Alliance for Batteries Technology, Training and Skills

2019-2023

Charging and Mid-downstream Production

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Executive Summary

The first part of the report provides an overview of the charging and charging infrastructure on the overall level as well as of the following battery applications: 1) passenger cards; 2) trucks and buses; 3) motorbikes; 4) micro-mobility; 5) aeroplanes; and 6) trains.

The second part of the report provides an updated overview of the battery sector and its legislation together with the overview of the battery production mid- and down-stream with a focus on the production machines and equipment, mainly: 1) electrode manufacturing; 2) cell assembly; 3) module and pack assembly; and 4) dry rooms.

Each section gives a general overview, together with the section focusing on skills intelligence.

The document is based on the following deliverables[1, 2].

[1] ALBATTS project. Charging Batteries of Electric Vehicles and Other Electric Means of Transport & Job Roles and Skills. ALBATTS Project Website. Retrieved November 20, 2023, from Publications_91_20231010_74042.pdf (project-albatts.eu)

[2] ALBATTS project. Batteries in the EU: Recent Legislative Evolution and Introduction to the Machines, Operators' Skills, and Competencies in Production. ALBATTS Project Website. Retrieved November 20, 2023, from Publications_92_20230918_9207.pdf (project-albatts.eu)

List of Abbreviations

AC	…	**Alternate Current**
AFIR	…	Alternative Fuels Infrastructure Regulation
BMS	…	Battery Management System
CAGR	…	Compound Annual Growth Rate
CCS	…	Combined Charging System
CHAdeMO	…	Fast-charging system for battery electric vehicles
CO2	…	Carbon Dioxide
CPO	…	Charging Point Operator
CRM	…	Critical Raw Material
DC	…	Direct Current
DMM	…	Digital Multimeter
DoC	…	Driver of Change
EMC	…	Electromagnetic Compatibility
EPBD	…	Energy Efficiency of Buildings
EU	…	European Union
EV	…	Electric Vehicle
GVW	…	Gross Vehicle Weight
HDV	…	Heavy-Duty Vehicle
ICE	…	Internal Combustion Engine
IEC	…	International Electrotechnical Commission
kW	…	Kilowatt Hour
LCA	…	Life-Cycle-Assessment
LCV	…	Light Commercial Vehicle
LNG	…	Liquefied Natural Gas
MCS	…	Megawatt Charging System
MRFR	…	Market Research Future
NMC	…	Nickle-Mangan-Cobalt
PHEV	…	Plug-in Hybrid Vehicle
R&D	…	Research and Development
SLI	…	Starting, Light, and Ignition (Battery)
SME	…	Small-Medium Enterprise
SoC	…	State of Charge
SoH	…	State of Health
UK	…	United Kingdom
USD	…	United States Dollar

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V2X	…	Vehicle-to-Everything

1 Battery Charging and Charging Infrastructure

Batteries are electrochemical sources of electrical energy. When the battery is connected to a device, the battery starts providing the power, and a chemical reaction occurs. Power transfer could be supported by cables in traditional circuits or wirelessly.

Cable power transfer is the most reliable connection possible, with the capability to transfer large amounts of energy with the lowest power losses. **Wireless** power transfer is more user-friendly, with no need to plug in cables; however, the power transfer is less effective. Several types of wireless transfers are usually based on electromagnetic principles; nevertheless, not all can provide enough power for mobile applications such as electric cars or buses. Typically, vehicles are charged slowly using **AC** (alternating current) up to 22 kW or fast via **DC** direct current up to 350 kW.

Battery Degradation due to charging

Understanding the battery degradation during fast charging is crucial to improving battery performance and lowering the concerns of electric vehicle owners. High current and voltage stress the battery's internal structure, as lithium ions are forcefully extracted from the positive electrode, transferred by the electrolyte, and subsequently to the negative electrode, potentially forming cracks that threaten the battery's life.

Fast charging can recharge the battery quickly; however, the side effect is excessive **heat** production. When this heat is not managed correctly, it can lead to chemical reactions, physical changes, and the growth of so-called **"dendrites"** that endanger the functioning of the battery.

Low temperatures can also negatively affect the battery's performance and lifespan. When the battery is fast charged while cold, it can lead to the "**lithium plating**" effect when lithium atoms are not transported into the anode but accumulate on its surface, potentially leading to short circuits and battery failure.

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To reduce or eliminate the adverse impacts of the temperature, manufacturers use **battery management systems** that manage charging power and battery cooling and heating when needed.

Charging Principle

Charging of a battery slows down at around **80%** of the state of charge (SoC) due to **increased heat**. The charger switches to a slower mode for the remaining 20% to **stabilise** the battery's ions, preserving its lifespan and health. As a result, the time needed to charge the battery from 80% to 100% can be similar to the time required to charge from 0% to 80%.

Some applications provided by vehicle manufacturers and some charging point operators (CPOs), enable charging stops at various limits, such as 80%, 90%, or 95%. Such a limitation can reduce waiting times for other electric car users, increase charging point utilisation, and improve overall efficiency.

1.1 PASSENGER CARS

The electrification of passenger cars has been driven, among other drivers, by advancements in lithium-ion battery technology, national and local regulations incentivising electric passenger cars, and, most of all, **EU legislation**. According to the "Fit for 55" package and relevant CO2 legislation, only zero-emission vehicles can be registered starting from 2035.

A robust public and private charging infrastructure must be ready to achieve these goals. The EU Energy Efficiency of Buildings (EPBD) regulation introduces requirements for charging stations and pre-cabling **in buildings** to support these goals. The EU Alternative Fuels Infrastructure Regulation (AFIR) addresses the **public charging** network, setting distance and fleet-based goals for charging spots on EU main roads. The EU Clean Vehicles Directive introduces a minimum quota for **procurement** of public fleets.

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1.1.1 Charging of passenger cars

Public chargers are typically equipped with multi-standard chargers using CHAdeMO, CCS (DC) and Type 2 (AC) standards, with the CHAdeMO standard being phased out.

For the charging of Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs), **charging modes 1 – 4** are defined by the International Electrotechnical Commission (IEC). Mode 1 is defined, but it is not widely used due to insufficient safety. Mode 2 is slow AC charging, which uses a charging cable connected to the electric socket and can be 1-phase (max 3.7 kW), 2-phase or 3-phase (max 11 kW).

Mode 3 uses AC charging from the wall box with the typical power from 3.7 kW up to 22 kW (depending on the vehicle's onboard charger). Mode 4 DC charging is the fastest, mainly using a stationary station with up to 350 kW power.

1.1.1.1 Charging locations

It is estimated that around 80% of all charging sessions occur at private premises at home or work (using mostly slow AC charging) and around 20% at public charging points (AC and DC charging).

Home charging (typically overnight) uses electricity from the grid or a photovoltaic system, often combined with battery energy storage. **"Smart charging"** from the grid optimises charging using time slots outside the peak hours.

Another opportunity for charging is (usually daytime charging) **at the workplace** since cars stay there eight or more hours a day. It allows slow AC charging, which is more friendly to the State of Health (SoH) of the battery and less demanding on the grid usage. Charging at work is an excellent possibility for people who cannot charge their cars at home.

Fire safety is one of the challenges related to charging EVs in enclosed areas such as buildings. Since lithium-ion batteries with specific chemistries, such as the Nickle Mangan Cobalt (NMC) technology currently dominating in the EU, are flammable and difficult to extinguish, some member states, often pushed by their fire brigades, have been discussing introducing

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guidelines or regulations to ensure public safety, particularly when a vehicle is **charged** in underground garages above which people live.

Public charging locations can be found at highway rest stops, on streets, parking lots, and shopping centres, and they are available for everyone who needs them. There is a trend to build **charging hubs** with many chargers in one place, making it easier for the driver to find a free charger there. Not every place has a suitable grid connection ready to accommodate several high-performance chargers, and **battery storage** supporting the chargers, potentially combined with photovoltaics, may be an option.

Public charging can be challenging for EV owners who cannot charge at home, for example, for those living in large (prefabricated) housing estates, where many people are concentrated, and their vehicles are parked within a relatively limited area. Charging from **streetlights** is being piloted by some cities to address it.

1.1.1.2 Alternatives

Wireless charging can be an alternative to standard charging by cable. It can offer higher customer comfort since no (un)plugging is needed. **Inductive** charging, similar to phone charging, can achieve an efficiency of up to 93%, comparable to cable charging. The crucial condition for effective charging is the perfect position of the vehicle and the charging pad.

Dynamic charging is a way of charging where the vehicle is being charged while moving. This type of charging needs a unique infrastructure with the coils inside of the road surface. The efficiency decreases with the speed.

Another alternative to cable charging is **battery swapping**. One of the most prominent players in the market is NIO, which has an extensive network with swapping stations in China and is developing its battery-swapping infrastructure in Western and Northern Europe. Battery swapping can offer shorter times than fast charging, and the time needed to have the battery pack exchanged is comparable to the fuelling of an ICE vehicle. Nevertheless, this market is still niche, as leading European car manufacturers have not adopted the battery-swapping concept. The business case and viability remain to be seen.

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1.1.1.3 Innovative services and concepts relevant to EV charging

Vehicle to everything (**V2X**) is a concept where electric vehicles can use the power from the battery to power external devices, charge other vehicles or serve as the storage for the grid to support and balance it. Nevertheless, the increased degradation of the vehicle's battery is among the most significant challenges to be overcome.

Innovative solutions are being developed for **fleet management, paying and invoicing** for charging services, aggregating charging services of multiple Charging Point Operators (CPOs), charging roaming for foreign cars and technologies like "Plug and charge", which make charging, car/client identification and payment more comfortable.

Automatic **charging robots** can help by plugging and unplugging cables or ensuring the charging process. **Emergency, movable or portable charging** solutions are also being piloted.

1.2 TRUCKS AND BUSSES

Drivers of electrification of heavy-duty vehicles (HDVs) are similar to the segment of passenger cars. CO2 fleet reduction targets, currently being revised in light of the "Fit for 55" package, are among the main drivers. Within the ongoing revision of the CO2 targets, the EU Commission proposed to **widen the scope** of the regulation to include more heavy-duty vehicle segments and to **toughen** the reduction targets to achieve an emission reduction of 45% in 2030, 65% in 2035 and 90% in 2040.

Like passenger cars, **AFIR** requires the member states to ensure minimum coverage and outputs on main highways and at urban nods for heavy-duty vehicles. The EU Clean Vehicles Directive introduces a minimum quota for procurement of public fleets. Sales numbers show that the European electric HDV market is increasing, driven chiefly by electric buses and smaller trucks with gross vehicle weight (GVW) between 3.5 t and 12 t.

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1.2.1 Charging

Heavy-duty vehicles (buses and trucks) have different modes of operation than passenger cars. Their operation could be divided into urban, national, and international. This division defines their battery configuration, ranges, needs for speed charging and type of charging. In **urban** operation, buses can charge overnight and during stops in the depot. The **national** operation will combine overnight charging and fast charging with medium-range rides. The **international** operations will be the most challenging, needing high-performance charging during stops to achieve the maximum possible range. Other alternatives, such as hydrogen or bioLNG, must be considered, particularly for the long international rides.

A **Megawatt Charging System (MCS)** is being developed to deliver power up to 3.75 MW to power HDVs. The load on the grid will be enormous, and battery storage might be needed to shave the peaks. **Battery management systems** and battery chemistries will need to be developed to help the battery receive energy without excessive heating and degrading the battery.

Supportive devices, such as charging arms or robots, can help handle the thick and heavy charging cables. Many ample parking and charging areas at **rest stop on the highways** and urban nods will need to be designed and built and the charging organised to avoid queues and delays in transport. Compulsory breaks for the rest of the drivers can recharge the trucks on long routes. Charging infrastructure at depots will need to be built and charging opportunities at the customer when up/unloading the cargo.

Table 1: Summary of wired stationary charging types

Charging type	Nominal power output	Charging standard	Location	Estimated charging times
Overnight	<43 kW AC 50-150 kW DC	Combined Charging System (CCS) (*or CHAdeMO*)	Depot, public parking space	8 hours
Opportunity fast	150-350 kW DC		The public charging station, depot,	0.5 hours

			destination location	
Opportunity ultra-fast	750 kW-3.75 MW DC	Megawatt Charging System (MCS) or ChaoJI	Public charging stations, depot, destination location	0.5 hours

1.2.1.1 Alternatives

Static wireless charging or charging with **pantographs or trolleys** can be used for truck charging in depots, at the customer, or for charging buses at the stops. **Dynamic** wireless charging during driving, using coils embedded in the road surface, can reduce the battery capacity needed in the vehicle. The charging efficiency decreases with the vehicle's speed and would require significant investments.

Another alternative is **battery swapping**. This technology could significantly reduce the vehicle's "charging" time, but implementation is rather demanding. There is no standardisation in the construction of electric HDVs, so manufacturers use different batteries, locations of the battery pack in the vehicle and connections.

Another challenge for battery swapping for HDVs is the high investment required to build battery swapping stations compared to a standard wired charger. Battery swapping is currently used in China with the business model "**battery as service**", where companies buy just the body of the vehicle, and the battery is leased.

1.3 MOTORBIKES

With a long and solid presence on most European roads, the motorcycles recently revealed their capacity to fill in an essential gap in the environmentally friendly personal transportation gap (inner city & short to medium-range trips) that has been eagerly taken advantage of by the industry to ensure a smooth transition to full green mobility.

Besides the already-known inconveniences, motorcycles are expected to overcome another significant shortcoming related to the use of passenger cars in urban and suburban areas - the increase in energy prices. Furthermore, they play an essential role in achieving other policies meant to reach primary sustainability goals, such as the "Cities Mission", an initiative of the European Commission to tackle significant challenges, currently in the phase-in stage as a test run in about 100 European cities.

In terms of pollution mitigation, the electrification of motorbikes has the potential to help solve two of the most critical challenges: pollutant and CO_2 emissions (that are less stringent compared to passenger cars emission standards) and noise pollution, as in some countries, limits are bypassed by some ICE motorcyclists using after-sales retrofitting, making the motorcycles deliberately, just for fun, louder.

On top of the abovementioned positive aspects, there is also the evolution of the battery packs' energy capacity, whilst prices have decreased consistently over the last few years and the spread of the public charging network. To speed up the penetration of electric motorbikes, some EU states recur to incentive schemes for electric vehicles, which sometimes include motorcycles.

This is why global electric motorbike sales are anticipated to grow from roughly 1.1 million units in 2020 to 3.6 million by 2030 (Figure 35) at a compound annual growth rate of 14.4 %. According to a Comprehensive Report by Market Research Future (MRFR), the global electric motorcycles market is predicted to have a value of around USD 17.21 billion by the end of 2030. In 2021, the electric motorcycle market was worth nearly USD 7.0 billion.

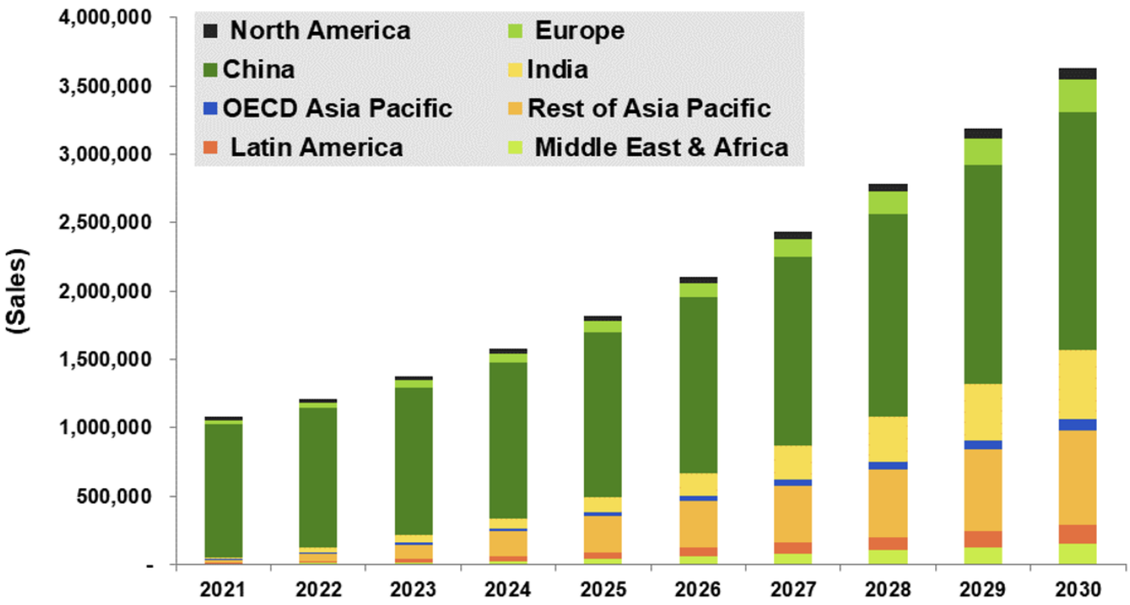

Figure 1: Annual sales of e-Motorcycles by regions and selected countries, world markets: 2021-2030

Regarding the legislation applicable in the field, electric motorbikes, except those with assistance up to 25 km/h and a maximum continuous rated power of 250 W must comply with the European harmonised technical rules in type-approval legislation, namely Regulation 168/2013 (since January 2017).

One of the major concerns that arise in the case of electric passenger cars and LCVs is less troublesome to e-motorbike riders as the charging of the electric motorcycle is faster than in the case of passenger cars or light commercial vehicles, given that the batteries they use are much smaller (around 10-15% the size and capacity of those used by electric passenger cars), which requires substantially shorter charging sessions.

Furthermore, electric motorcycles use the same standardised charger plugs as electric passenger cars. They can be charged at home, work or public charging stations used by passenger cars, although not all motorcycles can use Mode 4 chargers. Only a limited number of brands and models can use the Mode 4 fast DC charging - LiveWire One and any Energica models, for example. Depending on how the electric motorcycle is used, charging with Mode 2 and 3 chargers (mostly at home) can often be sufficient.

Figure 2: Motorbike charging at a public station

1.3.1 Charging

The optimistic outcome regarding the e-motorbikes that is anticipated can only be achieved with the direct support of a proficient and sufficient workforce. Currently, there are numerous openings for various jobs related to the production, distribution, maintenance and repair of e-motorbikes and the charging station installation, operation and maintenance. Among the sought-after candidates, there are the ones that can adequately deal with:

- R&D – developing and designing batteries and other electric systems for e-motorbikes.
- Hardware design, software development, EMC compliance.
- Embedded product development: in-vehicle and outside-vehicle deployment of various data protocols.
- Manufacturing – electric motor and battery pack assembly for e-motorbikes.
- Equipment and functional testing.
- Technicians (switches, transmitters, and light fixtures).
- Operation - assistance with charging.
- Electrical power line installation and maintenance.
- Servicing – maintenance of electric motorbikes (motor and batteries), malfunction diagnosis, servicing or replacement of malfunctioning or end-of-life battery packs, and refurbishing.
- Disassembly - end-of-life e-motorbikes and battery packs.

In the case of charging infrastructure, these are the leading positions that are offered to candidates:

- Field Service Technician – EV Charging Units
- Senior Electrical Diagnostics Engineer – EV Charging (DC)
- Installation Project Engineer – EV Charging Installation
- Lead Control Systems Engineer – EV Charging

Electrical Project and Standards Engineer – EV Charging Infrastructure.

1.4 MICROMOBILITY

Except for the bicycle, the moped, and the scooter, micromobility in and of itself is a relatively new concept that has gained massive ground over the last decade, mainly thanks to the breakthroughs in propulsion battery technology that proved to be the perfect match. Some micro-mobility devices, such as motorised skateboards and hoverboards (available in many variants), could not have been imagined outside the electric propulsion paradigm.

As the leading solution for covering short distances within cities and city centres and last mile trips in rural areas besides walking, electric micro-mobility includes small and lightweight personal mobility devices such as e-bicycles, e-scooters, e-mopeds, e-skateboards, e-hoverboards or other kinds of one or two-wheelers to be used by individuals to cover short distances within cities and city centres and last mile trips in rural areas.

As cities grow increasingly crowded and the infrastructure gets less and less friendly to the traditional propulsion - the internal combustion engine, the fleet of micromobility devices is expected to grow consistently until 2030. For example, the volume of bikes sold in Europe in 2030 should exceed the 30-million-unit threshold, with a minimum 50% share for the e-bikes.

Confederation of the European Bicycle Industry

ECF EUROPEAN CYCLISTS' FEDERATION

Cycling Industries Europe

Figure 3: Unit sales projection - Europe

The European electric scooter market is projected to reach $60.6 billion by 2030, at a CAGR of 20.4% from 2023–2030.

Regarding the practical aspects of micromobility devices, such as the battery charging options, it is noteworthy that the standard way to charge an e-bike or another micromobility device's battery is to plug the charger that comes with the device into a domestic or public power outlet and connect it to the charging inlet of the battery pack. The charging time depends on the size and type of the battery, but it usually ranges from 2 to 6 hours to reach total capacity. However, one can also charge the battery to 80 per cent in a couple of hours or less if the device supports fast charging. Especially in the case of rental scooters or e-bikes, wireless charging has been becoming available as a factory option or a retrofitting solution. It could be done by parking the device on a special charging pad or locking it in a dedicated slot in the dock.

An efficient solution, easily applicable in the case of rental fleets, turns out to be battery swapping, where an empty battery module is replaced by a fully charged one at an easily reachable dedicated facility. With specific differences in their strategic approach, the operators use this concept to increase the reliability and accessibility of the fleet but also to improve the profitability and efficiency of the business.

Figure 4: Remove a battery and replace it with a fully charged one

Another practical aspect to be observed, especially by the users, is that some (cheaper, imported models of) micromobility devices might not have an overcharging prevention solution. An electric charge timer would be necessary to restrict any excess current flow to the battery, thus preventing safety incidents which are less likely to occur in the presence of overcharge solutions.

As mentioned above, the overcharging prevention solution does not exclude unfortunate safety incidents. Therefore, caution is highly recommended. Over the last few years, lithium-ion battery fires have occurred more often and with more severe consequences. The main hazard associated with the overcharging and thermal runaway of the batteries in these devices is that they are usually charged indoors, sometimes close to the living areas of the inhabitants (garages, but even living rooms/bedrooms) and that the safety incidents can occur overnight during sleeping time.

It is also noteworthy that electric bikes mostly come with an original charging cable, but it bears drawing attention to the fact that e-bike chargers are not universal. Many e-bikes come with unique chargers specific to that bike's battery only.

1.4.1 Skills, Job Roles, and Education

Even though the micro-mobility devices are simpler and smaller, and the charging appears to be straightforward and headache-free, they still require specialised people in manufacturing, maintenance and repair as well as professionals to build, handle and troubleshoot the necessary charging infrastructure, especially in the case of public outlets, wireless pads and docks and battery swapping stations.

The most critical skills and competencies necessary to this sector are as follows:

- Systems Engineer for Battery Management Systems (BMS)
- Product Design Manager
- Electrical Engineering Technicians with competencies in retrofitting, maintaining, and repairing wireless charging units.
- Infrastructure development
- Infrastructure operation and maintenance
- App Developer
- Data Analyst

In general, many job roles rely on solid IT skills and electronics/electrical engineering and experience in software engineering. Additional competencies include strong communication skills, business intelligence, measurement and test technology handling, and others.

1.5 AVIATION

In recent years, electric aviation marked significant milestones, including the first fully certified electric aeroplane, Pipistrel Velis Electro, by the European Union Aviation Safety Agency (EASA) in 2020. EASA's 2019 electric aircraft framework plan and the drone market's rapid growth under EU regulations have further shaped the industry.

The Velis Electro, a small two-seater, is crucial in pilot training, contributing to reduced costs, emissions, and maintenance. Simultaneously, EU drone regulations implemented U-space in January 2023, creating dedicated airspace for drones and fostering safe and efficient operations.

Charging infrastructure is a key focus, with Pipistrel supporting various connections and ABB pioneering the MegaWatt Charging Standard for electric vertical take-off and landing (e-VTOL) aircraft. This standard aims for a rapid 30-minute charge, aligning with the evolving landscape of electric aviation.

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1.6 TRAINS

Trains in Europe are expected to start in May 2023, Germany, where the introduction of battery-powered trains is set to replace diesel locomotives. These environmentally friendly trains, currently undergoing testing, can reach a maximum speed of 160 kilometres per hour and utilise regenerative braking for energy efficiency. Designed for intercity service, the trains are just under 50 meters long.

A RailBaar charging station has been implemented to support their charging needs, offering a cost-effective and versatile platform side station concept. The charging system operates on 750V DC, with an AC version in development, providing up to 800kW of power for rapid charging. Depending on battery size, the number of coaches, and charger capacity, a full charge can take 10-30 minutes, with a quick top-up charge achievable in 1-3 minutes.

2 Battery Sector Equipment and Production Machines

As introduced in the executive summary, this section provides a summary of manufacturing equipment and an update on the battery sector and legislation.

2.1 THE CRITICAL RAW MATERIALS ACT AND THE NET ZERO INDUSTRY ACT

Raw materials are essential for the manufacturing process of technologies, which are vital for the green/digital transition. As three of the primary critical raw materials (lithium, cobalt, nickel) are fundamental for battery production, the diversification of the supply chain and the internal recycling, processing and production of these resources are essential to comply with future requests for this industry, which are expected to grow in the following years.

The Eurometaux Site estimates the future battery needs in the European Union in the context of the green and digital transition. By 2050, the demand for the production of European batteries is expected to reach up to 3500% of Europe's lithium consumption today, 330% of cobalt, and more than 100% of nickel[3].

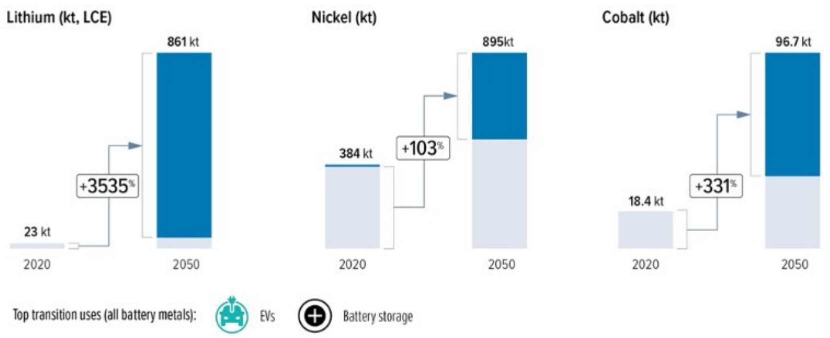

Figure 5: Europe's metal needs until 2050. Battery metals (blue: energy transition uses, grey: other uses)

According to the RECHARGE European industry association, recycling will be a crucial solution to comply with future batteries requests, covering 40-70% of the metals needed for batteries from 2040 onwards[4].

[3] Eurometaux Site, *Metals for Clean Energy. Pathways to solving Europe's raw materials challenge,* in https://eurometaux.eu/metals-clean-energy/, 19 of June 2023.
[4] RECHARGE Position Paper, *on the Critical Raw Materials Act,* November 2022.

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The **Critical Raw Materials Act**[5] underlines the growing need to address the European dependency on imported critical raw materials by diversifying the supply chain and securing domestic production. In the regulation's document, many aspects are considered: the economic one, as public and private financial investments are essential to secure a strong value chain[6]; the necessity to monitor the exploration of raw materials in the European Union's territory[7]; and the need to evaluate the environmental footprint during the production of these sources to ensure that critical raw materials placed in the European Union are as sustainable as possible[8].

The Critical Raw Materials Act plays a vital role in the growth and sustainability of the battery industry. Companies identified by European Member States that manufacture "strategic technologies" (including batteries for energy storage and e-mobility)[9] must perform every two years[10]:

- An accurate mapping that shows where the strategic raw materials used during their production process are extracted, processed or recycled;
- A stress test of their supply chain of strategic raw materials, which consists of assessing its vulnerability/security: the test consists of creating scenarios that could impact the disruptions and their potential effects.

Finally, the Act further specifies that the Commission would encourage the recycling process of these sources by introducing financial incentives (such as discounts, monetary rewards and deposit-refund systems). Member States will also play a focal role in encouraging the recovery of raw materials from extractive waste[11].

Available at: https://rechargebatteries.org/wp-content/uploads/2022/11/RECHARGE-paper_Critical-Raw-Materials-Act_public-consultation_November-2022.pdf

[5] European Commission Site, *Critical Raw Materials Act,* in https://single-market-economy.ec.europa.eu, accessed June 15th, 2023.

[6] Ivi, pp. 8-9.

[7] Ivi, p. 9.

[8] Ivi, p. 14.

[9] regulation of the European Parliament and of the Council of the 16 of March 2023, establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) 168/2013, (EU) 2018/858, 2018/1724 and (EU) 2019/1020, art. 23, p. 37.

[10] Ibidem.

[11] Ivi, art. 25, p. 39.

The European Commission proposed the Net Zero Industry Act in March 2023[12]. As the manufacturing industry is going to be more and more affected by the green and digital future requirements, the main goal of this Act is to achieve a situation of resilience for what concerns the availability of net-zero technologies, which are at the centre of the geostrategic interests[13]. The objective is to ensure that by 2030, the European manufacturing capacity reaches at least 40% of the Union's annual deployment needs[14]. In recent years, energy-intensive industries have been suffering from the impacts of the energy crisis: such industries will need access to net-zero technologies such as batteries, heat pumps, solar panels, and fuel cells to remain competitive in the future [15].

The Net Zero Industry Act identifies different objectives that have to be addressed to successfully scale up the manufacturing of green technologies, such as:

- Necessity to make available all the information regarding the Net Zero Industry project;
- Guaranteed access to markets for these technologies;
- Skills-enhancement;
- Innovation in the field;
- Creation of a Platform that ensures the exchange of best practices, information and issues.

The Net Zero Industry Act is considered a big step forward for all the industries involved, including the battery industry[16]. Batteries play a crucial role in the European Union's strategic autonomy, and they are a fundamental part of this declaration. Given their role, they should benefit from even faster permitting procedures, and support from additional crowd-in investments[17]. This regulation strongly encourages battery manufacturers to "consolidate their technology leadership"[18]. For battery technologies, European manufacturers are

[12] European Commission Site, *The Net-Zero Industry Act: Accelerating the transition to climate neutrality,* in https://single-market-economy.eu, accessed June 22nd, 2023.
[13] regulation of the European Parliament and of the Council of the 16 of March 2023, *on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net-Zero Industry Act),* 2023/0081, p. 2.
[14] Ivi, p. 12.; *and* FES Germany Site, *The Key provisions in the EU's Net Zero Industry Act,* in www.justclimate.de.fes, 30 March 2023.
[15] Ibidem.
[16] Ivi, p. 19.
[17] Ivi, p. 20.
[18] Ivi, p. 22.

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encouraged to produce 90% of European battery demand (which translates to reaching a European manufacturing capacity of 550 GWh by 2030)[19].

Another fundamental point is assessing the future skills needed in the industries affected by the Net Zero Industry Act Regulation. Member States will, therefore, need to identify the skills needed, develop education and training programs, and financially support the industries, explicitly focusing on SMEs[20].

Many stakeholders in the battery industry consider both the Net Zero Industry and the Critical Raw Materials Acts as "real game changers" for improving the competitiveness of the European battery value chain[21].

2.1.1 Minerals and Processing

Minerals are fundamental for battery production: lithium, cobalt, nickel, manganese and graphite are, in fact, crucial for battery performance, longevity and energy density[22]. The shift to cleaner energy systems will increase the request for these minerals: the green and digital transition will make the battery sector one of the fastest-growing segments, thus impacting the request for these resources[23].

The Critical Raw Materials Act mentions in various points the importance that mineral mapping, geochemical campaigns and geoscientific datasets will have in the future[24] . It establishes that Member States should make available the information while exploring these sources on their territory[25]. The recovery of critical raw materials from extractive waste will also have positive implications, such as revaluing mining sites, which will gain a new economic value and a new industrialisation process[26].

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[19] Ibidem.
[20] regulation of the European Parliament and of the Council of the 16 of March 2023, *on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net-Zero Industry Act),* 2023/0081, p. 33.
[21] Colthorpe A., *Net Zero Industry Act makes Europe competitive in battery value chain, trade groups said,* in www.energy-storage.news, 21 March 2023.
[22] IEA Site, *In the transition to clean energy, critical minerals bring new challenges to energy security,* in www.iea.org, accessed 26th June 2023.
[23] Ibidem.
[24] regulation of the European Parliament and of the Council of the 16 of March 2023, establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) 168/2013, (EU) 2018/858, 2018/1724 and (EU) 2019/1020, p. 9.
[25] Ibidem.
[26] Ibidem.

First of all, the regulation sets important objectives for what concerns the consumption of mined strategic minerals:

- 10% of these should be sourced domestically;
- The global supply chain should be diversified, as no more than 65% of the European annual consumption of minerals should come from a single third country[27].

The European regulation towards better-achieving minerals, including their processing, recycling and extraction, is considered very ambitious for different reasons. First, the EU will face several challenges in achieving its objectives because of how long the investigation of existing mines brings. Second, European countries have different levels of mines in their territories: it is estimated that Portugal, Sweden and Finland are the most likely locations for new mines, but all three are likely to face their own legislative barriers[28].

2.1.2 Circularity

Circularity refers to the sharing, leasing, reusing, repairing, refurbishing, and recycling of existing materials and products as long as possible to extend the latter's life[29]. The main advantage of achieving a circular economy is to optimise the resources, reduce the consumption of raw materials, and recover waste, thus reaching a consumption model that ensures sustainable growth over time[30]. In this framework, ensuring a longer life cycle for batteries is fundamental[31].

In December 2022, the Council and the European Parliament reached a general provision on new rules "**towards a sustainable, circular, European battery supply chain**", representing a crucial and revolutionary step to ensure the circularity of batteries[32]. The life cycle of batteries is supposed to be more sustainable in the future thanks to this first agreement, which covers the entire battery life cycle, from design to end-of-life.

[27] EIU Site, *EU acts to secure access to critical raw materials,* in https://www.eiu.com/n/eu-acts-to-secure-access-to-critical-raw-materials/ , 17 March 2023.
[28] EIU Site, *EU acts to secure access to critical raw materials,* in https://www.eiu.com/n/eu-acts-to-secure-access-to-critical-raw-materials/ , 17 March 2023
[29] European Parliament, *Circular economy: definition, importance and benefits,* in www.europarl.europa.eu, 24 May 2023.
[30] Repsol Site, *What is circular economy and why is it important,* in www.repsol.com, accessed July 27th, 2023.
[31] European Council, Council of the European Union Site, *Infographic – Towards a sustainable, circular, European battery supply chain,* in www.consilium.europa.eu, accessed 11th of July, 2023.
[32] Ibidem.

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The proposal will apply to all types of batteries sold in the European Union's territory (portable batteries, SLI batteries, light means of transport, and batteries providing power for wheeled vehicles, such as electric scooters and bikes[33]). One of the main goals is a mandatory requirement for a minimum percentage of recycled content[34].

In June 2023, the proposal was finally adopted by the European Council, permanently replacing the battery directive of 2006[35]. This regulation covers the sustainability criteria mentioned above, reconfirming the necessity to recycle a minimum of the battery content.

The regulation also sets labelling requirements with implementing a "battery passport", which will be introduced in 2027. The Battery Passport will be essential to specify the materials' chemistry, origin, and state of health, thus representing a powerful tool to track batteries throughout their life cycle and supporting the establishment of life extension and end-of-life treatment systems[36].

Given the new European requirements, many repercussions are expected for the battery manufacturing industry: implementing new methods that can more easily lead to battery recycling will indeed be very common. For example, the "design for recycling" process will imply a careful selection of materials for new battery chemistries and an improvement for existing ones to facilitate their future recycling[37]. The design for recycling (also defined as eco-design) will comprehend the application and study of methodologies. One of them is the Life Cycle Assessment (LCA), an analysis that allows the evaluation of the environmental impact of a product throughout its life cycle.

In this context, the theme of circularity also appears in the Critical Raw Materials Act[38]. The document's text specifies that the Act should contain measures to increase the circularity and sustainability of the critical raw materials (among which are substances that are essential to

[33] European Parliament, *Batteries: deal on new EU rules for design, production and waste treatment,* in www.europarl.europa.eu, 9 December 2022.
[34] European Council, Council of the European Union Site, *Council and Parliament strike provisional deal to create a sustainable life cycle for batteries,* in www.consilium.europa.eu, 9 December 2022.
[35] European Council Site, *Council adopts new regulation on batteries and waste batteries,* in www.consilium.europa.eu, 10 July 2023.
[36] ALBATTS Deliverable D4.4, *Battery Manufacturing,* 2021, p. 23.
[37] CIC Energigune Site, *Recycling of Lithium-Ion Batteries: the way for a sustainable energy transition,* in https://cicenergigune.com/en/blog/recycling-lithium-ion-batteries-sustainable-energy-transition, 25 May 2021.
[38] See above paragraph, 2.1: Critical Raw Materials Act.

produce batteries)[39]: recycling measures are encouraged, as they are fundamental to achieving a circular economy in the context of the green transition[40].

Similarly, **the Net Zero Industry Act** aims at reaching a circular system among its main objectives[41]. In the Act, the evaluation of possible net-zero solutions must consider different factors that are fundamental to achieving circularity, such as[42] the durability and reliability of the solution, the ease of repair and maintenance, the ease of upgrading and refurbishment, the ease and quality of recycling, and the consumption of energy, water, and other resources. As the European framework is directed towards a circular system, the battery industry will see a promotion of battery recycling and reuse, leading to the need to develop more skills and knowledge on the battery ecosystem. Different job roles will arise in this context, such as battery engineer, data scientist, analyst, data engineer/architect, software engineer and software architect[43]. An up/reskilling process is also necessary to ensure the workers' safety, as handling batteries can lead to different hazard levels.

2.2 MACRO TRENDS, DRIVERS OF CHANGE: A FORWARD-LOOKING PERSPECTIVE

The desk research and data analyses of the ALBATTS project have regularly produced an update of the main Drivers of Change in the sector, encompassing both mobile battery applications and stationary & industrial applications[44]. Therefore, A forward-looking perspective is of utmost importance to understand the future dynamics of the sector in light of the recent regulatory evolution at the EU level.

[39] regulation of the European Parliament and of the Council of the 16 of March 2023, establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) 168/2013, (EU) 2018/858, 2018/1724 and (EU) 2019/1020, p. 1, par. 3.
[40] Ivi, p. 12, par. 42.
[41] regulation of the European Parliament and of the Council of the 16 of March 2023, *on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net-Zero Industry Act),* 2023/0081, p. 2.
[42] Ivi, p. 24.
[43] ALBATTS Workshop of the 27th of January 2023.
[44] Release 1 is available at: https://www.project-albatts.eu/Media/Publications/5/Publications_5_20201106_123821.pdf
Release 2 is available at: https://www.project-albatts.eu/Media/Publications/23/Publications_23_20210920_83914.pdf
Release 3 is available at: https://www.project-albatts.eu/Media/Publications/68/Publications_68_20220912_82848.pdf

The driver of "globalisation" has re-gained progressive importance for this desk research, as the EU will have to increase its competitive advantage by, for example, improving the sourcing of critical raw materials for batteries. The climate goals, regulation, and environmental challenges remain significant in percentage (47%), as companies must commit to extensive decarbonisation and true sustainability.

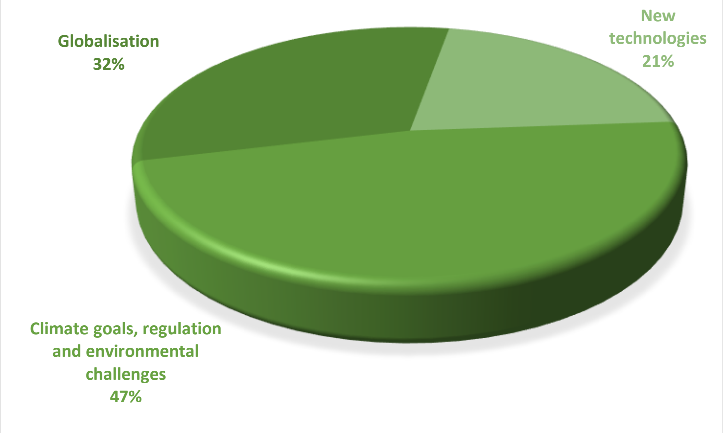

Figure 6: DoC occurrence – desk research Release 4

Regarding each DoC subcategory, as announced by the Critical Raw Materials Act and reiterated by the International Energy Agency, the increase in battery demand drives the demand for critical materials[45]. It is, therefore, evident how the subcategory "access to raw materials" within the DoC "globalisation" has increased in occurrence in the literature compared to the projections of the first desk research (Release 1)[46]. Release 2 already evidenced this trend[47].

2030 is a year where ambitious targets must be met across the battery value chain. From the first desk research of the ALBATTS project until now, all Drivers of Change identified continue to remain significant, and the outlook for the sector from today until 2030 shall allow proper skills and jobs forecasting and anticipation processes (this is the core of the ALBATTS project).

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[45] International Energy Agency Site, *Trends in batteries*, in https://www.iea.org/reports/global-ev-outlook-2023/trends-in-batteries, 2023.
[46] Please see page 26 of Release 1 available at: https://www.project-albatts.eu/Media/Publications/5/Publications_5_20201106_123821.pdf
[47] Please see page 19 of Release 2, available at: https://www.project-albatts.eu/Media/Publications/23/Publications_23_20210920_83914.pdf

As a way forward and guidance for future research and implementation strategies, the primary needs to be addressed by the sector from a high-level perspective can be summarised below (considering that they are strictly interrelated):

- **Holistic sustainability**: The battery sector is critical to achieving climate neutrality, and the decarbonisation targets are to be met by the EU. To do this, fundamental is having a holistic approach that, besides focusing on energy efficiency and emissions reduction, can achieve a truly positive environmental impact, such as safeguarding biodiversity and protecting natural habitats and land. At the same time, the social dimension of sustainability shall be considered: health, safety, fair-trade standards, human rights, and inclusive dialogues[48] are critical.
- **Resilience:** In light of the recent regulatory evolutions, achieving a resilient battery value chain means focusing on strategic partnerships. Fundamental is EU public funding and investment support and de-risking financing tools for strategic projects outside the EU to secure the CRM supply to the EU[49]. At the same time, ensuring constant data availability and transparency for compliance with legal requirements in the form of "Track and trace "is critical.
- **Circularity**: adopting a circular business model is expected to be a key factor for the future of the battery industry. The transformation from a linear battery value chain to a circular one will bring significant environmental benefits and enormous economic potential to open the door to various opportunities. A circular business model can increase the entire value chain resilience and mitigate risks (e.g., battery waste disposal). Again, cross-industry collaboration and partnerships are essential.

2.3 PRODUCTION EQUIPMENT AND RELATED COMPETENCE NEEDS

This chapter studies the skills and competencies needed with various equipment and machines used in battery production. Navigating a complex production environment demands a diverse skill set. From technical expertise in equipment operation to paying attention to

[48] McKinsey & Company Site, *Battery 2030: Resilient, sustainable, and circular,* in www.mckinsey.com, 16 January 2023.
[49] RECHARGE Position Paper, *on the Critical Raw Materials Act,* November 2022.
Available at: https://rechargebatteries.org/wp-content/uploads/2022/11/RECHARGE-paper_Critical-Raw-Materials-Act_public-consultation_November-2022.pdf

detail, operators play a pivotal role in ensuring productivity and quality. The fusion of safety compliance, troubleshooting, and a commitment to continuous improvement forms the backbone of successful manufacturing operations.

2.3.1 Electrode manufacturing

Europe's electrode manufacturing, crucial for automotive, energy storage, and renewables, thrives in Germany, France, the UK, Italy, and Sweden. Driven by EV demand, the region aims to bolster its battery industry with EU-backed R&D, reducing import reliance. Stringent environmental regulations shape sustainable practices, and the supply chain integrates domestic and global raw material sourcing, including importing precursors. Automation and digitisation enhance efficiency and quality standards in European electrode manufacturing.

Mixing equipment (e.g., Planetary Mixers and Ball Mills) in electrode manufacturing, the significance of mixing equipment, particularly planetary mixers and ball mills, is high. Planetary mixers, featuring a rotating, stationary container and agitator, are widely employed for electrode paste and slurry production. They efficiently blend high-viscosity materials across various batch sizes. Ball mills, characterised by rotating drums filled with grinding media, are often utilised for powder blending and refining processes.

Coating equipment (e.g., slot dies, doctor blades, roll coaters) ensures precise and uniform coatings to electrode materials. Slot dies are used in controlled coating applications, offering advantages like high uniformity and adjustable thickness. Working in tandem with slot dies, Doctor blades maintain coating thickness consistency. Roll coaters, utilising rollers for uniform coatings, are suitable for high-volume production.

Drying equipment (e.g., ovens, vacuum dryers) is a vital component in electrode manufacturing, ensuring electrode drying. Ovens provide a controlled environment with adjustable temperature settings and timers, catering to batch and continuous production requirements. Vacuum dryers excel in removing moisture at lower temperatures and reduced pressure, preserving the properties of sensitive electrode materials. Essential considerations

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with drying equipment include capacity, temperature control, energy efficiency, and specific requirements for processing electrode materials.

Slitting equipment (e.g., slitters, rewinders) are designed to slit large rolls of materials like metal foils or coated substrates and employ razor blades or rotary knives for precision cuts. Critical features of slitters for electrode manufacturing include width and diameter capacity, accuracy, speed and productivity, automation and control, and safety features. Rewinders complement slitters by rewinding slit electrode materials into smaller rolls suitable for further processing or packaging. Factors to consider for rewinding equipment encompass roll diameter and width capacity, tension control for maintaining material integrity, core handling to support appropriate core sizes, and automation features for efficient roll changeovers and material handling.

Electrode stacking equipment (e.g., stacking machines) is integral to the lithium-ion battery electrode manufacturing process, and the equipment for stacking electrodes is crucial. These machines involve meticulously stacking and aligning numerous layers of anode and cathode materials, along with separators, to construct the electrode structure. The electrode stacking process's precision significantly influences the battery's performance and quality.

2.3.2 Skills and Compete Needed in Electrode Manufacturing

General Skills Associated with All Equipment Categories:

- **Technical Knowledge:**
    - Understand principles, operation, and maintenance of equipment.
    - Familiarise with specific machine models, functionalities, programming, and troubleshooting.
- **Equipment Operation and Calibration:**
    - Set up equipment correctly, ensuring proper calibration for accurate dispensing.
    - Knowledge of calibrating sensors, nozzles, valves, and other components.
- **Materials Handling:**
    - Proficiency in handling various materials used in the assembly process.

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- Knowledge of material properties, storage requirements, and proper handling techniques.

- **Programming and Machine Operation:**
  - Competence in programming machines for specific tasks.
  - Adjust settings and optimise performance for different product requirements.
- **Quality Control:**
  - Attention to detail and focus on quality control measures.
  - Implement quality checks at various assembly stages and take corrective actions.
- **Problem Solving and Troubleshooting:**
  - Identify and resolve technical issues during the assembly process.
  - Troubleshoot problems with machines, materials, or components.
- **Safety Awareness:**
  - Comply with safety protocols and regulations.
  - Understand potential hazards and take necessary precautions.
- **Communication and Collaboration:**
  - Effective communication with team members and stakeholders.
  - Collaborate to streamline workflows, share knowledge, and address challenges.
- **Time Management:**
  - Efficiently manage time to meet production targets and deadlines.
  - Prioritise tasks and optimise machine use for maximum productivity.
- **Continuous Learning:**
  - Stay updated with advancements in technology and industry trends.
  - Seek opportunities for professional development.

Equipment Category-Specific Skills:

- **Mixing equipment (e.g., Planetary Mixers, Ball Mills):**
  - Ability to handle high-viscosity materials.
  - Troubleshooting skills for operational issues.
  - Compliance with environmental regulations.

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- **Coating Equipment (e.g., Slot Dies, Doctor Blades, Roll Coaters):**
  - Proficient in adjusting coating parameters.
  - Mechanical aptitude for routine maintenance.
  - Record-keeping skills for production data.
- **Drying equipment (e.g., Ovens, Vacuum Dryers):**
  - Analytical thinking for troubleshooting.
  - Adaptability to changing priorities.
  - Documentation skills for equipment operation.
- **Slitting Equipment (e.g., Slitters, Rewinders):**
  - Hand-eye coordination for precise adjustments.
  - Quality consciousness for maintaining standards.
  - Adaptability to changing production requirements.
- **Electrode Stacking Equipment (e.g., Stacking Machines):**
  - Mechanical aptitude for routine maintenance.
  - Record-keeping skills for production data.
  - Adaptability to changing production requirements.

2.3.3 Cell assembly

The European cell assembly industry is witnessing significant growth, particularly in the automotive sector, where it is crucial for electric vehicle (EV) battery production. Ongoing European research and development focus on enhancing cell assembly technology's performance, energy density, safety, and sustainability. The establishment of Gigafactories by significant industry players emphasises comprehensive production, covering the entire battery-making process, including cell assembly.

Cell stacking equipment encompasses machinery or devices specifically engineered to automate individual cells or batteries' organised and efficient stacking. Widely utilised in the production and assembly of battery packs, these machines play a crucial role in various applications, including electric vehicles, portable electronics, and energy storage systems.

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Tab welding equipment (ultrasonic welders, laser welders) plays an essential role in the battery cell assembly. Ultrasonic welders are extensively used, especially in manufacturing lithium-ion batteries for electric vehicles (EVs) and various equipment, offering a reliable and efficient method for joining battery cell components. Laser welding technology is employed in battery production for cell assembly, utilising a high-energy laser beam to generate localised heat that melts and fuses materials. Laser welders are particularly useful for combining components such as battery tabs, terminals, and busbars.

Winding Machines are essential in the cell assembly process for battery technology, specifically for manufacturing battery cells. These devices are crafted to precisely wind and assemble the electrode components, separators, and current collectors into a streamlined cell arrangement.

Electrolyte Filling equipment (vacuum filling machines, injection filling machines) plays a specialised role in battery production, specifically for adding electrolytes to battery cells. Electrolytes, crucial for supplying the ionic conductivity essential for electrochemical reactions inside cells, are precisely and effectively filled into battery cells through these machines. Similarly, electrolyte injection filling machines are employed in battery cell assembly to ensure accurate and efficient filling of battery cells with the electrolyte solution. These devices provide precise control over the amount and distribution of the electrolyte, ensuring optimal performance and security of the battery cells.

Sealing Equipment is utilised in the battery manufacturing process. Heat sealers are specialised machinery crucial for ensuring an airtight and secure enclosure during battery cell assembly. This technique, widely adopted in the battery production industry, involves using heat sealers to create a dependable and leak-proof seal for battery cells.

A crimping machine is utilised in battery cell assembly; a crimping machine is a specialised machinery crucial for establishing electrical and mechanical connections among various parts of a battery cell during the manufacturing process. This technique, widely adopted in the battery manufacturing industry, involves crimping machines to connect terminals, tabs, or connectors to the electrodes, creating a reliable and low-resistance electrical channel.

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Formation equipment battery cyclers, or formation equipment, are integral in battery production, facilitating the initial charging and discharging cycles needed to condition and activate cells. These machines, comprised of components like a customised power supply, control system for parameter adjustment, and data acquisition for quality assurance, ensure consistent and efficient formation. Safety features guarantee secure operation, including temperature sensors and emergency shutdown mechanisms. Formation equipment enables automated processes, quality control through data collection, and flexibility for different battery types.

Voltage/current testing equipment is used for measuring electrical systems, ensuring efficiency and safety. The Digital Multimeter (DMM) is a versatile tool for measuring voltage, current, and resistance in maintenance and troubleshooting. Clamp meters offer non-invasive current measurement by clamping around conductors. Power analysers provide in-depth electrical power analysis. Oscilloscopes display graphical representations of electrical waveforms for analysis. Programmable power supplies regulate voltage and current for testing electronic equipment in various applications. Current shunts precision resistors measuring high current levels, are applied in power distribution and industrial machinery.

2.3.4 Skills and competencies needed in cell assembly

General Skills Associated with All Equipment Categories:

- **Technical Knowledge:** Understand the principles, operation, and maintenance of specific equipment used in battery assembly, including machine models, functionalities, and troubleshooting.
- **Equipment Setup and Calibration:** Ability to set up and calibrate machinery for accurate and precise operations, adjusting parameters as needed.
- **Material Handling:** Proficient in handling relevant components, understanding their properties, dimensions, and proper handling techniques to maintain quality.
- **Quality Control:** Attention to detail for implementing and ensuring quality control measures at various stages of the assembly process.

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- **Troubleshooting:** Identify and resolve technical issues promptly, whether related to the machinery, parameters, or materials.
- **Safety Awareness:** Comply with safety protocols, understand potential hazards, and take necessary precautions for a secure working environment.
- **Communication and Collaboration:** Effectively communicate with team members and stakeholders, fostering collaboration for streamlined workflows.
- **Time Management:** Efficiently manage time, prioritise tasks, and optimise machinery use to meet production targets and deadlines.
- **Continuous Learning:** Stay updated on technological advancements and industry trends, seeking opportunities for professional development.

Equipment Category-Specific Skills:

- **Cell Stacking Equipment:**
    - **Stacking Techniques:** Competence in various stacking techniques, manual or automated, based on machine and application requirements.
- **Tab Welding Equipment (Ultrasonic Welders, Laser Welders):**
    - **Welding Techniques:** Proficiency in different welding techniques, such as ultrasonic or laser welding, depending on the machine and application.
- **Winding Machines:**
    - **Mechanical Aptitude:** Basic understanding of mechanical systems for routine maintenance and issue troubleshooting.
    - **Hand-eye Coordination:** Good manual dexterity and coordination for precise material handling and adjustments.
- **Electrolyte Filling Equipment (Vacuum Filling Machines, Injection Filling Machines):**
    - **Programming and System Operation:** Competence in programming the filling system for specific tasks and adjusting settings for optimal performance.
- **Sealing Equipment:**
    - **Mechanical Aptitude:** Basic understanding of mechanical systems for routine maintenance and issue troubleshooting.
- **Crimping Machine:**

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- **Hand-eye Coordination:** Good manual dexterity and coordination for handling wires or cables and making precise adjustments.

- **Formation Equipment:**
  - **Data Analysis Skills:** Proficiency in data acquisition, interpretation, and analysis for comprehensive testing evaluations.
- **Voltage/Current Testing Equipment**
- **Test Setup and Configuration:** Ability to set up testing equipment, configure measurements, and adhere to safety protocols for live circuits.

2.4 EDUCATION AND TRAINING ON PRODUCTION EQUIPMENT

The transition to a carbon-neutral economy and the rise of electromobility present a significant challenge in education and training for employees in new manufacturing processes, particularly in gigafactories. To effectively address this challenge, education strategies have been developed, focusing on critical areas:

1. Technical Skills Development: Private and public training programs are established to continuously upskill employees in various manufacturing aspects, including technologies, machinery operations, automation, and robotics.

2. Cross-Training Opportunities: Specialised training in multiple areas within gigafactories is encouraged, promoting flexibility for employees in specific job roles.

3. Continuous Learning: Large institutions provide continuous learning opportunities through workshops and online courses to enhance professional development and keep up with industry advancements.

4. Leadership Development: Higher-level education programs focus on managerial skills, decision-making, effective communication, and other soft skills for managers and future leaders within gigafactories.

5. Collaboration and Knowledge Sharing: Gigafactories promote collaboration and knowledge sharing among employees through teamwork, projects, and regular meetings, fostering process innovation.

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6. Sustainability and Green Technologies: Companies align with environmental objectives, training employees to focus on energy-efficient processes, water and waste reduction, and recycling initiatives.

7. Soft Skills Development: Soft skills such as teamwork, problem-solving, and communication receive increased attention to create a compelling and diverse working environment.

8. Career Development: Companies provide clear growth paths within the organisation to motivate employees and support their professional development in various job roles.

9. Partnership with Education Institutions: Collaboration with local universities, technical schools, and vocational training centres is emphasised to attract new candidates and create customised education programs.

10. Employee Feedback and Evaluation: Continuous feedback and evaluation of employees' needs and job satisfaction are crucial metrics for managers to maintain good performance and tailor educational programs.

Moreover, several EU job roles and skills education providers, such as ASA and InnoEnergy Skills Institute, offer specialised courses for gigafactory employees, contributing to the workforce's development.

The modern approach towards learning integrates digital tools, including VR and AR, and simulation-based techniques. Examples include:

- Simulation-based education for PV and storage optimisation tools.
- Virtual practical training in engineering fields through simulated enterprises.
- Building life-size vessel simulations in a technical VET school to provide real-world experiences.
- VR training simulations by Aptiv for assessing trainee engagement and knowledge application in high-voltage systems.
- AR, combining hands-on examinations with data capture for enhanced training versus traditional training methods.
- Battery factory simulation models by Siemens Digital Industries Software for design and engineering acceleration.

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Lastly, utilising digital twins in gigafactories bridges the gap between development and reality, providing a safer and more effective environment for training. The application of artificial intelligence (AI) in battery cell development, optimisation, and materials selection showcases the potential for advancements in this rapidly evolving field.

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