albatts

*Alliance for Batteries Technology, Training and Skills*

*2019-2023*

# Batteries in the EU: Recent Legislative Evolution and Introduction to the Machines, Operators' Skills and Competencies in Production

~~~

D4.10 - Desk research and data analysis for sub-sector ISIBA - Final

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

## DOCUMENT TITLE

| | | | |
|---|---|---|---|
| Report Title: | Batteries in the EU: Recent Legislative Evolution and Introduction to the Machines, Operators' Skills and Competencies in Production | | |
| | | | |
| Responsible Project Partner: | Kari Valkama, Merinova | Contributing Project Partners: | SPIN360, FEUP, EFACEC, HE3DA, VSB-TUO |
| | | | |

| | | | | |
|---|---|---|---|---|
| Document data: | File name: | D4.10 - Desk research and data analysis for sub-sector ISIBA - Final | | |
| | Pages: | 119 | No. of annexes: | 0 |
| | Status: | Final | Dissemination level: | PU |
| Project title: | Alliance for Batteries Technology, Training and Skills | | GA No.: | 2019-612675 |
| WP title: | WP4 Intelligence in Stationary and Industrial Battery Applications | | Project No.: | 612675-EPP-1-2019-1-SE-EPPKA2-SSA-B |
| | | | Deliverable No: | D4.10 |
| Date: | Due date: | 31.08.2023 | Submission date: | 16.09.2023 |
| Keywords: | Critical Raw Material Act, Raw Materials, Net Zero Industry Act, Minerals, Battery, Circularity, Battery Passport, Skills, Competencies, Life Cycle Assessment, Resilience, Machinery, Electrode Manufacturing, Macro Trends, Drivers of Change, Electrode manufacturing, Cell assembly, Module and pack assembly, Dry room, Gigafactory, Education, Training, AI, VR, AR, Digital Twin, Simulation | | | |
| Reviewed by: | Marek Spányik, VSB-TUO | | Review date: | 16.9.2023 |
| | | | | |
| Approved by: | Mika Konu, CEO, Oy Merinova | | Approval date: | 15.9.2023 |

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

## Table of Contents



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

## Executive Summary

Chapter 1 examines the Critical Raw Materials Act and the Net Zero Industry Act's importance in the battery sector during the green and digital transition. The Critical Raw Materials Act addresses the need for key raw materials like lithium, cobalt, and nickel in battery production, emphasising supply chain diversification and recycling for sustainability. The Net Zero Industry Act promotes resilience in the availability of net-zero technology from the manufacturing aspect and the aspect of the needed future skills. Macro trends like climate goals, globalisation and new technologies shape the battery industry, stressing the importance of, for example, following the decarbonisation pathway, access to raw materials, global technical harmonisation, and standardisations.

Chapter 2 studies the battery production-related skill and competence needs. This is a continuation of what we addressed in D4.4 - Desk Research and Data Analysis for sub-sector ISIBA – Release 2 (Chapter 4: Anatomy of a Gigafactory). Now, we take a deeper dive into mid- and downstream production processes, detailing some of the most important production equipment, their providers, and the skills, competencies, and job roles essential to operate those machines and tools. We cover electrode manufacturing, cell assembly, module and pack assembly, and dry room operations. Operator skills and competencies are pivotal for efficient manufacturing in a production environment. These include technical proficiency, attention to detail, troubleshooting abilities, safety compliance, effective communication, and maintenance skills. A continuous improvement mindset encourages identifying opportunities for process optimisation and efficiency enhancement. We discuss Europe's battery industry's expansion and the need for a skilled workforce with expertise in various technical areas, including production processes, chemistry, automation, sustainability, and recycling.

Chapter 3 sheds light on the modern education and training methods that can also be applied in battery manufacturing and related machinery and tools. The latest information technology can enable the delivery of immersive, interactive, and personalised learning experiences. Leveraging advanced technologies such as Virtual Reality (VR), Augmented Reality (AR), Artificial Intelligence (AI), and Digital Twins may enable training that is engaging, adaptable, and tailored to individual eds, setting the stage for a highly skilled and responsive workforce.

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

## Introduction and methodology

This deliverable continues on the basis of our earlier desk research work in the ALBATTS project. In this deliverable, we cover the evolution of the recent legislative developments in the EU regarding the battery industry and continue to explore battery production with a focus on the machinery, tools and related skills and competencies. We also provide a view of education and training methods enabled by the latest information technology.

The Critical Raw Materials Act (CRMA) and the Net Zero Industry Act are two 2023 regulations proposed by the European Commission[1], which are both aimed at reaching the ambitious EU's climate goals in the context of the Green Deal and of the Fitfor55. The CRMA is aimed at diversifying the EU's supply chain for the procurement of sources, among which there are lithium, cobalt, nickel, gallium, raw boron, titanium, and tungsten (the first three being fundamental for the batteries production)[2], as well as reducing its dependence on their imports. The European Union is strongly dependent on sourcing raw materials from countries outside its territory, and its supply chain is progressively vulnerable due to the growing demand for raw materials to comply with the green and digital transition.

To give some numbers, it has been estimated that[3]:

- About 63% of the world's cobalt is extracted in the Democratic Republic of Congo.
- About 97% of the EU's magnesium supply is sourced from China.
- 100% of the rare earths used for permanent magnets are refined in China.
- 98% of the EU's supply of borate is provided by Turkey.

The Critical Raw Materials Act also sets some provisions concerning the recycling, procurement, and processing of minerals. The regulation aims to find new possible sites that will be relevant for extracting relevant sources of this type. On the other hand, the Net Zero Industry Act aims to scale up the manufacturing of clean technologies in the European Union

[1] European Commission Site, *European Critical Raw Materials Act,* in www.commission.europa.eu, accessed June 20th, 2023; *and* European Commission Site, *Net-Zero Industry Act. Making the EU the home of clean technologies manufacturing and green jobs,* in www.commission.europa.eu, accessed June 20th, 2023.
[2] European Commission Site, *European Critical Raw Materials Act,* in www.commission.europa.eu, accessed June 20, 2023.
[3] European Commission Site, *European Critical Raw Materials Act,* in www.commission.europa.eu, accessed June 20th, 2023

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

by attracting investments and creating better conditions and market access for cleantech in the EU[4]. The "Net Zero Technologies" are the following[5]: renewable energy technologies, electricity and heat storage technologies, heat pumps, grid technologies, renewable fuels of non-biological origin technologies, sustainable alternative fuels technologies, electrolysers and fuel cells, advanced technologies to produce energy from nuclear processes, small modular reactors, carbon capture, utilisation and storage technologies and energy-system related energy efficiency technologies. The main objective of this regulation is to simplify the regulatory framework and make the energy system decarbonisation more resilient[6].

These regulations will have different consequences on the battery value chain, which will be further explained in the following chapters.

Additionally, we briefly discuss the development of job roles and skill needs at a macro level. The European battery manufacturing industry is rapidly expanding, requiring a skilled workforce proficient in technical and vocational skills. Key areas of expertise include production processes, chemistry, automation, sustainability, and recycling. Critical job roles encompass battery chemists, engineers, assemblers, managers, and specialists. Knowledge of regulations, circular economy principles, and emerging technologies is vital for sustained growth in this sector.

This desk research also describes the equipment and tools used in the battery manufacturing industry's mid- and downstream production processes. The study focuses on Electrode Manufacturing, Cell Assembly, Module and Pack Assembly, and Dry Room operations. For each stage, regarding some of the most common equipment and tools, it outlines the associated skills, competencies, and job roles required for proficient operation. Through this analysis, the research provides a view of the equipment, skills, and competencies needed in battery production.

The following equipment, tools and related skills and competencies are covered in this deliverable:

[4] European Commission Site, *Net-Zero Industry Act. Making the EU the home of clean technologies manufacturing and green jobs,* in www.commission.europa.eu, accessed June 20th, 2023.
[5] 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, art. 3., p. 36
Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52023PC0161
[6] Ivi, p. 1.

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

- Electrode manufacturing
  - Mixing Equipment (e.g., Planetary Mixers, Ball Mills)
  - Coating equipment (e.g., slot dies, doctor blades, roll coaters)
  - Drying equipment (e.g. ovens, vacuum dryers)
  - Slitting equipment (e.g. slitters, rewinders)
  - Electrode stacking equipment (e.g. stacking machines)
- Cell assembly
  - Cell stacking equipment
  - Tab welding equipment (ultrasonic welders, laser welders)
  - Winding Machines
  - Electrolyte Filling equipment (vacuum filling machines, injection filling machines)
  - Sealing Equipment (Heat sealer, Crimping Machines)
  - Formation equipment (e.g. battery cyclers, voltage/current testing equipment)
- Module and pack assembly
  - Pre-Assembly (Potentiostat)
  - Insulation and Tensioning (Clamping Device)
  - Electrical Contacting (Laser Welding Machine)
  - Mounting Slave Circuit Board and housing cover
  - Insertion of cell module and attachment
  - Electrical & Thermal Integration (Protection Equipment)
  - Sealing & Leak Test (Rubber Seals, Leak testing equipment)
  - Charging & Flashing (Testing Station)
  - End of line (BMS Testing Machine)
- Battery module automatic assembly line
  - Cell gluing (Cell Gluing Station)
  - Module stack pressing (Stack Pressing Station)
  - Strapping (Strapping Machine)
  - Insulation (Multimeter)
  - Laser cleaning (Cleaning Laser)
  - Busbar assembly and laser welding (Arc Welding Robot)

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

- Rack module and cabinet manufacturing
  - Punching & cutting (CNC)
  - Bending (Bending Machine)
  - Welding (Welding Machine)
  - Polishing (Polishing Machine)
  - Powder coating (Powder Coating Spray Gun, Spray Booth, Oven, Washing and Degreasing Equipment)
  - Packing/Assembling
- Clean and dry room
  - Generally, about operating clean and dry rooms
  - Glovebox

The last chapter discusses education and training methods. It highlights the critical challenge of educating and training the workforce in the rapidly evolving battery manufacturing sector, especially in gigafactories. It emphasises the need for a comprehensive education strategy covering technical skills, continuous learning, leadership development, collaboration, sustainability practices, and soft skills. It also discusses prominent EU education providers like the Automotive Skills Alliance and the EBA Academy. The text explores using AR, VR, and simulations for effective learning and training, with examples like PV and Storage Optimization Tools. Digital twins in gigafactories are introduced for enhanced safety and sustainability. Lastly, the role of AI in optimising battery manufacturing processes is discussed, including its potential in cell development and production optimisation.

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

## Abbreviations

| | | |
|---|---|---|
| AI | … | Artificial Intelligence |
| AR | … | Augmented Reality |
| ASA | … | Automotive Skills Alliance |
| BESS | … | Battery Energy Storage Systems |
| BMS | … | Battery Management System |
| CNC | … | Computerised Numerical Control |
| CRM | … | Critical Raw Materials |
| CRMA | … | Critical Raw Materials Act |
| DMM | … | Digital Multimeter |
| DoC | … | Driver of Change |
| EBA | … | European Battery Alliance |
| EIT | … | European Innovation & Technology |
| EV | … | Electric Vehicle |
| GW | … | Gigawatt |
| GWh | … | Gigawatt hour |
| IMO | … | International Maritime Organization |
| LCA | … | Life Cycle Assessment |
| MAG | … | Metal Active Gas |
| MIG | … | Metal Inert Gas |
| PPE | … | Personal Protective Equipment |
| PV | … | Photovoltaic |
| R&D | … | Research and Development |
| SLI Batteries | … | Starting, Lighting, and Ignition batteries |
| SMEs | … | Small and Medium-sized Enterprises |
| TIG | … | Tungsten Inert Gas |
| VR | … | Virtual Reality |

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

# 1 Battery sector update considering the recent EU legislative evolution

## 1.1 THE CRITICAL RAW MATERIALS ACT AND THE NET ZERO INDUSTRY ACT

Raw materials are essential for the manufacturing process of technologies which are key for the green/digital transition – like wind power generation, hydrogen storage or batteries[7]. As three of the main critical raw materials (lithium, cobalt, nickel) are fundamental for battery production,[8] the diversification of the supply chain and the internal recycling, processing and production of these resources are important to comply with future requests for this industry, which are expected to grow in the following years.

The Eurometaux Site (which represents the European voice of non-ferrous metal producers and recyclers) reports an estimate on the future battery needs in the European Union in the context of the green and digital transition. By 2050, the demand for 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[9].

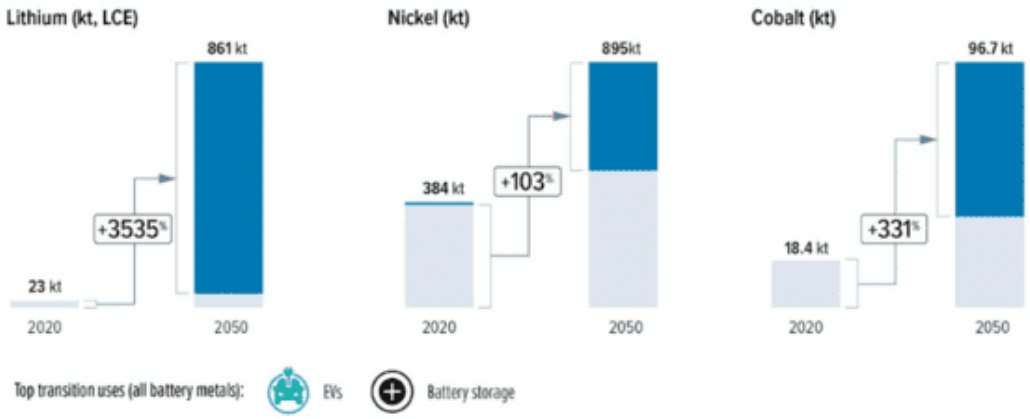


*Figure 1: Europe's metal needs until 2050. Battery metals (blue: energy transition uses, grey: other uses)*

In addition, battery energy storage systems (BESS) will have a Compound Annual Growth Rate of 30 per cent, and the GWh required to power these applications (in particular mobility

[7] European Commission Site, *Critical Raw Materials: ensuring secure and sustainable supply chains for EU's green and digital future,* in www.ec.europa.eu, 16 March 2023.
[8] European Commission Site, *Sustainable Supply of Raw Materials,* in www.commission.europa.eu, accessed July 24th, 2023.
[9] 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.

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

applications, such as electric vehicles (EVs), in 2030 will be comparable to the GWh needed for all applications today[10]. Lastly, according to the RECHARGE European industry association, recycling will be a key solution to comply with future battery requests, covering 40-70% of the metals needed for batteries from 2040 onwards[11]. However, there is a need for consistent investments to establish a European battery recycling industry.

The **Critical Raw Materials Act** was first announced in September 2022, underlying the growing need to address the European dependency on imported critical raw materials by diversifying the supply chain and securing domestic production. Some results have been previously achieved in supply chain diversification, thanks to agreements and especially Strategic Partnerships with third countries. However, until now, no regulatory framework could effectively reduce the risks that may arise or push the EU to create its own production of raw materials[12]. 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; the necessity to monitor the exploration of raw materials in the European Union's territory; 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[13].

Given these considerations, it can be evidenced how the Critical Raw Materials Act plays a key role in the growth and sustainability of the battery industry. Looking at the specific consequences of this Act for the batteries production, article 23 states that large companies identified as such by European Member States that manufacture "strategic technologies" (including batteries for energy storage and e-mobility)[14] must perform every two years[15]:

---

[10] McKinsey & Company, *Battery 2030: Resilient, sustainable, and circular,* in https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular, 16 January 2023.

[11] 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

[12] 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, pp. 1-2. Available at: https://eur-lex.europa.eu/resource.html?uri=cellar:903d35cc-c4a2-11ed-a05c-01aa75ed71a1.0001.02/DOC_1&format=PDF

[13] Ivi, p. 14.

[14] 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.

[15] Ibidem.

- 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 assesses its vulnerability/security: the test consists of creating potential scenarios that could impact the disruptions and their possible effects.
- The above-mentioned stress test must take into consideration different factors[16]:
    - Where the raw materials are extracted, processed, and recycled.
    - The capacities of the economic operators along the value chain.
    - Factors that could threaten the supply (such as geopolitical situations, logistics, energy supply).
    - The availability of alternative supply sources and substitute materials.
    - The users of the relevant raw material along their value chain and share demand.

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[17].

**The European Commission proposed the Net Zero Industry Act** in March 2023[18]. 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[19]. The objective is to ensure that, by 2030, the European manufacturing capacity

[16] 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. 19, p. 34.
[17] Ivi, art. 25, p. 39.
[18] European Commission Site, *The Net-Zero Industry Act: Accelerating the transition to climate neutrality,* in https://single-market-economy.eu, accessed June 22nd, 2023.
[19] 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.

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

reaches at least 40% of the Union's annual deployment needs[20]. In the last years, energy-intensive industries have been suffering from the impacts of the energy crisis: such initiatives will need access to net-zero technologies such as batteries, heat pumps, solar panels, and fuel cells to remain competitive in the future[21].

The necessity for this regulation has been further evidenced on two different occasions: in November 2022, selected stakeholders, including those from the battery industry, underlined the need to enhance the manufacturing capacity of net zero technologies. In February 2023, a specific survey was conducted to pinpoint battery and other industries' challenges. The results showed that the main concerns for relevant stakeholders are the following[22]:

- Long lead times for projects and ramping up production capacity;
- Non-equal competition with non-EU countries;
- Difficulties in finding deployment sites;
- Barriers related to public tenders;
- Difficulties in finding skilled workers;
- Insufficient production of key components and consequent dependency on what concerns the manufacturing capacity;
- High production costs.

Given the needs mentioned above, the Net Zero Industry Act identifies different objectives that must 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;

[20] 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.
[21] Ibidem.
[22] 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. 9.
Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52023PC0161

- 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 one[23]. Batteries play a crucial role in the European Union's strategic autonomy and are a fundamental part of this declaration. Given their position, they should benefit from even faster permitting procedures and support from additional crowd-in investments[24]. This regulation strongly encourages battery manufacturers to "consolidate their technology leadership"[25]. For battery technologies, European manufacturers are encouraged to produce 90% of European battery demand (which translates to reaching a European manufacturing capacity of 550 GWh by 2030)[26].

State aid should be considered to reach the Net Zero Industry Act goals better, and European Union funding programs, such as the Recovery and Resilience Facility, the InvestEU, and a European Sovereignty Fund, to provide a structural answer to the investments needed[27]. Another fundamental point is assessing the future skills required for the industries affected by the Net Zero Industry Act Regulation. Member States will, therefore, need to identify the necessary skills, develop education and training programmes, and financially support the industries, specifically focusing on SMEs[28].

For the practical next steps of the Net Zero Industry Act, three months after it enters into force, Member States shall designate one national competent authority to be responsible for facilitating and coordinating the projects[29]. The Net Zero Industry Act also establishes a time limit for the permit-granting process of putting into practice net-zero technology manufacturing projects, which is about 12 months for the construction of the projects with a yearly manufacturing capacity of less than 1GW and 18 months for the construction of net-

[23] Ivi, p. 19.
[24] Ivi, p. 20.
[25] Ivi, p. 22.
[26] Ibidem.
[27] Ibidem; and Ivi, p. 29.
[28] 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.
[29]Ivi , p. 2. art. 4, p. 38.

zero technology manufacturing projects with an annual manufacturing capacity of more than 1 GW[30]. The time limit for the permit-granting process can be extended in two special cases[31]:

- If the nature, complexity, location, or size of the proposed project requires an extension in time;
- If the proposed project raises exceptional risks for the health and safety of workers or the general population;

In both cases, the competent authority shall inform the project promoter of the reasons for the extension and the date when the comprehensive decision is expected in writing.

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[32].

### 1.1.1 Minerals and Processing

Minerals are fundamental for battery production: lithium, cobalt, nickel, manganese, and graphite are, in fact, crucial for the battery performance, longevity, and energy density[33]. 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 demand for these resources[34].

The Critical Raw Materials Act mentions in various points the importance that mineral mapping, geochemical campaigns and geoscientific datasets will have in the future. It establishes that Member States should make available the information during the exploration for these sources on their territory[35]. 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[36].

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

[30] Ivi, art. 6, pp. 39-40.
[31] Ibidem.
[32] Colthorpe A., *Net Zero Industry Act makes Europe competitive in battery value chain, trade groups said,* in www.energy-storage.news, 21 March 2023.
[33] IEA Site, *In the transition to clean energy, critical minerals bring new challenges to energy security,* in www.iea.org, accessed 26th June 2023.
[34] Ibidem.
[35] Ibidem.
[36] Ibidem.

- 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[37].

The CRM Act does delineate an approach of mapping the existing minerals in each territory, conducting geoscientific surveys, and processing the data gathered during explorations, including the development of predictive maps and also re-analysing already-existent geoscientific survey data to check for previously unidentified mineral occurrences that could be useful for a greener future[38].

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 existent 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[39].

### 1.1.2 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[40]. 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[41]. In this framework, ensuring a longer life cycle for batteries is fundamental[42].

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

[37] 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.
[38] Ivi, p. 33.
[39] 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
[40] European Parliament, *Circular economy: definition, importance and benefits,* in www.europarl.europa.eu, 24 May 2023.
[41] Repsol Site, *What is circular economy and why is it important,* in www.repsol.com, accessed July 27th, 2023.
[42] 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.

very important and revolutionary step to ensure the circularity of batteries[43]. 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.

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[44]). One of the main goals is a mandatory requirement for a minimum percentage of recycled content[45].

In June 2023, the proposal was finally adopted by the European Council, permanently replacing the battery directive of 2006[46]. This regulation covers the sustainability criteria mentioned above, reconfirming the necessity to recycle a minimum of the battery content.

The regulation sets[47]:

- A target for producers to collect waste of portable batteries, specifically:
  - 63% of waste by the end of 2027.
  - 73% of waste by the end of 2030.
- A target for lithium recovery from waste batteries of:
  - 50% by the end of 2027.
  - 80% by the end of 2031.
- Mandatory minimum levels of recycled content for industrial, SLI batteries and EV batteries, specifically:
  - 16% for cobalt.
  - 85% for lead.
  - 6% for lithium.
  - 6% for nickel.
- A recycling efficiency target for nickel-cadmium batteries of:
  - 80% by the end of 2025 for nickel-cadmium batteries.

[43] Ibidem.
[44] European Parliament, *Batteries: deal on new EU rules for design, production and waste treatment,* in www.europarl.europa.eu, 9 December 2022.
[45] 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.
[46] European Council Site, *Council adopts new regulation on batteries and waste batteries,* in www.consilium.europa.eu, 10 July 2023.
[47] Ibidem.

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

- 50% by the end of 2025 for other waste batteries.

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 battery 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[48]. This new tool will help to have more control and awareness of the batteries circulating within EU borders. This process will be facilitated by the visible QR code placed on storage systems, giving all the necessary information on the batteries' status[49]. In addition, the passport will also help check if the battery complies with the recycling requirements, for example, by assessing if the battery contains the minimum percentage required of recycled material, and it will also be essential to verify the environmental performance of the battery, by specifying fundamental aspects such as its carbon footprint.

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 carefully selecting materials for new battery chemistries and improving existing ones to facilitate their future recycling[50]. 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[51]. The document specifies that the Act should contain measures to increase the circularity and sustainability of the critical raw materials (including substances essential to produce batteries). Recycling measures are encouraged, as they are fundamental to achieving a circular economy in the context of the green transition[52].

[48] ALBATTS Deliverable D4.4, *Battery Manufacturing,* 2021, p. 23.
[49] CIC Energigune Site, *Battery Passport: the new regulation that determines the future of batteries in Europe,* in https://cicenergigune.com/en/blog/battery-passport-regulation-batteries-europe, 17 January 2023.
[50] 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.
[51] See above paragraph, 2.1: Critical Raw Materials Act.
[52] Ivi, p. 12, par. 42.

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

Similarly, **the Net Zero Industry Act** has among its main objectives of reaching a circular system[53]. In the Act, the evaluation of possible net-zero solutions must consider different factors that are fundamental to achieving circularity, such as among the most relevant[54]:

- 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;
- 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. The Critical Raw Materials Act specifically mentions the need to reskill the workforce, stating the need to: "ensure that the workforce is equipped with the skills needed to support the circularity of the critical raw materials value chain"[55]. Different job roles will arise in this context, such as battery engineer, data scientist, analyst, data engineer/architect, software engineer and software architect[56]. An up/reskilling process is also necessary to ensure the workers' safety, as handling batteries can lead to different hazard levels.

Lithium-ion batteries will receive more attention in the following years, as they can be used for small-scale and large-scale applications[57]. Even if considered one of the safest battery types, safety risks are still connected with handling them. Lithium-ion batteries have, in fact, a high voltage nature and can come with electrical hazards (short circuit, electrocution, electric shock and burning)[58], leading to the necessity to spread awareness among workers in the battery industry with the help of specific courses and training processes to avoid negative

[53] 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.
[54] Ivi, p. 24.
[55] 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. 39, art. 25.
[56] ALBATTS Workshop of the 27th of January 2023.
[57] Ellen MacArthur Foundation Site, *A circular economy for batteries to underpin renewable energy growth,* in www.ellenmacarthurfoundation.org, July 2021.
[58] Reneos Site, *Safety regulations and guidelines for lithium-ion batteries in different phases of their life cycle,* in www.reneos.eu, accessed July 18th, 2023.

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

consequences for their health. There have been recent incidents derived from the dangers that can arise from the use of batteries[59], which led to the assessment by international organisations such as the International Maritime Organization (IMO) on the implementation of additional measures for the transport of electric vehicles and on the precautions to be taken regarding batteries.

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

The desk research and data analysis of the ALBATTS project has regularly produced an update of the main Drivers of Change in the sector, encompassing both mobile battery applications and stationary and industrial applications[60]. Drivers of change are those factors which are key to transforming an industry and allow us to see the sector's evolution. A comparative analysis for this last desk research process (and a forward-looking perspective) is therefore of utmost importance to understand the future dynamics of the sector considering the recent regulatory evolution at the EU level.

The drivers of change identified during the first desk research process referred to:

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

  Here, the role of batteries was identified as crucial to follow the decarbonisation pathway. For this macro area, the following sub-categories have been identified:

  - Reducing CO2 emissions from battery manufacturing
  - Electrification and green energy
  - Widespread charging/refuelling infrastructure

- **Globalisation**

  According to this driver of change, the EU shall be prepared to get a competitive advantage, particularly within the following subcategories:

  - Access to raw materials

[59] The news regarding a recent incident related to the battery transportation can be viewed here: https://www.reuters.com/world/europe/one-dead-cargo-ship-fire-electric-car-suspected-source-dutch-coastguard-2023-07-26/

[60] 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

- Global regulatory dialogue
- Restructuring

- **New technologies**

  Investing in storage systems, like batteries, for mobile and stationary usage is essential to swiftly act and mitigate climate change and make renewable energy a reliable alternative source. The identified sub-categories were:

  - Cybersecurity
  - Global technical harmonisation and standardisation
  - Smart Grid

It is worth reminding that each driver of change was analysed according to three parameters:

- **Occurrence**: indicating whether a Driver of Change was cited in the analysed reports reviewed.
- **Importance,** using a ranking from 0 to 5 (0 = not possible to evaluate, 1= not important, five 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 make its consequence appear overwhelming.

When it comes to the occurrence of each driver of change, we can provide evidence that 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.

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

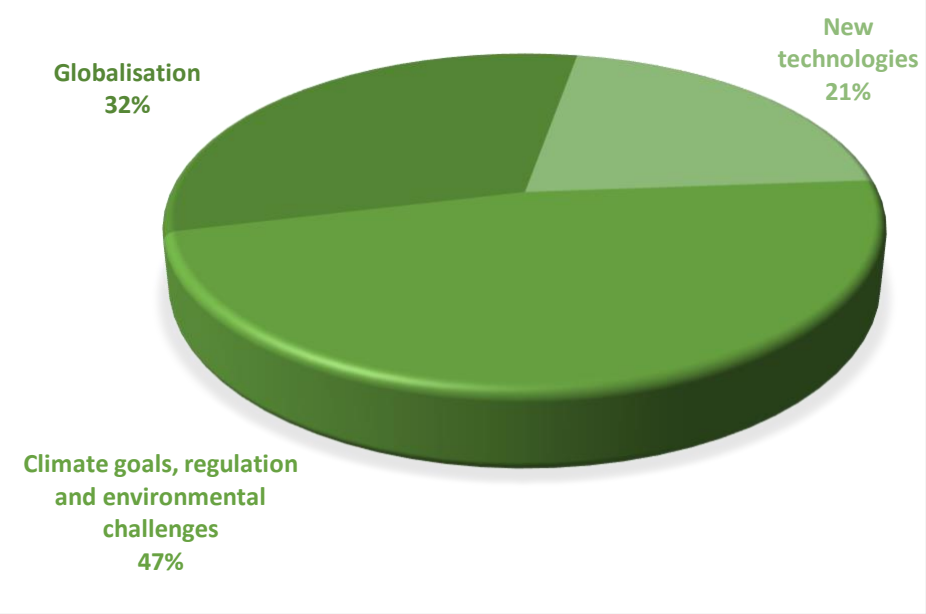


*Figure 2: DoC occurrence – desk research - final*

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[61]. 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)[62]. Release 2 already evidenced this trend[63]. Also, the subcategory "global regulatory dialogue" has increased in occurrence: even with a successful domestic investment strategy, the EU will remain reliant on imports for battery materials; thus, securing responsible and diversified imports is of utmost importance.

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

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

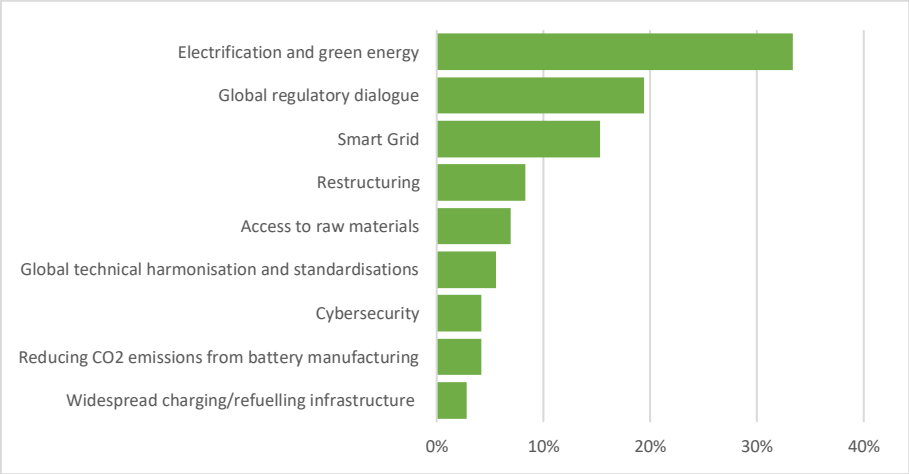


*Figure 3: Occurrence of each DoC according to desk research - Release 1*

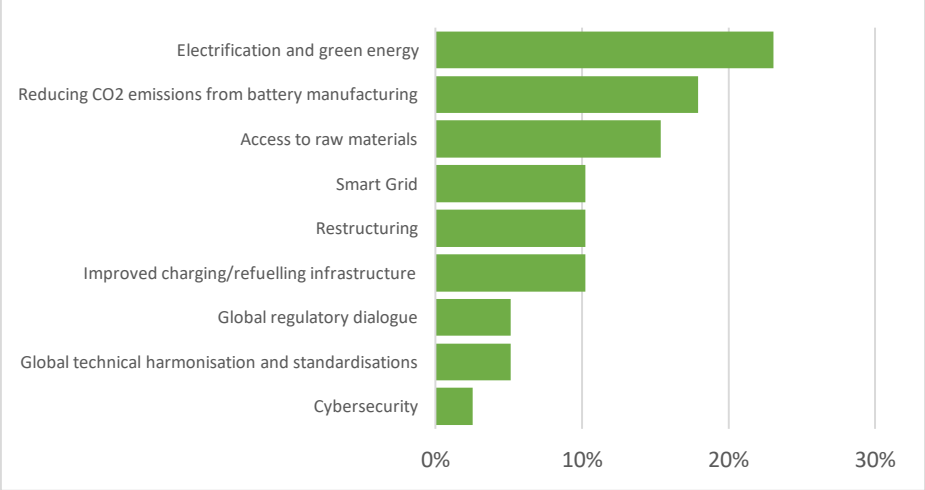


*Figure 4: Occurrence of each DoC according to desk research - Release 2*

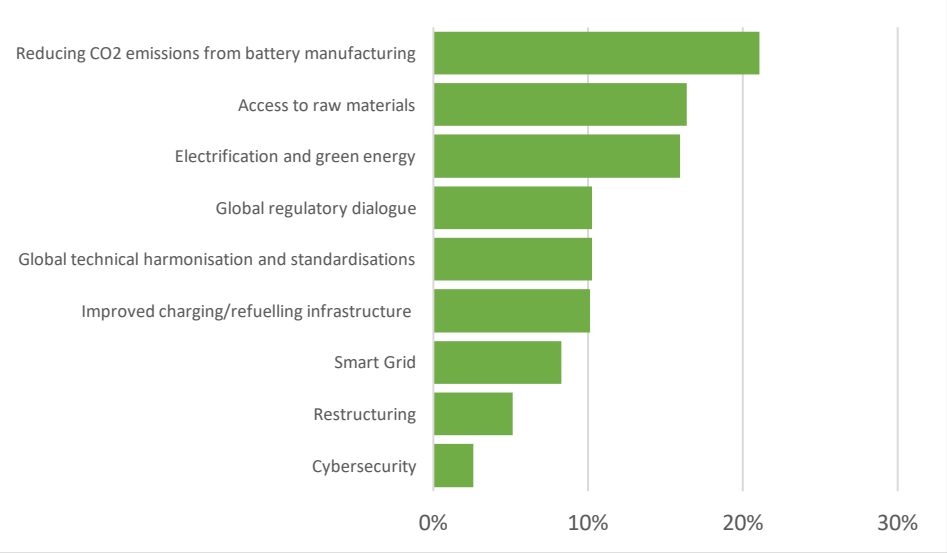


*Figure 5: Occurrence of each DoC according to desk research final*

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

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). As a way forward and guidance for future research and implementation strategies, the main 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 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[64] are key.
- **Resilience:** Achieving a resilient battery value chain considering the recent regulatory evolutions 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[65]. 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 great environmental benefits and huge 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 key.

[64] McKinsey & Company Site, *Battery 2030: Resilient, sustainable, and circular,* in www.mckinsey.com, 16 January 2023.
[65] 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

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

## 1.3 RELATED SKILLS AND JOB ROLES AT THE MACRO LEVEL

The battery manufacturing industry in Europe is growing rapidly, and there is a need for professionals with the right skills and competencies. The European battery sector requires a skilled workforce with a range of technical and vocational skills to ensure the efficient and sustainable production of batteries, from raw materials to recycling.

The sector also requires legislation, circularity, sustainability, and digitalisation knowledge to keep up with the new technologies and materials used in battery production. The skills needed include knowledge of high-volume production processes and techniques, the chemistry of future batteries and the purity of the materials required, skills to maintain automation systems, artificial intelligence and big data skills, electrical and mechanical skills, skills for first responders, electricians, and mechanics trained in electric vehicles and battery energy storage systems, new skills for recycling facility workers in the safe handling of lithium-ion batteries, knowledge of the supply of raw materials, knowledge of battery manufacturing equipment, and knowledge of battery recycling. The job roles needed include battery chemist, battery engineer, battery material scientist, battery pack assembler, battery production manager, battery quality control technician, battery recycling technician, battery research and development scientist, battery safety engineer, battery systems engineer, battery test engineer, battery thermal management engineer, environmental health and safety specialist, industrial engineer, logistics specialist, manufacturing engineer, process engineer, and supply chain specialist.

The sector also requires knowledge of the Battery Passport and the EU's Battery Regulation, circular economy principles, sustainable production practices, sustainable sourcing of raw materials, and battery recycling. Finally, the sector requires knowledge of automation systems, artificial intelligence, and big data skills to keep up with the new technologies and materials used in battery production.

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

# 2 Deep dive: mid- and downstream production

## 2.1 PRODUCTION EQUIPMENT AND THE RELATED SKILLS AND COMPETENCE NEEDS

In a production environment, various equipment and machinery are utilised to carry out manufacturing processes efficiently. The skill and competence needs associated with production equipment are diverse and crucial for achieving optimal productivity and quality outcomes. Operators must possess technical knowledge and proficiency in operating the specific equipment understanding its controls, settings, and safety features. They must exhibit attention to detail, ensuring precise alignment, measurement, or positioning of materials. Troubleshooting skills are vital to promptly identify and resolve operational issues or equipment malfunctions. Safety compliance is essential to maintain a secure working environment and prevent accidents. Effective communication and teamwork facilitate coordination among operators and other stakeholders, promoting smooth workflow. Maintenance skills are valuable to conduct routine upkeep and address minor repairs. A continuous improvement mindset encourages identifying opportunities for process optimisation and efficiency enhancement. Overall, the competencies and skills related to production equipment contribute to successful and effective manufacturing operations.[66]

### 2.1.1 Electrode manufacturing, including related skills and competencies[66]

Electrode manufacturing in Europe is a significant industry that supports various sectors, such as automotive, energy storage, electronics, and renewable energy. The production of electrodes involves fabricating both anode and cathode materials, which are crucial components in batteries, fuel cells, and other electrochemical devices. Here are some key points regarding electrode manufacturing in Europe:

[66] University of Porto Faculty of Engineering, Department of Chemical and Biological Engineering.

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

*Figure 6: Dürr Megtec offers a system for the coating of lithium-ion electrodes in batteries* [67]

1. Market Overview: Europe has a robust electrode manufacturing sector, with several countries actively involved in production. Germany, France, the United Kingdom, Italy, and Sweden are among the leading European countries in electrode manufacturing.
2. Battery Industry: The increasing demand for electric vehicles (EVs) and the growing energy storage sector have driven the expansion of electrode manufacturing in Europe. The region aims to establish a strong domestic battery industry to reduce import dependence and support the transition towards sustainable energy systems.
3. Research and Development: European countries emphasise research and development (R&D) efforts to improve electrode materials and manufacturing processes. Collaborative projects and initiatives receive funding from the European Union (EU) to accelerate innovation and enhance the competitiveness of the European battery industry.
4. Environmental Regulations: Europe has stringent environmental regulations that impact electrode manufacturing. Companies must comply with emissions, waste management, and hazardous materials regulations to ensure sustainable and environmentally friendly production processes.
5. Supply Chain: The electrode manufacturing supply chain in Europe involves the sourcing of raw materials such as graphite, lithium, cobalt, nickel, and other metals from both domestic and international sources. European companies also import precursors and intermediates for electrode production.

[67] Green Car Congress Site, Dürr and Techno Smart partner on manufacturing of lithium-ion batteries for e-cars, in www.greencarcongress.com, 2 October 2020.

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

6. Automation and Digitization: European electrode manufacturing increasingly adopts automation and digitisation technologies to improve efficiency and maintain high-quality standards. This includes automated production lines, robotics, machine learning, and data analytics for process optimisation.

#### *2.1.1.1 Mixing Equipment (e.g., Planetary Mixers, Ball Mills)*

In the context of electrode manufacturing, mixing equipment plays a crucial role in the preparation of electrode materials. Planetary mixers and ball mills are commonly used in the industry for various mixing and blending processes. Here's an overview of these mixing equipment types:

**Planetary Mixers**

Planetary mixers are versatile mixing systems that consist of a rotating, stationary container and agitator. They are widely used in the production of electrode pastes and slurries. The container rotates on its axis while the agitator moves around it, providing efficient mixing and uniform dispersion of ingredients. Planetary mixers are preferred for high-viscosity materials and can handle both small and large batch sizes.


*Figure 7: Planetary mixer by German mixing technology supplier Eirich.*[68]

**Ball Mills**

[68] Best Mag Site, *Excellent slurries and electrode dry mixes for lithium-ion battery manufacturing,* in https://www.bestmag.co.uk/excellent-slurries-and-electrode-dry-mixes-lithium-ion-battery-manufacturing/, 25 November 2021.

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

Ball mills are equipment used for grinding and mixing materials. They consist of a rotating drum filled with grinding media such as balls or beads. In electrode manufacturing, ball mills are often utilised for powder blending and refining processes. The grinding media within the mill impact and grind the materials, resulting in homogenisation and particle size reduction. Ball mills are suitable for both dry and wet grinding applications.

*Figure 8: MSE PRO 20L (4 x 5L) Vertical High Energy Planetary Ball Mill[69]*

**Advantages and Considerations**

Planetary mixers offer advantages such as precise control over mixing parameters, ease of scale-up, and the ability to handle high-viscosity materials. On the other hand, ball mills provide efficient particle size reduction and can be operated in both batch and continuous

[69]Mse Supply Sales Section, accessed 1 of September 2023.
Available at: https://www.msesupplies.com/collections/planetary-milling-equipment-planetary-ball-mills/products/20l-4-x-5l-vertical-high-energy-planetary-ball-mill-vpmc-20?variant=23100862627898

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

modes. Factors such as the desired final product characteristics, batch size, and process requirements influence the selection of mixing equipment.

**Skills and competencies[70]:**

- Technical Knowledge: Understand mixing machines' principles, operation, and maintenance. Familiarise yourself with the specific machine model you'll be working with and learn its functionalities, programming, and troubleshooting.
- Equipment Setup and Calibration: Ability to set up the dispensing and mixing machine correctly, ensuring proper calibration for accurate and precise dispensing of materials. Knowledge of calibrating sensors, nozzles, valves, and other components is essential.
- Materials Handling: Proficiency in handling different materials, such as adhesives, sealants, resins, or other substances used in the assembly process. This includes knowledge of material properties, storage requirements, and proper handling techniques to maintain quality and prevent contamination.
- Programming and Machine Operation: Competence in programming the dispensing and mixing machine to perform specific assembly tasks. Understand how to input parameters, adjust settings, and optimise the machine's performance for different product requirements.
- Quality Control: Attention to detail and a strong focus on quality control measures to ensure that the assembled cells meet the required specifications and standards. Implement quality checks at various stages of the assembly process and take corrective actions when necessary.
- Problem Solving and Troubleshooting: Ability to identify and resolve technical issues that may arise during the assembly process. Troubleshoot problems with the machine, materials, or assembly components and implement appropriate solutions promptly.
- Safety Awareness: Comply with safety protocols and regulations in the workplace. Understand potential hazards associated with the materials, machinery, and processes involved in cell assembly production. Take necessary precautions to prevent accidents and promote a safe working environment.

[70] Indeed Site Home Page, accessed 27 of July 2023.
Available at: https://pt.indeed.com/jobs?q=Ball%20Mills%20instrument%20engineer&l=

- Communication and Collaboration: Effective communication skills to interact with team members, supervisors, and other stakeholders involved in the assembly process. Collaborate with colleagues to streamline workflows, share knowledge, and address challenges collectively.
- Time Management: Efficiently manage your time to meet production targets and deadlines. Prioritise tasks, plan workflows, and optimise the use of the dispensing and mixing machine to maximise productivity.
- Continuous Learning: Stay updated with the latest advancements in dispensing and mixing technology and industry trends related to cell assembly production. Seek opportunities for professional development and expand your knowledge to enhance your skills over time.

#### *2.1.1.2 Coating equipment (e.g., slot dies, doctor blades, roll coaters)*[71]

Coating equipment plays a crucial role in electrode manufacturing by applying precise and uniform coatings onto electrode materials. Several European coating equipment manufacturers and suppliers include slot dies, doctor blades, and roll coaters. Here is some information about these types of coating equipment commonly used in electrode manufacturing:

**Slot Dies**

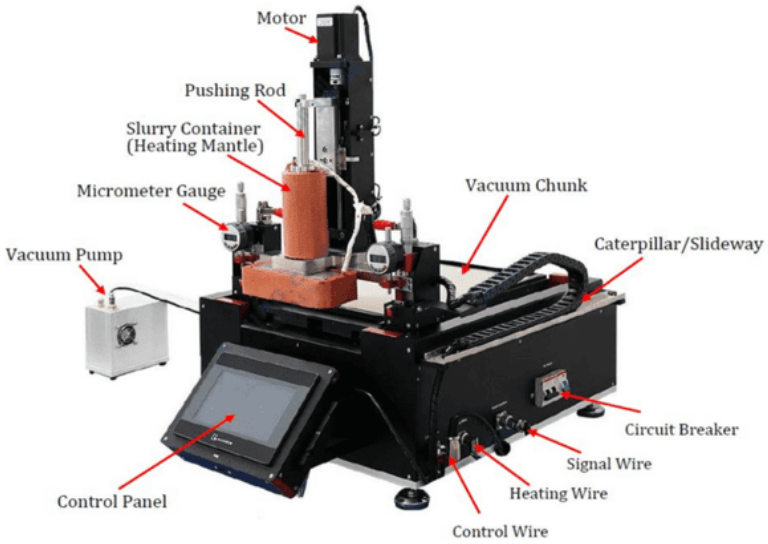


*Figure 9: Slot Die Sheet Coater w/ Vacuum Chuck (W200XL300 mm) and Optional Heating - MSK-AFA-PD200*[72]

[71] University of Porto Faculty of Engineering, Department of Chemical and Biological Engineering.
[72] MTI Corporation Site, *Slot Die Sheet Coater w/Vacuum Chuck (W200XL300 MM) and Optional Heating – MSK – AFA- PD200,* in https://www.mtixtl.com/MSK-AFA-PD200.aspx, accessed 1 of September 2021.

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

Slot dies are widely employed in the electrode manufacturing industry for precise and controlled coating applications. They consist of a narrow, flat channel called a "slot" through which the coating material flows onto the substrate. Slot dies offer advantages such as high coating uniformity, adjustable coating thickness, and minimal material wastage. In Europe, there are various companies specialising in slot die manufacturing and supply, including:

- RK Print Coat Instruments Ltd. (United Kingdom): They offer slot dies suitable for electrode coating applications, providing customised solutions and expertise in slot die design.
- TSE Troller AG (Switzerland): This company manufactures precision slot dies used in diverse coating processes, including electrode manufacturing. They offer customisable slot dies tailored to specific customer requirements.

**Doctor Blades**

*Figure 10: Doctor Blade Coating Machine for Battery Electrode Coating*[73]

[73] Alibaba Sales Section, accessed 27 of July 2023.
Available at: https://www.alibaba.com/product-detail/Doctor-Blade-Coating-Machine-for-Battery_1600130521882.html#

Doctor blades are used in conjunction with slot dies to control the thickness of the coating applied to the substrate. They remove excess coating material from the slot die's surface, ensuring a consistent coating thickness. In Europe, there are several manufacturers and suppliers of doctor blades catering to the electrode manufacturing industry, such as:

- Tresu Group (Denmark): Tresu provides doctor blades designed for precise coating applications. They offer doctor blades made from high-quality materials, ensuring long-lasting performance and accurate coating control.
- Swedev AB (Sweden): Swedev manufactures doctor blades for various coating applications, including electrode manufacturing. Their doctor blades are known for their durability, uniformity, and excellent edge quality.

**Roll Coaters:**

*Figure 11: Faster Roll to Roll Coating System (400mm Width) for Pilot Scale of Battery Electrode - MSK-AFA-E400-LD*[74]

Roll coaters are another type of coating equipment utilised in electrode manufacturing. They employ a set of rollers to apply a uniform coating layer onto the substrate. Roll coaters are

[74] MTI Corporation Site, *Faster Roll to Roll Coating System (400 mm Width for Pilot Scale for Battery Electrode - MSK – AFA – E400 – LD,* in https://www.mtixtl.com/MSK-AFA-E400-UL.aspx, accessed 1 September 2023.

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

suitable for high-volume production and can handle a wide range of coating materials. Some prominent roll coater manufacturers in Europe are:

- NDC Technologies (United Kingdom): NDC Technologies offers roll coaters designed for precise and consistent coating applications. Their roll coaters are known for their versatility, accuracy, and efficient coating control.
- Olbrich GmbH (Germany): Olbrich specialises in roll-to-roll coating systems, including roll coaters for electrode manufacturing. They provide customised solutions and advanced coating technologies to meet specific customer requirements.

**Skills and competencies[75]**

- Technical Knowledge: Possess a good understanding of roll coater operation, including controls, settings, and safety features, with the ability to operate and control the machine effectively.
- Coating Application Skills: Proficient in adjusting coating parameters such as thickness, speed, and pressure to achieve desired coating results on different substrates.
- Mechanical Aptitude: Demonstrate a basic understanding of mechanical systems and equipment, enabling the ability to perform routine maintenance tasks and troubleshoot minor operational issues.
- Attention to Detail: Exhibit a high level of accuracy and precision in roll coating operations, ensuring proper alignment, coating thickness, and quality of the coated substrates.
- Problem-solving skills: Apply logical reasoning and problem-solving techniques to identify and resolve operational issues or equipment malfunctions during roll coating.
- Hand-eye coordination: Possess good manual dexterity and hand-eye coordination to handle substrates, load them onto the roll coater, and make precise adjustments.
- Quality Consciousness: Have a keen eye for detail and a commitment to maintaining high-quality standards in the coated substrates, ensuring they meet customer specifications.

[75] Glass Door Site Homepage
Available at: https://www.glassdoor.com/Community/index.htm

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

- Safety Awareness: Follow safety protocols and guidelines, recognising potential hazards and taking appropriate precautions to prevent accidents or injuries during roll coating operations.
- Communication Skills: Clearly convey information, instructions, and observations verbally and in writing, facilitating effective communication within the team and with other stakeholders.
- Time Management: Effectively manage time and prioritise tasks to ensure efficient workflow and meet production targets.
- Record-Keeping Skills: Maintain accurate and organised records of production data, material usage, maintenance activities, and quality control checks.

#### *2.1.1.3 Drying equipment (e.g. ovens, vacuum dryers)*[76]

Drying equipment plays a crucial role in the electrode manufacturing process, ensuring the electrodes are dried efficiently and effectively. Several types of drying equipment are commonly used in Europe, including ovens and vacuum dryers. Here is some information about these drying equipment options for electrode manufacturing in Europe:

**Ovens**

Ovens are widely used in electrode manufacturing for drying processes. They provide a controlled environment with consistent heat distribution to remove moisture from the electrodes. Ovens used in electrode manufacturing are typically equipped with adjustable temperature settings and timers to optimise the drying process. Depending on the production requirements, they can be batch ovens or continuous ovens.

[76] University of Porto Faculty of Engineering, Department of Chemical and Biological Engineering.

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

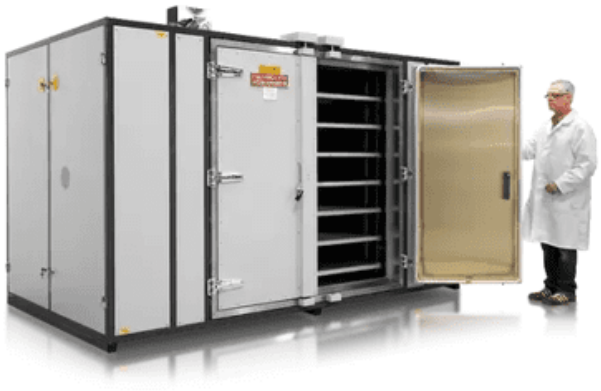

*Figure 12: Large general-purpose industrial oven - LGP*[77]

In Europe, various manufacturers and suppliers of industrial ovens cater to the specific needs of electrode manufacturing. Some well-known European manufacturers include:

- Carbolite Gero: Carbolite Gero offers a range of industrial ovens suitable for electrode drying, including batch ovens and continuous conveyor ovens.
- Memmert: Memmert manufactures precision drying ovens suitable for electrode drying and heat treatment.
- Nabertherm: Nabertherm provides industrial ovens and drying chambers designed for various applications, including electrode manufacturing.
- Binder: Binder offers a selection of drying ovens that can be tailored to meet the specific requirements of electrode drying.

**Vacuum Dryers**

Vacuum dryers are another common type of drying equipment used in European electrode manufacturing. Vacuum drying involves removing moisture from the electrodes at lower temperatures and under reduced pressure, which helps to prevent oxidation and preserve the electrode's properties. This method is particularly suitable for sensitive or delicate electrode materials.

[77] Carbolite Gero Site, *Large General Purpose Industrial Oven,* in https://www.carbolite-gero.com/products/ovens/industrial-ovens/lgp-large-general-purpose-ovens/, accessed 1 September 2023.

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


*Figure 13: Vacuum drying system.*[78]

European manufacturers and suppliers of vacuum dryers for electrode manufacturing include:

- CEE Engineering: CEE Engineering provides custom vacuum drying solutions tailored to the specific needs of electrode manufacturers, including vacuum dryers for lithium-ion battery electrodes.
- Italvacuum: Italvacuum specialises in producing vacuum dryers and vacuum pumps suitable for various industrial applications, including electrode drying.
- Vakuumix: Vakuumix offers a range of vacuum drying systems, including paddle dryers and vacuum tray dryers, suitable for electrode manufacturing and other industries.

When considering drying equipment for electrode manufacturing, evaluating factors such as drying capacity, temperature control, energy efficiency, and any specific requirements for the electrode materials being processed is essential.

**Skills and competencies**[79]

- Technical Knowledge: Possess a thorough understanding of vacuum drying principles, equipment operation, and related processes.

[78]Meier Prozesstechnik Site, *Vacuum Drying,* in https://www.meier-prozesstechnik.de/en/products/vacuum-drying/?gclid=Cj0KCQjw7aqkBhDPARIsAKGa0oI3hXm-BcrJTTqZ4impBNHVhkVaSj03__349NIu_l3s9zO9hc7O0hMaAn5tEALw_wcB, accessed 1 September 2023.
[79]Manatal Site Homepage, accessed 1 of September 2023.
Available at:
https://www.manatal.com/?utm_source=capterra&utm_medium=recruiting_agency&utm_campaign=GetApp)

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

- Mechanical Aptitude: Demonstrate proficiency in operating and troubleshooting mechanical systems, understanding the interactions between components, and performing basic maintenance tasks.
- Analytical Thinking: Apply logical reasoning and problem-solving skills to diagnose equipment malfunctions, identify root causes, and implement effective solutions.
- Attention to Detail: Exhibit high accuracy and precision in monitoring process parameters, recording data, and ensuring compliance with specifications.
- Time Management: Efficiently manage time and prioritise tasks to meet production schedules and deadlines.
- Adaptability: Adapt to changing priorities, production demands, or unexpected situations, demonstrating flexibility in work assignments and responsibilities.
- Safety Consciousness: Maintain a strong commitment to safety protocols, including personal protective equipment (PPE) usage, equipment lockout/tagout procedures, and hazard identification.
- Communication Skills: Clearly convey information, instructions, and observations verbally and in writing, fostering effective communication within the team and with other stakeholders.
- Troubleshooting Skills: Apply systematic approaches to problem-solving, utilise technical knowledge, and effectively utilise available resources to diagnose and resolve equipment or process issues.
- Documentation Skills: Ability to accurately record and maintain detailed logs, reports, and documentation related to equipment operation, maintenance, and quality control.

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

#### 2.1.1.4 Slitting equipment (e.g. slitters, rewinders)[80]

*Figure 14: Slitter for Battery Materials*[81]

Slitting equipment, such as slitters and rewinders, are essential in electrode manufacturing processes.

**Slitters**

Slitters are machines designed to slit large rolls of material into narrower widths. In electrode manufacturing, slitters are used to slit electrode materials, such as metal foils or coated substrates, into the desired widths for electrode production. These machines are typically equipped with razor blades or rotary knives to make precise cuts.

Some key features to consider for slitters for electrode manufacturing are:

- Width and diameter capacity: The slitter should be capable of handling the maximum width and diameter of the electrode material rolls you intend to process.
- Precision and accuracy: Offer high precision cutting to ensure consistent electrode dimensions.
- Speed and productivity: According to the desired production output, we choose a slitter with an appropriate speed rating to meet our requirements.
- Automation and control: Advanced slitting machines may offer automation features for improved efficiency and control over the slitting process.

[80] University of Porto Faculty of Engineering, Department of Chemical and Biological Engineering.
[81] Ultrasonic Cuttings Site, *Slitter for Battery Materials,* in http://ultrasonic-cuttings.com/14-slitter-for-battery-materials.html, accessed 1 September 2023.

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

- Safety features: The slitter has safety mechanisms to protect operators during operation.

**Rewinders**

Rewinders complement slitters by rewinding the slit electrode material into smaller rolls suitable for further processing or packaging. These machines are crucial for organising and managing the slit electrode material.

Key considerations for rewinding equipment include:

- Roll diameter and width capacity: The rewinder should accommodate the dimensions of the smaller rolls you require.
- Tension control: Precise tension control during rewinding helps maintain the integrity and quality of the electrode material.
- Core handling: The rewinder should support the appropriate core sizes to ensure compatibility with downstream processes.
- Automation and control: Advanced rewinding machines may offer automation features for efficient roll changeovers and material handling.

**Skills and competencies**

- Mechanical Aptitude: Possess a good understanding of mechanical systems and equipment, with the ability to operate, troubleshoot, and perform basic maintenance on rewinding machines.
- Attention to Detail: Exhibit a high level of accuracy and precision in rewinding operations, ensuring proper alignment, tension, and quality of the rewound materials.
- Problem-solving skills: Apply logical reasoning and problem-solving techniques to identify and resolve operational issues or equipment malfunctions during rewinding.
- Hand-eye coordination: Use good manual dexterity and hand-eye coordination to handle materials, load them onto the rewinding machine, and make precise adjustments.
- Quality Consciousness: Have a keen eye for detail and a commitment to maintaining high-quality standards in the rewound materials, ensuring they meet customer specifications.

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

- Safety Awareness: Follow safety protocols and guidelines, recognising potential hazards and taking appropriate precautions to prevent accidents or injuries during rewinding operations.
- Communication Skills: Clearly convey information, instructions, and observations verbally and in writing, facilitating effective communication within the team and with other stakeholders.
- Time Management: Effectively manage time and prioritise tasks to ensure efficient workflow and meet production targets.
- Record-Keeping Skills: Maintain accurate and organised records of production data, material usage, maintenance activities, and quality control checks.
- Adaptability: Adapt to changing production requirements, work demands, or unexpected situations, demonstrating flexibility and the ability to adjust to new challenges

#### *2.1.1.5 Electrode stacking equipment (e.g. stacking machines)*[82]

Battery electrode stacking equipment is an essential part of the electrode manufacturing process for lithium-ion batteries. It involves the precise stacking and alignment of multiple layers of anode and cathode materials along with separators to create the electrode structure. The electrode stacking process plays a critical role in determining the performance and quality of the battery.

[82] University of Porto Faculty of Engineering, Department of Chemical and Biological Engineering.

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

*Figure 15: Automatic Layer by Layer Stacking Machine for Pouch Cell up to 200 Lx150W (mm) - MSK-111A-E*[83]

Several European companies specialise in producing and supplying battery electrode stacking equipment. These companies offer various types of equipment designed to meet the specific needs of battery manufacturers. Some well-known European manufacturers of battery electrode stacking equipment include:

- Manz AG: Manz AG, headquartered in Germany, is a leading global manufacturing equipment provider for various industries, including energy storage. They offer a range of equipment for lithium-ion battery production, including electrode stacking machines.
- Targray: Targray, based in Canada with operations in Europe, supplies advanced materials and equipment for the battery industry. They provide electrode stacking equipment that enables precise and automated stacking of battery electrodes.
- Wirtz Manufacturing: Wirtz Manufacturing, located in Belgium, specialises in providing equipment for battery manufacturing processes. They offer electrode stacking machines designed to handle various battery sizes and electrode types.

[83] MTI Corporation Site, *Automatic Layer by Layer Stacking Machine for Pouch Cell up to 200Lx150W(mm) – MSK – 111A- E ,* in https://www.mtixtl.com/PreciseSemi-AutoStackingMachineforPouchCellElectrode-MSK-111A-E.aspx, accessed 1 September 2023.

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

- Bühler Group: Bühler Group, headquartered in Switzerland, is a global technology company that provides solutions for various industries, including battery manufacturing. They offer equipment for producing lithium-ion battery electrodes, including stacking systems.
- KROENERT GmbH & Co KG: KROENERT, based in Germany, is a renowned coating and laminating equipment manufacturer. They provide customised solutions for battery electrode manufacturing, including stacking equipment for high-precision electrode stacking.

**Skills and competencies**[84]

- Equipment Operation: Possess a good understanding of stacking machine operation, including controls, settings, and safety features, with the ability to operate and control the machine effectively.
- Mechanical Aptitude: Demonstrate a basic understanding of mechanical systems and equipment, enabling the ability to perform routine maintenance tasks and troubleshoot minor operational issues.
- Attention to Detail: Exhibit a high level of accuracy and precision in stacking operations, ensuring proper alignment, stacking height, and adherence to quality standards.
- Problem-solving skills: Apply logical reasoning and problem-solving techniques to identify and resolve operational issues or equipment malfunctions during stacking.
- Hand-eye coordination: Use good manual dexterity and hand-eye coordination to handle materials, load them onto the stacking machine, and make precise adjustments.
- Quality Consciousness: Have a keen eye for detail and a commitment to maintaining high-quality standards in the stacked materials or products, ensuring they meet customer specifications.

[84] LinkedIn Home Page, accessed 1 of September 2023.
Available at: https://www.linkedin.com/feed/

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

- Safety Awareness: Follow safety protocols and guidelines, recognising potential hazards and taking appropriate precautions to prevent accidents or injuries during stacking operations.
- Communication Skills: Clearly convey information, instructions, and observations verbally and in writing, facilitating effective communication within the team and with other stakeholders.
- Time Management: Effectively manage time and prioritise tasks to ensure efficient workflow and meet production targets.
- Record-Keeping Skills: Maintain accurate and organised records of production data, material usage, maintenance activities, and quality control checks.

### 2.1.2 Cell assembly, including related skills, competencies, and job roles[85]

Cell assembly is a major European industry that assists numerous sectors, including electronics, automotive, energy storage, and renewable energy. Fabrication of anode and cathode materials, which are essential elements in electrochemical devices, batteries, and fuel cells, is required to produce electrodes. The following are some crucial considerations about cell assembly in Europe. Market Growth: The cell assembly market in Europe has been experiencing significant growth due to increasing demand from various industries, including automotive, electronics, and healthcare.

1. Automotive Industry: Cell assembly is a critical step in manufacturing batteries for electric vehicles (EVs), and Europe has a significant presence in the automotive industry. The expanding use of EVs in Europe drives the demand for cell assembly technologies.
2. Electronics Sector: Cell assembly is crucial to manufacturing batteries for electronic devices like smartphones, tablets, and wearables, and Europe has a strong electronics manufacturing sector. The market for cell assembly is expanding due to the rising demand for these devices.
3. Healthcare Applications: Manufacturing batteries for medical equipment like pacemakers, implantable defibrillators, and insulin pumps depends heavily on cell assembly. The need for such devices is being driven by the growing elderly population

[85] University of Porto Faculty of Engineering, Department of Chemical and Biological Engineering.

and developments in medical technology, which is boosting the cell assembly market in Europe.

4. Research and Development: European nations fund research and development to improve cell assembly technology. Batteries' performance, energy density, safety, and sustainability are improving.
5. Gigafactories: Several significant battery industry firms and automakers have established or intend to create gigafactories in Europe. These massive production facilities handle every step of the battery-making process, including cell assembly.
6. Supply Chain Integration: Europe is working to create a self-sufficient battery supply chain to decrease its reliance on imports. A whole value chain from raw material extraction to cell assembly is ensured by efforts to guarantee a sustainable and localised raw material supply.
7. Recycling and Circular Economy: The circular economy and battery recycling are given much attention in Europe. As cell construction techniques advance, batteries will become simpler to disassemble and recycle, reducing their negative environmental effects and fostering sustainability.

*Figure 16: Battery production at BMW's BBA battery centre in China*[86]

[86] Automotive Manufacturing Solutions, *German carmakers race to secure European battery cell production,* in https://www.automotivemanufacturingsolutions.com/ev-battery-production/german-carmakers-race-to-secure-european-battery-cell-production/41586.article, 15 February 2021.

### 2.1.2.1 Cell stacking equipment

Cell stacking equipment refers to machinery or devices designed to automate the process of stacking individual cells or batteries in an organised and efficient manner. These machines are commonly used in the manufacturing and assembly of battery packs, such as those used in electric vehicles, portable electronics, and energy storage systems.

*Figure 17: Pouch cell stacking Machine* [87]

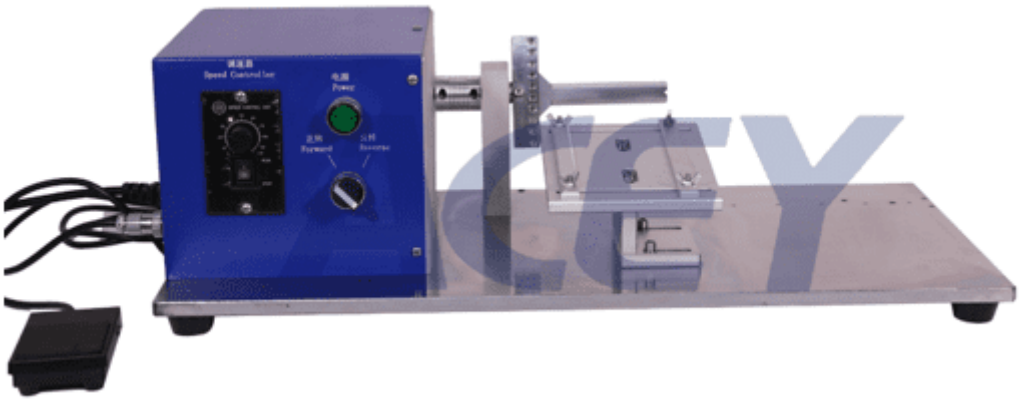

*Figure 18: Semi-Automatic Pouch Battery Electrode Winding Machine Manufacturers*[88]

[87] Battery Making Site, *Products,* in https://www.batterymaking.com/product/pouch-cell-stacker-stacking-machine_p637.html, accessed 1 September 2023.
[88] X Macey Site, *PRODUCTS,* in https://www.xmacey.com/semi-automatic-pouch-battery-electrode-winding-machine_p185.html, accessed 1 September 2023.

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

**Skills and competencies**[89]

- Technical Knowledge: Understand the principles, operation, and maintenance of cell stacking machines specifically used for battery cell assembly. Familiarise yourself with the specific machine model you'll be working with and learn its functionalities, programming, and troubleshooting.
- Equipment Setup and Calibration: Ability to set up the cell stacking machine correctly, ensuring proper calibration for accurate and precise cell stacking. Knowledge of adjusting parameters such as pressure, alignment, and positioning is crucial to achieve desired stacking results.
- Material Handling: Proficiency in handling battery cell components, such as electrodes, separators, and current collectors. Understand the properties of different cell components, their dimensions, and proper handling techniques to ensure the quality and integrity of the stacked cells.
- Stacking Techniques: Competence in different stacking techniques, such as manual stacking or automated stacking, depending on the machine and application. Understand each technique's principles, advantages, and limitations and select the appropriate one for the specific battery cell assembly requirements.
- Quality Control: Attention to detail and a strong focus on quality control measures to ensure that the stacked cells meet the required specifications and standards. Implement quality checks at various stages of the stacking process and take corrective actions when necessary.
- Troubleshooting: Ability to identify and resolve technical issues that may arise during the stacking process. Troubleshoot problems with the machine, stacking parameters, or cell components and implement appropriate solutions promptly.
- Safety Awareness: Comply with safety protocols and regulations in the workplace. Understand potential hazards associated with cell stacking machines, stacking processes, and materials involved in battery cell assembly. Take necessary precautions to prevent accidents and promote a safe working environment.

[89]LinkediìIn Site Job Search Section, accessed 1 of September 2023.
Available at:
https://www.linkedin.com/jobs/search/?currentJobId=3598746374&keywords=Cell%20stacking%20equipment

- Communication and Collaboration: Effective communication skills to interact with team members, supervisors, and other stakeholders involved in the assembly process. Collaborate with colleagues to streamline workflows, share knowledge, and address challenges collectively.
- Time Management: Efficiently manage your time to meet production targets and deadlines. Prioritise tasks, plan workflows, and optimise the use of the cell stacking machine to maximise productivity.
- Continuous Learning: Stay updated with the latest advancements in cell stacking technology and industry trends related to battery cell assembly. Seek opportunities for professional development and expand your knowledge to enhance your skills over time.

#### *2.1.2.2 Tab welding equipment (ultrasonic welders, laser welders)*

**Ultrasonic welders**

Ultrasonic welders are widely used throughout the battery cell assembly process, particularly when working with lithium-ion batteries for use in electric vehicles (EVs) and other forms of equipment. These ultrasonic welding tools were developed to provide a reliable and efficient method of joining battery cell components.


*Figure 19:Ultrasonic-welding systems USP[90]*

[90] Telsonic Ultrasonic Site, *Ultrasonic- weldingsystems USP,* in https://www.telsonic.com/en/products/ultrasonicweldingsystems-usp/, accessed 1 September 2023.

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

Several companies in Europe provide ultrasonic welders and related equipment.

- Herrmann Ultraschall: Herrmann Ultraschall, based in Germany, is a leading global supplier of ultrasonic welding technology. They offer a wide range of ultrasonic welding machines and systems for various industries, including automotive, electronics, packaging, and medical.
- TELSONIC: TELSONIC is a Swiss company specialising in ultrasonic technology. They provide ultrasonic welding machines and components for applications such as plastic welding, metal welding, and cutting. TELSONIC serves industries like automotive, packaging, textiles, and electronics.
- Weber Ultrasonics: Weber Ultrasonics, headquartered in Germany, manufactures ultrasonic welding and cleaning equipment. They offer ultrasonic welding machines, converters, sonotrodes, and accessories for automotive, electrical engineering, and medical technology industries.
- Rinco Ultrasonics: Rinco Ultrasonics, based in Switzerland, is known for its ultrasonic welding equipment. They provide ultrasonic welding machines and generators for plastic welding, cutting, and sealing applications. Rinco serves industries including automotive, packaging, and textiles.
- Sonotronic: Sonotronic, located in Germany, provides ultrasonic welding systems and solutions. They offer ultrasonic welding machines, components, and customised systems for various industries, including automotive, packaging, and electrical appliances.

**Laser welders**

Laser welding is another type of welding technology utilised in cell assembly for battery production. Using a high-energy laser beam to generate localised heat that melts and fuses materials is known as laser welding. Laser welders are frequently employed in battery cell construction to combine various parts, such as battery tabs, terminals, and busbars. Here is a summary of how laser welders are used in battery cell assembly.

Various European businesses offer laser welding methods for cell assembly in the production of batteries. Here are a few well-known businesses in Europe with a reputation for being experts in laser welding for battery cell assembly.

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

- TRUMPF: TRUMPF, based in Germany, is a global leader in laser technology. They offer laser welding systems suitable for battery cell assembly, including their TruLaser Cell series. TRUMPF's laser welding solutions provide high precision and efficiency for joining battery components.
- ROFIN-SINAR Laser GmbH: ROFIN-SINAR Laser, headquartered in Germany, specialises in laser technology and offers a range of laser welding systems. They provide laser welding solutions for battery cell assembly applications, ensuring precise and reliable welds.
- LPKF Laser & Electronics AG: LPKF, based in Germany, provides laser welding and laser processing solutions. They offer laser welding systems suitable for battery cell assembly, ensuring high-quality welds with excellent precision.
- Amada Weld Tech: With operations in various European countries, Amada Weld Tech offers laser welding systems for battery cell assembly. Their laser welding solutions are designed to provide high-speed, precise, and reliable welding for battery components.
- Precitec GmbH & Co. KG: Precitec, based in Germany, specialises in laser material processing solutions. They offer laser welding systems suitable for battery cell assembly, providing advanced welding capabilities with high productivity and precision.

*Figure 20: 280A Big LifePO battery cells welding*[91]

[91]Laser Wobble Welding Site, *Battery Welding,* in https://www.laserwobblewelding.com/photonweld-laser-welding-applications/laser-welding-in-battery-production-and-in-battery-pack-assembly, accessed 1 September 2023.

**Skills and competencies**[92]

- Technical Knowledge: Understand the principles, operation, and maintenance of tab welding machines specifically used for cell assembly. Familiarise yourself with the specific machine model you'll be working with and learn its functionalities, programming, and troubleshooting.
- Equipment Setup and Calibration: Ability to set up the tab welding machine correctly, ensuring proper calibration for consistent and reliable tab welding. Knowledge of adjusting parameters such as current, time, pressure, and electrode alignment is crucial to achieve the desired weld quality.
- Material Handling: Proficiency in handling tab materials, such as metal foils or strips, used in cell assembly. Understand the properties of different tab materials, their dimensions, and proper handling techniques to ensure the quality and integrity of the welds.
- Welding Techniques: Competence in different tab welding techniques, such as resistance welding or laser welding, depending on the machine and application. Understand each technique's principles, advantages, and limitations and select the appropriate one for the specific cell assembly requirements.
- Quality Control: Attention to detail and a strong focus on quality control measures to ensure that the tab welds meet the required specifications and standards. Implement quality checks at various stages of the welding process and take corrective actions when necessary.
- Troubleshooting: Ability to identify and resolve technical issues that may arise during the welding process. Troubleshoot problems with the machine, welding parameters, or tab materials and implement appropriate solutions promptly.
- Safety Awareness: Comply with safety protocols and regulations in the workplace. Understand potential hazards associated with tab welding machines, welding processes, and materials involved in cell assembly. Take necessary precautions to prevent accidents and promote a safe working environment.

[92] Indeed Site Job Offers Section, accessed 1 of September 2023.
Available at: https://www.indeed.com/q-laser-welding-jobs.html?vjk=63e65f5a08ba91ab

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

- Communication and Collaboration: Effective communication skills to interact with team members, supervisors, and other stakeholders involved in the assembly process. Collaborate with colleagues to streamline workflows, share knowledge, and address challenges collectively.
- Time Management: Efficiently manage your time to meet production targets and deadlines. Prioritise tasks, plan workflows, and optimise the use of the tab welding machine to maximise productivity.
- Continuous Learning: Stay updated with the latest advancements in tab welding technology and industry trends related to cell assembly. Seek opportunities for professional development and expand knowledge to enhance your skills over time.

#### *2.1.2.3 Winding Machines*

Winding machines are crucial in the cell assembly process for battery technology, specifically to make battery cells, such as lithium-ion batteries. These devices are made to precisely wind and assemble the electrode components, separators, and current collectors into a streamlined cell arrangement. Here is a summary of winding machines used to manufacture battery cells.

*Figure 21: Automatic Winder for The Assembling of Multi Cylindrical Cell at 10 PPM Speed for 200 Cell/Batch*[93]

[93] MTI Corporation Site, *Automatic Winder for the Assembling of Multi Cylindrical Cell at 10 PPM Speed for 200 Cell/Batch – MSK-112A-SA,* in https://www.mtixtl.com/MSK-112A-SA.aspx, accessed 1 September 2023.

Numerous European companies provide winding machines for cell assembly in battery technology.

- Manz AG: Based in Germany, Manz is a global high-tech equipment manufacturer specialising in battery production systems. They offer winding machines and complete production lines for lithium-ion battery manufacturing. Manz provides customised solutions tailored to specific battery cell designs and requirements.
- ITECH Automation GmbH: ITECH Automation, headquartered in Germany, specialises in automation solutions for various industries, including battery production. They offer winding machines for battery cell assembly, ensuring precise winding of electrode materials and separators.
- F & K Delvotec Bondtechnik GmbH: F & K Delvotec, based in Germany, manufactures advanced bonding and assembly equipment. They provide winding machines specifically designed for battery cell assembly, ensuring accurate winding and alignment of electrode materials.
- CeraCon GmbH: CeraCon, located in Germany, offers a range of equipment and automation solutions for battery production, including winding machines. Their winding machines are designed to meet the requirements of different battery cell formats and deliver high precision in the winding process.
- Cerafiltec AG: Cerafiltec, headquartered in Switzerland, specialises in developing and producing advanced ceramic filtration systems. They also offer winding machines for battery cell assembly, ensuring precise winding and layering of electrode materials and separators.

**Skills and competencies[94]**

- Technical Knowledge: Possess a good understanding of winding machine operation, including controls, settings, and safety features, with the ability to operate and control the machine effectively.

[94] Glass Door Site Job Offers Section, accessed 1 of September 2023.
Available at: https://www.glassdoor.com/Job/coil-winding-machine-operator-jobs-SRCH_KO0,29.htm

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

- Mechanical Aptitude: Demonstrate a basic understanding of mechanical systems and equipment, enabling the ability to perform routine maintenance tasks and troubleshoot minor operational issues.
- Attention to Detail: Exhibit a high level of accuracy and precision in winding operations, ensuring proper alignment, tension, and quality of the wound materials.
- Hand-eye coordination: Use good manual dexterity and hand-eye coordination to handle materials, load them onto the winding machine, and make precise adjustments.
- Problem-solving skills: Apply logical reasoning and problem-solving techniques to identify and resolve operational issues or equipment malfunctions during winding.
- Quality Consciousness: Have a keen eye for detail and a commitment to maintaining high-quality standards in the wound materials, ensuring they meet customer specifications.
- Safety Awareness: Follow safety protocols and guidelines, recognising potential hazards and taking appropriate precautions to prevent accidents or injuries during winding operations.
- Communication Skills: Clearly convey information, instructions, and observations verbally and in writing, facilitating effective communication within the team and with other stakeholders.
- Time Management: Effectively manage time and prioritise tasks to ensure efficient workflow and meet production targets.
- Record-Keeping Skills: Maintain accurate and organised records of production data, material usage, maintenance activities, and quality control checks.

#### *2.1.2.4 Electrolyte Filling equipment (vacuum filling machines, injection filling machines)*

**Vacuum filling machines**

Electrolyte vacuum filling machines are specialised machinery used during the battery production process, specifically for adding electrolyte to battery cells. A crucial part of batteries is the electrolyte, which supplies the ionic conductivity required for the electrochemical reactions inside the cells. Electrolyte vacuum filling equipment ensures precise and effective electrolyte solution filling of the battery cells.

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

*Figure 22: Automatic Vacuum Cylindrical Cell Electrolyte Filling Machine* [95]

Various European companies provide Vacuum filling machines:

1. Manz AG: Manz, based in Germany, is a global high-tech equipment manufacturer offering various battery production solutions. They provide electrolyte vacuum filling machines in their comprehensive battery manufacturing equipment portfolio.
2. Targray: Targray, headquartered in Canada with a presence in Europe, is a leading supplier of materials and equipment for the battery industry. They offer electrolyte filling systems, including vacuum filling machines, for various battery technologies.
3. Wirtz Manufacturing: Wirtz Manufacturing, based in Germany, specialises in equipment and machinery for battery manufacturing. They provide vacuum-filling machines designed specifically for electrolyte filling in battery production processes.
4. Ecoprogetti Srl: Ecoprogetti, based in Italy, provides photovoltaic and battery production equipment. They offer electrolyte filling systems, including vacuum filling machines, for different battery types, such as lithium-ion batteries.

[95] Cam Energy Site, *Automatic Vacuum Cylindrical cell Electrolyte Filling Machine,* in https://cam-energy.com/product/automatic-vacuum-cylindrical-cell-electrolyte-filling-machine/, accessed 1 September 2023.

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

5. Sovema Group: Sovema Group, headquartered in Italy, supplies equipment and technologies for the battery industry. They offer electrolyte-filling solutions, including vacuum-filling machines, as part of their battery manufacturing equipment portfolio

**Injection filling machines** [96]

Electrolyte injection filling machines are used in battery cell assembly to fill the battery cells correctly and effectively with the electrolyte solution. These devices guarantee exact control over the electrolyte's amount and distribution, ensuring the battery cells' best performance and security. An overview of electrolyte injection filling equipment for cell assembly is provided below:

*Figure 23: Compact Vacuum Electrolyte Injection System for Pouch and Cylinder Cells - MSK-113-CP*[97]

The following European-based companies provide Electrolyte injection filling machines:

- Manz AG: Manz, based in Germany, is a global high-tech equipment manufacturer offering various battery production solutions. They provide electrolyte injection filling machines in their comprehensive battery manufacturing equipment portfolio.
- Targray: Targray, headquartered in Canada with a presence in Europe, is a leading supplier of materials and equipment for the battery industry. They offer electrolyte

[96]Monster Site Job Offers Section, accessed 1 of September 2023.
Available at: https://www.monster.com/job-openings/injection-mold-machine-operator-3rd-shift-leominster-ma--9ef7f88f-160a-4dda-b0e6-dc822e9ae744?mstr_dist=true

[97] MTI Corporation Site, *Compact Vacuum Electrolyte Injection System for Pouch and Cylinder Cells – MSK- 113-CP,* in https://www.mtixtl.com/msk-113-cp.aspx, accessed 1 September 2023.

injection filling systems for various battery technologies, including automated filling machines.

- Ecoprogetti Srl: Ecoprogetti, based in Italy, provides photovoltaic and battery production equipment. They offer electrolyte injection filling machines designed specifically for battery cell assembly, ensuring precise and efficient electrolyte filling.
- Sovema Group: Sovema Group, headquartered in Italy, supplies equipment and technologies for the battery industry. They provide electrolyte injection filling solutions, including automated filling machines, as part of their battery manufacturing equipment portfolio.
- Wirtz Manufacturing: Wirtz Manufacturing, based in Germany, specialises in equipment and machinery for battery manufacturing. They offer electrolyte injection filling machines designed for various battery cell formats, ensuring accurate and controlled electrolyte filling.

**Skills and competences**

- Technical Knowledge: Understand electrolyte filling systems' principles, operation, and maintenance specifically used for battery cell assembly. Familiarise yourself with the specific system model you'll work with and learn its functionalities, programming, and troubleshooting.
- Equipment Setup and Calibration: Ability to correctly set up the electrolyte filling system, ensuring proper calibration for accurate and precise electrolyte filling. Knowledge of adjusting parameters such as flow rate, pressure, and volume is crucial to achieve desired filling results.
- Material Handling: Proficiency in handling electrolyte solutions and other materials involved in the filling process. Understand the properties of different electrolyte solutions, their storage requirements, and proper handling techniques to ensure quality and prevent contamination.
- Quality Control: Attention to detail and a strong focus on quality control measures to ensure that the electrolyte-filled battery cells meet the required specifications and standards. Implement quality checks at various stages of the filling process and take corrective actions when necessary.

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

- Programming and System Operation: Competence in programming the electrolyte filling system to perform specific filling tasks. Understand how to input parameters, adjust settings, and optimise the system's performance for different battery cell configurations and specifications.
- Safety Awareness: Comply with safety protocols and regulations in the workplace. Understand potential hazards associated with electrolyte solutions, equipment, and processes involved in battery cell assembly. Take necessary precautions to prevent accidents and promote a safe working environment.
- Troubleshooting: Ability to identify and resolve technical issues that may arise during the filling process. Troubleshoot problems with the system, filling parameters, or electrolyte solutions, and implement appropriate solutions promptly.
- Communication and Collaboration: Effective communication skills to interact with team members, supervisors, and other stakeholders involved in the assembly process. Collaborate with colleagues to streamline workflows, share knowledge, and address challenges collectively.
- Time Management: Efficiently manage your time to meet production targets and deadlines. Prioritise tasks, plan workflows, and optimise the use of the electrolyte filling system to maximise productivity.
- Continuous Learning: Stay updated with the latest advancements in electrolyte filling technology and industry trends related to battery cell assembly. Seek opportunities for professional development and expand your knowledge to enhance your skills over time.

#### *2.1.2.5 Sealing Equipment (Heat sealer, Crimping Machines)*

**Heat sealers**

To maintain a hermetic and secure enclosure, a heat sealer for battery cell assembly is a specialised piece of machinery used to manufacture batteries. Heat sealing is a widely utilised technique in the battery production industry to provide a trustworthy and leak-proof seal for battery cells. A summary of heat sealers for battery cell assembly is shown below:

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

*Figure 24: VEVOR Continuous Band Sealer, 0.24-0.6 in/6-15 mm Seal Width, FR900 220V/50Hz Horizontal Sealing Machine, Band Heat Sealer with Digital Temperature Control for PVC Membrane Bag Film*[98]

The following European companies are the key providers of heat sealer equipment.

- Manz AG: Manz, based in Germany, is a global high-tech equipment manufacturer offering a range of battery production solutions. They provide heat sealers as part of their comprehensive battery manufacturing equipment portfolio.
- Targray: Targray, headquartered in Canada with a presence in Europe, is a leading supplier of materials and equipment for the battery industry. They offer heat-sealing machines designed for battery cell assembly, ensuring secure and reliable seals.
- Bielomatik Leuze GmbH + Co. KG: Bielomatik, based in Germany, manufactures special-purpose machinery and systems. They provide heat-sealing solutions for battery cell assembly, offering equipment that meets the specific requirements of the battery industry.
- Crest Technology GmbH: Crest Technology, located in Germany, specialises in designing and producing battery manufacturing equipment. They offer heat-sealing

[98] Vevor Site, *Sealing Machine Sale*, accessed 1 of September 2023.
Available at: https://eur.vevor.com/sealing-machine-c_10462/vevor-continuous-band-sealer-fr900-auto-horizontal-sealing-machine-220v-for-bag-p_010226389223?adp=gmc&utm_source=g

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

machines tailored for battery cell assembly, ensuring efficient and consistent sealing processes.

- Assurich Industries Pte Ltd: Assurich, headquartered in Singapore with a presence in Europe, supplies industrial equipment and machinery. They provide heat-sealing machines suitable for battery cell assembly, offering solutions for different battery cell formats.

**Skills and competencies**[99]

- Technical Knowledge: Possess a good understanding of heat-sealing equipment operation, including controls, settings, and safety features, with the ability to operate and control the machine effectively.
- Mechanical Aptitude: Demonstrate a basic understanding of mechanical systems and equipment, enabling the ability to perform routine maintenance tasks and troubleshoot minor operational issues.
- Attention to Detail: Exhibit a high level of accuracy and precision in heat sealing operations, ensuring proper alignment, pressure, and temperature for effective and consistent seals.
- Problem-solving skills: Apply logical reasoning and problem-solving techniques to identify and resolve operational issues or equipment malfunctions during heat sealing.
- Hand-eye coordination: Possess good manual dexterity and hand-eye coordination to handle materials, load them onto the heat sealer, and make precise adjustments.
- Quality Consciousness: Have a keen eye for detail and a commitment to maintaining high-quality standards in the sealed materials, ensuring they meet customer specifications.
- Safety Awareness: Follow safety protocols and guidelines, recognising potential hazards and taking appropriate precautions to prevent accidents or injuries during heat sealing operations.

[99] Career Builder Site Homepage, accessed 1 of September 2023.
Available at: https://www.careerbuilder.com/regional_sites

- Communication Skills: Clearly convey information, instructions, and observations verbally and in writing, facilitating effective communication within the team and with other stakeholders.
- Time Management: Effectively manage time and prioritise tasks to ensure efficient workflow and meet production targets.
- Record-Keeping Skills: Maintain accurate and organised records of production data, material usage, maintenance activities, and quality control checks.

**Crimping Machine**

To establish the electrical and mechanical connections between the parts of a battery cell, a crimping machine for battery cell assembly is a specialised piece of machinery used to manufacture batteries. To link terminals, tabs, or connectors to the electrodes and create a dependable and low-resistance electrical channel, crimping is a frequently used technique in the battery manufacturing industry. An overview of crimping equipment for battery cell assembly is given below:


*Figure 25: Hydraulic Crimping Machine for All Coin Cells*[100]

[100] Nanografi Site Homepage , accessed 1 of September 2023.
Available at: https://nanografi.com/contact-us/

The following companies in Europe provide crimping machines:

- Manz AG: Manz, based in Germany, is a global high-tech equipment manufacturer offering a range of battery production solutions. They provide crimping machines as part of their comprehensive battery manufacturing equipment portfolio.
- Schunk Group: Schunk, headquartered in Germany, is a technology company specialising in materials and systems engineering. They offer crimping machines for battery cell assembly, providing reliable and precise crimping solutions.
- AMADA WELD TECH: AMADA WELD TECH, with locations across Europe, is a global manufacturer of advanced joining and welding equipment. They offer crimping machines designed specifically for battery cell assembly, ensuring consistent and high-quality crimp connections.
- Telsonic Group: Telsonic, based in Switzerland, is a leading supplier of industrial ultrasonic systems and solutions. They provide crimping machines utilising ultrasonic technology, offering efficient and reliable crimping for battery cell assembly.
- Autosplice Europe GmbH: Autosplice, headquartered in Germany, specialises in providing interconnect solutions for various industries, including battery manufacturing. They offer crimping machines for battery cell assembly, ensuring secure and high-performance electrical connections.

**Skills and competencies[101]**

- Technical Knowledge: Possess a good understanding of crimping machine operation, including controls, settings, and safety features, with the ability to operate and control the machine effectively.
- Mechanical Aptitude: Demonstrate a basic understanding of mechanical systems and equipment, enabling the ability to perform routine maintenance tasks and troubleshoot minor operational issues.
- Attention to Detail: Exhibit a high level of accuracy and precision in crimping operations, ensuring proper alignment, pressure, and crimp quality for reliable connections.

[101] Simply Hired Site Job Offers Section, accessed 1 of September 2023.
Available at: https://www.simplyhired.com/search?q=crimping+machine+operator

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

- Problem-solving skills: Apply logical reasoning and problem-solving techniques to identify and resolve operational issues or equipment malfunctions during crimping.
- Hand-eye coordination: Possess good manual dexterity and hand-eye coordination to handle wires or cables, load them into the crimping machine, and make precise adjustments.
- Quality Consciousness: Have a keen eye for detail and a commitment to maintaining high-quality standards in the crimped connections, ensuring they meet customer specifications.
- Safety Awareness: Follow safety protocols and guidelines, recognising potential hazards and taking appropriate precautions to prevent accidents or injuries during crimping operations.
- Communication Skills: Clearly convey information, instructions, and observations verbally and in writing, facilitating effective communication within the team and with other stakeholders.
- Time Management: Effectively manage time and prioritise tasks to ensure efficient workflow and meet production targets.
- Record-Keeping Skills: Maintain accurate and organised records of production data, material usage, maintenance activities, and quality control checks.

#### *2.1.2.6 Formation equipment (e.g. battery cyclers, voltage/current testing equipment)*

**Battery cyclers**

Battery cyclers, commonly referred to as formation equipment, are specialised machinery used in the battery production sector to facilitate the formation of batteries. The initial charging and discharging cycle that the cells go through to condition and activate them before they are ready for use is known as battery formation. By giving the battery cells carefully regulated cycles of charging and draining, formation equipment or battery cyclers aid this process. Here is a description of battery cyclers or forming equipment.

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


*Figure 26: Bitrode unveils first in a new generation of battery cyclers*[102]

- Purpose: Battery cells are conditioned and activated using formation equipment by being put through certain charging and discharging cycles. This procedure aids in determining the appropriate performance traits, battery capacity, and reliability.
- Machine Configuration: Formation equipment or battery cyclers typically consist of the following components:
- Power Supply: A power source that supplies the required voltage and current to charge and discharge the battery cells is part of the apparatus. The power supply was created according to the battery chemistry and cell structure demands.
- Control System: The control system built into formation equipment enables operators to adjust and monitor variables, including charging voltage, current, discharge rate, and cycle time. A number of battery cells are formed precisely and consistently thanks to this control.
- Data Acquisition: Many battery cyclers have data-collecting features that let them monitor and examine crucial variables like voltage, current, temperature, and time as

[102] CHARGED EV Engineering News Site, *Bitrode unveils first in new generation of battery cyclers under new management with Schuler Group,* in https://chargedevs.com/whitepapers/bitrode-unveils-first-in-new-generation-of-battery-cyclers-under-new-management-with-schuler-group/, 19 of May 2023.

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

they change during the creation process. This information aids in quality assurance and performance evaluation of the battery.

- Safety Features: To ensure safe and dependable operation throughout the formation process, formation equipment frequently contains safety features, including temperature sensors, current and voltage protection, and emergency shutdown mechanisms.
- Advantages of Formation Equipment: Formation equipment offers several advantages in battery manufacturing:
- Consistency: Battery cyclers offer fine-grained control over the parameters for charging and discharging, providing reliable formation procedures and consistent battery performance.
- Efficiency: Formation equipment enables automated and efficient formation cycles, reducing manual labour and increasing production throughput.
- Quality Control: Battery cyclers' data collecting capabilities enable quality control and performance analysis, guaranteeing that batteries fulfil predetermined standards.
- Flexibility: Formation equipment is designed to accommodate a variety of battery chemistries and cell configurations, making it suitable for different types of batteries

**Skills and competencies[103]**

- Technical Knowledge: Possess a solid understanding of battery cycling principles, chemistries, and testing standards. Familiarity with battery cycler operation and control software.
- Data Analysis Skills: Proficient in data acquisition and analysis techniques, including using software tools for data interpretation, graphical representation, and statistical analysis.
- Troubleshooting Skills: Ability to identify, diagnose, and resolve technical issues or anomalies in battery cycling tests, utilising problem-solving skills and technical knowledge.

[103]LinkedIn Site Job Offers Section, accessed 1 of September 2023.
Available at:
https://www.linkedin.com/jobs/search/?currentJobId=3662372358&geoId=100364837&keywords=Battery%20cyclers&location=Portugal&refresh=true

- Equipment Maintenance Skills: Knowledge of routine maintenance tasks, calibration procedures, and basic troubleshooting techniques for battery cycling equipment.
- Attention to Detail: Demonstrate high accuracy and precision in test setups, data recording, and observation of battery cycling conditions.
- Safety Awareness: Follow strict safety protocols and guidelines when handling batteries, including knowledge of proper handling, storage, and disposal practices.
- Communication Skills: Clear communication to effectively convey test parameters, observations, and results to team members and stakeholders, both verbally and in written reports.
- Analytical Thinking: Ability to analyse complex data sets, identify trends, and draw meaningful conclusions from battery cycling test results.
- Time Management: Efficiently manage time and prioritise tasks to meet testing schedules and project deadlines.
- Record-Keeping Skills: Maintain organised records of test setups, test data, equipment maintenance, and other relevant documentation.

**Voltage/current testing equipment**

Equipment used to measure and analyse electrical parameters like voltage and current in diverse applications is called voltage and current testing equipment. These testing instruments are essential for evaluating the efficiency, usefulness, and security of electrical systems and apparatus. These tools for evaluating voltage and current are frequently used.

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

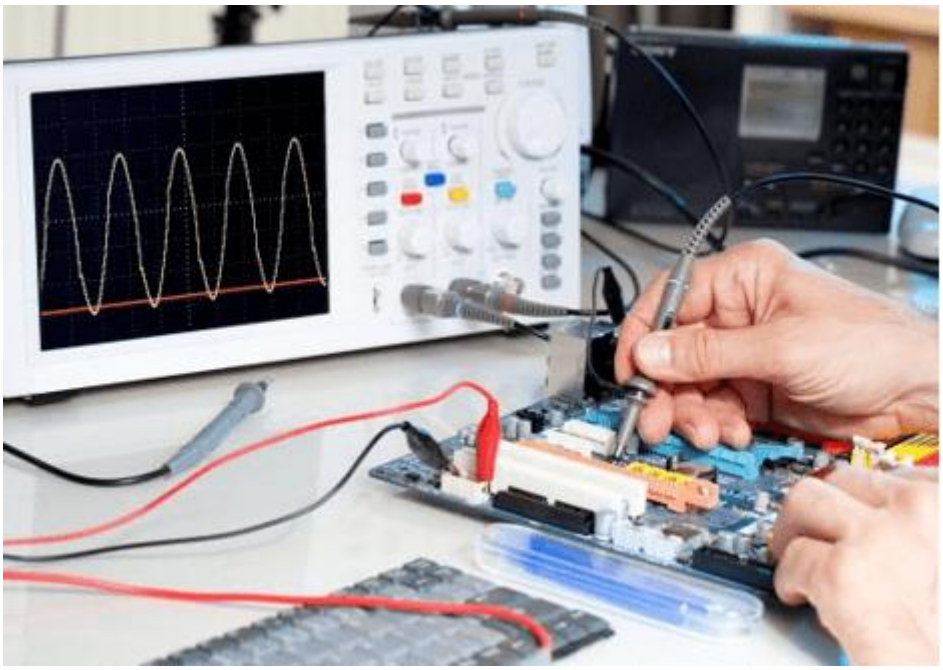

*Figure 27:What is Test Equipment.*[104]


*Figure 28:What is Test Equipment.*[105]

[104]Kietzmann S., *What is Test Equipment,* in https://www.aboutmechanics.com/what-is-test-equipment.htm, 22 of August 2023.
[105] Kietzmann S., *What is Test Equipment,* in https://www.aboutmechanics.com/what-is-test-equipment.htm, 22 of August 2023.

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

The following instruments are used to test voltage, current and oscillation.

- Digital Multimeter (DMM): An adaptable handheld instrument called a digital multimeter is used to gauge voltage, current, and resistance. A digital display and several measuring modes are frequently included, letting users choose the right measurement range and function for their testing requirements. DMMs are commonly employed in electrical and electronic maintenance, quality assurance, and troubleshooting.
- Clamp Meter: A clamp meter, sometimes referred to as a current clamp or an amp meter, is a portable device used to measure current without having to interrupt the circuit. It clamps around a conductor, making it possible to measure the current passing through it directly. Clamp meters are frequently utilised when non-invasive current measurements are necessary, such as in electrical installations and power distribution utilised
- Power Analyzer: A power analyser is a specialist tool for thorough electrical power examination. It measures several things, such as voltage, current, power factor, harmonics, and energy usage. In industrial and commercial contexts, power analysers are used to examine power quality, energy economy, and load balance.
- Oscilloscope: An oscilloscope is a flexible testing tool that shows electrical waveforms, including voltage and current signals, and analyses them. It gives the signal a temporal graphical representation, enabling a thorough investigation of its properties like amplitude, frequency, and waveform distortion. Engineering for electronic, telecommunications, and power systems frequently uses oscilloscopes.
- Programmable Power Supplies for testing and powering electronic equipment: Programmable power supplies offer a controlled and changeable voltage and current supply. They provide accurate regulation of voltage and current, programmable settings, and a range of safety features. Programmable power supply is frequently utilised in the manufacturing, laboratory, and product development industrialised
- Current Shunts: Precision resistors with low resistance, known as current shunts, are utilised to measure high current levels. The voltage drop across the shunt is monitored to ascertain the current flowing through it, and they are connected in series with the

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

load or circuit. High-current applications include power distribution systems, testing of electric vehicles, and industrial machinery that frequently uses current shunts.

**Skills and competencies**[106]

- Technical Knowledge: Possess a strong understanding of electrical principles, including voltage, current, resistance, and circuitry, to effectively operate and interpret readings from voltage/current testing equipment.
- Equipment Familiarity: Demonstrate proficiency in operating various types of voltage/current testing equipment, such as multimeters, clamp meters, oscilloscopes, or power analysers, understanding their functions, controls, and capabilities.
- Test Setup and Configuration: Set up the testing equipment, including selecting appropriate test ranges, connecting test leads or probes, and configuring measurement settings based on the specific testing requirements.
- Safety Protocols: Adhere to safety protocols and guidelines when working with live circuits and electrical systems, ensuring proper grounding, isolation, and use of personal protective equipment (PPE).
- Measurement Techniques: Apply proper measurement techniques, such as accurate probe placement, maintaining stable connections, and mitigating external interference, to obtain precise voltage and current readings.
- Data Analysis: Analyse and interpret test results, identifying patterns, trends, or abnormalities in voltage or current levels. Compare readings against specified limits or standards to assess compliance or identify potential issues.
- Troubleshooting Skills: Utilize voltage/current testing equipment to troubleshoot electrical problems, such as circuit faults, voltage drops, or excessive current flow, employing systematic approaches and logical reasoning to diagnose and resolve issues.
- Calibration and Maintenance: Perform calibration procedures and routine maintenance tasks on the testing equipment, ensuring accurate and reliable measurements. Identify and address any equipment malfunctions or deviations.

[106] Simply Hired Job Offers Section, accessed 1 of September 2023.
Available at: https://www.simplyhired.com/search?q=Voltage%2Fcurrent+testing+equipment&l=

- Documentation and Reporting: Maintain accurate records of test setups, measurement data, equipment calibration, maintenance activities, and any incidents or deviations encountered. Prepare reports summarising test results and provide documentation for quality assurance purposes.
- Communication Skills: Effectively communicate technical information, observations, and test results to team members, supervisors, and other stakeholders, both verbally and in a written report.

### 2.1.3 Module and pack assembly, including related skills, competencies, and job roles

The battery module is a complex system comprising components, each with their functionality from where it is possible to highlight the battery cells, cooling system, battery management system slave, sensors, module casing, cables, electrical connections, and protection circuit[107]. According to the required performance and geometry for each module, the number of cells in series and/or parallel will vary, also impacting the cooling system adapted to the needs of each module's geometry and number of cells. Due to the degree of customisation and the high number of different products and process variants, it is impossible to define one exact process for the module assembly. However, it is possible to consider some similarities.

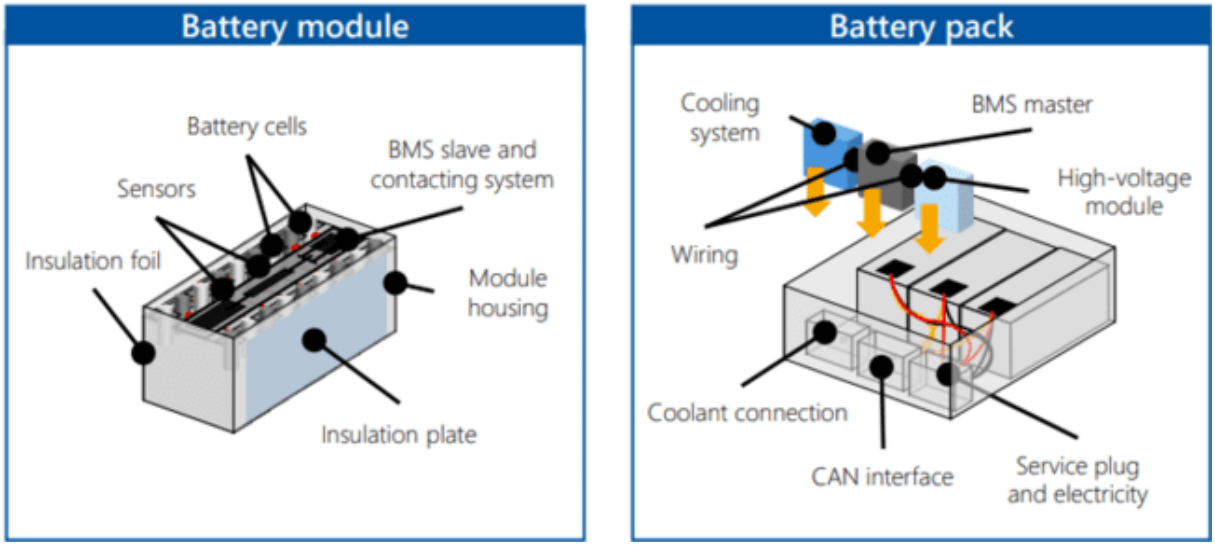


*Figure 29: Example of the battery module and pack parts[108]*

[107] RWTH AACHEN University and VDMA Battery Production, *Battery Module and Pack Assembly Process,* accessed 20 June 2023.
Available at: https://www.pem.rwth-aachen.de/global/show_document.asp?id=aaaaaaaaabdqbtl
[108] RWTH AACHEN University and VDMA Battery Production, *Battery Module and Pack Assembly Process,* accessed 20 June 2023.

Essentially, three geometries of cells are used for battery modules: pouch cells, cylindrical cells, and prismatic cells. The techniques and requirements for their aggregation will change depending on it and are resumed in *Figure 30*[109].

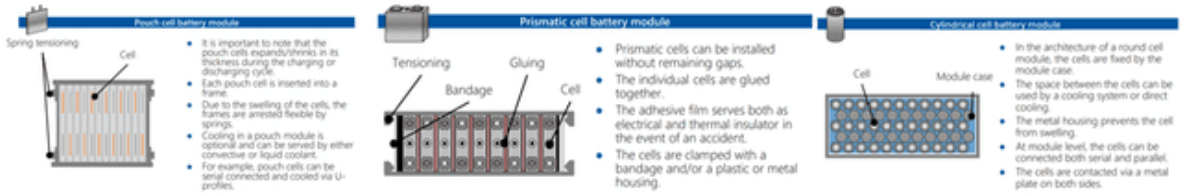


***Figure 30. Different characteristics of the module for each cell geometry[110]***

The assembly of battery packs (for prismatic cells in particular) is divided into nine steps:

1. Pre-Assembly
2. Insulation and Tensioning
3. Electrical Contacting
4. Mounting Slave Circuit Board and housing cover
5. Insertion of cell module and attachment
6. Electrical & Thermal Integration
7. Sealing & Leak Test
8. Charging & Flashing
9. End of line

### 1. Pre-Assembly

In the first step, an initial inspection is carried out in the cells – Electrochemical Impedance Spectroscopy, Voltage measurements, capacity analysis – and the suitable cells are directed to the assembly line, where the surface will be cleaned, and glue applied (usually polyurethane adhesive). The cells are stacked, and the solvent vapours are extracted.

Available at: https://www.pem.rwth-aachen.de/global/show_document.asp?id=aaaaaaaaabdqbtl
[109] Ibidem.
[110] Ibidem.

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

**Potentiostat**

*Figure 31: Potentiostat*[111]

**Skills and Competencies for Battery Pack Assembly by using a Potentiostat in pre-assembly**[112]

- Cell Testing Expertise: Proficiency in conducting Electrochemical Impedance Spectroscopy, voltage measurements, and capacity analysis to assess the quality and performance of the cells before assembly.
- Adhesive Application: Knowledge of handling and applying adhesive materials, particularly polyurethane adhesive, to ensure proper bonding of cells during stacking.
- Safety Protocols: Understanding safety protocols when working with solvents and other potentially hazardous materials to maintain a safe working environment for the team.

## 2. Insulation and Tensioning

The stacked cells are pressed by a clamping device to minimise swelling during operation, and plastic plates are inserted in a housing to limit the module and isolate the cells electrically. The case can be glued, bandaged or screwed.

[111] PalmSens Site, *MultiEmStat4* Quotation Page, accessed 27 of July 2023.
Available at: https://www.palmsens.com/product/multi-emstat4/
[112] PalmSens Site, *MultiEmStat4* Quotation Page, accessed 27 of July 2023.
Available at: https://www.palmsens.com/product/multi-emstat4/

**Clamping Device**

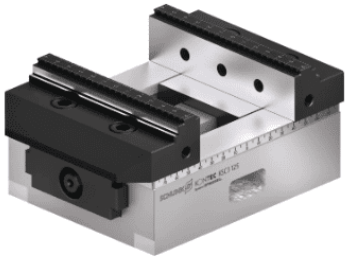

*Figure 32: Clamp Vise to minimise swelling* [113]

**Skills and Competencies for Battery Pack Assembly by using a Clamping Vise**

- Clamping Techniques: Competence in clamping devices to press and tension stacked cells, minimising cell swelling during operation.
- Material Selection: Knowledge of appropriate plastic plates and housing materials to provide insulation and protection for the battery cells.
- Assembly Techniques: Proficiency in assembling and securing the cells within the housing using appropriate methods such as gluing, bandaging, or screwing.

### 3. Electrical Contacting

Cells are wired by connecting the current collectors and the contact tabs. Depending on the requirements for the modules, the cells can be connected in series or parallel. The connection can be performed by laser (faster and more efficient but high heat input for the cells), ultrasonic welding (high precision but expensive) or by screwing (simple and detachable connection, but high contact resistances). After the link, joins are tested for resistance measurements and electrical continuity.

[113] Schunk Site, *Manual Clamping Systems,* in https://schunk.com/de/en/workpiece-clamping-technology/manual-clamping-systems/c/PUB_8334, accessed 27 of July 2023.

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

**Laser Welding Machine**

*Figure 33: Laser Welding Machine*[114]

**Skills and Competencies for Battery Pack Assembly by performing electrical contracting**[115]

- Welding Expertise: Skill in using laser welding or ultrasonic welding techniques to establish robust electrical connections between the current collectors and contact tabs.
- Screwing Techniques: Competency in using screws and other fastening methods for electrical connections, providing a simple and detachable connection with low contact resistances.
- Quality Control: Ability to conduct resistance measurements and electrical continuity tests to verify the reliability of the electrical connections.

### 4. Mounting Slave Circuit Board and housing cover

The slave circuit board is installed in the module by welding or screwing, connecting the BMS to the temperature current and voltage sensors via plug connections.

[114] IPG Photonics Lase Systems Site, *Handheld Laser Welding and Cleaning Systems,* in https://lasersystems.ipgphotonics.com/products/Handheld-Systems/Handheld-Laser-Welding-and-Cleaning-System, accessed 27 of July 2023.
[115] IPG Photonics Lase Systems Site, *Handheld Laser Welding and Cleaning Systems,* in https://lasersystems.ipgphotonics.com/products/Handheld-Systems/Handheld-Laser-Welding-and-Cleaning-System, accessed 27 of July 2023.

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

**Skills and Competencies for Battery Pack Assembly by Mounting Slave Circuit Board and Housing Cover**

- Circuit Board Handling: Knowledge of proper handling procedures for slave circuit boards during installation to prevent damage.
- Welding or Screwing Proficiency: Expertise in using welding or screwing tools to attach the circuit board to the module housing securely.
- Connector Assembly: Skill in connecting the Battery Management System (BMS) to the temperature, current, and voltage sensors via plug connections.

### 5. Insertion of cell module and attachment

If liquid cooling is used, this step starts by installing the cooling plates in the pack housing, followed by the battery modules previously assembled, which are secured by screws. The additional screw connections increase the rigidity and extra protection against vibrations during operation.

**Skills and Competencies for Battery Pack Assembly by Inserting cell module and attachment**

- Cooling System Integration: Competence in installing cooling plates and other components required for liquid cooling, ensuring efficient thermal management of the battery pack.
- Secure Attachment: Proficiency in using screwing tools to secure the battery modules within the housing, providing additional rigidity and protection against vibrations during operation.

### 6. Electrical & Thermal Integration

Due to the high voltage of the modules/pack, protection equipment must be installed in the electrical connection, such as relays, fuses, pre-charge and current measuring system, insulation monitoring, and the high voltage and low voltage connections. The BMS Master is connected to the cooling system and the slave circuit boards.

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

**Protection Equipment**

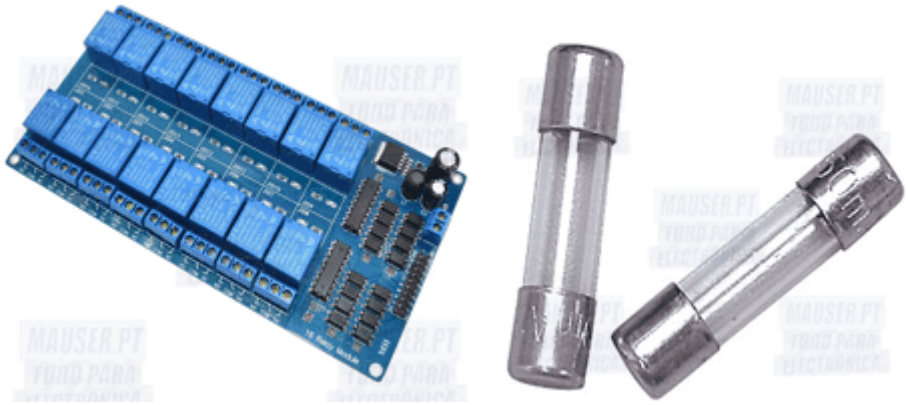

*Figure 34:Electronics protection equipment (relays, fuses etc.)* [116]

**Skills and Competencies for Battery Pack Assembly by performing electrical contacting** [117]

- Electrical Connection Expertise: Knowledge of integrating protection equipment such as relays, fuses, and pre-charge systems into the electrical connections, ensuring the safety and reliability of the high-voltage system.
- Thermal Management Knowledge: Understanding the principles of thermal integration, ensuring that the cooling system effectively dissipates heat generated during operation.
- BMS Master Connection: Skill in connecting the BMS Master to the cooling system and the slave circuit boards, establishing effective communication and control within the battery pack.

## 7. Sealing & Leak Test

The pack is sealed in the edge of the housing or cover using rubber or glued seals. The upper part is used to cover and is connected to the pack housing by screwing after the pack is checked for leaks.

[116] Mauser Site Catalogue, accessed 27 of July 2023.
Available at: https://mauser.pt/catalog/
[117] Mauser Site Catalogue, accessed 27 of July 2023.
Available at: https://mauser.pt/catalog/

**Rubber Seals**

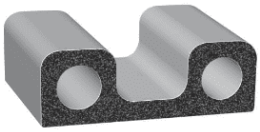

*Figure 35: Rubber Seals to avoid leakage [118]*

**Leak testing equipment**

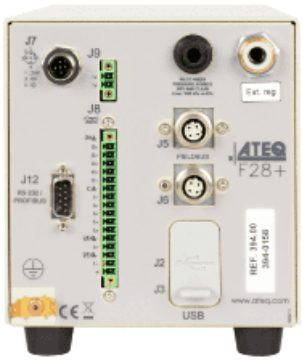


*Figure 36: Leak Tester[119]*

**Skills and Competencies for Battery Pack Assembly by Sealing**[120]

- Sealing Techniques: Proficiency in using rubber seals or glue to effectively seal the edges of the pack housing or cover, preventing moisture ingress and ensuring pack integrity.
- Leak Testing Expertise: Knowledge of leak testing procedures to verify that the pack is sealed correctly and meets the required standards for safety and performance.

[118] Trimlok Site, *Lid Seals,* in https://www.trimlok.com/rubber-extrusion/epdm-seal/double-bulb-lid, accessed 27 of July 2023.
[119] Ateq Site, *Leak Tester,* in https://www.ateq-leaktesting.com/products/leak-tester/, accessed 27 of July 2023.
[120] Ateq Site, *Leak Tester,* in https://www.ateq-leaktesting.com/products/leak-tester/, accessed 27 of July 2023.

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

## 8. Charging & Flashing

The BMS is connected to a testing station, and an electrical and thermal assessment is performed to verify the correct functioning of the pack.

### Testing Station


*Figure 37:Testing Station* [121]

### Skills and Competencies for Battery Pack Assembly by performing electrical contacting[122]

- Testing Procedures: Competence in using testing stations and conducting electrical and thermal assessments to ensure the battery pack functions correctly before finalisation.
- BMS Verification: Expertise in verifying the proper functioning of the BMS, ensuring it communicates with the cells, sensors, and other subcomponents as intended.

## 9. End of line

Final testing is performed to test the BMS's performance and the temperature, sensors, slave circuit board, etc., that compose its subcomponents. Cycling is performed to assess and establish the desired state of charge. Finally, testing is completed, and labels are placed in the pack.

[121] Arbin Site, *HPS Series,* in https://arbin.com/battery-test-equipment/battery-test-product-series/hps-series/, accessed 27 of July 2023.
[122] Arbin Site, *HPS Series,* in https://arbin.com/battery-test-equipment/battery-test-product-series/hps-series/, accessed 27 of July 2023.

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

**BMS Testing Machine**

*Figure 38: BMS Testing Machine [123]*

**Skills and Competencies for Battery Pack Assembly by performing electrical contacting**[124]

- Final Testing Proficiency: Knowledge of final testing procedures, including assessing the performance of the BMS, temperature sensors, slave circuit board, etc., to confirm all subcomponents function properly.
- State of Charge Assessment: Competence in cycling the battery pack to establish the desired state of charge and verify its operational capacity.
- Labelling and Packaging: Skill in labelling the battery pack appropriately to provide essential information and ensure proper identification and packaging for shipment.

**Battery module automatic assembly line**

The intelligent assembly production line takes robot technology as the core and integrates all automation equipment for collaborative operation. The main process of the entire assembly line is fully automated, such as incoming, conveying, handling, sorting, cleaning, testing, gluing, screw locking, labelling, packaging, palletising, depalletizing, etc. According to product characteristics, operation content and production rhythm, the automatic assembly line can adopt a layout that is

[123] Winack Site, *Battery Pack BMS Test Equipment,* in https://www.winackbattery.com/products/Battery-Pack-BMS-Testing-Machine.html, accessed 27 of July 2023.
[124] Winack Site, *Battery Pack BMS Test Equipment,* in https://www.winackbattery.com/products/Battery-Pack-BMS-Testing-Machine.html, accessed 27 of July 2023.

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

consistent with the production process, such as tree structure, series structure, parallel structure, etc. The layout of each station is of reasonable design to maximise the assembly operation efficiency. Several companies present solutions for automatic assembly lines of battery modules. A Hylaser Machine, for instance, presents a line of machining that performs the module assembling up to step 3—Electrical Contacting (it does not include BMS and cooling mechanisms).

The following steps can summarise the assembly line:

### 1. Cell gluing

The worker places the battery cells on the feeding conveyor belt, and the equipment in *Figure 39* can automatically complete the cleaning and gluing.

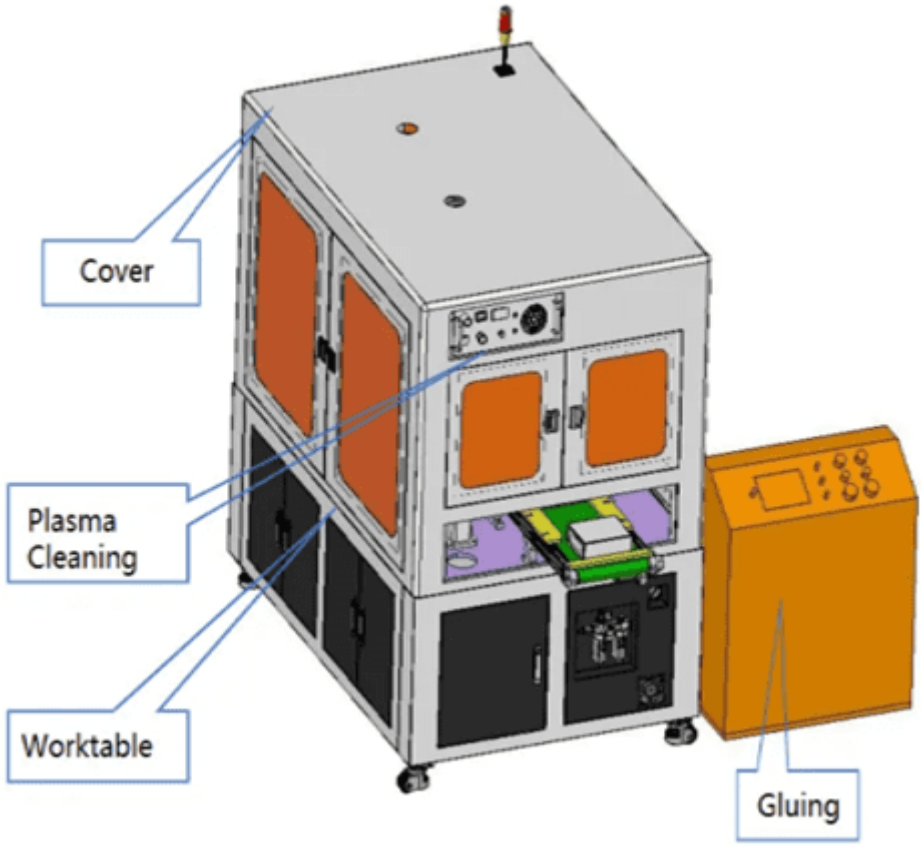


*Figure 39:Cleaning Gluing Station*[125]

[125] YouTube Site, *How to Manufacture a Server Rack Cabinet,* in https://www.youtube.com/watch?v=eKLHhxhIy5Q&ab_channel=BrendaBolein, 4 July 2020.

**Cell Gluing Station**


*Figure 40: Cell Gluing Machine*[126]

**Skills and Competencies for Cell Gluing**[127]

- Precise Material Placement: Skill accurately placing battery cells onto the feeding conveyor belt to ensure proper alignment and positioning.
- Adhesive Application: Competently applying adhesive material accurately and uniformly ensures reliable bonding between cells and other components.
- Basic Equipment Operation: Ability to operate the cleaning and gluing equipment effectively for consistent and high-quality results.

## 2. Module stack pressing

The cell stacking robot[128] feeds the glued cells into the double station stacking tool (Figure 41), which will be alternated with insulating plates fed by the insulation board stacking robot (Figure 41). After

[126] Graco Site, *UniXact C500 Dispensing Cell,* in https://www.graco.com/us/en/in-plant-manufacturing/product/c500-unixact-c500.html#features, accessed 27 of July 2023.
[127] Graco Site, *UniXact C500 Dispensing Cell,* in https://www.graco.com/us/en/in-plant-manufacturing/product/c500-unixact-c500.html#features, accessed 27 of July 2023.
[128] YouTube Site, *How to Manufacture A Server Rack Cabinet,* in https://www.youtube.com/watch?v=eKLHhxhIy5Q&ab_channel=BrendaBolein, 4 July 2020.

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

stacked, the cells are clamped by the clamping cylinder. When the A station is stacking, the B station synchronously performs the moving work before extrusion, and the double station alternates to improve the efficiency of stacking and moving.

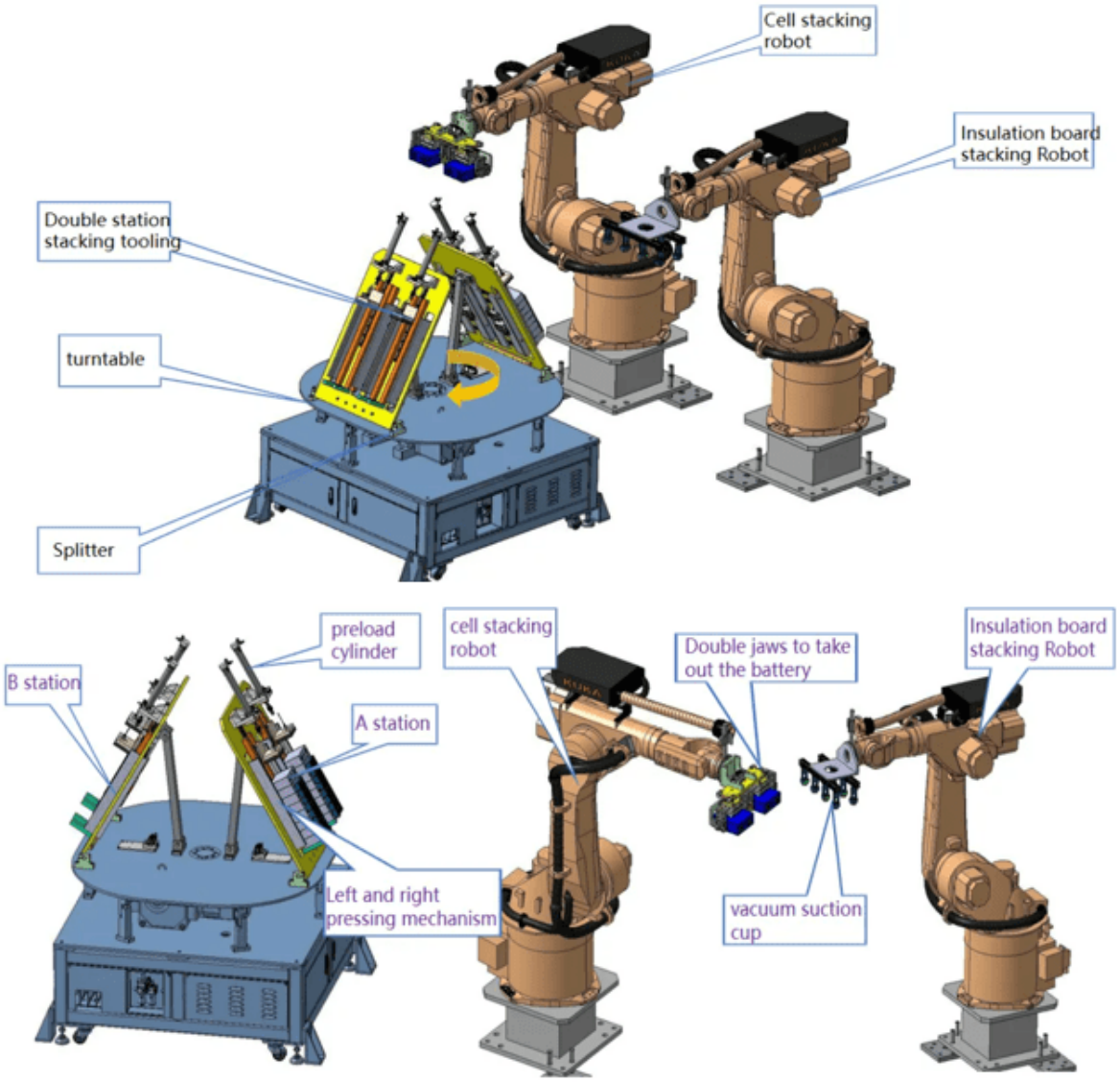


*Figure 41: Stacking Rotary Tables*[129]

[129] YouTube Site, *How to Manufacture A Server Rack Cabinet,* in https://www.youtube.com/watch?v=eKLHhxhIy5Q&ab_channel=BrendaBolein, 4 July 2020.

**Stack Pressing Station**


*Figure 42: Robotic Arms*[130]

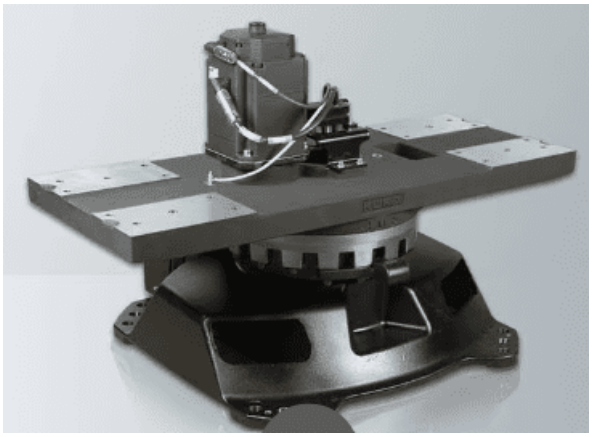

*Figure 43: Rotary platform*[131]

[130] KUKA Site, *KR CYBERTECH,* in https://www.kuka.com/pt-pt/produtos-servi%c3%a7os/sistemas-de-rob%c3%b4/rob%c3%b4s-industriais/kr-cybertech, accessed 27 of July 2023.
[131] KUKA Site, *KP1-MB single-axis modular rotary table,* in https://www.kuka.com/en-us/products/robotics-systems/robot-periphery/positionierer/kp1-mb, accessed 27 of July 2023.

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

*Figure 44:Loading Cylinders*[132]

**Skills and Competencies for Stack Pressing**[133]

- Robotic Handling: Proficiency in robot operation to feed cells and insulating plates into the stacking tool, ensuring proper alignment and smooth movement.
- Coordination and Timing: Skill in coordinating the actions of the cell stacking robot, insulation board stacking robot, and clamping cylinder to achieve precise and secure cell stacking.

### 3. Strapping

The handling robot transports the single-row stacks 1 and 2, respectively, from the stacking turntable to the extrusion sliding table. The middle partition, the insulation board, and the end plates (see Figure 45) are manually installed[134]. Then, the operator presses the extrusion start button Figure 46) and automatically applies the steel cable ties[135].

[132] KC Denmark Research Equipment Site, *KC pore-water pressing bench stainless steel cylinders,* in https://www.kc-denmark.dk/products/other-products/pore-water-pressing-and-filtration-units/kc-pore-water-pressing-bench,-stainless-steel-cylinders.aspx, accessed 27 of July 2023.
[133] YouTube Site, *How to Manufacture A Server Rack Cabinet,* in https://www.youtube.com/watch?v=eKLHhxhIy5Q&ab_channel=BrendaBolein, 4 July 2020.
[134] YouTube Site, *How to Manufacture A Server Rack Cabinet,* in https://www.youtube.com/watch?v=eKLHhxhIy5Q&ab_channel=BrendaBolein, 4 July 2020.
[135] Ibidem.

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

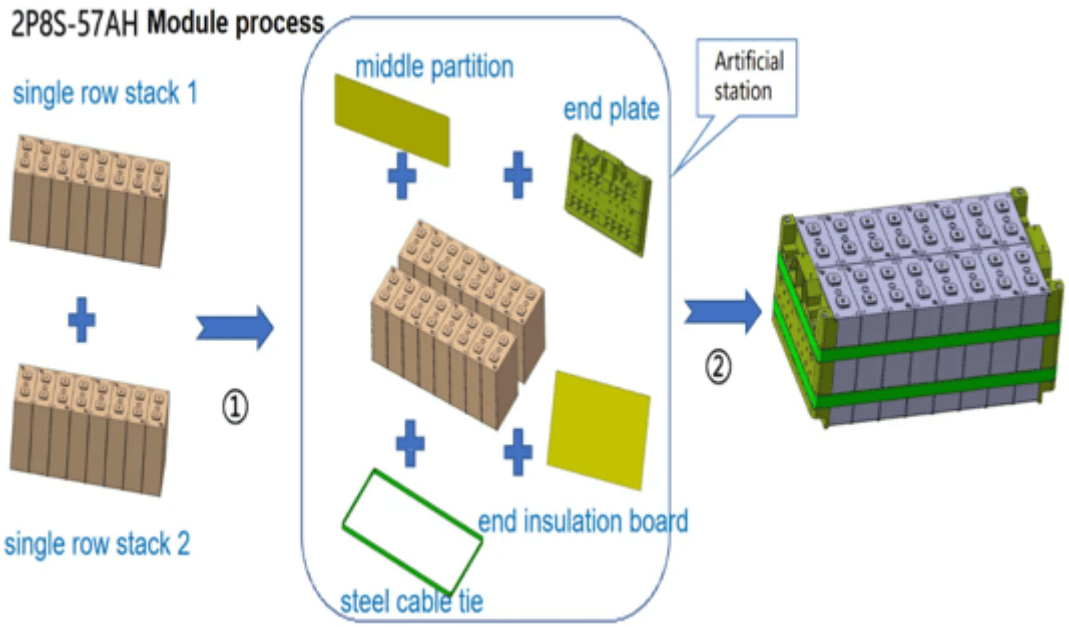


*Figure 45: Double-row module process*[136]

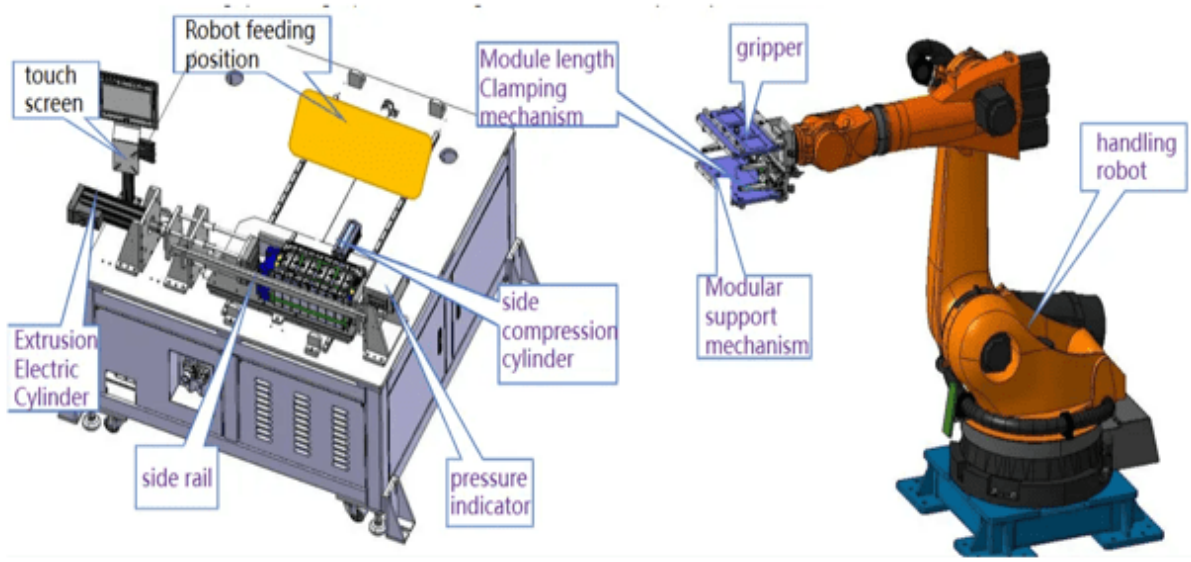


*Figure 46: Extrusion station*[137]

[136] YouTube Site, *How to Manufacture A Server Rack Cabinet,* in https://www.youtube.com/watch?v=eKLHhxhIy5Q&ab_channel=BrendaBolein, 4 July 2020.
[137] Ibidem.

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

**Strapping Machine**


*Figure 47: Strapping Machine*[138]

**Skills and Competencies for Strapping**[139]

- Manual Assembly: Ability to manually install middle partitions, insulation boards, end plates, and steel cable ties accurately and securely.
- Equipment Operation: Skills in using the extrusion sliding table and pressing the extrusion start button for automated strapping.

## 4. Insulation

Step where all the insulations are tested. Cell and cell insulation, insulation between pole series and housing and between negative pole series and housing.

[138] Eam Mosca Site, *ROMP – 6B SoniXs,* in https://www.eammosca.com/product/romp-6b-sonixs/, accessed 27 of July 2023.
[139] Eam Mosca Site, *ROMP – 6B SoniXs,* in https://www.eammosca.com/product/romp-6b-sonixs/, accessed 27 of July 2023.

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

**Multimeter**


*Figure 48: Multimeter*[140]

**Skills and Competencies for Insulation**

- Quality Inspection: Competency in visually inspecting and testing insulation between cells, between pole series and housing, and between negative pole series and housing.
- Attention to Detail: Ability to identify potential insulation issues or defects that could impact battery safety and performance.

## 5. Laser cleaning

The robot program automatically adjusts the height and then performs distance measurement and MARK point photography of each pole. Then, each pole is automatically cleaned according to the coordinates sent by the pole photographing station (Figure 49).

[140] Mauser.pt Site, *Multìmetro digital,* in https://mauser.pt/catalog/product_info.php?products_id=096-7693&utm_source=google&utm_medium=cpc&utm_campaign=shopping_catalog_pt_011&utm_content=feed&gclid=Cj0KCQjwrfymBhCTARIsADXTabkdHiwl2Qy2IuvCNndU9u9uM18h7TomvRsND8QOw9wiKvp4QMNsgOAaAqq_EALw_wcB Accessed on 27/07/2023

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

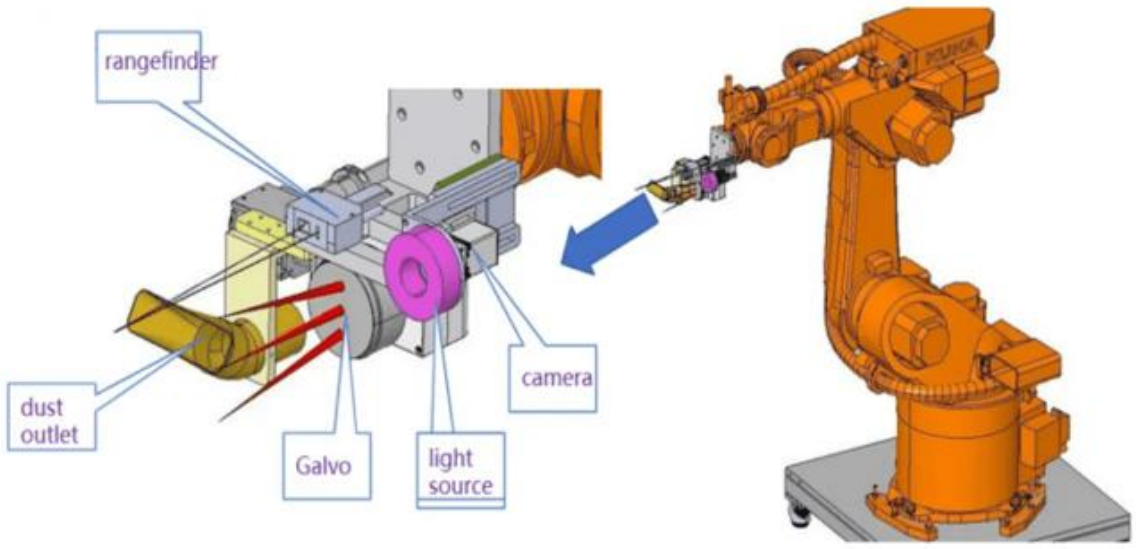


*Figure 49:Pole photographing station*[141]

## Cleaning Laser


*Figure 50: Cleaning Laser*[142]

[141] YouTube Site, *How to Manufacture A Server Rack Cabinet,* in https://www.youtube.com/watch?v=eKLHhxhIy5Q&ab_channel=BrendaBolein, 4 July 2020.
[142] CleanLASER Site, *Lasers with 150 to 600 watts,* in https://www.cleanlaser.de/en/products/lasers/mid-power-laser-systems/, accessed 27 of July 2023.

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

**Skills and Competencies for Laser Cleaning**[143]

- Robotic Programming: Proficiency in programming the robot for automatic height adjustment, distance measurement, and precise laser cleaning based on coordinate data.

## 6. Busbar assembly and laser welding

In Figure 51, this station first takes the MARK point of the module and then calculates the offset of each pole based on the data sent by the photographing station. Then, all busbar welding positions are measured for distance, and laser welding is automatically performed.

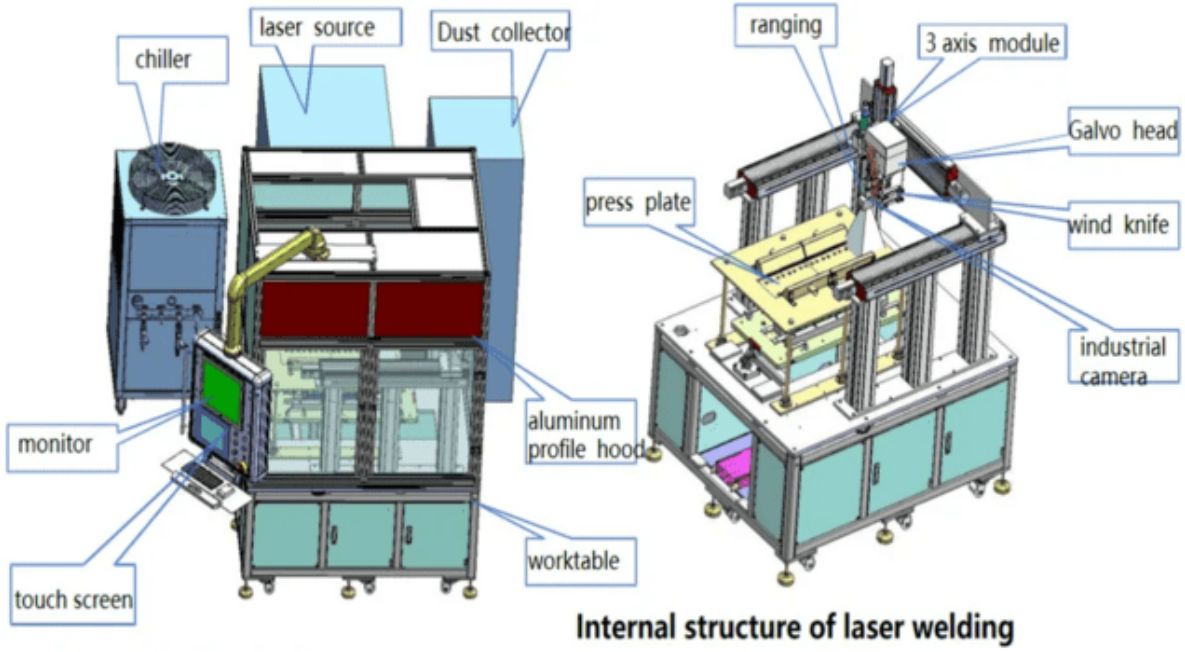


*Figure 51:Pole photographing station*[144]

[143] CleanLASER Site, *Lasers with 150 to 600 watts,* in https://www.cleanlaser.de/en/products/lasers/mid-power-laser-systems/, accessed 27 of July 2023.
[144] YouTube Site, *How to Manufacture A Server Rack Cabinet,* in https://www.youtube.com/watch?v=eKLHhxhIy5Q&ab_channel=BrendaBolein, 4 July 2020.

**Arc Welding Robot**

*Figure 52:Arc Welding Robot*[145]

**Skills and Competencies for Busbar assembly and laser welding**[146]

- Robotic Coordination: Skill in coordinating the robot's actions to accurately position and weld busbars based on calculated offsets and welding positions.

**Service & Maintenance Consideration**

- Preventive Maintenance: Regularly scheduled maintenance to ensure that all equipment, robots, sensors, and other components are functioning optimally.
- Troubleshooting: Ability to identify and diagnose issues that may arise during operation, such as sensor malfunctions or robotic errors.

[145]ABB Cobot Aarc Welding Package, Complex Welding at the touch of a button, accessed 27 of July 2023. Available at: https://search.abb.com/library/Download.aspx?DocumentID=9AKK108468A4149&LanguageCode=en&DocumentPartId=&Action=Launch

[146]ABB Cobot Aarc Welding Package, Complex Welding at the touch of a button, accessed 27 of July 2023. Available at: https://search.abb.com/library/Download.aspx?DocumentID=9AKK108468A4149&LanguageCode=en&DocumentPartId=&Action=Launch

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

- Technical Expertise: In-depth knowledge of the assembly line components to perform repairs, adjustments, and replacements as needed.
- Collaboration: Effective communication with maintenance and technical teams to address complex or specialised service requirements.
- Documentation: Maintaining detailed records of service and maintenance activities, including schedules, repairs, and replacements, for traceability and continuous improvement.

**Rack module and cabinet manufacturing**

When the rack modules and cabinets are based on the plastic deformation of metal sheets, like those in Figure 53, their manufacturing process is very similar.

*Figure 53:Rack module (left) and cabinet (right)*[147]

The production of rack cabinets consists of subjecting metal sheets to consecutive manufacturing processes. The whole process is divided into six steps:

1. Punching & cutting

[147] Export Delivers Site, Sales Section, accessed 27 of July 2023.
Available at: https://export.rsdelivers.com/es/product/rs-pro/caja-de-montaje-en-rack-de-19-1u-rs-pro-de-245-x-x/1881313

2. Bending
3. Welding
4. Polishing
5. Powder coating
6. Packing/Assembling

### 1. Punching & cutting

The safest and most accurate way to perform punching and cutting is by using a CNC machine, resorting to punching and cutting tools, or a laser tool that can do both. A CNC requires a technical specialist to operate it.

**CNC**


*Figure 54: CNC to ensure accurate punching and cutting*[148]

**Skills and Competencies for Module Manufacturing by using a CNC**[149]

- Technical Knowledge: The operator should have a solid understanding of computer numerical control (CNC) systems, including programming, setup, and troubleshooting.
- Blueprint Reading: The ability to read and interpret engineering drawings, blueprints, and technical specifications to program the CNC machine accurately.

[148] Mach4Metal Sales Section, accessed 27 of July 2023
Available at: https://mach4metal.com/en/cnc-machining-centers/5-axis/dmg-mori-dmf-2607
[149] Mach4Metal Sales Section, accessed 27 of July 2023
Available at: https://mach4metal.com/en/cnc-machining-centers/5-axis/dmg-mori-dmf-2607

- Material Knowledge: Familiarity with various types of metal sheets and their properties to optimise cutting and punching parameters.
- Machine Setup: Competency in setting up the CNC machine, including loading tools, setting cutting paths, and ensuring proper workpiece positioning.
- Maintenance Skills: Basic maintenance and cleaning of the CNC machine to ensure optimal performance and longevity.

### 2. Bending

Performed in the bending machines that require a technical operator. After the first bending, the accuracy of the bending width is measured (with a vernier or so), and the machine is adjusted accordingly. Then, batch bending is performed.

**Bending Machine**


*Figure 55: Bending machine to perform bending on metal sheets*[150]

[150] Trumpf Site, *Bending machines,* in https://www.trumpf.com/en_CA/products/machines-systems/bending-machines/, accessed 27 of July 2023.

**Skills and Competencies for Module Manufacturing by using a Bending Machine**[151]

- Bending Techniques: Proficiency in various bending techniques, such as air bending, bottoming, and coining, to achieve the desired angle and precision.
- Tooling Knowledge: Understanding the different types of bending tools and selecting the appropriate tooling based on material thickness and bending requirements.
- Machine Setup: Skill in setting up the bending machine, including adjusting backstops, gauges, and other parameters for accurate bending.
- Quality Control: Ability to inspect and verify the accuracy of bent metal sheets to meet dimensional tolerances and quality standards.

## 3. Welding

Welding can be performed manually or automatically. A technical specialist must perform manual welding and measure it to ensure the right angle. The error is controlled within 2mm, and if it is serious, it must be corrected. There are several options for welding automatically, resorting to a robot arm.

**Welding Machine**

*Figure 56: Welding machine to perform welding*[152]

[151] Trumpf Site, *Bending machines,* in https://www.trumpf.com/en_CA/products/machines-systems/bending-machines/, accessed 27 of July 2023.
[152] Fronious Site, *Plasma,* in https://www.fronius.com/en/welding-technology/products/robotic-welding/plasma-welding/plasma/plasma, accessed 27 of July 2023.

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

**Skills and Competencies for Module Manufacturing by using a Welding Machine**[153]

- Welding Processes: Competence in various welding processes like TIG (Tungsten Inert Gas), MIG (Metal Inert Gas), or spot welding, depending on the materials and joint requirements.
- Material Compatibility: Understanding the compatibility of different metals and filler materials to ensure strong and reliable welds.
- Safety Practices: Thorough knowledge of welding safety protocols and personal protective equipment (PPE) to prevent accidents and ensure a safe working environment.
- Weld Quality Inspection: Skill in inspecting welds for defects and ensuring they meet industry standards and specifications.

## 4. Polishing

A simple step that only requires a polish machine.

**Polishing Machine**

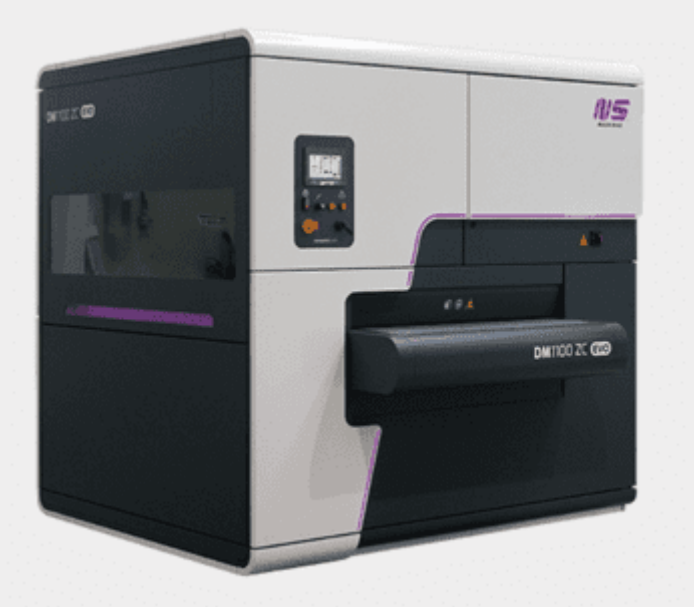


*Figure 57: Polishing machine to remove metal chips*[154]

[153] Fronious Site, *Plasma,* in https://www.fronius.com/en/welding-technology/products/robotic-welding/plasma-welding/plasma/plasma, accessed 27 of July 2023.
[154] NS Maquinas Site, *Remocao de Rebarba Arredondamento de Arestas,* in https://nsmaquinas.com/pt-pt/product/lixadoras-rebarba-arredondamento-dupla-face-dm1100-z2c-evo/, accessed 27 of July 2023.

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

**Skills and Competencies for Module Manufacturing by using a Polishing Machine**

- Surface Preparation: Knowledge of surface preparation techniques, including sanding and cleaning, before polishing to achieve the desired finish.
- Polishing Methods: Proficiency in using various polishing methods, such as abrasive wheels or buffing, to achieve the desired surface smoothness and shine.
- Material Considerations: Understanding different metal characteristics and how they respond to polishing to avoid over-polishing or damaging the material.
- Finishing Standards: Familiarity with finishing standards and customer requirements to ensure the final product meets the desired appearance and quality.

## 5. Powder coating

After several washes, a degreasing and a silane treatment, the metal sheets are hung and sprayed with a spray gun to perform the powder coating. Then, curing is achieved by introducing the metal sheets in an oven (180 degrees minimum). [155]

**Powder Coating Spray Gun**

*Figure 58: Spray Gun to apply the powder coating*[156]

[155] Nordson Site, *Robot Powder Coating Guns,* in https://www.nordson.com/en/products/industrial-coating-systems-products/robot-powder-coating-guns, accessed 27 of July 2023.
[156] Nordson Site, *Robot Powder Coating Guns,* in https://www.nordson.com/en/products/industrial-coating-systems-products/robot-powder-coating-guns, accessed 27 of July 2023.

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

### Spray Booth

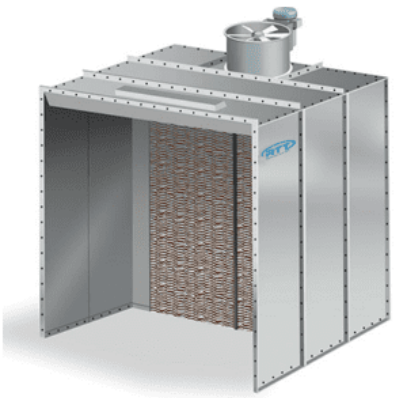

*Figure 59: Spray booth to enclosed/ventilated spraying*[157]

### Oven

*Figure 60: Oven for curing*[158]

### Washing and Degreasing Equipment

[157] RTT Solutions Site, *Open Front Paint Booth,* in https://rttsolutions.com/products/paint-booths/industrial/open-front-booths/, accessed 27 of July 2023.
[158] Lenton, *Specialist Ovens,* accessed 27 of July 2023
Available at: lenton 14001 oven brochure (approvedbusiness.co.uk)

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

*Figure 61: Washing and degreasing equipment*[159]

**Skills and Competencies for Module Manufacturing by performing a powder coating**

- Powder Coating Application: Operators should have expertise using the powder coating spray gun to apply an even and consistent coating on the metal sheets. This includes adjusting the gun settings, controlling the flow rate, and achieving the desired thickness.
- Surface Preparation: Competency in preparing the metal sheets before the powder coating process is crucial. This includes washing, degreasing, and ensuring the surfaces are clean and contaminant-free.
- Understanding of Powder Coating Materials: Knowledge about different types of powder coating materials and their properties is essential. This allows operators to select the appropriate powder coating material for the specific metal sheets and application requirements.

[159] Vevor Site, Sales Section, accessed 27 of July 2023.
Available at: https://eur.vevor.com/ultrasonic-cleaner-c_11064/30l-30-l-digital-ultrasonic-cleaner1400w-led-display-stainless-steel-jewelry-p_010353125527?adp=gmc&utm_source=google&utm_campaign=13621937902&utm_term=124365333056&gclid=CjwKCAjwq4imBhBQEiwA9Nx1Bij3Gucr3gGLgY3J9Qy5U6D5MIhhkMKfQcxDqyl9dCXh-C6Fhv9SYRoCbKkQAvD_BwE

- Curing Process: Operators should understand the curing process and how to properly set the oven temperature and time for effective curing without causing any defects.
- Safety and Environmental Compliance: Operators must follow safety guidelines when working with powder coating materials and operating the equipment. They should be aware of potential hazards and proper handling procedures. Operators should also be familiar with environmental regulations related to powder coating, such as proper disposal of unused powder and waste management.
- Quality Control and Inspection: Competency in inspecting the powder-coated metal sheets for uniformity, adhesion, and defects is necessary. This ensures that the final product meets quality standards and customer requirements.

### 6. Assembling

After completely manufactured, the metal sheets must be assembled, which is a process that does not require anything but basic tools, such as impact drivers.

**Skills and Competencies for Module Manufacturing to assemble metal sheets**

- Mechanical Assembly Skills: A strong understanding of mechanical assembly techniques is crucial for properly joining metal sheets. This includes aligning the parts accurately, inserting fasteners, and ensuring proper fit and finish.
- Reading Engineering Drawings: Competency in reading and interpreting engineering drawings is essential to understand the assembly instructions, dimensions, and tolerances.
- Fastening Methods: Knowledge of different fastening methods, such as screws, bolts, nuts, rivets, or welding, depending on the design and material of the metal sheets.
- Hand Tools Usage: Proficiency in using various hand tools, such as wrenches, screwdrivers, hammers, and pliers, to perform the assembly tasks.
- Power Tools Usage: Capability in using power tools like drills, impact drivers, and pneumatic tools to expedite the assembly process and achieve consistent results.
- Measurement and Precision: Skills in using measuring tools, such as calipers, rulers, and levels, to ensure precise positioning and alignment during the assembly.
- Teamwork and Communication: Effective communication within the team is essential to coordinate assembly tasks, share insights, and work together efficiently.

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

- Quality Control: A keen eye for detail and the ability to conduct quality checks throughout the assembly process to ensure that the final product meets quality standards.
- Safety Awareness: Knowledge of safety protocols when handling tools, materials, and heavy objects to prevent workplace accidents.

### 2.1.4 Dry room, including related skills, competencies, and job roles

In battery production, where precision is crucial for electronics and chemical manoeuvring, both gloveboxes and dry rooms play vital roles. The glovebox ensures a controlled, oxygen-free environment for handling sensitive battery materials, while the dry room maintains low humidity levels to preserve material integrity. These controlled environments safeguard against contamination and moisture exposure, ensuring high-quality battery components throughout the manufacturing process. Gloveboxes are mostly used in research labs, and the dry rooms are more appropriate for industry.

**Glovebox**


*Figure 62: Glovebox*[160]

**Skills and Competencies for Dry environment by using a Glovebox**[161]

- Glovebox Operation and Maintenance: Competency in operating the glovebox's control panel and understanding its functions, such as setting gas flow rates,

[160] Environmental Expert Site, *Braun Model,* in https://www.environmental-expert.com/products/mbraun-model-unilab-plus-glove-box-workstation-595479, accessed 27 of July 2023.
[161] Environmental Expert Site, *Braun Model,* in https://www.environmental-expert.com/products/mbraun-model-unilab-plus-glove-box-workstation-595479, accessed 27 of July 2023.

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

controlling humidity levels, and managing the internal atmosphere. Knowledge of routine maintenance tasks, such as checking gas supplies, replacing filters, and ensuring proper sealing of the glovebox.

- Handling Inert Gases: Understanding the properties and handling of inert gases, such as nitrogen or argon, used in the glovebox atmosphere to create an oxygen-free environment.
- Material Handling and Contamination Control: Skill in handling materials inside the glovebox while avoiding contamination or exposure to moisture and oxygen from the external environment. Knowledge of material transfer techniques using the attached gloves and airtight transfer chambers.
- Safety Protocols: Awareness of safety procedures specific to glovebox operation, including emergency shutdown procedures, gas leak detection, and handling hazardous materials.
- Troubleshooting: Ability to identify and troubleshoot common issues that may arise during glovebox operation, such as gas leaks, faulty seals, or improper pressure levels.
- Glove Change and Maintenance: Competency in changing gloves properly to maintain airtight seals and prevent glovebox contamination. Knowledge of glovebox maintenance procedures, such as cleaning the interior, replacing damaged components, and performing routine checks.
- Material Compatibility: Understanding the compatibility of materials with the glovebox environment, especially when handling reactive or moisture-sensitive materials.
- Record Keeping: Keeping accurate glovebox operation, maintenance, and material transfer records to ensure traceability and quality control.
- Communication and Collaboration: Effective communication within the team to coordinate tasks, report any issues, and ensure smooth glovebox operation.
- Environmental Control: Monitoring and adjusting the environmental conditions inside the glovebox to maintain the desired humidity, temperature, and gas atmosphere.

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

**Clean and Dry Room**

Diverse battery materials exhibit varying prerequisites concerning their ambient surroundings. Electronic components evince sensitivity to particulate matter and micro-constituents, which could compromise the integrity of these minuscule elements, thereby giving rise to instances of short circuitry. Similarly, battery electrodes manifest susceptibility to moisture, which can lead to contamination and subsequent occurrences of chemical reactions not conducive to desired outcomes. In this context, clean rooms assume paramount significance, proffering environments characterised by minimal dust particulates while maintaining relative humidity levels within the 40 to 60% range. Conversely, dry rooms, akin to clean rooms, support rigorous dust control protocols but distinguish themselves by maintaining a relative humidity threshold not exceeding 1%. The allocation of clean rooms and dry rooms within the battery manufacturing process is judiciously determined by the specific materials and components undergoing fabrication, thereby affording each their specialised role.[162,163]

*Figure 63: Clean Room[164]*

[162] Oberberger M., *Clean Production for Battery Cell Assembly,* in https://blog.flexlink.com/clean-production-for-battery-cell-assembly/, 2 November 2022.
[163] Nicos Group Site, *Cleanrooms & Dry Rooms for Automotive Battery Manufacturing,* in https://www.nicosgroup.com/post/cleanrooms-dry-rooms-for-ev-battery-manufacturing-lithium-ion-battery-facilities-for-renewable-energy-automotive, accessed 17 of August 2023.
[164] Exyte Site, *Cleanroom products – new ideas for new markets,* in https://www.exyte-technology.net/en/products-solutions/cleanroom-products, accessed 27 of July 2023.

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

**Skills and Competencies for a clean environment by operating a Clean Room**[165]

- Clean Room Protocol: Understanding and adherence to clean room protocols, including gowning procedures, hygiene practices, and contamination control measures to maintain the cleanliness of the environment.
- Material Handling: Skill in handling materials, tools, and equipment within a clean room environment while preventing contamination and maintaining cleanliness.
- Gowning and Personal Protective Equipment (PPE): Competency in correctly donning and doffing clean room garments and PPE, such as gloves, masks, and coveralls, to ensure a contamination-free work environment.
- Aseptic Techniques: Knowledge of aseptic techniques to avoid introducing contaminants and maintaining sterile conditions while performing tasks within the clean room.
- Equipment Operation: Proficiency in operating clean room-specific equipment, such as laminar flow hoods and particle counters, to ensure proper functionality and prevent contamination.
- Cleaning and Maintenance: Skill in cleaning and maintaining a clean room environment, including routine cleaning of surfaces, equipment, and workstations according to established procedures.
- Documentation and Record Keeping: Accurate record-keeping of activities, materials used, and any deviations from clean room procedures for traceability and quality control.
- Attention to Detail: A keen eye for detail to identify and address potential contamination risks, such as particle generation, and take appropriate corrective actions.
- Communication and Teamwork: Effective communication and collaboration within the clean room team to ensure smooth operations and minimise the risk of contamination.
- Emergency Response: Understanding emergency procedures and protocols within a clean room environment, including handling spills, equipment malfunctions, and other unexpected situations.

[165] Exyte Site, *Cleanroom products – new ideas for new markets,* in https://www.exyte-technology.net/en/products-solutions/cleanroom-products, accessed 27 of July 2023.

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

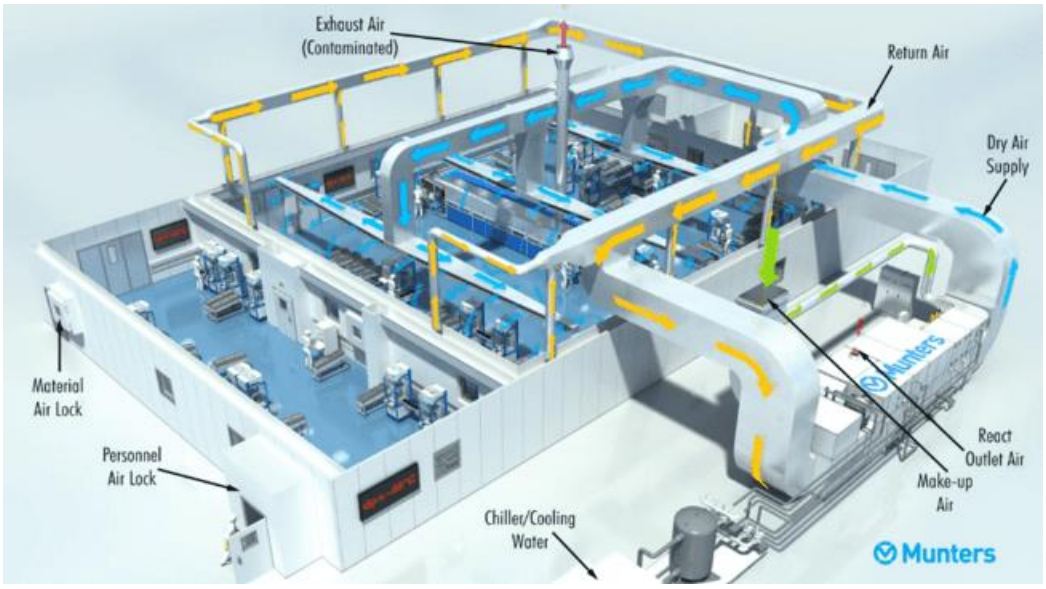


*Figure 64: Dry Room*[166]

**Skills and Competencies for Dry environment by operating a Dry Room**[167]

- Environmental Control: Competency in operating and adjusting the environmental control systems, including dehumidification units and temperature control, to maintain the desired low humidity level within the dry room.
- Humidity Monitoring: Skill in using humidity monitoring equipment to continuously measure and monitor the humidity levels in the dry room, ensuring they remain within the specified range.
- Maintenance and Troubleshooting: Knowledge of routine maintenance tasks for the dehumidification system, including filter replacement and system checks, to ensure proper functioning. Ability to identify and troubleshoot issues that may affect the dry room's environmental control system and address them promptly.
- Material Handling and Contamination Control: Understanding proper material handling techniques to prevent contamination and moisture exposure in the dry room environment. Knowledge of procedures for transferring materials in and out of the dry room without compromising the low humidity conditions.

[166] Munters Site, *Lithium battery dry room dehumidifiers for a production-perfect environment,* in https://www.munters.com/en/industries/battery/, accessed 27 of July 2023.
[167] Munters Site, *Lithium battery dry room dehumidifiers for a production-perfect environment,* in https://www.munters.com/en/industries/battery/, accessed 27 of July 2023.

- Safety Protocols: Awareness of safety procedures specific to the dry room environment, including precautions related to handling sensitive materials in low-humidity conditions.
- Record Keeping: Keeping accurate records of humidity levels, maintenance activities, and any material transfers in and out of the dry room for traceability and quality control purposes.
- Material Compatibility: Understanding the compatibility of materials with low-humidity environments and ensuring that only suitable materials are brought into the dry room.
- Communication and Collaboration: Effective communication within the team to coordinate tasks, report any issues related to the dry room's environmental control, and ensure smooth operations.
- Environmental Monitoring and Alarm Response: Skill in responding to environmental alarms or deviations from the desired humidity levels and taking appropriate actions to restore proper conditions.
- Cleanliness and Organization: Maintaining cleanliness and organisation within the dry room to prevent dust or particulate contamination and ensure an efficient working environment.

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

# 3 Education and training on production equipment

The green transition process towards a carbon-neutral economy and favour electromobility has created a great challenge in terms of education training for employees in the new processes and diverse range of manufacturing operations. The everyday question for current and newly built gigafactories is how to effectively train many employees through the whole process of the production line as well as demanding soft skills among the companies' teams.

## 3.1 EDUCATION STRATEGY FOR EMPLOYEES IN GIGAFACTORIES IN EUROPE AND BEYOND

The battery sector is carefully watched from many perspectives, including investors, media, public and local authorities to support the incentives in terms of money and education strategy throughout publicly funded associations and other training providers. In general, there are multiple approaches for Gigafactories in Europe to successfully operate and educate the staff from every level. Here are the ten key points to further expand the education strategy within companies operating within the Gigafactory:

1. Technical Skills Development: Companies are creating their private and public comprehensive training programs to establish continuous learning strategies for their current employees due to upskilling trends not only in technologies but also in the general development of the manufacturing processes, machinery operations, automation, robotics, and others.
2. Cross-Training Opportunities: Unique strategy to support specialised training in multiple areas within the Gigafactory as well as encouraging flexibility for certain employees at specific job roles
3. Continuous Learning: Large institutions provide continuous learning for their employees by offering workshops and online courses to enhance professional development and maintain their knowledge with a rapid upgrade in the industry
4. Leadership Development: Higher level education for managers and future leaders within the gigafactory. Companies are providing special learning courses on managerial skills, decision-making and effective communication and on other soft skills

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

5. Collaboration and Knowledge Sharing: Part of the education and learning process in the gigafactories is similar to other non-manufacturing companies by establishing collaboration and knowledge sharing among employees through teamwork, projects, and regular meetings. Sharing opinions, exchanging practices, and creating greater innovation in the processes to improve and compete is one of the most crucial aspects of the continuation of the business.
6. Sustainability and Green Technologies: Followed by the European Green Deal and the approach towards carbon neutral economy, the companies are following the public environmental objectives and, therefore, train their employees to focus on energy-efficient processes, water and waste reduction and recycling initiatives
7. Soft Skills Development: Soft skills are generating more attention. It is crucial for companies to establish an environment where teamwork, problem-solving and communication are widely recognised and accepted to work effectively within such a diverse community of professionals in different fields under one roof.
8. Career Development: In an organisation such as gigafactories, employees need to see a certain growth path within the organisation to keep them motivated and pursue their maximum abilities to work towards future progress. Therefore, companies need to focus on a clear strategy to offer such programs for each job role category to support their professional growth
9. Partnership with Education Institutions: As mentioned above, large companies in such progressive business field are focusing on collaboration with local universities, technical schools, and vocational training centres to attract new candidates as well as creating customised education programmes with professionals from such institutions
10. Employee Feedback and Evaluation: The last point is well underrated, but it is a key metric for managers within such companies to follow on employees' needs and feeling about their job role to maintain good performance and

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

consider different approaches in creating various workshops or courses for employees

## 3.2 WELL-KNOWN EU JOB ROLES AND SKILLS EDUCATION PROVIDERS IN THE BATTERY FIELD

**ASA – Automotive Skills Alliance**

The Automotive Skills Alliance (ASA) is focused on the re-skilling and up-skilling of workers in the automotive sector, developing intelligence and fostering dialogue among all relevant partners and stakeholders in the industry, and supporting the elaboration of specific plans for re-skilling, up-skilling, and training of workers in the EU automotive sector.

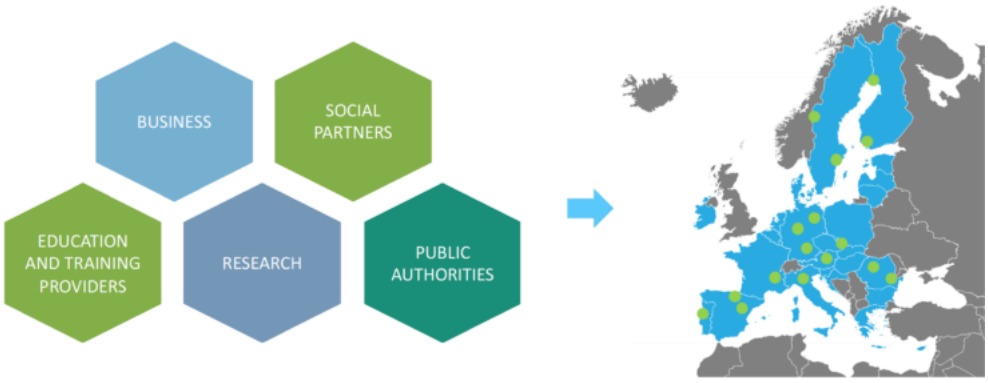


Figure 65: The ASA Mission[168]

The ASA mission is to contribute to better coordination of relationships at the European level of all the relevant national or regional stakeholders in the automotive ecosystem to ensure and develop a common platform for collaboration and best practice sharing across borders. In this regard, ASA intends to ensure continuous, pragmatic, and sustainable cooperation on the skills agenda in the ecosystem.

The ASA created specific battery-oriented courses that are publicly available. Each course focuses on different job topics and areas, providing employers with more opportunities to choose from.

[168] ASA Site, *Automotive Skills Alliance,* in https://automotive-skills-alliance.eu/about-us/#:~:text=The%20ASA%20mission%20is%20to,best%20practice%20sharing%20across%20borders, accessed 15 September, 2023.

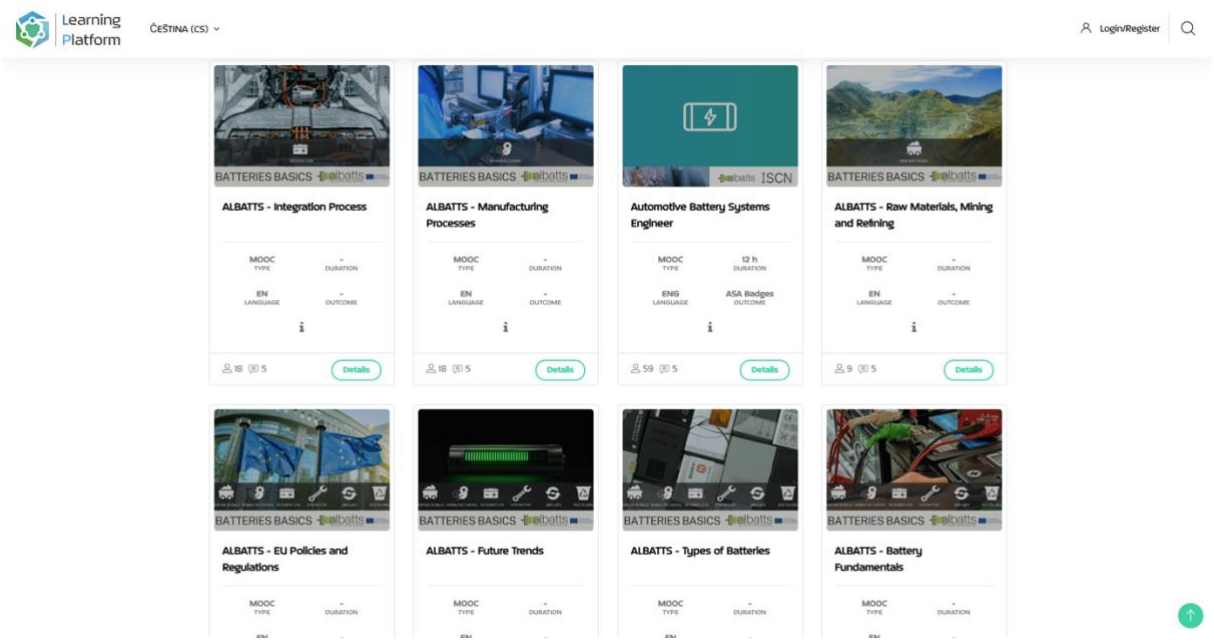


Figure 66: EBA Academy (Former Innoenergy)[169]

**EBA Academy (former InnoEnergy)**

The European Battery Alliance (EBA) was launched in October 2017 by European Commission Vice President Maroš Šefčovič. The purpose is to ensure that all Europeans benefit from safer traffic, cleaner vehicles, and more sustainable technological solutions. All this will be achieved by creating a competitive and sustainable battery cell manufacturing value chain in Europe.

The economic upside is clear: the market will have an estimated annual value of up to €250 billion by 2025. By combining European cutting-edge competencies, financial strength and a cross-industrial approach, a competitive and sustainable production capacity is clearly within reach.

EIT InnoEnergy drives the industrial development programme of the European Battery Alliance. Thanks to its experience in supporting battery and storage innovations, EIT InnoEnergy was asked by VP Šefčovič in October 2017 “to continue its groundwork in partnership with the EU industry, academia, and financial sectors to deliver first recommendations on enabling framework conditions” by March 2018.

EIT InnoEnergy led this work, bringing together more than 120 European and non-European stakeholders representing the entire battery value chain. The result is a definition of 43

[169] Learning Platform, *Courses,* in https://learn.skills-framework.eu/?lang=cs, accessed 15 of September 2023.

necessary actions to set up a dynamic and efficient European Battery Alliance and to capture a significant share of the rapidly expanding global battery market.

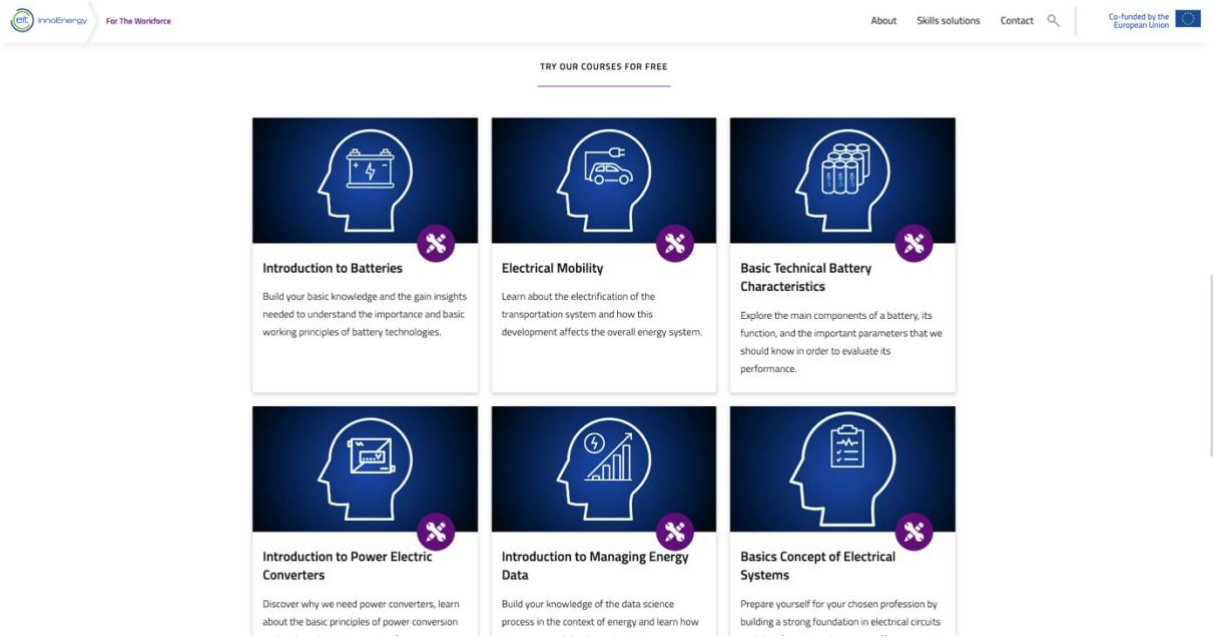


Figure 67: EIT Innoenergy Courses[170]

## 3.3 MODERN APPROACH TOWARDS LEARNING BY USING AR, VR AND SIMULATION-BASED TECHNIQUES

The education and training on production equipment is a process where digital tools of VR and AR are practically used in all modern courses. Apart from technological advancements, a collaborative approach is considered part of the courses to enhance collaboration between participants working effectively in teams and between institutions creating advanced courses together. Below are several examples of new courses in growing business fields where transformation towards electrification is already ongoing, and students with technological companies are working together to simulate tasks and experience real-world examples from companies.

[170] EIT Innoenergy Site, *Try our courses for free,* in https://www.innoenergy.com/skillsinstitute/, accessed 15 of September 2023.

**Digital Tools – Simulation-based Education for the PV and Storage Optimization Tools**

The «PV and Storage Optimisation Tool» is an online tool to enable installers and prosumers to evaluate the economic viability of a PV+Storage system. The tool considers parameters such as detailed load and production profiles, electricity costs, supporting schemes, etc. The user enters various inputs: electrical consumption, solar irradiation, PV and battery size, and electricity costs. The tool calculates the Levelised Cost of Electricity, the Net Present Value and the Internal Rate of Return. The tool may be used to estimate the best PV+Storage system sizing from an economic point of view.

The «StoRES Living Lab» provides an interactive web platform which displays data collected from the project «StoRES» pilot sites (or any other pilot site provided that the data input is in the same format as that underpinning the tool) and allows users to experiment with different parameters that influence energy storage. Different pilot plants can be compared, and a parametric study is also included to assess the sizing of the PV and the BESS. Under the parametric study feature, the user may modify the size of the PV capacity and the BESS size and observe how the performance rates are affected. For each profile, the following values are represented:

- PV production power
- Load consumption power
- Direct PV power use
- Power charged/discharged in/from the battery
- Power imported/exported from/to the grid
- State-of-Charge percentage level

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

Figure 68: Smart grid optimisation tools and business modelling energise Europe's future[171]

Participants in the «StoRES» stakeholders training received a «Certificate of Attendance» for attending a 2-hour training on Battery Energy Storage. The Certificate had the logos of the institutions involved and, therefore, were recognised in their respective countries. The tools should include upcoming technologies, new policies, etc. Within participating countries and across other countries.[172]

**Digital Tools at Virtual Practical Training in Engineering Fields**

Simulated enterprise for technical work in technology companies is a European Social Fund project implemented by the Ministry of Education in partnership with the Politehnica University of Bucharest, Politehnica University of Timisoara, Constantin Brancusi University of Targu-Jiu, conducted between 2011 and 2013.

The project aimed mainly at increasing the employability of university graduates in terms of training and development of the practical engineering skills required by employers by developing and implementing an integrated information platform that simulates real working technology companies and hiring specialists from these companies for students' practical training and for developing supporting materials. These goals were accomplished using an innovative tool for Romanian higher education: simulated enterprise.

[171] AGUASOL Site, Smart grid optimisation tools and business modelling energise Europe's future, in https://aiguasol.coop/smart-grid-optimisation-tools-and-business-modelling-energise-europes-future/, accessed 15 of September 2023.

[172] Photovoltaic Technology Laboratory Offoss  *Research Centre for Sustainable Energyuniversity of Cyprus. PV Technology - University of Cyprus*, in https://fosscy.eu/laboratories/pvtechnology-lab/ accessed September 15, 2023.

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

According to the project evaluation, done from the perspective of all involved actors (companies, universities, students), the results proved to be positive. The companies were pleased that they were able to provide specific training for the students from the first year of study and to accommodate students with a real working mentality about deadlines, internal communication, discipline, etc.

In the following year, many of the students participating in the project were accepted by the companies for internships participating in joint project research. Companies are expected to cut down the cost of training for their future young employees, who should be better prepared for their careers. The university was happy to provide better practical training and take advantage of the mentality change for some of the students proved to become better motivated for studying and building their future careers.[173]

**Building a block of a life-size vessel simulating the working conditions of a shipyard within the educational environment**

CIFP Ferrolterra is a technical VET school located in Ferrol (Northwest of Spain), where Navantia, one of the most important shipyards in Europe, is also settled. Once they have completed their VET degree, most students are employed either by Navantia or by one of the related auxiliary companies.

The Freeboard PE's main goal was to provide a naval work environment for students and to simulate the work conditions of a real shipyard, which is the most likely workplace for local students in the future. As a result, a real-scale part of a ship's hull was constructed.

VET students of Welding Boiler making, and HE students of Metallic constructions improved their skills in tubular welding and assembly work, "learning by doing" during the construction phase of this project, facing real working conditions. Block Assembly Process and the same standards and methodologies as in shipyards were applied in this Pilot Experience.

The Pilot Experiences' outcomes provide indispensable knowledge for bridging the maritime skills gap and increasing both sectors' overall competitiveness and attractiveness.

The constructed ship hull provided a working environment for students to conduct technical training in a setting comparable to real life. They experienced conditions that they would face in a real work environment. The hands-on training was conducted under controlled conditions with the same materials and design standards conventionally used in shipyards. Participants

[173] Research Gate Site, *ICT and E-Learning in Higher Education in Croatia, Strategies And Current State,* in https://www.researchgate.net/publication/310460675_ICT_and_e-learning_in_higher_education_in_Croatia_strategies_and_current_state, accessed September 15, 2023.

learned to carry out the processes of manufacture, assembly and repair processes of boiler-making elements, pipes, metallic structures, and metallic joinery, applying welding, machining and shaping techniques, and complying with the specifications on quality, labour risk prevention and environmental protection.

- Applying labour and ethic habits in their professional activity according to the characteristics of the job position and the procedures established.
- Preparing materials, equipment, and machinery for the scribing, cutting, machining, shaping and joining of elements, building structures, metallic joinery and industrial piping installations by the established procedures, applying the regulations concerning labour risk prevention and environmental protection.
- Machining and shaping sheet metal, profiles, and pipes in accordance with manufacture specifications, applying the regulations concerning labour risk prevention and environmental protection.
- Fitting pipes, metallic structures, and metallic joinery, complying with the plans concerning labour risk prevention and environmental protection from the provided technical documentation.
- Obtaining welded or surfaced sheet metal, profiles and pipes through electric welding, oxy-fuel gas welding, TIG, MAG/MIG, submerged arc welding and surfaces through thermal or arc spraying from the building plans complying with the plan on labour risk prevention and environmental protection.
- Verifying dimensions and characteristics of manufactured pieces, following the instructions established in the control plan.
- Two companies signed Dual programmes with the CIFP Ferrolterra as a result of the implementation of this PE. Navantia & CT Engineers in the 2021/2022 academic year and Gabadi & Windar renovables in the 2022/2023 academic year improve employability for students from the specialities of welding, boiler-making and mechanical manufacturing design.[174]

[174] Freeboard. *Project Mates 2022*, in https://www.projectmates.eu/pilotexperience/freeboard/, accessed September 15, 2023.

**VR Training Simulations**

Conducting live training in and around live high-voltage systems is not advisable due to the danger associated with electricity. Instead, virtual reality offers a safer alternative that offers many distinct advantages over real-world training for assessing trainee engagement and applying knowledge to the tasks they need to perform. A global technology leader, Aptiv provides a portfolio of technologies that make vehicles safer, greener, and more connected.

Figure 69: VR Training Simulations on the electric engine and BMS[175]

Gemba's virtual reality learning platform provides everything needed to deliver successful VR learning in one place. “People trained with VR recall as much as 75% of the learning material within 24 hours, which is significantly more than e-learning can ever achieve,” says Murray. “We saw it as the next best option to being in the room with our employees.”[176]

**AR versus traditional training methods**

Certifications and hands-on assessments have drawbacks. With paper and digital exams, trainers fail to assess if trainees grasp the real-world concepts required to be successful. With hands-on assessments, trainees are tested on valuable concepts, but data, such as human

[175] Xalter. *Why VR training can improve safety for EV industry workers*. Xalter 2022, in https://www.xalter.com/why-vr-training-can-improve-safety-for-ev-industry-workers/#, accessed September 15, 2023.
[176] Aptiv virtual reality business uses: Oculus for business. Aptiv Virtual Reality Business Uses | *Oculus for Business,* in https://business.oculus.com/case-studies/aptiv/, accessed September 15, 2023.

error and overall performance measures, is lost. This data is instrumental to improving future training programs.

Figure 70: AR and VR[177]

AR provides a means of combining the best of both evaluation methods by subjecting trainees to hands-on examinations while capturing essential data required to enhance training. AR can recognise when the wrong part is leveraged, when assembly steps are completed out of order, when it takes too long to complete a task, or when a misstep causes a safety risk.

**Battery Factory Simulation Model**

Factory simulation is more than a tool for manufacturing process optimisation. It is a way to explore options to communicate and discuss ideas more effectively. For integrators using automation processes in their factories, simulation is essential for business development and satisfying customers. The importance companies place on simulation is evident, as they are committed to incorporating it into their future projects.

One of the most advanced and high-reputation systems comes from Siemens Digital Industries Software. The complex product offers battery modelling and simulation solutions and engineering and consulting services to accelerate the design and engineering of batteries by virtually exploring design variants and assessing multi-level performance. Siemens aims at solutions that range from system simulation to 3D and CFD simulation, covering the wide scope of engineering domains required for battery systems design. Engineers can easily model various cell chemistry and battery pack designs and evaluate the overall performance in a vehicle context. The battery modelling and simulation

[177] Van Meteric Site, *How AR and VR are transforming training in manufacturing,* in How AR and VR are transforming training in manufacturing | Van Meter Inc., accessed 15 of September 2023.

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

solutions also enable us to consider battery charging and thermal management aspects and investigate the best possible control strategies for optimal performance. [178]

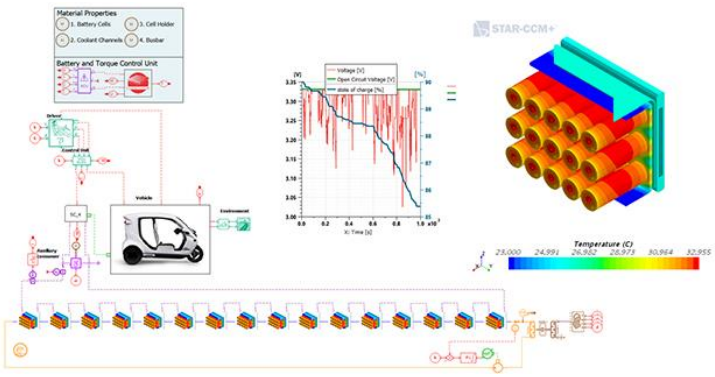

Figure 71: Battery Modelling and Simulation[179]

**Using digital twin in gigafactories**

The digital twin bridges the gap between development and reality, which is otherwise as large for few technologies as it is in the battery industry. An enormous number of parameters already determine the quality and performance of a cell, and the technologies that ultimately interact with the battery introduce many additional variables. All the data in the digital twin can be visualised, and their interaction can be better understood with the help of technologies such as artificial intelligence.


Figure 72: What is a digital twin? [180]

[178] Battery Modeling and Simulation: Siemens Software. *Siemens Digital Industries Software,* in https://www.plm.automation.siemens.com/global/en/industries/automotive-transportation/battery-modeling-simulation.html, accessed September 15, 2023.

[179] Battery Modeling and Simulation: Siemens Software. *Siemens Digital Industries Software,* in https://www.plm.automation.siemens.com/global/en/industries/automotive-transportation/battery-modeling-simulation.html , accessed September 15, 2023.

[180] Essex D. *What is a digital twin? ERP 2022*, in https://www.techtarget.com/searcherp/definition/digital-twin accessed September 15, 2023.

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

The digital twin gives the battery its brain — it acquires a memory, can provide information about its current status and dares to look into the future. The result pays dividends for the safety of the cell, as well as for the issue of sustainability. After all, with any lithium-ion battery, there is always the question of resources. However, to best ensure a second-life application of a battery, an understanding of what the battery has already accomplished in its previous life is needed. Simply looking at the charging capacity is not enough here.[181]

**Using AI to optimise battery machine learning optimisation with extension towards cell development**

Battery cells are incredibly complex, and the number of possible parameters that determine the qualities of a cell is high. Anodes, cathodes, separators, electrolytes, and housing materials influence the chemical reactions inside the cell and determine, among other things, the charging properties and service life. Artificial intelligence, specifically machine learning and other technologies, can contribute to optimisation and make complexity manageable, at least in part. For example, by independently recognising which process parameters achieve desirable results, production systems help to improve manufacturing quality and increase production. In these cases, the system continuously compares the properties of the cell and its subcomponents with the parameter sets of the individual process steps.

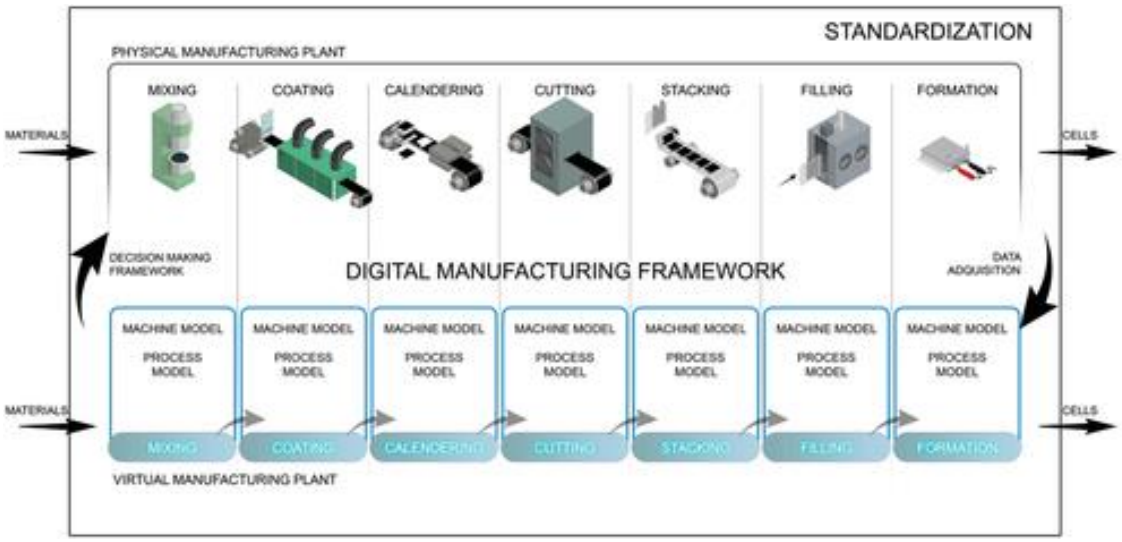


Figure 73: Digital Manufacturing Framework [182]

[181] CustomCells, *The Digital Twin Of A Battery: How It Works. Medium 2023*, in https://medium.com/master-of-batteries/the-digital-twin-of-a-battery-how-it-works-cd3456b4666c (accessed September 15, 2023).
[182] Photovoltaic Technology Laboratory Offoss , *Research Centre for Sustainable Energyuniversity of Cyprus. PV Technology - University of Cyprus* in https://fosscy.eu/laboratories/pvtechnology-lab/ (accessed September 15, 2023).

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

While attention is currently focused on machine learning for process optimisation in production, the technology also offers enormous potential in development — especially in combination with a digital twin. For example, instead of developing application-specific battery cells using a broad matrix of experiments, various settings can be adjusted in a digital environment controlled by AI. This could be the correct configuration of the mixing unit for the electrode slurries or the discovery of innovative material combinations, for example.

However, the road to fully automated development is long, especially one that provides the suitable materials and cell design for the application-specific purpose at the push of a button and constantly evolves by reinforcement learning. Numerous constraints must be taken into account during development. For example, an AI could use machine learning to identify promising electrode configurations. Appropriate approaches are already being pursued in research. In these cases, the AI learns to predict the electrochemical properties of a wide range of materials. In the future, this should help speed up development processes. AI could then help, for example, pre-select materials or focus on materials that have received little attention.[183]

[183] ICT and E-Learning in Higher Education in Croatia: *Strategies And . n.d.* https://www.researchgate.net/publication/310460675_ICT_and_e-learning_in_higher_education_in_Croatia_strategies_and_current_state (accessed September 15, 2023).

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