerships as EITInnoenergy, BatteriesEurope, European

[485] http://www.si.ips.pt/ips_si/
[486] See page 21ff in ALBATTS Deliverable 6.1
[487] https://www.skelleftea.se/yrkesutbildning
[488] See page 44ff in ALBATTS Deliverable 6.1

Battery Alliance and the research roadmap project Batteries2030+. We will also work with the sectoral stakeholders via a series of workshops and online surveys.