Project Nr.: 2024-1-SK01-KA220-VET-000256192

BATPOWER
Preparation of the VET sector on battery energy transition

BatPower: Preparation of the VET sector on battery energy transition

2024-1-SK01-KA220-VET-000256192

WP2/A2.1

Desk research on industrial trends and effects of mass application of battery technology

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BATPOWER
Preparation of the VET sector on battery energy transition

INDEX

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BATPOWER
Preparation of the VET sector on battery energy transition

ANNEXES

-Desk research on industrial trends and effects of mass application of battery technology, **Spain**

-Desk research on industrial trends and effects of mass application of battery technology, **Hungary**

-Desk research on industrial trends and effects of mass application of battery technology, **Italy**

-Desk research on industrial trends and effects of mass application of battery technology, **Slovakia**

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BATPOWER
Preparation of the VET sector on battery energy transition

Introduction

The energy transition and the spread of electric mobility are profoundly transforming the European industrial landscape, posing new challenges and opening up significant opportunities for national production systems. In this context, the battery supply chain plays a strategic role, both as a lever for decarbonization and as a driving force for the reindustrialization and technological development of the continent.

This report offers a cross-sectional analysis of the main industrial trends observed in four European countries – Italy, Spain, Slovakia and Hungary – with the aim of identifying common trajectories, national specificities, replicable good practices and emerging critical issues. The analysis was conducted based on the national reports prepared by each partner country and focuses on three main areas: investments in battery production (gigafactories and related infrastructure), integration with the automotive sector and the development of research and innovation ecosystems. Two chapters are dedicated to the analysis of this last area, with a view to highlighting, in all the contexts analyzed, the relationship between industry and the VET system and the need to strengthen this collaboration, in order to guarantee an effective transfer of knowledge and the availability of the skills necessary for the sustainability of the ongoing transition.

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Preparation of the VET sector on battery energy transition

From a methodological point of view, the work was divided into three successive phases. The first phase involved a comparative analysis of the evidence gathered in the national reports, with the aim of classifying the content according to recurring themes and common strategic priorities. Subsequently, this content was synthesized in a common analysis structure, aimed at highlighting the common challenges at a European level, the existence of best practices at a national level and the recurring critical issues in the different contexts. Finally, the evidence that emerged was integrated into a unified analytical framework, aimed at defining recommendations and intervention models useful for strengthening industrial competitiveness and the coherence of public policies in the various national contexts.

The approach adopted allows for an overview of the dynamics at work in the battery sector, while at the same time enhancing the diversity of local experiences.

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Preparation of the VET sector on battery energy transition

1. Industrial trends

1.1 Battery Manufacturing Investments

The cross-sectional analysis of the country reports prepared by Italy, Spain, Slovakia and Hungary shows how battery production is assuming a strategic role in the European industrial transition, with significant investments in new gigafactories and production infrastructures distributed on a continental scale. The four countries share some common traits in their strategies, while expressing approaches and peculiarities that reflect their own economic structure and industrial positioning.

Common elements between partner countries

One of the most obvious traits shared by the partners is the increasing attraction of investments for the construction of gigafactories dedicated to the production of batteries for electric vehicles and energy storage systems. In all analysed contexts, these investments are considered a key asset to support the transition towards more sustainable production and mobility models.

A further shared element concerns the objective of reducing dependence on imports, in particular from Asian suppliers, by localising the most critical stages of the value chain in the country. Security of supply, combined with the desire to generate domestic added value, is a common strategic priority.

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BATPOWER
Preparation of the VET sector on battery energy transition

The international nature of the supply chain is another constant: industrial investments are often channelled through joint ventures or partnerships with global players, mainly from China, South Korea, Japan and Germany. This approach reflects the need to integrate know-how, capital and technology within an increasingly interdependent global network.

All countries also highlight the crucial role of public support, both in the form of direct subsidies and tax incentives, and through recognition of the sector as strategic at national level. The presence of structured government plans, sometimes linked to European funds (e.g. IPCEI, PNRR, Fit for 55), is indicated as a decisive lever to catalyse private investment.

Finally, alignment with climate and energy transition goals emerges as a cross-cutting dimension. Local battery production is interpreted as an enabler for achieving decarbonisation targets, particularly in the area of mobility and electrification of consumption.

National best practices

Each country contributes relevant examples that can be considered good practices that can be replicated in other contexts:

- Italy: The Teverola project, led by the FAAM (SERI) group, represents an integrated model covering the entire production chain, from basic material to recycling. Vertical integration, combined with the adoption of low environmental impact technologies and experimentation on new

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generation batteries (solid-state, sodium), makes Italy an emblematic case of a circular and sustainable approach.

- Spain: It stands out for the diversification of industrial investors, with the simultaneous presence of players such as Stellantis, CATL, Volkswagen and Envision-AESC. This plurality strengthens the resilience of the national ecosystem, reducing the risk of dependence on a single player.
- Slovakia: The experience of the Gotion InoBat Batteries (GIB) project, a collaboration between the Slovakian government and Chinese industrial partners, is a virtuous example of a strategic public-private partnership supported by targeted investment in infrastructure and research.
- Hungary: It has capitalised on its role as an automotive hub to attract battery manufacturers in the vicinity of plants of car manufacturers such as Mercedes-Benz, Audi and BMW. The synergy between automotive and battery manufacturing is one of the main success factors of the Hungarian model.

Critical issues raised

In spite of progress, the analysis also highlights some major critical issues:

- In Slovakia, the planned production capacity may not be sufficient to compensate for employment losses due to the decline in the production of endothermic engines. This imbalance between supply and demand raises questions about the sustainability of employment in the sector.

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- Italy and Spain are lagging behind in the construction of adequately robust technological innovation ecosystems. The attraction of production facilities, if not accompanied by investment in R&D and training, runs the risk of not translating into technological leadership.
- In Hungary, the geographical concentration of investments (mainly in the east of the country) could generate territorial imbalances, limiting the fair distribution of socio-economic benefits.
- Finally, a critical issue across all countries concerns the dependence on critical materials and the need to develop recycling and reuse chains to ensure environmental sustainability and industrial safety in the long term.

1.2 Automotive Sector and Battery Integration

The comparative analysis of the country reports drawn up within the BATPOWER project confirms that the ongoing transformation of the automotive sector, driven by the electrification of mobility, is a shared priority among the partner countries. The transition from internal combustion engine vehicles to electric propulsion systems is not only a technological change, but a real systemic reconfiguration, which substantially affects industrial policies, value chains, employment dynamics and supporting infrastructure.

Common elements between partner countries

In all the contexts analysed, there is a clear recognition of the transformative scope of the shift to electromobility, brought about on the one hand by the

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strengthening of European environmental regulations (such as the 'Fit for 55' package), and on the other hand by a growing consumer focus on transport solutions with a lower environmental impact. This transition has led to a significant increase in the demand for high-performance batteries, which are now essential to sustain the competitiveness of electric vehicles (EVs). As a result, the production and integration of batteries within automotive value chains is becoming strategically important, imposing new forms of industrial coordination.

A cross-cutting element highlighted in the reports is the need to strengthen the physical and logistical integration between battery production plants and automotive assembly plants. Proximity between the two sectors is considered essential to reduce transport costs, increase production efficiency and mitigate the risks of supply disruptions.

Similarly, there is a strong focus on the localisation of supply chains, with the aim of reducing dependence on non-European, especially Asian, suppliers. The ability to produce batteries domestically is seen as a lever to strengthen strategic autonomy and generate more domestic added value.

Finally, all the analysed countries recognise the strategic importance of the development of an extensive, widespread and efficient electric recharging infrastructure network, identified as a necessary condition to support the large-scale diffusion of electric mobility.

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BATPOWER
Preparation of the VET sector on battery energy transition

National best practices

Each country has outlined different operational strategies, from which some experiences emerge that can be considered good practice in the European context.

Hungary represents an emblematic case of industrial and territorial integration, having favoured the establishment of battery gigafactories in the vicinity of pre-existing automotive poles (BMW, Mercedes-Benz, Audi). The case of the CATL plant in Debrecen - among the largest in Europe - shows a high capacity for coordination between industrial policies, logistics and territorial attractiveness.

Italy and Spain, on the other hand, stand out for their initiatives aimed at strengthening the recharging infrastructure network, partly supported by their respective National Recovery and Resilience Plans. While acknowledging a certain delay compared to other Member States (e.g. Germany, the Netherlands), both countries are implementing public and private actions to promote a homogeneous coverage of the territory, aimed at overcoming the resistance to the adoption of the electric vehicle related to the uncertainty on the range.

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BATPOWER
Preparation of the VET sector on battery energy transition

Critical issues raised

The cross-sectional analysis also highlights some critical issues that could undermine the effectiveness of national strategies if not addressed in a systemic manner:

- In Slovakia, according to an analysis reported in the country paper and prepared by Cambridge Econometrics, the currently planned battery production capacity may not be sufficient to compensate for the expected job losses in the endothermic propulsion sector. This raises questions about the social sustainability of the ongoing transition.
- Italy and Spain lag behind in charging infrastructure compared to European standards, both in terms of density of charging points and available power. This infrastructure gap risks being an obstacle to the full implementation of electric mobility.
- Italy also points to the urgency of launching industrial reconversion processes for companies operating in the combustion engine sector. Failure to retrain them technologically and professionally could jeopardise their competitiveness and, in the long term, the sector's job security.
- In Hungary, the authorities emphasise the environmental challenges posed by the combination of car production and the expansion of gigafactories. The management of environmental impacts - particularly with regard to water resources, emissions and waste management - is an open issue that requires effective and coordinated responses.

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BATPOWER
Preparation of the VET sector on battery energy transition

1.3 Research and Innovation Ecosystem

The joint analysis of the country reports drawn up by the BATPOWER project partner countries (Italy, Spain, Slovakia and Hungary) highlights a strong consensus on the central role of research and innovation in the sustainable development of the battery industry and the transition towards electric mobility and advanced energy storage systems.

Common elements between partner countries

All countries surveyed recognise that strengthening science and technology skills is a prerequisite for sustaining industrial competitiveness in the long run. Innovation is seen not only as a lever to reduce dependence on non-European suppliers, but also as an enabling tool to address complex challenges such as energy efficiency, security of supply and environmental sustainability.

In each national context, there is active participation of universities, research centres and technology consortia in the development of solutions for battery design, management, reuse and recycling. R&D activities focus on emerging technologies such as sodium-ion batteries, solid-state, alternative materials with low environmental impact, energy management systems and second-life strategies for spent batteries.

A cross-cutting element is the increasing focus on the circular economy, promoted through disassembly, testing, reuse and recycling initiatives, in order

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to reduce dependence on critical materials and minimise the environmental impact of the entire battery life cycle.

The four countries have also established technology hubs, national consortia and collaborative platforms dedicated to the development of the sector, in some cases in synergy with major European strategies (e.g. European Battery Alliance). These structures aim to facilitate cooperation between public research, industry and institutions, creating the conditions for a dynamic and technology-transfer-oriented innovation ecosystem.

National best practices

While sharing similar objectives, partner countries have adopted differentiated approaches that offer relevant examples of good practice:

Spain stands out for strengthening the certification, validation and quality assurance of batteries, thanks to the work of bodies such as SGS TECNOS and centres of excellence such as CIDETEC and ITE. The MUBIL Hub, in particular, represents a European best practice for verifying battery performance in extreme conditions. In addition, TECNALIA's RHINOCEROS initiative testifies to an advanced commitment to promoting the reuse and sustainable recycling of lithium-ion batteries.

Italy proposes an innovative model through the CIRC-eV laboratory at the Politecnico di Milano, which integrates disassembly, testing, reassembly and recycling functions in a single infrastructure. This holistic approach represents a

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BATPOWER
Preparation of the VET sector on battery energy transition

European benchmark in the field of circular economy applied to electric mobility. The interaction between academic research and business also manifests itself in projects aimed at the development of alternative materials and low-impact technologies.

Slovakia presents an interesting experience of cooperation between the public sector, universities and industry, as demonstrated by the project for a flow battery jointly developed by Pavol Jozef Šafárik University, Košice Technical University and the company INO-HUB Energy. The establishment of the National Battery Centre represents a strategic initiative for the coordination of national efforts in the field of research.

Hungary is characterised by its attempt to directly link academia with industrial production through structured collaborations between universities (e.g. University of Debrecen and University of Pannonia) and major players in the battery industry such as CATL and Profigram. These initiatives focus on topics such as battery chemistry, material recycling and sulphuric acid regeneration, with a strong orientation towards sustainability and industrial application of scientific results.

Critical issues raised

The comparative analysis highlights some critical issues that may hinder the full exploitation of the sector's innovation potential in different countries:

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BATPOWER
Preparation of the VET sector on battery energy transition

- In Spain, despite the solid testing infrastructure, there is a need to link research more effectively to industrial production and to attract highly specialised profiles.
- In Italy, the system presents a vibrant research landscape, but suffers from a structural gap between academic research and industrial application, aggravated by the lack of skills in digitised and automated production environments.
- In Slovakia, there is a difficulty in transferring research results into concrete applications, highlighting the need for more effective mechanisms to move from the experimental phase to industrial-scale production.
- In Hungary, the national report points to a multiplicity of obstacles: insufficient public funding, poor collaboration between businesses and universities, difficulties in knowledge transfer and protection of intellectual property, and the absence of incubation and acceleration programmes that could foster the development of innovative start-ups.

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BATPOWER
Preparation of the VET sector on battery energy transition

2. Workforce Challenges and Educational Gaps

The spread of electric mobility and energy storage technologies has accelerated the demand for new professional skills, generating increasing pressure on education and training systems. The national reports of the countries participating in the BATPOWER project unanimously highlight the presence of systemic and structural criticalities in the adaptation of education provision and in the preparation of the current and future workforce for the new industrial context.

Common elements between partner countries

One of the recurring elements that emerged from the analysis is the significant shortage of specialised technical skills in key areas of the battery supply chain. This shortage concerns professionals with advanced knowledge in electrochemistry, materials engineering, computer-aided design (CAD-CAM), industrial automation, robotics applied to battery production, Battery Management Systems (BMS), as well as skills in recycling and product life cycle management.

This is accompanied by a widespread weakness of the practical component in education, both at vocational education level and in the university context. Educational paths, in most cases, do not include up-to-date laboratory modules or meaningful experience in real industrial environments. Schools and

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universities often lack adequate equipment for the assembly, testing and recycling of batteries, thus compromising the operational readiness of students.

A further critical element concerns the mismatch between educational curricula and the actual needs of the labour market. In all the countries analysed, there is evidence of a delay in the updating of educational pathways with respect to the rapid technological evolution of the sector. Collaboration between training institutions and companies is still poorly structured, with a low incidence of co-design of training content.

However, the shortcomings are not limited to technical skills. The national reports also point to insufficient attention being paid to the development of soft skills: problem-solving, critical thinking, effective communication, ability to work in a team, project management and digital skills. In a highly technologically complex and strongly interconnected sector , these skills are considered indispensable.

The ongoing industrial transformation also requires increasing efforts in terms of retraining (reskilling) and updating (upskilling) the workforce from traditional sectors, in particular the automotive sector. This transition poses major organisational and financial challenges, in a context where the speed of change often exceeds the adaptability of training systems.

Finally, in some countries (notably Spain and Italy), the difficulty in retaining highly qualified talent, attracted by better job opportunities abroad, is

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reported. This brain drain phenomenon represents a threat to the sustainability of industrial and innovation policies.

National best practices

In spite of shared criticalities, the partner countries offer outstanding examples of virtuous initiatives and innovative approaches in training:

Spain stands out for the implementation of a solid Dual Vocational Training (VET Dual) system, with specific modules on batteries and strong synergies with companies in the sector. The Sagunto Battery Campus, developed with PowerCo, and the partnerships with SEAT and Volkswagen represent an advanced example of integration between theory and practice, inspired by the German model.

Italy values its technical and vocational education system, recognising its quality but also the room for improvement. The report's recommendations emphasise the need to build structured partnerships between schools, training centres and businesses, aimed at co-designing educational pathways and continuously updating teachers and laboratory equipment.

Slovakia stands out for the certification and apprenticeship initiatives developed in cooperation with industry, in particular with InoBat Auto. The establishment of the National Battery Centre contributes to strengthening the

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specialised training offer and promoting a practice-oriented learning ecosystem.

Hungary has significant experiences of direct business involvement in training, as demonstrated by the collaboration between CATL and the University of Debrecen. The interaction between large industrial groups and academic institutions represents an opportunity to facilitate technology transfer and the practical application of skills.

Critical issues raised

- In Spain, a mismatch between supply and demand of skills is reported, with a high drop-out rate in STEM pathways and still insufficient preparation in EV and batteries among workers in the automotive sector. Soft skills are poorly integrated into VET pathways, and the phenomenon of professional migration to other European countries is growing.
- In Italy, in addition to a shortage of up-to-date laboratories, there is still limited participation of companies in dual training and an excessive slowness in adapting curricula to rapid technological change. Moreover, territorial imbalances persist, both in terms of industrial opportunities and support infrastructures.
- In Slovakia, the main critical issue is the absence of specialised VET programmes, accompanied by a lack of practical activities and curricula that are not aligned with the needs of the battery industry. There are also shortcomings in soft skills and marked regional disparities.

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BATPOWER
Preparation of the VET sector on battery energy transition

- In Hungary, the problems relate to inadequate curricula, limited practical experience and insufficient training for trainers. The dual training system is still poorly structured, and there is a lack of materials in the national language, as well as deficiencies in the mechanisms of skills transfer between industry and the education system.

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Preparation of the VET sector on battery energy transition

3. Recommendations for Education and Industry Collaboration

Methodology

The analysis of the recommendations in the national reports was based on a comparative and structured approach, aimed at identifying common themes, national specificities and promising practices for strengthening vocational education and training (VET) in the battery technology sector. The methodological process consisted of three main steps:

1. Comparative analysis of the recommendations: the recommendations in each report were examined and grouped according to recurring thematic areas, such as the updating of curricula, practical training, collaboration with industry, retraining programmes, the creation of centres of excellence and the role of institutional support. This phase made it possible to highlight the strategic priorities shared between the different contexts.
2. Synthesis of key issues: the recommendations were further synthesised in order to extract cross-cutting principles and guidelines, potentially applicable across national borders. This process facilitated the identification of a coherent set of common strategic guidelines.
3. Elaboration of an integrated methodological framework: the results of the analyses were finally organised into a unified conceptual framework, useful to guide the development and implementation of effective training policies responsive to the needs of the battery industry.

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Preparation of the VET sector on battery energy transition

Results of cross-sectional analysis

Through this cross-sectional analysis, a strong convergence emerges among the four countries on the need for a synergetic approach involving educational institutions, companies and governments to address the challenges of the battery workforce. The recurring recommendations emphasise the importance of up-to-date and relevant curricula, a strong practical component in training, close links between education and industry, and an ongoing commitment to reskilling the workforce to ensure a successful transition to electric mobility and sustainable battery production.

To ensure sustainable and competitive growth in the battery sector, it is crucial to bridge the gap between the skills required by the labour market and those available through educational systems. A central element is the upgrading and innovation of vocational education and training (VET) programmes to include specific modules on battery technology, such as their structure, chemistry, operation (including lithium batteries and alternatives such as solid-state and sodium batteries), industrial automation and circular economy principles. It is also essential to invest in educational and technological infrastructure, creating centres of excellence with well-equipped laboratories for battery assembly and testing. The integration of modules on battery certification in VET programmes, including internships in companies in the sector, is another key recommendation.

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Preparation of the VET sector on battery energy transition

Another crucial aspect is the strengthening of practical training and cooperation between industry and educational institutions. This can be achieved through the creation and dissemination of structured paid traineeship and apprenticeship schemes for students from technical colleges and universities. Companies should be more involved in the definition of training content through the co-design of joint modules and courses and the organisation of seminars and workshops with industry experts. The expansion of dual training models, which combine classroom learning with practical experience in real industrial settings, is considered an effective strategy.

In parallel, it is imperative to implement retraining and refresher programmes for the existing workforce (reskilling and upskilling). These programmes should be aimed at providing marketable skills at short notice, especially for workers from traditional industries, with a focus on interdisciplinary knowledge and specialisation in battery technology. The development of digital education and distance learning programmes with interactive and practice-oriented materials can expand access to such retraining opportunities.

The creation of regional centres of excellence and training poles has been suggested to concentrate resources and reduce skills shortages in specific areas. These centres could host practical laboratories equipped with industrial testing tools and promote collaboration between academia and companies.

Government support and funding play an essential role in stimulating investment in training and technology development in the battery industry

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through subsidies, tax incentives and benefits for companies hiring qualified personnel.

Finally, strengthening collaboration with certification centres and promoting research and development (R&D) and technology transfer are considered important to ensure high quality and safety standards and to stimulate innovation in the sector. This includes the encouragement of joint research projects between universities, research centres and companies, as well as the creation of shared laboratories.

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BATPOWER
Preparation of the VET sector on battery energy transition

Conclusion

The cross-sectional analysis of industrial trends in the partner countries has highlighted how the battery supply chain represents a strategic axis for the sustainable industrial development of Europe. Despite the differences in levels of industrial maturity, in governance models and in investment policies, some common elements clearly emerge: the importance attributed to the localization of production, the growing integration with the automotive sector, the centrality of research and innovation and the essential role of technical and professional training.

All the countries examined are trying to position themselves along the battery value chain, attract productive investments, strengthen their technological capabilities and develop local ecosystems capable of supporting the energy transition. In this process, collaborations between industry, research centers, training institutions and public authorities play a decisive role in ensuring consistency, effectiveness and continuity of the strategies adopted.

The comparative analysis has also made it possible to identify a series of good practices that can inspire replicable interventions, as well as some recurring critical issues that require coordinated responses at the European level. Among the latter, we note in particular the difficulty of bridging the gap between innovation and industrial application, the territorial fragmentation of opportunities, the lack of technical skills and the structural weakness of the link between the education system and the productive world.

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BATPOWER
Preparation of the VET sector on battery energy transition

In this context, an in-depth understanding of the main industrial trends in the battery and automotive sectors is a fundamental step towards integrating this evidence into VET courses, bringing the education system closer to the real dynamics of the production sectors, supporting consistency between the demand for skills and the training offer and helping to prepare a workforce capable of effectively accompanying the battery and energy transition.

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WP2/A2.1:

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Table of contents

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1. Executive summary

This document analyses the impact and trends of battery technology in Spain, focusing on its application in the industry and its role in the energy transition.

Spain holds a significant position in the battery industry, driving initiatives in testing, certification, and quality assurance. The increasing adoption of renewable energy has created the need for efficient storage systems, with lithium-ion batteries standing out for their flexibility and fast response capabilities. Additionally, the reduction in battery production costs and the growing investment in gigafactories strengthen the country's position as a key player in the sector.

The development of the sector faces several challenges, including:

- **Shortage of specialized talent:** There is a significant gap between academic training and the skills required by the industry.
- **Automation and digitalization**: Technological transformation requires labour market adaptation and professional training in new competencies.
- **Talent retention**: The migration of specialists to other countries with better working conditions poses a risk to Spain's competitiveness.
- **Regulations and certifications**: Compliance with international standards requires greater investment in infrastructure and training in battery certification.

To strengthen the sector and improve its competitiveness, the following recommendations are proposed:

- Promotion of Dual Vocational Training: Integration of battery certification modules into educational programs, including internships in industry-related companies.
- Continuous training for workers: Implementation of professional development programs focused on new technologies and regulations.
- Strengthening collaboration with certification centers: Establishing strategic partnerships with SGS TECNOS and other institutions for skill validation.

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- Creation of centers of excellence in testing and certification: Development of specialized infrastructures for advanced battery testing.
- Government support and funding: Grants and tax incentives to encourage investment in training and technological development in batteries.

Spain has the opportunity to establish itself as a leader in the battery sector, but addressing challenges in training, innovation, and regulation is essential. Collaboration between the government, industry, and educational institutions will be key to ensuring the sustainable growth of the sector and its contribution to the energy transition.

2. Introduction

Since the Industrial Revolution, humanity has heavily relied on fossil fuels to fuel its economic growth and technological development. For over a century, coal, oil, and natural gas have been the foundation of industrial progress, enabling unprecedented advances in transportation, power generation, and consumer goods production. However, the intensive use of these resources has brought severe environmental consequences, including climate change, air pollution, and the depletion of natural resources.

During the 20th century, global energy demand skyrocketed due to population growth, rapid urbanization, and industrial development. The oil crisis of the 1970s exposed the vulnerability of countries dependent on fossil fuels, prompting many nations to seek more sustainable and secure energy alternatives. In this context, interest in developing renewable sources such as solar and wind energy emerged, as they promised clean production and reduced dependence on hydrocarbons.

However, as these renewable energies were integrated into power grids, a fundamental issue became evident due to their nature: their production is intermittent and does not always align with peak energy demand. This created an urgent need to develop energy storage systems capable of storing surplus production and releasing it when necessary.

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The 21st century has witnessed a revolution in energy storage. Batteries have transitioned from a secondary technology to becoming the foundation of the energy transition. Their role is not only essential for balancing electricity production and consumption but has also enabled the expansion of electric mobility, replacing internal combustion engines with more sustainable alternatives.

Spain, aligned with the European Union's decarbonization goals, has taken on a key role in the energy transition by promoting the adoption of large-scale energy storage technologies. The growing electrification of transportation and the implementation of storage systems in the power grid have created a constantly evolving market where batteries play a strategic role.

Energy storage through batteries reduces dependence on conventional and fossil fuel-based energy sources, facilitating the integration of renewables. Without adequate storage solutions, the power system must resort to traditional sources during peak demand periods, reducing the efficiency of the renewable model and increasing greenhouse gas emissions.

On the other hand, the expansion of electric vehicles has driven the demand for high-performance batteries, leading to the evolution of more efficient technologies with greater storage capacity. Sustainable mobility is one of the pillars of the energy transition, and lithium-ion batteries have enabled electric vehicles to offer competitive ranges, reduced charging times, and longer lifespans.

Despite the growth of the battery sector, significant challenges must be addressed to ensure its sustainable and competitive development. One of the main challenges in the industry is the lack of qualified talent. Technological advancements have created a growing demand for specialists in electrochemistry, materials engineering, and energy storage management. However, the training available in Spain is not yet fully aligned with market needs. To bridge this gap, it is essential to strengthen education in battery technologies. Dual vocational training programs and specialized courses in

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energy storage technologies will help train a new generation of technicians and battery specialists.

Another crucial aspect is the need for regulations and certifications that ensure the safety and efficiency of batteries. Battery certification in Spain has advanced significantly thanks to the participation of organizations such as SGS TECNOS and specialized research centers. However, harmonization with international standards and the development of more advanced testing infrastructures will be crucial to strengthening the country's competitiveness in battery certification and approval.

Spain has attracted significant investments for the construction of gigafactories dedicated to battery production. Companies such as Stellantis, Volkswagen, and Envision-AESC have announced large-scale projects that will boost the country's manufacturing capacity. These initiatives not only aim to reduce dependence on imports but also represent an opportunity to create jobs and strengthen the battery value chain in Spain.

Government support and tax incentives will be key factors in fostering investment in the sector. Additionally, collaboration between companies, research centers, and public administrations will be crucial to developing a strong industrial ecosystem around battery manufacturing and certification.

Battery recycling and sustainability are key aspects that require priority attention. Lithium-ion battery production involves the use of critical materials such as lithium, cobalt, and nickel, whose extraction has a significant environmental impact. In this regard, implementing efficient material recovery and reuse processes will be essential to minimizing the sector's ecological footprint and advancing toward a circular economy in the energy storage industry.

This report provides a detailed analysis of these aspects, offering a comprehensive overview of the current state of the battery sector in Spain and the necessary actions for its strengthening. The document is structured into several sections: first, it examines industry trends, highlighting Spain's role in

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battery certification and testing. Next, it analysis the main challenges the country faces, including the skills gap, automation, and the need to attract specialized talent. Finally, strategic recommendations are presented to improve training, promote certification, and strengthen the industrial ecosystem around batteries.

3. Industrial trends

3.1 Spain's Leadership in Battery Testing, Quality Assurance, and Certification

The energy revolution is already underway. With the unstoppable growth of renewable energy, energy storage has become a fundamental pillar to ensure a stable and efficient power supply. Solar and wind energy have proven to be the sources of the future, but their intermittent nature presents a major challenge: **how do we ensure a constant electricity supply when the sun isn't shining, or the wind isn't blowing?**

This is where energy storage plays a crucial role. Without efficient solutions, surplus energy generated during periods of low demand would go to waste, while periods of high consumption would still rely on traditional, less sustainable sources. The goal is clear: to capture, store, and distribute energy intelligently to optimize its use and minimize reliance on polluting energy sources.

With 3,300 MW of installed capacity, pumped hydro storage plants dominate the energy storage landscape in Spain, accounting for over 95% of the total stored energy [1]. . Their operation is simple yet highly effective: when excess energy is available, it is used to pump water to an upper reservoir. When energy demand rises, the water flows downward, generating electricity through turbines. However, these plants require specific geographical conditions, such as steep elevations and water availability, which limits their expansion.

Batteries are gaining ground as a complementary and more flexible alternative. As of 2023, Spain had 24.5 MW of batteries connected to the grid and 1,878 MWh in behind-the-meter systems, mainly in homes and businesses [2].

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Why Are Lithium Batteries a Key Solution?

- **Ultra-fast response:** They stabilize the grid and absorb demand peaks within seconds.
- **Total flexibility:** They can be installed in homes, industries, renewable energy plants, or electric vehicle charging stations.
- **Scalability:** They range from small home batteries to large-scale industrial storage systems.

However, batteries are not a perfect solution. They have a shorter lifespan compared to other technologies, and their replacement costs remain high. Despite these challenges, advancements in battery storage and recycling promise to improve efficiency and significantly reduce costs in the coming years. In fact, recent progress gives us reasons to be optimistic about an even better future.

According to a **BloombergNEF (BNEF) study**, between 2010 and 2018, battery costs dropped by 85%. Furthermore, projections estimate an additional 50% reduction in cost per kWh by 2030. [3]

Growth in Battery Demand

Batteries have evolved from a mere supporting technology to becoming the epicentre of the energy and technological transformation. Demand has been growing at an unstoppable pace, and all indications suggest that this trend will continue to accelerate in the coming years.

What is driving this market explosion?

- Electric vehicles (EVs) have transitioned from an alternative to the future of transportation. Improvements in range, charging times, and costs have fuelled their widespread adoption. A study by Finbold (Finance in Bold) indicates that global electricity demand for EVs will skyrocket by 2030. In 2023 alone, demand increased by 120% compared to 2022, and this trend is expected to accelerate further. Estimates indicate that the world will require 710,000 GWh to power electric vehicles, representing a nearly 632% increase from 2023 [4].
- The growth of solar and wind energy has made storage systems essential to ensure a stable energy supply.

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- From smartphones to laptops, smart homes, and decentralized power grids, batteries are at the core of our digital lives.
- As mentioned earlier, battery prices have dropped by over 85% in the last decade and will continue to decline, making electrification more accessible than ever.
- More individuals and businesses are investing in electric solutions and batteries as the pathway to a sustainable future.

Among all battery options, lithium-ion batteries have established themselves as the undisputed leaders. Their high storage capacity, fast charging, and efficiency have made them the backbone of electric vehicles and electronic devices. The lithium-ion battery market is expected to grow at a compound annual growth rate (CAGR) of 11.5%, increasing from $38 billion in 2020 to $101 billion by 2029 [5].

Although growing at a more moderate rate of 5.05% annually, lead-acid batteries remain relevant for industrial applications and stationary storage, ensuring stability in key sectors. [6]

Battery Safety

Despite their efficiency and versatility, lithium-ion batteries present certain inherent risks that must be properly managed:

- **Overheating and thermal runaway.** Overheating is one of the most critical issues in lithium-ion batteries. It can be caused by overcharging, manufacturing defects, or physical impacts that damage the cell, triggering a chain reaction known as thermal runaway. This phenomenon can lead to fires and explosions.
- **Leakage of toxic chemicals.** Batteries contain flammable electrolytes and heavy metals that can be released if the cell is punctured or damaged. These substances can be corrosive, flammable, and harmful to the environment.
- **Environmental impact of production.** The extraction of lithium, cobalt, and nickel—key components in batteries—raises environmental and social concerns. Mining these materials can lead to pollution, excessive water consumption, and ecosystem degradation.

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Regulations and Standards

To mitigate these risks and ensure battery quality, international regulations and certifications govern their production, use, and transportation. Below are some of the most important ones:

Among the key certifications, UN38.3 Certification, established by the United Nations [7], focuses on ensuring battery safety during international transport. This standard evaluates how batteries react to low pressure, vibrations, shocks, and sudden temperature changes that may occur during shipping.

Meanwhile, the IEC 62133 Standard, developed by the International Electrotechnical Commission (IEC), focuses on operational safety in daily use, particularly for consumer electronics and power tools [8]. While both certifications assess risks such as short circuits or overheating, their objectives differ:

- **UN38.3 ensures safe transportation,**
- **IEC 62133 certifies reliability in end-use applications.**

Additionally, international certifications such as IEC 62133 or the Certified Body (CB) Scheme [9] serve as a basis to streamline approvals in specific markets. This means they comply with widely recognized standards, making it easier for manufacturers to adapt their products to local regulations.

For specific markets, certain certifications are mandatory. For instance:

- The CE marking (Conformité Européenne) is mandatory for selling batteries in the European Union [10].
- The UKCA (United Kingdom Conformity Assessed) marking plays an equivalent role in the United Kingdom after Brexit [11].

At the same time, environmental regulations such as:

- RoHS Directive (Restriction of Hazardous Substances) [12] restricts the use of hazardous substances in batteries and electronic products.
- REACH Regulation (Registration, Evaluation, Authorization, and Restriction of Chemicals) [13] oversees the management of chemicals throughout the entire supply chain.

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With technological advancements, certifications have expanded or adapted to cover new applications. For example:

- UL2054 Certification, originally designed for household and portable batteries [14], shares some requirements with UL1973 Certification [15], which is more focused on advanced systems such as stationary storage and electric vehicle batteries.

This evolution reflects how certifications adapt to meet emerging safety and functionality demands in an increasingly electrified world.

While many certifications may seem similar, each one addresses specific needs related to safety, transportation, or environmental impact. These certifications ensure that batteries meet the highest standards at every stage of their lifecycle and in every market where they are sold.

Certification	Purpose	Main Application	Types of Batteries
UN38.3	Ensures battery safety during transportation under extreme conditions (vibrations, pressure, etc.).	Air, sea, and land transport.	Lithium-ion (Li-ion), Lithium Iron Phosphate (LFP), Lithium-Sulfur (Li-S), Nickel-Metal Hydride (NiMH).
IEC 62133	Evaluates operational safety of batteries in daily use, especially in electronic devices.	Portable devices, power tools, electric vehicles.	Lithium-ion (Li-ion), Lithium-Sulfur (Li-S), Nickel-Metal Hydride (NiMH).
CB (Certified Body)	Facilitates mutual recognition of safety certifications across 50+ countries.	International trade and local approvals.	Lithium-ion (Li-ion), Nickel-Metal Hydride (NiMH), Solid-state batteries.

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CE (Conformité Européenne)	Ensures compliance with European safety, health, and environmental directives.	Commercialization in the European Union.	All battery types (Li-ion, NiMH, Lead-Acid, emerging technologies).
UKCA (United Kingdom Conformity Assessed)	Meets safety and environmental protection standards required in the UK post-Brexit.	Commercialization in the United Kingdom.	All battery types (Li-ion, NiMH, Lead-Acid, emerging technologies).
RoHS (Restriction of Hazardous Substances)	Restricts hazardous substances such as lead, mercury, and cadmium in electrical products.	Environmental regulation for electronics sold in the EU.	All battery types.
REACH (Registration, Evaluation, Authorization, and Restriction of Chemicals)	Oversees the management of chemicals during production and commercialization.	Chemical substance management in battery manufacturing and export.	All battery types.
UL2054	Assesses the safety of portable and household batteries.	Electronic devices, laptops, mobile phones.	Lithium-ion (Li-ion), Nickel-Metal Hydride (NiMH).
UL1973	Ensures the safety of batteries in stationary storage and electric vehicle systems.	Renewable energy storage, electric vehicles, industrial applications.	Lithium Iron Phosphate (LFP), Lithium-ion (Li-ion), Redox Flow Batteries.

Table 1: Battery Certifications and Purpose

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The Battery Industry in Spain

Spain is establishing itself as a key player in battery manufacturing, attracting strategic investments to build gigafactories that will drive electric mobility and energy storage. These initiatives aim to position the country as a leader in battery production in Europe.

One of the most ambitious projects is the alliance between Stellantis and the Chinese company CATL, which will invest €4.1 billion in an LFP (Lithium Iron Phosphate) battery gigafactory in Zaragoza. With a projected capacity of 50 GWh, this plant will be able to equip up to 500,000 electric vehicles per year [16]. To put this into perspective, as of late 2023, Spain had 466,178 electrified vehicles, according to AEDIVE (Business Association for the Development and Promotion of Electric Mobility) [17].

The challenge is clear: Spain's Integrated National Energy and Climate Plan (PNIEC) aims to reach 5.5 million electric vehicles by 2030 [18]. Achieving this goal will require a major shift in mobility and a robust battery production ecosystem.

Another major investment comes from Envision-AESC, which has begun constructing a gigafactory in Navalmoral de la Mata. With an initial investment of over €1 billion, the plant is set to become operational in 2025 with a 30 GWh annual capacity. It is expected to create up to 900 direct jobs, with room for future expansion based on demand. Production will start in 2026 with an initial capacity of 10 GWh [19].

Lastly, PowerCo's gigafactory in Sagunto, Valencia, is a standout project. This Volkswagen Group initiative is dedicated to producing battery cells for electric vehicles. With an investment of approximately €3 billion, the plant is expected to begin production in 2026, starting with 20 GWh capacity, with plans to expand up to 40 GWh in later phases. This capacity will enable the supply of batteries for around 500,000 electric vehicles per year [20].

For Spain to solidify its position as a leader in battery manufacturing, attracting production investments is not enough. It is essential to develop a strong ecosystem of innovation and technological development. Spain's commitment is not only in manufacturing capacity but also in advanced research, product certification, and the development of new energy storage solutions.

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Several research and technology centers are playing a crucial role in shaping the future of batteries.

In the Basque Country, the MUBIL Hub has established itself as a leading center for innovation and development in smart and sustainable mobility. More than just a research space, MUBIL serves as a meeting point where technology, industry, and innovation come together to drive the future of electric transportation [21].

The MUBIL ecosystem includes state-of-the-art laboratories, leading companies, and R&D centers, all focused on the development and certification of advanced electromobility, energy storage, and digital transportation technologies.

With strong investments in gigafactories, ambitious mobility targets, and a growing innovation ecosystem, Spain is positioning itself as a European leader in battery manufacturing and technology development. The collaboration between industry, government, and research centers will be key to ensuring a sustainable and competitive battery sector in the years ahead.

One of the pillars of the MUBIL Hub is the CIDETEC Energy Storage laboratory, a state-of-the-art facility designed to validate batteries under real and extreme conditions, ensuring that the batteries of the future are safer, more durable, and more efficient [22].

Another major player in applied research is TECNALIA, recognized as Spain's largest applied research and technological development center and a benchmark in Europe. TECNALIA has established specialized battery laboratories to drive innovation in energy storage and sustainable mobility. It collaborates closely with automotive manufacturers, renewable energy companies, and energy storage infrastructure developers, ensuring that its innovations have a real impact on the industry [23].

One of its flagship laboratories is the Power Electronics Laboratory in Vizcaya, where product certification tests are conducted under UNE, EN, IEC, and UL standards for power converters (AC-DC). These tests focus on the most critical components of conventional and renewable energy systems, including solar power plants, fuel cells, energy storage systems, wind farms, and electric vehicle charging infrastructure.

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Additionally, TECNALIA leads the RHINOCEROS initiative, focused on developing innovative technologies for the reuse and sustainable recycling of lithium-ion batteries. The goal is to achieve high recycling rates, high material purity, a low carbon footprint, and greater scalability potential, reducing dependency on imports of critical raw materials [24].

At the Valencia Technology Park, the Institute of Energy Technology (ITE) is a reference in battery certification and advanced testing. Its work is crucial to ensuring that batteries meet the highest safety and performance standards before reaching the market. Among the tests conducted at ITE are safety assessments, performance validation, and extreme condition simulations [25].

Moreover, ITE has a real-time monitoring system [26], an advanced technology that allows:

- Live data collection on temperature, voltage, and electrical current.
- Instant anomaly detection, reducing risks and development times.
- Optimization of battery performance before commercialization.

This approach not only accelerates the certification process but also reduces costs and improves battery reliability, positioning ITE as a key partner for national and international manufacturers.

With centers of excellence such as CIDETEC, TECNALIA, and ITE, Spain is not only ensuring the quality and safety of future batteries but is also establishing itself as a hub of innovation and technological development in Europe. As battery demand continues to grow, the country is preparing to lead the energy transformation, providing advanced solutions for electric mobility and sustainable energy storage.

3.2 SGS TECNOS contributions to the battery cycle

SGS was founded in 1878 in Rouen, France. In 1915, its headquarters were moved from Paris to Geneva, Switzerland. In 1919, the company adopted the name Société Générale de Surveillance (SGS). It was established in Spain in 1929 and currently operates in all Autonomous Communities through its offices, laboratories (fixed and mobile), and Vehicle Inspection Stations (ITV).

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SGS is a global leader in inspection, verification, testing, and certification services. It offers a wide range of services, including the inspection and verification of the quantity, weight, and quality of traded products; testing to evaluate the quality and safety of products according to health and regulatory standards; and certification to ensure that products, processes, systems, or services comply with national or international standards.

In Spain, SGS provides services to various industrial sectors. In the energy sector, SGS offers inspection, testing, and certification services to ensure quality and safety in energy projects. In the battery sector, SGS provides numerous services, as outlined below:

Performance and Safety Testing

- Charge and discharge cycle testing. SGS conducts lifecycle and performance tests for batteries, evaluating energy efficiency, state of charge (SoC), and driving cycles.
- Temperature, vibration, and extreme condition testing. The company offers environmental condition simulations, including tests for temperature, humidity, condensation, vibration, and impact.
- Validation of durability and long-term reliability.

Specific Certifications and Standards

- SGS assists manufacturers in complying with various international regulations, including CE certification and UN transport safety requirements for batteries (UN 38.3). It also provides certification services based on IEC 62133 and IEC 62619 standards.
- Issuance of certifications that guarantee quality and safety, instilling confidence in both manufacturers and consumers.

Consulting and Technical Advisory Services

- Process improvement studies for battery manufacturing. SGS helps companies implement best practice systems for managing quality and sustainability.
- Support for companies in optimizing efficiency and reducing costs.
- Advisory services on battery recycling and second life applications.

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Through these services, SGS plays a fundamental role at every stage of the battery lifecycle, ensuring quality, safety, and sustainability [27]. As a result, other companies are increasingly interested in collaborating with SGS.

In June 2024, SGS announced several innovative projects in North America focused on the sustainable extraction of critical battery metals. These metals are essential to produce high-tech devices, renewable energy systems, and electric vehicles [28].

SGS and Coniagas Battery Metals ("Coniagas") established a strategic partnership to advance sustainable technological innovations for the rapidly expanding electric vehicle industry in North America. SGS is conducting rigorous tests and assessments in Quebec to help Coniagas supply high-quality battery metals to the EV industry with lower carbon-intensive solutions and shorter lead times.

SGS and The Metals Company ("TMC"), an explorer of the largest estimated untapped source of critical battery metals, have successfully produced the first nickel and cobalt sulfates derived exclusively from the seabed, demonstrating the potential for responsible resource utilization in marine environments. Similar tests are being conducted to sustainably extract other critical battery metals from seabed rocks. Through these initiatives, SGS is playing a key role in helping TMC relocate high-quality battery metal production to the U.S.

These collaborations and projects highlight SGS's international commitment to innovation and sustainability in the battery sector, working alongside various companies to develop greener and more efficient solutions for the production of essential components for modern technology.

SGS also contributed to the "II Annual Report on Electric Mobility" published by the Business Association for the Development and Promotion of Electric Mobility (AEDIVE). This document serves as a reference for public administrations, businesses, and industry professionals, providing analysis and key data on electric mobility in Spain. SGS's participation in this report underscores its commitment to and collaboration in the development of electric mobility in the country [29].

In Spain, SGS has participated in various initiatives and collaborations in the battery sector. Some of these are detailed below:

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Phase	Role	Description
Design and Prototyping Phase	Support in early validation of materials and components	SGS provides testing services for battery cells, modules, and complete systems, ensuring that materials and components used in the initial stages comply with international standards for safety, reliability, durability, and performance.
	Simulations and preliminary tests	The company conducts environmental condition simulations and performance tests, including temperature, humidity, vibration, and impact tests, to evaluate battery behavior under various conditions from the early development phases.
Production and Quality Control Phase	Implementation of quality controls in the assembly line	SGS helps manufacturers apply construction criteria and compliance requirements from the design stage to the end of the product lifecycle, ensuring quality at every stage of production.
	Audits and verification of manufacturing processes	SGS provides certification services that include manufacturing process verification and audits to ensure that management and production systems meet applicable regulations and standards.
Usage and After-Sales Phase	Monitoring programs and predictive maintenance	SGS participates in lithium battery research projects and collaborates with standardization committees, engaging in the development of monitoring and predictive maintenance programs for batteries in use.
	Real-use battery evaluation	SGS conducts performance and lifecycle testing for batteries, assessing energy efficiency and state of charge in real-use conditions, which is crucial for applications like electric vehicle fleets.
End-of-Life and Recycling Phase	Methodologies for certifying safe reuse and recycling	SGS takes part in standardization committees and research projects, contributing to the development of methodologies to certify the safe reuse and recycling of batteries.
	Consulting on hazardous waste management and material traceability	SGS offers consulting services to help companies implement construction criteria and compliance requirements, including hazardous waste management and material traceability throughout the product lifecycle.

Table 2. SGS TECNOS Contributions Across the Battery Lifecycle.

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4. Challenges

4.1. General Overview of the Labor Market in Spain: Focus on Clean Technologies and Batteries

The labor market in Spain is undergoing an unprecedented transformation. The shift toward a sustainable economy, driven by European climate neutrality goals and the rise of clean technologies, is redefining both employment opportunities and the most in-demand skills.

Renewable energy, electric mobility, and energy storage are the sectors leading this revolution. In particular, the battery industry has become a key pillar.

The reason? The electrification of transportation and the need for efficient energy storage in power grids.

While this is a rapidly growing sector, it also presents a critical challenge: the surge in clean technologies has dramatically increased the demand for specialized professionals. However, there is a significant skills gap. Fields such as electrochemistry, advanced manufacturing, and digitalization require specialized training, and the fast pace of innovation makes continuous knowledge updates essential. Moreover, digitalization skills, data analysis, the Internet of Things (IoT), and artificial intelligence are becoming increasingly important.

The data supports this. According to Spain's National Institute of Statistics (INE) and the Ministry for the Ecological Transition, the renewable energy sector employed more than 130,000 people in 2022, almost double the number in 2016 [30]. And this is just the beginning. The Integrated National Energy and Climate Plan (PNIEC) forecasts that the policies being implemented will create between 253,000 and 348,000 new jobs between 2021 and 2030 (on an annual, non-cumulative basis). It estimates that renewable energy investments alone will generate between 107,000 and 135,000 jobs during the decade [31].

The electrification of transportation is also generating new job opportunities. The installation of charging stations, maintenance of electric vehicles, and battery recycling have become key sectors for sustainable job creation.

A revealing fact: the number of professionals with skills in electric mobility and batteries in Spain grew by 13.42% in 2024, according to LinkedIn. Spain ranks

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among the countries with the highest growth in this field, behind only Indonesia, India, Mexico, and the Netherlands. But there's a problem. Although progress is being made rapidly, only 3.35% of workers in Spain's automotive sector have training in electric vehicles and batteries. In countries like Germany, the UK, or the US, the percentage ranges between 8.9% and 4.3% [32].

The energy transition is not just creating jobs—it is redefining the skills necessary for professional success. The clean technology labor market is expanding rapidly, and the battery sector is a key component of this transformation. However, to fully capitalize on its potential, a coordinated strategy between governments, businesses, and educational institutions is essential.

4.2 Skills Gap and Training

The battery sector is undergoing rapid expansion, driven by the energy transition and the increasing demand for energy storage and electric mobility. However, this growth faces a critical barrier: the shortage of qualified professionals.

There is a significant mismatch between the technical skills required by the industry and the training provided by educational institutions. A report by DigitalES indicates that although 25% of students in Spain choose STEM careers, a high dropout rate leaves 30% of seats unfilled, worsening the shortage of talent in technology sectors [33].

Among the most in-demand fields of study are:

- Advanced electrochemistry – Essential for the development and optimization of battery cells.
- Materials engineering – Key to researching new components that increase efficiency and durability.
- Energy storage management – Crucial for designing and maintaining efficient storage systems.
- Electric vehicle maintenance – Requires specialized knowledge of advanced electrical and electronic systems.

The rapid technological evolution prevents training programs from keeping pace with industry needs. Additionally, the lack of collaboration between educational institutions and companies creates a gap between labor supply and demand. Insufficient investment in infrastructure and specialized training further limits access to these essential skills.

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This gap is not exclusive to Spain. The European Commission has acknowledged the problem and launched initiatives like the European Battery Alliance Academy to train workers in battery and electric vehicle manufacturing [34].

The lack of technical talent is already affecting the industry. The gigafactory planned by Stellantis and CATL in Figueruelas (Zaragoza) will require 3,000 qualified employees, mainly vocational training operators. Faced with this situation, trade unions and the Government of Aragón have called for urgent measures to adapt training programs to industry needs [35].

The skills gap extends beyond technical expertise—soft skills are also lacking. The battery industry needs professionals who not only master technology but also possess communication, adaptability, and teamwork skills. A report by the State Foundation for Training in Employment (Fundae) [36] highlights the importance of these skills for employability:

- Effective communication – Facilitates collaboration in multidisciplinary teams.
- Teamwork – Essential for efficiency in battery manufacturing.
- Adaptability and flexibility – Crucial in a constantly evolving sector.
- Problem-solving – Fundamental for optimizing processes and addressing technical challenges.

For years, vocational training programs have prioritized technical instruction, leaving soft skills in the background. Moreover, the lack of collaboration between educational institutions and companies prevents a practical approach that fosters these cross-disciplinary competencies.

This issue is not unique to Spain. A European study on higher education found that graduates often lack the soft skills required by the job market [37].

The absence of these skills slows down innovation and reduces production efficiency. Companies like Scoobic, an electric vehicle manufacturer, have identified this gap and are implementing training programs in both technical and soft skills to improve team cohesion and productivity [38].

The skills gap in the battery sector is a major challenge that Spain and Europe must address immediately. Without qualified professionals, the industry risks falling short of its potential and losing competitiveness in a rapidly growing global market. It is essential for vocational training to evolve, integrating cutting-edge technical skills while also fostering soft skills development.

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4.3 Impact of Automation and Digitalization

Automation and digitalization are profoundly transforming the clean technology industry, particularly in battery manufacturing. Smart factories, powered by robotics, artificial intelligence (AI), and the Internet of Things (IoT), are replacing traditional processes and reshaping the labour market. This shift presents significant challenges, but also new opportunities for professionals with expertise in automated system management. Vocational training in this sector is crucial to prepare workers and ensure employability in an evolving job market.

Automation has revolutionized production lines, replacing many manual tasks with automated processes. In the battery sector, smart factories now incorporate advanced machinery to assemble cells, monitor quality in real time, and optimize energy consumption. These innovations lower costs and enhance efficiency, but they also impact workers previously responsible for repetitive or mechanical tasks.

According to the "Future of Jobs 2025" report by the World Economic Forum (WEF), it is projected that by 2030, 170 million new jobs will be created, while 92 million jobs could be displaced due to automation, resulting in a net increase of 78 million jobs. In the battery industry, this shift affects tasks such as material handling, component assembly, and initial quality testing [39].

This change creates uncertainty among traditional workers, especially those with lower levels of education, who face the risk of job displacement if they do not acquire new skills. The rapid pace of automation also poses challenges for vocational training programs. Many educational institutions are not yet equipped to incorporate advanced technologies such as industrial robotics or AI system management into their curricula. This results in a skills gap between industry demands and graduates' capabilities.

While automation replaces certain jobs, it also creates new employment opportunities. Smart factories require skilled technicians to operate and maintain automated machinery, as well as programmers to develop and optimize control algorithms. In the battery sector, specialists are needed in areas such as:

- Predictive maintenance – Technicians using AI-based tools to anticipate machine failures and minimize downtime.

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- Robot programming – Professionals who design and program robots for cell assembly, high-precision welding, and automated inspections.
- Data analysis – Experts who analyze large datasets generated by IoT sensors to optimize production efficiency.
- Systems integration – Technicians responsible for coordinating different automated components, ensuring they operate synchronously in factory environments.

According to the WEF Future of Jobs 2025 report, 85% of new industrial roles will require advanced technical skills in automation and digitalization [39]. These emerging opportunities highlight the urgent need to adapt vocational training programs to equip workers with the skills necessary for these evolving roles.

4.4 Talent Retention and Brain Drain

The battery and energy storage industry in Spain faces a critical challenge: brain drain. Engineers, technicians, and specialists are seeking better opportunities in countries like Germany, France, and the Nordic nations, where working conditions are more attractive. This issue does not only affect university graduates but also vocational training (VET) professionals, who are the essential workforce of this sector.

According to Eurostat, Spain leads in labour migration in technological sectors, with a constant outflow of skilled workers to countries with better conditions [40]. This reality raises a crucial question: **How can Spain compete to retain and attract talent in a sector that is vital for its economy and sustainability?**

When discussing brain drain, the focus is often on engineers or highly specialized profiles. However, vocational training technicians are the backbone of production, installation, and maintenance in clean technology industries, and their migration has a direct impact on the country's industrial capacity.

Without a sufficiently qualified workforce, domestic companies face delays, increased costs, and reduced innovation capacity, jeopardizing industry growth.

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There are four main reasons why vocational training professionals seek employment abroad:

1. Higher salaries. Specialized technicians in Germany or Sweden can earn 30-40% more than in Spain, according to Eurostat data. While in Spain, a battery technician earns between €22,000 and €28,000 annually, in Germany, salaries range from €35,000 to €45,000.

2. Job instability. Temporary contracts and precarious conditions remain common in emerging sectors like batteries. In many cases, six-month or one-year contracts prevent technicians from developing long-term careers. In Germany and Nordic countries, companies offer permanent contracts with additional benefits such as health insurance and pension plans.

3. Lack of professional growth. Career development is a key factor in talent retention. However, in Spain, vocational training technicians have limited opportunities for specialization. The lack of continuous training, certifications, and technology update programs makes many workers feel their career prospects are limited within the country.

4. Lack of recognition and appreciation. Despite being essential to the sector, vocational training technicians still face lower recognition compared to university graduates. In Germany and Sweden, vocational education enjoys higher recognition, and workers have access to development programs that allow them to progress within the industry.

This brain drain issue highlights the urgent need for policy changes to improve working conditions, salaries, and career development opportunities for skilled professionals in the battery and clean technology industry in Spain.

4.5 Labor Policies and Regulatory Framework

The development of clean technologies in Spain heavily relies on a strong regulatory framework and labour policies that promote employment and facilitate the transition toward a sustainable economy. Initiatives in renewable energy, energy storage, and electric mobility not only create new job opportunities but also require up-to-date vocational training to prepare workers for the technological challenges of this industry.

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Spain has taken significant steps in this direction. The Integrated National Energy and Climate Plan (PNIEC) 2021-2030 sets ambitious goals for renewable energy generation, energy storage, and carbon emission reduction. These objectives aim to meet international climate commitments while fostering job creation in strategic sectors [31].

The success of these policies largely depends on workforce training, particularly for technical professionals from vocational training. These workers are essential for the installation, maintenance, and operation of advanced energy systems. However, their professional development is often hindered by the lack of specialized programs tailored to industry needs. A strong regulatory framework should facilitate investment in training and enhance the connection between technical education and industry requirements.

The Next Generation EU funds are a key tool for boosting employment in clean technologies. In Spain, these funds finance projects ranging from the installation of renewable energy infrastructure to the construction of advanced battery manufacturing plants. These investments have the potential to create thousands of jobs in sectors such as manufacturing, recycling, and digitalization.

For vocational training (VET) workers, these European funds present a unique opportunity for training and professional development. Some ways to leverage these resources include:

- Upgrading vocational training centers: Investments in advanced machinery, simulators, and robotics technology to align with the demands of modern factories.
- Continuous training programs: Development of specialized courses for workers in areas such as industrial automation, battery recycling, and predictive maintenance.
- Youth employment initiatives: Promotion of internship and dual-training programs that enable VET students to quickly integrate into the labour market.

Several initiatives in Spain aim to strengthen vocational training in the battery sector through collaborations between educational institutions, companies, and public administrations. For instance, the Ministry of Education is working on new VET training programs linked to electric mobility, ensuring a skilled workforce for the industry's demands [41].

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These efforts demonstrate Spain's commitment to training specialized professionals in the battery sector, addressing growing industry needs and supporting the transition toward sustainable mobility.

5. Recommendations

5.1 Introduction: The Need to Strengthen the Certification Sector and Invest in Training

The previous chapter identified key challenges in Spain's battery industry, including the skills gap, lack of practical training programs, and the impact of automation. Currently, there is a shortage of trained professionals in battery testing and quality assurance, which limits the sector's growth and competitiveness. Moreover, available training programs are not always aligned with industry needs, making it difficult for new workers to integrate into the job market.

Ensuring quality and safety in battery production is crucial, especially considering the sector's rapid growth and its role in the energy transition. Specialized certifications play a key role in setting standards that guarantee safe and efficient products. Without proper regulation and qualified technicians, the risk of battery failures increases, potentially compromising user safety and market confidence.

In this context, training plays a critical role in meeting the growing demand for specialists in battery testing and quality assurance. The creation of specific educational programs and collaboration with testing laboratories will enhance technical training, prepare professionals for automation challenges, and ensure the industry has a highly skilled workforce. The following sections present strategic recommendations to strengthen certification training and quality assurance in Spain's battery sector.

5.2 Promoting Dual Vocational Training

The growing importance of the battery industry in Spain requires specialized vocational training that addresses the sector's needs. Implementing certification modules in vocational education is essential to train technicians in

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battery testing and quality assurance. Integrating these modules into curricula will ensure students acquire specific skills aligned with labour market demands.

In Spain, vocational training programs specializing in energy storage batteries are still emerging. The following are current educational options at the Intermediate Degree, Advanced Degree, and Specialization Course levels:

Intermediate Degree

- Currently, there are no dedicated Intermediate Vocational Training programs exclusively focused on energy storage batteries. However, some electricity and electronics programs include modules related to energy storage.

Advanced Degree

- Higher Technician in Renewable Energies: This 2,000-hour training program, part of the Energy and Water sector, covers solar photovoltaic system development, management, and maintenance, where energy storage is a key component. Graduates can work as solar photovoltaic project designers or maintenance supervisors.

Specialization Courses

- Specialization Course in Hybrid and Electric Vehicle Maintenance: Designed for graduates in Automotive Electromechanics, this course covers high-voltage electrical systems, battery technologies, and charging infrastructure, providing specific skills for electric vehicle maintenance.

- Energy Storage Specialist Course: Offered by the Institute of Energy Technology (ITE), this program explores various electrochemical storage technologies, battery management, and their applications in stationary systems. It is aimed at professionals seeking technical knowledge about batteries and their integration into energy systems.

- Master Course: Expert in Energy Storage and Batteries: An executive-level program that provides comprehensive training on cutting-edge energy storage and battery technologies, covering technical, regulatory, and business aspects. It is designed for professionals leading innovative battery projects.

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Given the rising demand for skilled professionals in the battery sector, the Ministry of Education is developing new VET programs focused on lithium, hydrogen, and biomass battery technologies, aiming to adapt educational offerings to the evolving energy sector [42].

A key strategic approach is the creation of training pathways in collaboration with industry partners, aligned with international certifications such as UN38.3, IEC 62133, CE, and RoHS. This collaboration ensures that educational content remains up to date and meets global safety and quality standards.

Along these lines, the European Union's Strategic Action Plan for Batteries promotes cooperation between research centers and industry to provide access to testing laboratories and specialized training. A notable example in Spain is the energy storage training program, developed jointly by the Ministry of Industry and the Extremadura Employment Service (SEXPE). This program includes seven training modules covering battery storage, management, fundamentals, control, applications, and regulations [43].

Additionally, it is essential to integrate technical training in critical areas such as durability testing, failure analysis, battery safety, and transportation regulations. Institutions like CIDETEC Energy Storage have expanded their battery testing capabilities, offering R&D services and tests that include performance analysis, durability assessments, and safety evaluations. The development of specialized courses within battery testing laboratories would allow technicians to train in real-world environments, gaining hands-on experience with tools and procedures essential for battery evaluation.

Dual Vocational Training emerges as an effective solution for preparing professionals in this field. This model combines classroom education with paid internships in companies, enabling students to gain practical experience and improve their employability. According to data from the Spanish Chamber of Commerce, 70% of VET Dual graduates find employment in their field, and one in three secures a permanent contract [44].

A notable example is the agreement between the Generalitat Valenciana and PowerCo to establish the Battery Campus in Sagunto, which will offer vocational and university programs related to battery production, as well as training for future gigafactory workers [45]. Similarly, companies such as SEAT and Volkswagen Navarra have implemented VET Dual programs in collaboration with training centers, allowing students to alternate between theoretical learning and practical experience in real industrial settings [46].

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Looking at best practices in other European countries, Germany stands out for successfully adopting this approach, integrating theoretical education with company experience, proving to be highly effective in training specialized battery technicians. Companies like S-Volt have set up factories in Germany, fostering collaborations with educational institutions to develop tailored training programs.

France, on the other hand, has promoted the creation of sodium battery factories, such as Tiamat's initiative, alongside specialized training programs to ensure a qualified workforce.

In conclusion, incorporating specialized vocational training in the battery sector is crucial to strengthening this industry in Spain. The development of certification modules in VET and universities, the creation of specialized courses in battery testing laboratories, and the implementation of VET Dual programs with company placements are key strategies to ensure high-quality education and successful job placement for future professionals.

5.3 Continuous Training for Workers

The rapid evolution of the energy sector in Spain requires effective strategies for continuous training, ensuring that workers stay up to date with new regulations and emerging technologies. The transition to more sustainable energy sources has increased the need for training in areas such as new battery chemistries, recycling techniques, and product lifecycle analysis. In this context, it is essential to develop training programs that allow professionals to update their knowledge and skills.

Institutions such as AENOR offer specialized courses in energy management, energy efficiency, and sustainability, tailored to current industry needs. For example, the "Energy Efficiency in Industry" course is designed to identify and understand key strategies to improve energy efficiency in equipment and production processes, enhancing industrial sustainability [47].

Meanwhile, the Institute of Energy Technology (ITE) provides advanced technical training in photovoltaic energy. The "Photovoltaic Specialization Course" focuses on the characteristics, technologies, and actions driving the use of photovoltaic energy as a renewable resource [48].

The Spanish government has launched various initiatives to promote continuous training in companies. The Startups Law (Law 28/2022, of December

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21) introduces tax incentives and administrative facilitation for startups, promoting investment in training and technological development. For instance, corporate tax rates are reduced from 25% to 15% for the first four years after a company achieves a positive tax base [49].

Additionally, programs such as Kit Digital offer grants to SMEs to adopt technological solutions, including training. This program aims to fund the implementation of digital solutions available on the market, enabling beneficiary companies to achieve significant progress in their digital maturity [50]. These incentives help reduce barriers to skill enhancement, facilitating workers' adaptation to industry changes.

Furthermore, integrating testing laboratories into technical and university education is a key strategy for preparing students for challenges in the energy sector, particularly in battery technology. This not only enriches academic training but also strengthens collaboration between educational institutions and the industry, ensuring effective alignment between theory and practice.

Continuous training in Spain's energy sector is essential to maintain competitiveness and adapt to technological innovations. A combination of upskilling courses, government incentives, and specialized programs in emerging fields ensures that professionals have the necessary skills to meet industry challenges and contribute to sustainable development.

5.4 Strengthening Collaboration with SGS TECNOS and Other Certification Centers

SGS TECNOS, a subsidiary of SGS in Spain, has demonstrated a strong commitment to practical training for students. In 2018, the company joined the Alliance for Dual Vocational Training, a national network promoting collaboration between businesses, educational institutions, and public entities to enhance youth employability through high-quality Dual Vocational Training [51].

Additionally, SGS TECNOS has established agreements with various educational institutions to offer professional internships. For example, in 2019, the company signed 27 collaboration agreements with different educational centers and universities nationwide, facilitating internships and final-year projects [52].

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Integrating SGS TECNOS facilities into training programs allows students to access advanced testing laboratories, where they can apply their knowledge in real-world scenarios. This collaboration enhances educational experiences and ensures that future professionals are familiar with current industry standards and certification procedures.

To further strengthen this collaboration, it is proposed to establish a standardized certification system within vocational training centers. This system would enable students to obtain industry-recognized certifications during their education, increasing their competitiveness in the job market. Implementing this system would require cooperation between certification bodies such as SGS TECNOS and educational institutions, ensuring that training programs align with industry standards.

Beyond SGS TECNOS, other companies and certification centers in Spain have expressed interest in collaborating with educational institutions. For instance, the Institute of Energy Technology (ITE) provides product certification services and has specialized energy storage laboratories, offering an opportunity to establish agreements that grant students access to training and internships in these facilities.

In summary, strengthening collaboration between educational institutions and certification centers like SGS TECNOS is essential for developing skilled professionals in the battery sector. Integrating testing facilities into training programs and establishing standardized certification systems within VET centers will ensure that students are well-prepared for labour market demands and contribute to a safer and more efficient energy industry in Spain.

5.5 Creation of Centers of Excellence for Battery Testing and Certification

The creation of centers of excellence dedicated to battery testing and certification is a key strategy to position Spain as a leader in the energy and technology sector. These centers would serve as hubs for innovation, training, and collaboration between universities, technology centers, and industry, driving the development of advanced technologies and ensuring high standards of quality and safety in energy storage systems.

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Institutions such as **CIDETEC Energy Storage** and the **Institute of Energy Technology (ITE)** have already taken significant steps in this direction. In 2020, CIDETEC inaugurated a new Battery Testing Laboratory at the MUBIL Electromobility and Energy Storage Hub, investing over €6 million in equipment. This laboratory is designed to support both research and development needs and the testing and certification demands of businesses [53].

Meanwhile, ITE has developed a unique testing facility for rapid battery diagnostics and reconditioning, consolidating its position as an international reference in battery technology. Its Battery Lab enables advanced testing of safety, durability, and performance, essential for developing and validating new energy storage technologies [54].

The creation of these centers of excellence requires significant public and private investment. Public funding can be sourced from national and European programs supporting R&D in renewable energy and energy storage. For example, **Spain's Recovery, Transformation, and Resilience Plan** includes investments in research and technological development infrastructures for the energy transition.

On the private sector side, investment can be incentivized through policies that promote collaboration between businesses and research centers. Battery manufacturers play a crucial role in designing internship programs and defining testing and certification requirements. Their participation ensures that training programs align with real market demands and that testing infrastructure meets international standards.

A successful example of collaboration is the agreement between CIDETEC Energy Storage and the **Official Central Laboratory of Electrotechnics (LCOE)** for battery certification and approval testing. This agreement allows for a comprehensive testing service for certification, compliance evaluation, and approval of batteries, leveraging the strengths of both organizations [55].

In summary, enhancing collaboration between educational institutions and certification centers such as CIDETEC and ITE is crucial for developing highly skilled professionals in the battery sector. Integrating testing facilities into training programs and creating standardized certification systems within vocational training centers will ensure that students are fully prepared for labor market demands and contribute to a safer and more efficient energy industry in Spain.

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5.6 Government Support and Funding for Battery Training and Certification

The training of new professionals in the battery sector is essential to drive innovation and ensure Spain's competitiveness in the energy field. To achieve this, it is crucial to establish funding mechanisms and support programs that facilitate specialized training and the integration of qualified technicians into the labour market.

The Spanish government has implemented various initiatives to strengthen the battery industry, including grants for institutions offering specialized certifications. For example, the Strategic Project for the Recovery and Economic Transformation of Electric and Connected Vehicles (PERTE VEC) provides financial aid for projects related to battery training, specifically targeting "Technology and/or knowledge providers: Universities, technology centers, research organizations, and other public or private entities providing the knowledge and/or technology necessary to support an industrial promoter". These subsidies aim to encourage the development of training programs incorporating battery testing certifications, ensuring professionals are trained in cutting-edge technologies and industry regulations [56].

Additionally, the Batteries Call of the 2024 Innovation Fund, launched by the European Commission, has allocated €1 billion to finance battery cell manufacturing projects for electric vehicles. This initiative seeks to strengthen the EU's industrial capacity in this key technology and represents an opportunity for educational institutions to develop specialized certification programs in battery testing [57].

Government support should focus not only on initial training but also on upskilling and retraining active professionals. The rapid evolution of the sector requires continuous education programs and certifications to keep technicians up to date with new regulations, materials, and emerging technologies in energy storage. In this sense, strengthening collaboration between universities, vocational training centers, and industry is key to ensuring that education aligns with market needs.

To encourage the hiring of specialized battery quality and safety technicians, it is advisable to establish tax benefits for companies. Currently, Spanish legislation offers tax deductions for R&D activities, allowing businesses to claim up to 42% in corporate tax credits for R&D participation. Additionally, there are

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Social Security reductions of up to 40% for each R&D professional, with a maximum of three years of bonuses per researcher [58].

Implementing specific incentives for hiring certified battery technicians could include additional corporate tax deductions or reductions in Social Security contributions. These measures would encourage the integration of qualified personnel into companies, driving innovation and ensuring compliance with quality and safety standards in the battery industry. Additionally, promoting public-private partnerships would enable greater investment in specialized training, ensuring that companies have access to highly skilled talent without bearing the full cost of training themselves.

Furthermore, aligning educational policies with the needs of the battery sector is essential for enhancing employability and specialization. Dual training programs, specialization scholarships, and the creation of specific degrees in collaboration with the industrial sector would be key strategies to optimize the impact of public funding on professional training.

Moreover, offering tax benefits to companies dedicated to battery certification could incentivize their establishment in Spain, positioning the country as a leader in training and competency validation in this sector. Attracting foreign certification entities would not only generate highly specialized jobs but also facilitate the national industry's access to international quality standards, boosting the competitiveness of Spain's battery sector.

Ultimately, government support and funding for battery training and certification are crucial to consolidating Spain's competitiveness in the energy sector. Through subsidies, tax incentives, and collaboration programs between educational institutions and industry, the talent ecosystem needed to ensure leadership in the development and production of next-generation batteries can be strengthened.

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6. Conclusions

The battery industry in Spain is at a crucial stage of its development. As the energy transition advances and the demand for energy storage grows, the country has the opportunity to establish itself as a leader in battery manufacturing, certification, and technology development. However, to realize this potential, it is essential to address the challenges identified in this report, including the shortage of skilled talent and the improvement of technical training, which are fundamental to ensuring the long-term sustainability and competitiveness of the sector.

One of the main challenges facing the industry is the skills gap in the labor market. The rapid technological evolution requires highly qualified professionals in materials engineering, electrochemistry, automation, and digitalization. However, the current training programs are not fully aligned with industry needs. To overcome this obstacle, it is crucial to strengthen collaboration between companies, research centers, and vocational training institutions, ensuring that educational curricula match labor market demands. In this regard, dual vocational training and continuous training programs play a key role in creating a workforce prepared for future challenges, preventing the brain drain of talent to other countries that offer better working conditions.

Quality assurance and certification are also emerging as critical factors for the sector's development. The need to comply with international regulations, ensure safety, and improve battery efficiency requires significant investment in testing and certification infrastructure. In this context, the expansion and consolidation of centers of excellence such as CIDETEC, the Institute of Energy Technology (ITE), and SGS TECNOS will help strengthen Spain's ability to compete globally. Additionally, the creation of standardized certifications within vocational training programs will ensure that workers acquire the necessary skills before entering the labor market, reducing the gap between educational offerings and industrial needs.

Government support and funding also play a determining role in the sector's growth. Investments in gigafactories by companies such as Stellantis, Volkswagen, and Envision-AESC demonstrate confidence in Spain's potential, but it is crucial that these initiatives are accompanied by public policies that encourage innovation and specialized training. Grant programs, tax incentives, and hiring benefits for qualified personnel can accelerate the development of a robust and sustainable industrial ecosystem. Likewise, implementing measures that promote public-private collaboration can

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facilitate new development opportunities, ensuring the long-term stability of the industry.

Finally, recycling and sustainability must be central pillars in the battery sector's development strategy. The growing demand for lithium, cobalt, and other critical materials poses environmental challenges that can only be addressed through the implementation of efficient reuse and material recovery processes. Promoting a circular economy within the sector will reduce dependence on raw materials and minimize environmental impact. Furthermore, advancing research in new energy storage technologies can lead to the development of more efficient and sustainable batteries, using less polluting materials and offering longer lifespans.

In summary, Spain has the capacity and resources to become a leader in the battery industry, but this will depend on its ability to overcome current challenges. Investment in training, certification, and collaboration between the public and private sectors will be essential to ensuring sustainable and competitive growth. With an adequate strategic approach, the battery industry can not only drive the energy transition in Spain but also position the country as a global leader in the energy storage economy, securing its leadership in a market that will define the future of sustainability and technological innovation.

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Project Nr.: 2024-1-SK01-KA220-VET-000256192

BATPOWER
Preparation of the VET sector on battery energy transition

BatPower: Preparation of the VET sector on battery energy transition

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WP 2/ A 2.1.

Hungary: Industrial Trends and Effects of Mass Application of Battery Technology

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Table of contents

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BATPOWER
Preparation of the VET sector on battery energy transition

Executive Summary

Hungary has become a European hub for battery manufacturing in recent years, driven by growing demand for electromobility and large-scale industrial investments. East Asian battery manufacturers, including China's CATL, South Korea's SK Innovation and Japan's GS Yuasa, have built significant plants in the country, mainly in Debrecen, Iváncsa and Göd. The demand for battery technology is being driven by the electrification of the automotive industry fueled by the global trend in which Hungary has become a key partner in the supply chain to the European Union market. However, the rapid development of the industry has created numerous challenges in the labor market and education. (Bemutatjuk Magyarország nagy autóipari térképét – így rajzolja át hazánkat a zöld forradalom, 2024)

Battery production requires specialized technological and engineering skills that are not adequately provided by local vocational and higher education institutions. The shortage of specialists is a critical problem , especially in the fields of electrical engineering, mechatronics and chemical engineering. Industrial partners often complain that graduates lack sufficient practical experience in the production, assembly and recycling of battery cells. The curriculum of educational institutions do not keep pace with rapidly evolving industry expectations, resulting in significant knowledge gaps among graduates.

The dual training system does not provide sufficient industrial experience for students, as the cooperation between battery manufacturing companies and educational institutions is not tight enough. The transition from the automotive industry to battery manufacturing is an additional challenge, as the retraining of workers specialized in the production of conventional internal combustion engines is slow and further training opportunities are limited. Regional differences are also significant, as battery factories are mainly concentrated in Eastern Hungary, while skilled labor is available in greater numbers in Western Hungary and Budapest.

To address these challenges, the education system needs to be adapted to industry expectations. Battery technology subjects need to be integrated into vocational and higher education curriculum, with particular attention to safety standards, recycling processes and energy storage solutions. Closer cooperation with industry is needed to ensure that practical training is properly

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integrated into the curriculum and that students receive relevant professional experience. Retraining programmes need to be intensified so that traditional automotive workers can also adapt quickly to the new technological environment.

The establishment of regional training centers that provide education and research opportunities specialized in battery technology are essential for the long-term development of the industry. Strengthening industry-education cooperation and modernizing training programs can ensure that Hungary remains competitive in the field of battery manufacturing in the next decade and achieves sustainable labor market development. (Nemzeti Akkumulátor Iparági Stratégia 2030, 2022)

Introduction

The rapid development of battery technology and alternative drive technologies is fundamentally changing the automotive industry and related vocational training systems. The rise of electric and hybrid vehicles requires new professional competencies in the areas of vehicle maintenance, diagnostics and servicing. Hungary's automotive industry is of paramount importance to the national economy, as the sector employs more than 170,000 people and is a key pillar of GDP. Large international manufacturers such as Audi, Mercedes-Benz, BMW and their supplier networks are increasingly in need of highly qualified professionals to apply new technologies. The rise of battery production and electromobility not only requires the expansion of industrial capacity, but also calls for the modernization of the vocational training system. (Nemzeti Akkumulátor Iparági Stratégia 2030, 2022)

The BatPower project aims to promote cooperation between educational institutions and industrial partners to modernize vocational training in the automotive industry in the field of battery technology and electromobility . During the research, we analyze the current state of the Hungarian vocational training system, with particular attention to battery technology education and the gaps in relation to industrial needs. The examination of the training and outcome requirements (TERs) of automotive professions and their comparison with industry needs provides an opportunity to explore the problems that hinder the training of marketable professionals.

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1. Examining industrial and educational challenges

The rapid development of electromobility and battery technology is fundamentally reshaping the structure of the automotive industry. The integration of new technologies into the education system is essential to ensure a competitive workforce, but in Hungary, cooperation between industry and education is not properly organized. This gap results in professionals graduating from vocational training often not having the up-to-date competencies expected by the manufacturing industry .

1.1.Educational challenges

Hungarian automotive industry vocational training is deficient on case of international requirements in several aspects, especially in the areas of battery technology and electromobility :

- **Outdated curriculum and methodology** : Current curriculum does not include sufficient details on battery operation, energy storage systems, diagnostic procedures, and industrial-level safety standards.
- **Lack of professional materials in Hungarian** : A significant portion of the latest industry knowledge materials are only available in English or German, which hinders the development of instructors and students.
- **Shortcomings in continuing education for instructors** : To impart knowledge of modern battery technology, instructors would need ongoing training, which is currently not provided.
- **Limited practical training opportunities** : A significant number of vocational training institutions do not have adequate laboratory equipment, electric and hybrid vehicles, or battery diagnostic tools.

1.2.Industrial challenges

Both domestic and international automotive companies face serious problems in the production and servicing of electric vehicles:

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- **Skill shortage** : Due to the rise of electromobility , at least 40,000 professionals will need to be retrained by the end of 2025, according to industry forecasts.
- **Handling high-voltage systems** : Working with high-voltage batteries poses an increased safety risk, and there is currently no unified certification system in Hungary in this area.
- **Incomplete dual training model** : Collaboration with industrial partners is not often planned, so students do not receive adequate industrial experience.
- **Information flow problems** : Industrial sectors often do not receive accurate feedback on what knowledge is taught in vocational training institutions, so the training structure is not aligned with current industrial needs.

1.3.Objectives

The research aims to contribute to the development of the Hungarian vocational training system in the field of battery technology and electromobility . The specific objectives are as follows:

- **Exploring the gaps between the vocational training system and industrial needs** , with particular attention to battery technology education.
- **Investigating the development possibilities of dual training** in order to allow students to gain experience in an industrial environment.
- **Developing a training program for instructors** that ensures effective teaching of new technologies.
- **Facilitating labor market adaptation** to make it easier for the existing workforce to transition to the areas of electromobility and battery technology.

2. Industrial Trends in Hungary

2.1.Battery Manufacturing Investments

In recent years, Hungary has become one of the most important centers of the European battery industry, especially thanks to investments from East Asian companies. The country has become

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an attractive destination for global battery manufacturers such as CATL, Samsung SDI and SK On , who are investing billions of euros to build factories in Hungary. But why are these companies choosing Hungary? (Battery - Hungarian Investment Promotion Agency, 2025)

2.1.1. Why Hungary?

1. Central geographical location and logistical advantages

Hungary's geographical location is strategically ideal for supplying European automotive hubs. The country has direct connections to Germany , one of the largest electric vehicle manufacturing markets in Europe. From a logistical perspective, batteries and electric car components can also be delivered quickly and at low cost to assembly plants in Germany and Western Europe.

2. Strong automotive infrastructure and industrial supply chains

Hungary has become a hub for automotive investment in recent years, with around HUF 8,000 billion worth of development currently underway. Western carmakers operating in the country, such as Mercedes and Audi, are preparing to make significant investments in electric vehicle production, while BMW is building a new factory in Debrecen, which is expected to start production in 2025. One of the main drivers of the automotive transformation is the presence of Chinese and South Korean companies, which are building battery factories and component plants, such as CATL, BYD, Sunwoda and Eve Power .

The investments could increase Hungary's annual car production capacity to 750,000 units, approaching Slovakia's production level of one million. The plant of Mercedes-Benz in Kecskemét is switching to electric models with a HUF 400 billion development, while Audi factory in Győr is investing in the production of electric motors. The role of battery factories is increasingly decisive, as CATL's Debrecen plant will become one of the largest manufacturer in Europe with a capacity of 100 gigawatt hours . In addition, BYD is planning its first European car factory in Szeged, joining the domestic industrial environment as a new player. The new investments will ensure that the country covers the entire production vertical, thus strengthening

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its place in the global transformation of the automotive industry. (Bemutatjuk Magyarország nagy autóipari térképét – így rajzolja át hazánkat a zöld forradalom, 2024)

1Car and battery factories in Hungary

The well-established automotive infrastructure and existing supplier networks provide favorable conditions for battery manufacturers to produce directly near major automobile producers. With the rise of electric vehicles, the automotive industry is transforming and there is a growing demand for locally produced batteries.

3. Favorable labor and production costs

Although Hungary is not the cheapest manufacturing location in Europe, it still operates with significantly lower labor costs than, for example, Germany or France. Battery manufacturing is a labor-intensive industry that requires a skilled workforce, but some work processes also require lower-skilled workers.

4. State aid and EU investment incentives

The Hungarian government offers significant state subsidies and tax breaks to battery manufacturers. For example:

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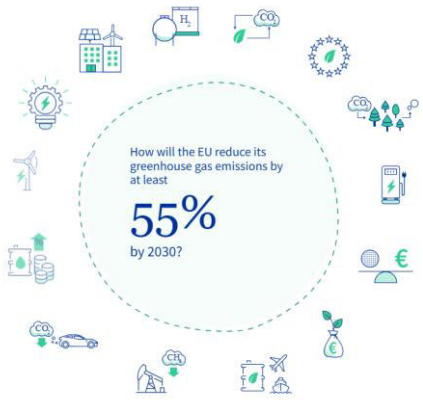
- Samsung SDI's Göd factory → received 108 million euros in state aid
- SK On Ivancsa investment → 80 billion forints state subsidy
- CATL's Debrecen factory → 320 billion forints infrastructure development

The European Union also supports the development of battery production as part of the green transition , so Hungary is in an advantageous position in investment programs to support the industry .

5. European green transition and the rise of electromobility

The European Union presented the "Fit for 55" package in July 2021, which aims to reduce greenhouse gas emissions by at least 55 % by 2030 compared to 1990 levels. The package includes a number of measures to decarbonise the transport sector , with a particular focus on promoting electromobility . (Fit for 55 - Consilium, 2025)



2Fit for 55

Main measures in the field of electromobility :

1. **Tightening CO_2 emission standards for cars and vans:**
    - According to the proposal, by 2030, CO_2 emissions from new cars should be reduced by 55% and from lorries by 50% compared to 2021 levels.
    - Starting in 2035, all new cars and vans must be zero -emission, effectively phasing out internal combustion engines.

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2. **Development of alternative fuels infrastructure:**
    - The new regulation sets binding targets for Member States for the deployment of electric vehicle charging stations.
    - For example, high-capacity charging stations will be mandatory at specified distances along highways, ensuring the efficient use of zero- emission vehicles.
3. **Increasing the share of renewable energy sources in transport:**
    - By amending the Renewable Energy Directive, they also intend to increase the use of renewable energy sources in the transport sector.
    - This includes increasing the proportion of green energy needed to charge electric vehicles and supporting smart charging solutions.

These measures aim to accelerate the deployment of electric vehicles, build the necessary infrastructure and significantly reduce the carbon footprint of the transport sector in the European Union.

Although the "Fit for 55" package does not directly contain detailed measures for training professionals, achieving the goals envisaged in the field of electromobility and battery technology will require retraining of the workforce and acquisition of new skills.

In the automotive industry, for example, the transition from internal combustion engines to electric powertrains requires new technical knowledge from engineers and technicians. The development of battery technology and the spread of electric vehicles require new competencies from specialists in the production, maintenance and recycling of batteries .

To address these changes, Member States and the industries concerned need to take a proactive approach to training and retraining to ensure that the workforce is adequately prepared for the new challenges arising from the green transition.

The Hungarian “National Battery Industry Strategy 2030” is a long-term industrial policy initiative that simultaneously supports economic growth of Hungary, industrial innovation and sustainable energy management. The strategy aims to make Hungary a leading hub in the European battery technology value chain, while promoting the sustainable development of the

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industry and labor market adaptation in the field of electromobility and energy storage. (Nemzeti Akkumulátor Iparági Stratégia 2030, 2022)

2.1.2. Challenges and reasons

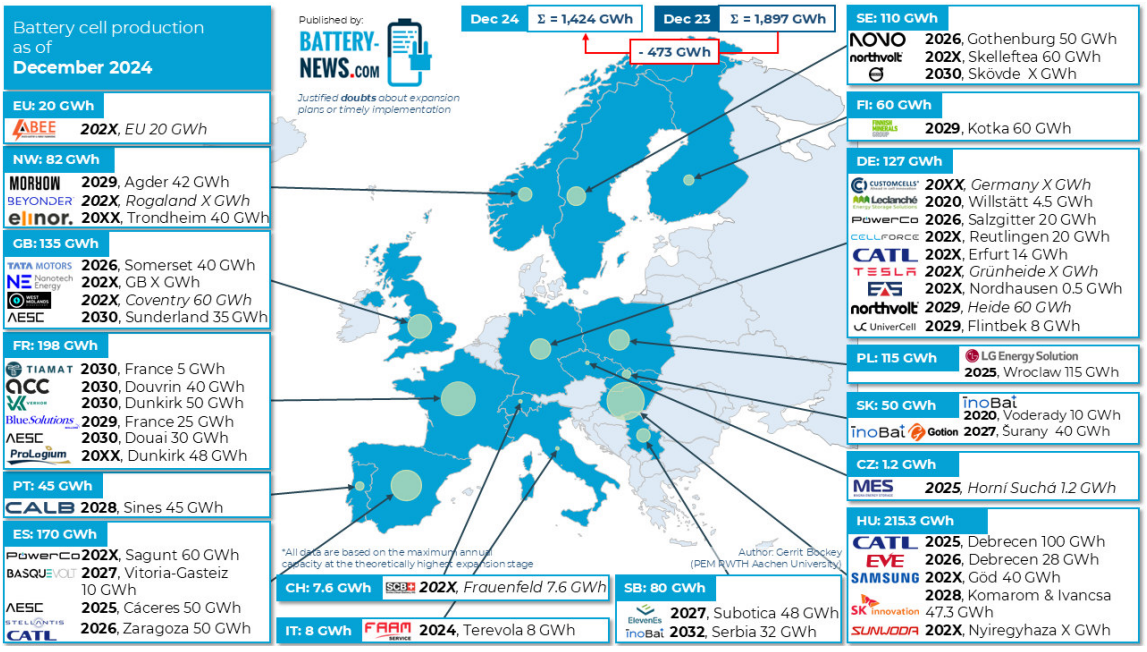
Reasons for developing the national Battery Industry Strategy 2030:

1. Supporting climate policy and decarbonization goals

The strategy is in line with the EU's Fit for 55 initiative, which calls for a 55 % reduction in greenhouse gas emissions by 2030. Battery technology plays a key role in the decarbonisation of transport and energy supply , enabling electricity storage and the uptake of electric vehicles.

2. The strategic role of Hungary in the European battery market

Hungary has attracted significant investment in battery manufacturing in recent years. It has the 12th largest battery manufacturing capacity in the world and has become one of the largest manufacturing bases in Europe with factories established by SK Innovation , Samsung SDI and CATL.



3Battery cell manufactures [https://battery-news.de]

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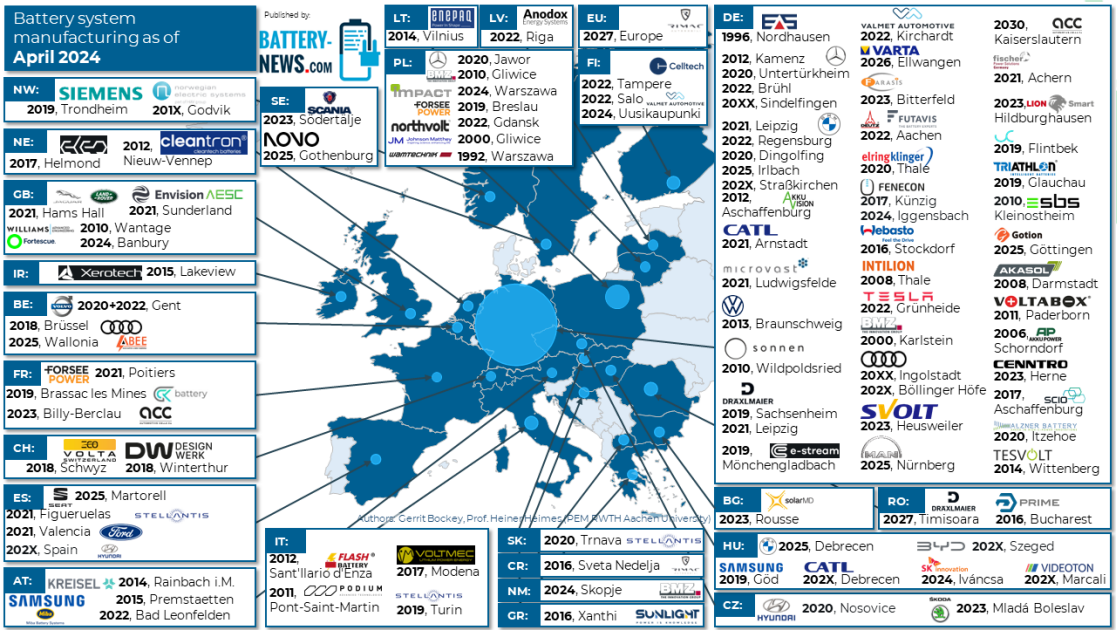

4Module & Pack Production [https://battery-news.de]

The strategy aims to make Hungary not only a manufacturing hub, but also to produce high value-added products through R&D&I developments. In order to achieve it, it is necessary to strengthen local research and development capacities to improve domestic supplier networks.

3. Labor market challenges and vocational training development

A key priority of the strategy is to ensure a skilled workforce at all levels of the battery value chain . It is estimated that at least 40,000 people will need to be retrained in the battery industry by 2025 to meet new technological requirements.

The strategy envisages several measures:

- Launching new vocational and adult education programs in the field of battery technology.
- Expansion of dual training in cooperation with Hungarian universities and industrial sectors.
- Joining international training programs, such as the European Battery Alliance and the ALBATTS project.

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4. Supporting sustainability and the circular economy

In parallel with the development of the battery industry, the strategy prioritizes environmental aspects, especially battery recycling and sustainable raw material supply .

The main objectives are:

- Increasing the recycling rate of batteries in line with European regulations.
- Exploiting opportunities for domestic production of lithium and other raw materials (e.g. lithium extracted from geothermal wells).
- Supporting sustainable manufacturing technologies to reduce carbon footprint and environmental impact.

5. International cooperation and European integration

The Hungarian government aims to become an active partner in the European Battery Alliance (EBA) and the Important Projects of Common European Interest (IPCEI) programmes. The strategy outlines the following measures:

- Encouraging foreign investment in battery technology.
- Participation in international research and development programs .
- International integration of the battery value chain for Hungarian manufacturers.

2.2.Automotive Sector and Battery Integration

The global automotive industry is in the midst of a major transformation, driven by the rise of electromobility , stricter emissions regulations and changing consumer expectations. The gradual decline of internal combustion engines and the rise of electric vehicles pose new challenges and opportunities for automobile producers and the battery industry.

Hungary, with its decades-long tradition of automotive investments, has become a key partner in this industry transformation. Closer integration between automobile producers and battery

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manufacturers is key to making electric vehicle production more efficient and supply chains more stable and sustainable.

The relationship between battery production and the automotive industry is not just a matter of logistics and supply, but also a close intertwining of technological developments. One of the most important components of electric vehicles is the battery, which determines not only the performance of the car, but also its range and lifespan.

The most important integration points:

- **Building vehicle platforms on batteries** : Car manufacturers are increasingly developing dedicated electric platforms that ensure maximum compatibility with battery systems. For example, the electric models produced at BMW's Debrecen plant are already based on the so-called "Neue Klasse " platform, which is specifically optimized for electric propulsion.
- **Shortening the production chain and increasing efficiency :** Compared to previous models , the production of electric cars requires closer supplier cooperation. It is crucial for car manufacturers to have battery cell and module production as close as possible to the assembly plants. CATL's investment in Debrecen is therefore of strategic importance for both BMW and Mercedes.
- **Joint developments and innovations:** The world's leading car manufacturers are increasingly developing battery technology in-house or working closely with their battery manufacturing partners. Mercedes-Benz, for example, is working with China's CATL on new, on the development of high energy density cells, which will be used in future electric models at the Kecskemét plant.

By integrating automotive and battery manufacturing, Hungary can become not only a supplier hub, but also a technology hub. Closer ties between battery manufacturers and automakers contribute to the stability and economic growth of the industry, while also creating new challenges.

Strengthening supply chains and increasing competitiveness

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Closer integration of car and battery manufacturing offers significant supply chain optimization opportunities. In electric car manufacturing, battery transportation is the biggest logistical challenge: the closer the cell production is to the car assembly plant, the lower the transportation costs and the lower the production risk.

Hungary is in an advantageous position in this regard, as battery manufacturing plants are already operating or being built in Debrecen, Iváncsa and Göd, and Komárom , which provide the largest car manufacturers with locally produced batteries.

Addressing sustainability challenges

One of the biggest challenges of merging car and battery manufacturing is ensuring environmental sustainability. The production of electric cars and batteries involves significant water and energy consumption, so it is important to make the production processes more environmentally friendly .

The expansion of battery manufacturing in Hungary has raised concerns about water use and waste management. For example, the CATL factory in Debrecen will require 60,000 cubic meters of water per day , which could have a significant impact on local water supplies.

Changes in vocational training and labor market needs

The integration of automotive and battery manufacturing creates new skills and labor needs. Hungary is already experiencing a serious labor shortage in the battery technology sector, and according to forecasts, at least 40,000 new professionals will be needed by 2025.

An important challenge for the Hungarian vocational training system is to adapt to new industry needs and provide a sufficient number of well-trained professionals for the battery manufacturing and electric vehicle industry.

2.3.Research and Innovation Ecosystem in Hungary

The development and innovation of battery technology plays a key role in maintaining Hungary's competitiveness in the field of electromobility . The development of the industry requires not only the expansion of production capacities , but also the strengthening of the research and development (R&D) ecosystem. Hungarian universities, research institutes and

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industrial players are increasingly involved in battery technology research, but the transfer to practical industrial applications remains challenging.

2.3.1. Hungarian research institutes and higher education sectors

In Hungary, universities and research centers play a significant role in the development of battery technology. The following institutions are particularly involved in research into energy storage technologies and electromobility :

- **Budapest University of Technology and Economics (BME) : The university's Faculty of Electrical Engineering and Informatics** coordinates several research projects to increase battery life and improve energy storage efficiency. BME is a leading institution in the education of electric powertrains and high-voltage systems.
- **Széchenyi István University (Győr)** : The Automotive Research Center (JKK) of Széchenyi István University in Győr plays a prominent role in supporting sustainable transportation, with a particular focus on the research and development of hybrid and electric vehicles, as well as autonomous vehicles. The center's research areas include electromobility, self-driving vehicle control systems, machine learning, environmental sensing, and vehicle simulation. This research contributes to the development and application of battery technology in the automotive industry.
- **HUN-REN Energy Research Center** : The HUN-REN Energy Research Center (EK) focuses on the development of battery technology, in addition to research in materials science and health technology. The institute aims to contribute to the development of sustainable energy storage solutions and to increase the efficiency of batteries.
- **University of Debrecen** : A research center also interested in battery manufacturing has been established, which works closely **with CATL's battery factory in Debrecen** , with a particular focus on the development of battery chemistry and recycling.
- **University of Pannonia** : The Faculty of Engineering and the Institute of Chemical Engineering of the University of Veszprém are involved in the development of electrochemical energy storage technologies , paying special attention to the sustainability aspects of battery production . Profigram Zrt . and the Faculty of

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> Engineering of the Pannon University of Veszprém have taken a significant step towards reducing the environmental impacts of battery production. The development, implemented within the framework of the Széchenyi 2020 program GINOP-2.2.1-15-2017-00059 application, aimed to industrially regenerate and reuse contaminated sulfuric acid generated during production processes . (Profigram, 2025)

These institutions play a key role in Hungary becoming a hub for battery technology development. However, as the industry grows, there remains a significant gap between university research and industrial applications.

2.3.2. Challenges of the transition between R&D and industry

Although battery technology research and innovation are receiving increasing emphasis in Hungary, its implementation into industrial applications is facing obstacles.

1. **Funding and support gaps:** Funding for R&D projects often depends on EU grants, and local support structures do not always provide sufficient resources for long-term developments for industrial applications. Support programs launched by the Ministry of Innovation and Technology help local companies, but it is difficult for SMEs to access the necessary resources.
2. **Lack of industrial collaborations:** Research results often do not reach industry directly, as collaborations between companies and universities are not structured enough. Compared to foreign examples, there are few technology incubators and startup programs in Hungary that would facilitate the practical use of battery technology.
3. **Skill shortage and knowledge transfer problems:** The high-level technical knowledge required by the industry is currently not taught in sufficient depth at few universities and vocational training institutions. Further training of researchers and developers is not always ensured, so the industrial application of new innovations is slower than in countries with advanced battery technology.
4. **Regulatory and licensing barriers:** The regulatory frameworks required to bring new technologies to market often lag behind industry developments. Environmental and waste

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management regulations related to battery production are stringent, which can hinder the rapid market adoption of new recycling technologies.

2.3.3. Proposed solutions to reduce the gap between research and industry

1. **Encouraging university-industry collaborations :** Supporting joint research programs between universities and industrial sectors, which provides an opportunity for the rapid market application of innovations.
2. **Strengthening practical training and knowledge transfer :** Incorporating mandatory industrial internships into university courses related to battery technology and developing closer ties with manufacturing companies.
3. Promoting **international collaborations :** Strengthening connections to European battery technology research networks, which can contribute to the local application of international developments.

3. Workforce Challenges and Educational Gaps

3.1. Technical Skills Gaps

The development of battery technology and the rise of electromobility require new expertise from professionals working in the industry. Battery production, servicing and recycling require specialized knowledge that is currently not available in sufficient depth in the Hungarian technical and vocational training system. According to industry sectors, due to the gap between education and the real work environment, newly graduated professionals do not have the skills needed to effectively manage battery technology processes.

- **One of the biggest problems is the lack of knowledge of the complex operation and diagnostic procedures of battery systems** . Lithium-ion batteries used in electric vehicles and energy storage systems require special handling procedures, the incorrect application of which not only reduces the performance of the device, but can also pose a risk of accidents. A deep understanding of battery operation would be essential in both the industrial and service sectors, however, domestic technical training still pays little

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attention to topics such as maintaining the balance of battery cells, programming charge control systems, or increasing energy storage efficiency under different environmental conditions.

- **The lack of knowledge of production processes and industry standards is also a serious problem for the Hungarian battery industry.** The mass production of batteries requires extremely precise technical and quality assurance procedures. People working in an industrial environment should be familiar with it. Basic manufacturing processes such as electrolyte treatment, electrode production, or the assembly of modules and packs are currently only covered to a limited extent in training materials. This is particularly problematic for students participating in dual training, as they often do not receive adequate practical training from industrial partners, which may hinder their ability to find work immediately after graduation.
- **Battery diagnostics and condition monitoring is another area where training systems do not provide adequate in-depth education.** The use of condition monitoring systems that can predict potential failures and performance degradation is essential for the long-term operation of battery systems. However, the majority of students do not have sufficient experience with the operation of battery management systems (BMS) , which are essential for modern electric vehicles and energy storage systems.
- **The ability to adapt to rapidly evolving industry standards is also an increasing challenge for educational institutions and professionals.** Due to the constantly changing industry standards in battery technology, training programs should keep up with new regulations and developments, but in Hungary this adaptation process is slow. International standards such as IEC 62660 (test standard for lithium-ion batteries), ISO 26262 (functional safety of vehicles) or EU environmental regulations are often not incorporated into vocational training programs, so newly graduated professionals do not have up-to-date knowledge of the requirements set by the industry. (What are the top ten Li battery regulations? , 2025)
- **Technical skills gaps are also a problem in battery repair and recycling** . As the number of electric vehicles continues to grow, there is a growing need for professionals

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who can professionally repair batteries and extend their lifespan . However, there are currently few service networks that provide specific training in repairing electric vehicle batteries. In addition, knowledge of recycling processes is also lacking, so that used batteries are not processed properly and valuable materials are not recovered in an efficient manner.

3.2.Practical Training Deficiencies

The Hungarian vocational training system faces significant challenges in adapting to the growing needs of the battery industry. Battery production and maintenance require increasingly complex technological processes that require both theoretical and practical knowledge. However, current vocational training curricula do not provide sufficient practical experience in battery assembly, testing and recycling, which hinders the fulfillment of labor market needs.

3.2.1. Lack of practical experience in battery assembly, testing and recycling

Modern battery technology involves highly complex processes, including the production of battery cells, their assembly into modules and packs, performance testing and the safe dismantling of failed units. However, most Hungarian vocational training institutions do not have adequate laboratory infrastructure, so students have few opportunities to experience these processes directly.

battery assembly, vocational training institutions do not provide access to modern production lines that would allow students to master assembly technologies in an industrial production environment. Battery testing is also barely covered in the curriculum, even though quality control and diagnostic processes are essential in the industry. Recycling and sustainability knowledge are even less prominent in the curricula, despite new EU regulations imposing increasingly strict requirements on the environmentally friendly management of batteries.

3.2.2. The gap between vocational training programs and industry-specific needs

Current vocational training programs are not sufficiently adapted to the growing needs of the battery industry. The rapid development of the industry requires continuous updating of curricula, but the training system is slow to respond to these changes. According to industry

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players, recent graduates may be well-qualified in theory, but lack the practical competencies needed for immediate employment.

In Hungary, the Training and Output Requirements (KKK) define the framework for the development and operation of the control, measurement and evaluation system of a profession. This document collects the requirements that are necessary for a successful professional examination. The KKK is therefore the basis of professional education, and the professional education aimed at acquiring individual professions must be structured according to what is specified in it, and the requirements of the professional examination are also recorded in it.

Based on the analysis of the Training and Output Requirements (TER), it can be concluded that battery technology education is given a more prominent role only in a few specific professions. These include alternative vehicle drive technician , hybrid and electric vehicle mechatronics , and vehicle mechatronics technician training.

Battery education focuses primarily on the servicing and maintenance of electric vehicles , but does not cover in detail battery assembly and industrial quality control procedures , which are of paramount importance for battery manufacturing.

The curriculum includes safety regulations for high-voltage systems , which are essential for the repair and maintenance of electric vehicles. In addition, students will learn the basics of operating hybrid and electric vehicles , with a focus on efficient battery management and optimizing their lifespan.

However, knowledge about battery recycling is only minimally present in the curriculum , despite the increasing importance of sustainability requirements and circular economy principles in the industry. Vocational training programs should be better aligned with industry expectations, especially in the field of battery production, maintenance and recycling.

3.3.Soft Skills Gaps

soft skills of professionals – including engineers, technicians and production line workers. These skills include problem -solving skills, digital literacy, project management and effective

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teamwork. However, current Hungarian vocational training programs do not pay enough attention to these skills, which negatively affects their ability to succeed in the labor market.

3.3.1. problem -solving skills and digital literacy

In modern battery manufacturing, technicians and production line workers often have to solve complex technical problems and manage digital systems. However, the lack of digital literacy and problem- solving skills poses a serious challenge.

Research results:

Employer expectations for soft and hard skills regarding skills : The study looks at the soft and hard skills expected by employers examines the importance of soft skills in the labor market, especially from the perspective of students at universities in Central Hungary. The results show that soft skills are Skills such as emotional intelligence, empathy , critical thinking, problem solving and leadership skills are increasingly valued. Although hard Skills such as professional and IT skills remain important, with employers placing increasing emphasis on collaboration, communication and adaptability.

The research highlighted three main soft skills: emotional (e.g. empathy, ethical skills), operational (e.g. time management, conflict management) and leadership skills (e.g. entrepreneurial attitude, critical thinking). Employers say these skills are essential for long-term success, but they are difficult to measure in job interviews . Educational institutions should place more emphasis on soft skills. for the practical development of skills , as their lack may be a disadvantage for young workers in the labor market. (HORVÁTH-CSIKÓS & JUHÁSZ)

3.3.2. The role of project management in battery manufacturing

Battery manufacturing is an extremely complex industrial process, the effective management of which requires thorough project management. Optimizing production processes with automated systems, complying with occupational health and safety regulations, and increasing productivity are all areas where, without coordination, production efficiency can be significantly reduced. However, in Hungarian battery factories, the lack of project management

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knowledge poses a serious challenge not only among engineers, but also among technicians and production line workers.

Battery manufacturing processes consist of several steps, from material procurement, through electrochemical component processing, assembly, testing, quality control, and recycling . The coordinated operation of each step is crucial, as battery manufacturing requires high precision, and even a small deviation can cause significant quality degradation.

Project management appears in three key areas in these processes:

1. Coordination of production processes: In order to effectively connect the individual production stages, precise planning and scheduling methods must be used.
2. Quality Assurance and Process Optimization : Industrial project managers must continuously monitor product quality while integrating new technologies into manufacturing processes.
3. Workforce management and efficiency: Training workers and effectively scheduling production schedules minimizes production delays and scrap.

3.3.3. Lack of project management skills among employees

Project management is traditionally a role associated with engineers and managers, but in battery manufacturing, production line workers also need to acquire certain project management skills to ensure processes run efficiently.

There is also an increasing expectation for technicians and production line operators working in production to efficiently organize their own workflows, handle unexpected problems , and make quick decisions during production.

Main skills gaps:

- **Independent work organization and time management** : Operators often do not receive adequate training on how to effectively allocate time on the production line.
- **Developing decision-making skills** : Identifying and quickly resolving production issues is key, but workers don't always have the right decision-making frameworks.

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- **Communication and teamwork:** Developing communication skills between shift managers and operators is essential for the smooth running of production.

3.4.Regional Challenges

Hungary's industrial development has contributed significantly to economic growth and employment expansion in recent decades. However, the geographical distribution of industrial investments is uneven, leading to regional differences in labor market opportunities and educational infrastructure. Below, we review the location of car and battery factories and their impact on vocational training and regional development.

Geographical distribution of automotive investments

The automotive industry is one of the most important sectors in Hungary, attracting many foreign investments to the country. Below we present the most significant car factories and their geographical distribution:

Audi Hungaria Zrt . (Győr): Audi has been present in Győr since 1993, where it manufactures engines and vehicles. The company plays a significant role in the economic life and labor market of the region. The factory produces more than 170,000 Audi vehicles annually and develops and manufactures drivetrains for Audi AG and other Volkswagen Group companies.

Mercedes-Benz Manufacturing Hungary Kft. (Kecskemét): Mercedes-Benz opened its factory in Kecskemét in 2012, which has been one of the largest employers in the city and the surrounding area ever since. The plant currently produces the Mercedes-Benz A-Class models, the CLA Coupé and Shooting Brake. Brake models, as well as the Mercedes-Benz EQB, are being produced. The two millionth car, a purely electric EQB (Mercedes-Benz, 2025), will be produced in October 2024.

Opel Szentgotthárd Kft. (Szentgotthárd): Opel has been operating in Szentgotthárd since 1992, primarily producing engines. The factory is operating at full capacity and plays a significant role in the local economy.

Suzuki Hungary Zrt . (Esztergom): Suzuki started production in Esztergom in 1991 and has been a significant player in the Hungarian automotive industry ever since . The Esztergom

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factory produces several models that are sold not only in the domestic but also in the international markets.

BMW Group Plant Debrecen (Debrecen): In 2018, BMW announced that it would build its newest plant in Debrecen, which will cover an area of more than 400 hectares. The foundation stone of the plant was laid on June 1, 2022, and production is planned to start in 2025 with more than 1,500 employees. The Debrecen plant will produce BMW's fully electric Neue Klasse models, which will usher in a new era in sustainable mobility. The plant will use state-of-the-art technologies, including a press shop, body shop, paint shop and assembly hall. It will also house a unique battery assembly plant, which will enable the assembly of battery cells for electric drives in-house. BMW's investment in Debrecen will not only strengthen the local economy, but will also contribute to further strengthening Hungary's position in the automotive industry.

These factories are not only the engines of the Hungarian economy, but also contribute to the development of local communities as significant employers.

Battery factories and their distribution

The growing demand for electric vehicles has resulted in a boom in battery manufacturing in Hungary. Below are some of the major battery factories and their locations:

- **Samsung SDI (Göd):** Samsung SDI established its Hungarian subsidiary in Göd in 2001, initially producing cathode ray tubes. Over the years, the company's profile has changed and now primarily produces lithium-ion batteries for electric vehicles. The company is continuously expanding its capacities . In March 2024, Samsung SDI announced the construction of a third factory in Göd, which will supply batteries for Hyundai Motor Company's new generation electric vehicles for the European market .
- **SK Innovation (Komárom, Ivácsa):** SK Innovation is a leading energy and chemical company in South Korea, which established its first European battery manufacturing plant in Komárom in 2017, under the name SK Battery Hungary. The plant produces third- generation , pouch- technology battery cells for global electric vehicle manufacturers. After the Komárom plant, SK Innovation built another factory in Iváncsa, with an investment of approximately 700 billion forints, for which it also used

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80 billion forints of state support. The Iváncsa factory was built with the most modern technology and represents a significant capacity expansion for the company. (ABOUT US | SK On Hungary, 2025)

- **CATL (Debrecen):** China-based Contemporary Amperex Technology Co., Limited (CATL) to build 100 GWh with an investment of 7.34 billion euros capacity battery factory in Debrecen. This project will create more than 9,000 new jobs and is considered the largest greenfield investment in Hungary. The factory's proximity to car manufacturers such as Mercedes-Benz, BMW, Stellantis and Volkswagen will enable a more efficient supply chain and contribute to the spread of e-mobility in Europe. is concentrated , which contributes to the industrial development of these areas.
- **W - Scope (Nyíregyháza)** : The Japanese W- Scope Corporation is establishing its first European factory in Nyíregyháza, where it will produce separator foil for lithium-ion batteries. The €720 million investment will create 1,200 jobs and is expected to start production in the second half of 2024. The factory will have an annual capacity of 1.2 billion square meters, making it one of the largest facilities of its kind in the world.
- **Toyo Ink Hungary Kft. (Újhartyán) :** The Japanese Toyo Ink Group has opened a new plant in Újhartyán, Pest County, where they produce CNT dispersions used for lithium-ion batteries. The 7 billion forint investment has created 45 jobs and contributes to the European supply of raw materials needed for the production of electric vehicle batteries.
- **Iljin Materials (Gödöllő) :** South Korean Iljin Materials is establishing its first European production unit in Gödöllő, where it will produce thin copper foil used in electric car batteries. The investment of more than 11 million euros will build a 5,000 square meter plant with a monthly capacity of 320 tons.

These investments will significantly contribute to increasing Hungary's battery production capacity , strengthening the country's role in the European electric vehicle market.

Impact on vocational training and regional development

Industrial investments not only create jobs, but also have a significant impact on vocational training and the development of educational institutions. Through cooperation between

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companies and local educational institutions, dual training programs are created, which ensure the supply of skilled labor that meets the needs of the labor market.

- **Audi Hungaria and its partners (Győr): Within the framework of** the dual vocational training cooperation between Audi Hungaria Zrt . and the Győr Vocational Training Center Lukács Sándor Automotive and Mechanical Engineering Technical School and College, students can acquire practical knowledge of their profession in a real industrial environment. Students participating in the program can get acquainted with the most modern technologies and production processes, thereby facilitating their successful entry into the labor market. Audi Hungaria launched its dual vocational training model more than 20 years ago, from which more than 2,300 young people have graduated so far, and most of them have started their professional careers as employees of the company. The professions available in the dual vocational training include, among others, automotive mechatronics technician, mechatronics technician, machine production technology technician and alternative vehicle drive technician. These training courses provide students with the opportunity to gain up-to-date knowledge in various areas of the automotive industry and gain direct experience in the application of cutting-edge technologies.

  The benefits of the cooperation include that students can build close relationships with key players in the labor market during their training, so that they have competitive knowledge and experience after completing their studies. This partnership contributes to the economic development of the region and to ensuring the supply of skilled labor.
- **Mercedes-Benz and vocational training in Kecskemét:** Mercedes-Benz supports local vocational training in Kecskemét, in cooperation with the Kecskemét Vocational Training Center, to ensure the supply of a well-trained workforce.
- **CATL and University of Debrecen:** CATL and the University of Debrecen signed a strategic cooperation agreement in the field of battery technology and the energy industry on October 15, 2024. The partnership aims to support the practical training of technical specialists, develop curriculum, and implement joint research projects. Within this framework, CATL provides practical opportunities for the university's students at its Debrecen factory, where they can get acquainted with the most modern production

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processes and technologies. The cooperation covers several fields, including computer science, engineering and natural sciences, as well as research and development and industrial areas. In this way, the company intends to secure the qualified graduate workforce necessary for the operation of the Debrecen plant in the long term, while the university has the opportunity to develop engineering training that meets the needs of the company. (Stratégiai partnerségre lépett a Debreceni Egyetem és a CATL Debrecen, 2024)

- Samsung **SDI's** Göd plant has launched a €61.9 million research and development project, as part of which it has established a battery technology training program in collaboration with **Óbuda University . This is the first such industry-** focused program in Hungary, providing engineering students with the opportunity to gain theoretical and practical knowledge applicable to the electric vehicle industry. The training is an important step in strengthening cooperation between industry and education, which contributes to addressing labor market challenges and the long-term sustainability of the Hungarian battery industry. (A HIPA történetének legnagyobb volumenű K+F projektjét valósítja meg a Samsung SDI, 2023)

These collaborations contribute to the development of the local labor market, the improvement of educational standards, and the reduction of regional economic inequalities.

4. Recommendations for Education and Industry Collaboration

The rapid growth of the battery technology industry necessitates the urgent transformation of vocational education and training to ensure that graduates meet industry expectations. In Hungary, automotive companies – especially Audi Hungaria, Mercedes-Benz, BMW and battery manufacturers such as CATL or SK Innovation – are urging the expansion of battery technology-related knowledge in vocational education and training. To this end, the following measures are recommended in the short term .

4.1.Short -Term Recommendations

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4.1.1. Updating vocational training curricula with the involvement of industry stakeholders

With the rise of electromobile production it has become necessary to integrate knowledge on the safety regulations, lifecycle management and recycling of batteries into the Hungarian vocational training system. Current curricula focus primarily on the repair and maintenance of electric vehicles , but do not address the full lifecycle of batteries in sufficient detail, which includes production, diagnostics and sustainable recycling . Finally, the training should include practical modules in collaboration with industrial partners, which provide students with competencies that meet current market expectations. (Andrea:, 2023)

Key development areas:

- **Battery Operation and Types:** Education should start with the basics, including how batteries work and the electrochemical processes involved. Students should be familiar with the most common types, such as lead-acid, nickel-base, and lithium-ion batteries . It is important to be aware of the advantages, disadvantages, and applications of each type to understand which technology is best suited for which environment.

- **Battery Manufacturing and Assembly:** During the training, students will learn the entire battery manufacturing process, from raw material production to the assembly of finished battery packs. This includes cell manufacturing, module and pack construction, and safety system integration. They will also learn manufacturing standards and quality control procedures to navigate the modern industrial environment.

- **Applications and Uses** : Students should understand the key roles batteries play in various applications, particularly in electric vehicles, industrial energy storage systems, and consumer electronics. It is important to understand the requirements of each industry and how batteries are used in different systems. This will help them to select and integrate the right battery type later on.

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- **Charging and Discharging Technologies:** Understanding the charging and discharging processes is essential for the efficient operation of batteries. Students should be aware of the different charging methods, including normal, fast and ultra-fast charging. They should also understand the factors that affect battery life, efficiency and safety, with particular attention to temperature effects and energy management.

- **Maintenance and diagnostics:** To extend the life of batteries, students should be familiar with maintenance and condition assessment methods. This includes troubleshooting, electrochemical testing, and the use of diagnostic tools. With the appropriate knowledge, they will be able to monitor the condition of batteries and detect potential failures in a timely manner.

- **Safety and Sustainability:** Safety is of paramount importance when handling and storing batteries. Students should learn about the potential risks of using batteries, appropriate protective measures, and environmental regulations. They should also learn about recycling. processes and sustainable battery production methods to contribute to the implementation of the principles of the circular economy.

- **Innovation and development opportunities:** To understand the technologies of the future, it is essential for students to gain insight into the continuous development of battery technology. They need to know about new development directions, such as solid-state batteries and hydrogen-based energy storage systems. With this knowledge, they will be able to adapt to the rapid changes in the industry and contribute to the development of new technologies.

4.1.2. Introducing certificate-based training with industry partners

Recommended programs:

- **Safe handling of high-voltage systems:** With the direct participation of automotive companies, such as Audi Hungaria and Mercedes-Benz, certifications should be

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introduced that allow students to work with high-voltage systems in industrial environments.

- **Battery manufacturing quality assurance:** Introduction of training courses related to battery assembly and inspection in cooperation with Széchenyi István University and Audi Hungaria.

- **Recycling and sustainable battery management:** Education on waste management procedures, in collaboration with industrial players interested in battery production.

Certificate programs help students find employment in the industry faster and easier, and retraining programs provide opportunities for already working professionals to learn new skills.

4.1.3. Strengthening practical training and industrial cooperation

The role of practical training should be increased, especially by expanding dual training models. This requires closer cooperation with industrial partners, creating opportunities for students to gain experience directly in the industrial environment.

Key steps:

- **Development of practical laboratories:** Establishment of battery technology laboratories in educational institutions, such as the Lukács Sándor Automotive and Mechanical Engineering Technical School of Győr and other vocational training institutions.

- **Corporate internship programs:** Expanding the existing partnerships between Audi Hungaria and Széchenyi István University to allow students to participate in industrial internship programs in greater numbers.

- **Training of trainers:** Provide regular training for trainers with the involvement of industrial partners to ensure that they have up-to-date knowledge in the field of battery technologies.

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Addressing the labor market challenges of the Hungarian battery industry in the short term requires updating the education system, closer cooperation with industry players, and the development of practical training. Certificate-based training and the expansion of dual training programs developed with industry partners, such as Audi Hungaria, CATL, and SK Innovation , can play a key role in ensuring that students graduating from vocational training institutions meet modern industry expectations.

4.2.Long-Term Recommendations

In order to maintain the competitiveness of the Hungarian battery industry, long-term measures are needed to ensure close cooperation between industry players and educational institutions. These measures would help students gain practical experience, better align education with industry expectations, and establish regional training centers to alleviate the labor shortage in the battery technology sector. (Egyuttmukodesi-megallapodast-kotott-a-debreceni-egyetem-es-a-catl, 2024)

4.2.1. Development of industry-educational collaborations

Creating strategic partnerships between industry and academia allows students to learn in a real industrial environment, while industry also has access to a well-trained workforce.

Internship programs with automotive companies and battery factories .

Hungarian battery manufacturers and automotive companies can offer a variety of practical opportunities for students in vocational training. The goal is to create programs that:

- They provide students with hands-on experience in battery manufacturing and the electric vehicle industry.
- They create close links between companies and educational institutions, ensuring that students are exposed to the latest industrial technologies.

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- They contribute to reducing labor shortages by aligning education with real workplace requirements with the involvement of industry players.

Possible steps:

- with other battery manufacturers (e.g. SK Innovation , Samsung SDI), modeled on the cooperation between CATL and the University of Debrecen.
- Expanding the cooperation between Audi Hungaria and the Győr SZC Lukács Technikum with an internship program focusing on the maintenance and diagnostics of electric vehicles and batteries.

4.2.2. Integrating hands-on labs with industrial testing tools

With the support of industry players, there is a need to develop training labs that simulate real industrial environments:

- They can gain practical experience in battery assembly, diagnostics and recycling .
- They can work with modern industrial equipment, which is provided by industrial partners or acquired from other grant sources.
- They can develop their problem- solving and project management skills, which are key to working effectively in an industrial environment.

Possible steps:

- Expansion of the laboratory equipment of the Lukács Technical Center of Győr SZC with the support of Széchenyi István University and Audi Hungaria
- Establishing joint labs with battery manufacturing companies that allow students to learn hands-on in an industrial environment.

4.2.3. Establishing regional training centers to reduce skills shortages

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The development of the battery industry has resulted in a labor shortage in some regions, especially in eastern and central Hungary. Regional training centers supported by industry players can contribute to the decentralization of professional training and increase the flexibility of the labor market.

Possible steps:

- Eastern Region: Establishment of a battery technology training center in collaboration with CATL and the University of Debrecen.
- Western Hungary: Expansion of the training program between the Győr SZC Lukács Technikum and Audi Hungaria so that students can learn about the entire process of electromobility and battery production.
- South Hungary: SK Innovation Creation of new professional training programs supported by the Ivancsa factory.

These are the things that the training centers provide:

- They provide educational and practical training in the field of new technologies.
- They provide training opportunities for retraining and further training for professionals coming from the automotive industry or other industries.
- They promote professional mobility, reducing labor shortages between regions.

4.3. Upskilling Existing Workforce

of battery production and electromobility in Hungary , there is a growing need to retrain workers from traditional industries. Workers specializing in the production and maintenance of internal combustion engines need to acquire new skills in order to be employed in the battery technology and energy storage sector. The aim of the retraining programs is to provide marketable knowledge to professionals in a short time, enabling them to make a smooth transition.

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4.3.1. Development of targeted retraining programs

transition to battery assembly, maintenance and recycling .

Required competencies and training areas:

- Battery Module Assembly and Maintenance – Assembly processes, safety protocols, and parts management.
- electric and hybrid vehicles – Structure, diagnostics and maintenance of high-voltage batteries.
- Sustainable industrial processes and recycling – Battery dismantling, material recovery and reuse options.
- Quality Assurance and Testing Methods – Battery cell condition testing and troubleshooting techniques.

4.3.2. Development of digital education and distance learning programs

The effectiveness of further training can be increased by introducing distance learning opportunities, which also provide opportunities for employees who are actively working and want to acquire new skills while working.

Possible improvements:

- Online courses and interactive courses – Providing educational materials accessible through digital platforms.
- Virtual Simulations – Modeling battery manufacturing and maintenance with interactive, practice-oriented learning materials.
- E- learning modules – Learning materials validated by industry players that develop both theoretical and practical knowledge.

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5. Conclusion

Hungary's battery industry transformation is a dynamic and rapidly evolving process, taking place in parallel with the growing global demand for electromobility and green technologies . The country's strategic geographical location and significant foreign investment have made it one of the hubs of the European battery value chain. However, the rapid development of the industry has also created serious challenges, especially in the areas of education, the labor market and research and development.

Key findings

1. **Labor market and educational gaps** Battery production requires specialized engineering and technological skills that are only partially provided by current Hungarian vocational training and higher education institutions. Companies often complain that recent graduates lack practical experience in the production, assembly and recycling of battery cells . Therefore, strengthening industrial and educational cooperation is essential to meet market needs.

2. **Training and continuous development of educators** Improving the quality of education requires the continuous development of not only students, but also educators. The constantly changing world of battery technology poses new challenges for educators, which is why regular training, cooperation with industrial partners and access to modern technologies are essential for them. Only in this way can we ensure that students enter the labor market with the latest and most relevant knowledge.

3. **The need for R&D cooperation** Hungary has significant R&D capacity , especially through the Budapest University of Technology and Economics (BME), Széchenyi István University and the University of Debrecen. However, cooperation between industry and universities is weak, which hinders the practical application of innovations. Targeted funding and technology incubator programmes can stimulate the flow of knowledge between universities and companies.

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4. **Regional training centers and dual education.** To alleviate the shortage of professionals, it is necessary to establish regional training centers and develop dual education programs. Integrating practical training into the industrial environment gives students the opportunity to enter the labor market with up-to-date knowledge. Audi, Mercedes-Benz and other large industrial players have already started to support local vocational training programs, but these efforts need to be expanded at the national level.

5. **Sustainability challenges and regulatory compliance** The environmental impacts of battery manufacturing, especially in the areas of water use and waste management, are receiving increasing attention. The EU's new battery regulation imposes strict recycling and sustainability requirements on manufacturers, which Hungary must also comply with. The introduction of sustainable industrial practices and the spread of innovative recycling technologies will be key to the long-term success of the industry. (Regulation - 2023/1542 - EN - EUR, 2025)

Recommendations

- **Modernizing vocational training and university curricula** to meet industry expectations.
- **Strengthening dual education and industrial partnerships** in the field of battery technology.
- **Continuous training of instructors and support for their industrial experience** .
- **Establish regional training centers** to facilitate practical training.
- **Encourage research and development programs and industrial collaborations** , especially in the field of sustainable battery production.
- **Integrating sustainability and environmental regulations** into manufacturing processes.

Summary

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Hungary has huge opportunities in battery technology and electromobility , but significant educational, industrial and regulatory reforms are needed to exploit them. Strengthening industry and education cooperation, developing educators and increasing research and development capacities will enable the country to remain competitive in European battery production in the long term. (EU Batteries Regulation 2023, 2025)

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Project Nr.: 2024-1-SK01-KA220-VET-000256192

BATPOWER
Preparation of the VET sector on battery energy transition

BATPOWER: PREPARATION OF THE VET LEVEL ON BATTERY ENERGY

2024-1-SK01-KA220-VET-000256192

WP2/A2.1

Desk research on industrial trends and effects of mass application of battery technology in Italy

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Executive Summary

In recent years, Italy has progressively strengthened its position in the European energy transition framework, developing a growing commitment to the electric mobility sector and energy storage technologies. In this context, Lombardy is one of the main industrial and technological centers, thanks to the presence of a well-structured production network, strategic investments in battery production and the concentration of excellent research and innovation centers.

However, alongside promising industrial expansion, significant critical issues are emerging in terms of the availability and adequacy of skills. The rapid technological evolution of the sector requires highly qualified professionals in fields such as electrochemical engineering, CAD-CAM design, battery management systems (BMS), industrial automation and maintenance of electric vehicles. In addition to this, there is a growing demand for transversal skills, particularly in the digital, design and communication fields.

The current training offer, both at a technical-professional and academic level, is in many cases not aligned with the needs of the sector, especially with regard to the practical component and structured collaboration with the production world. This misalignment risks hindering the development of the national battery supply chain and limiting its growth potential.

A targeted strengthening of the education and training system, in synergy with industrial and territorial policies, is a necessary condition to guarantee Italy's competitiveness in the new electrification economy.

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Introduction

The transition to a low-carbon economy is one of Europe's main challenges and strategic priorities. In this context, the spread of electric mobility and the development of energy storage technologies play a central role, both for the decarbonization of the transport sector and for the stabilization of energy systems based on renewable sources.

Italy is progressively strengthening its position within this emerging supply chain, investing in battery production, scientific research and the development of advanced technological infrastructures. Alongside industrial growth, however, there is a growing awareness of the need to adapt the national training system, particularly in the technical and vocational education segments, to respond effectively to the new skills requirements of the sector.

This report analyzes the main industrial trends related to the diffusion of battery technologies in Italy, with particular reference to investments in production, dynamics of integration with the automotive sector, the role of research and innovation, and implications for the labor market.

Through the analysis of emblematic cases, regional initiatives and statistical reference sources, the document aims to outline an updated picture of the opportunities and critical issues that characterize the national production system. Particular attention is paid to the issue of skills, understood as a factor enabling the competitiveness of the Italian supply chain and its ability to contribute to the European strategy of industrial autonomy and sustainability.

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1. Industrial Trends in Italy

1.1 Battery Manufacturing Investments

Italy is one of the leading European players in the battery and electric mobility sector, with Lombardy at the centre of innovation and technological development. The country is making significant investments in battery production, electric vehicle infrastructure, and renewable energy integration. However, to remain internationally competitive, it must address several challenges related to workforce skills, research, and innovation.

Italy is making significant progress in battery manufacturing, with major investments in new gigafactories and the supply chain of raw materials essential for production.

Key Investments and Industrial Initiatives

In recent years, leading companies and new market players have announced strategic projects to strengthen the country's production capacity:

- **FAAM (SERI Group)**: FAAM is the only company in Italy to manage the entire battery production chain, from the base material to recycling.Unlike other assemblers, FAAM also produces the cells and will inaugurate a new plant for the production of lithium cells. The company is actively involved in the European Battery Alliance to increase research and innovation in the sector. The Teverola project, developed by FAAM represents a significant example of best practice in the Italian and European energy transition. Divided into two

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distinct phases, Teverola 1 and Teverola 2, the project highlights a concrete commitment to technological innovation, environmental sustainability and local economic development. Teverola 1, inaugurated in 2021, was the first plant in Italy dedicated to the production of lithium cells, modules and battery packs. It uses LFP technologies with a low environmental impact thanks to aqueous-based production processes and targets sectors such as industrial traction, defence and energy storage. Teverola 2, currently under construction, will bring production capacity up to 8 GWh per year, introducing prismatic cells with advanced technologies (LFP/LMFP) and focusing on next-generation batteries such as solid-state and sodium-ion. The site will also integrate a plant for the recovery of spent batteries, reinforcing the circular dimension of the project. Within the framework of the European IPCEIs, Teverola is a candidate to become Southern Europe's first technology hub for battery production, making a concrete contribution to the energy transition, strategic autonomy and economic development of the area.

- **STMicroelectronics** is a key player in semiconductor and electronic component production for batteries and energy management systems. The company is investing in new technologies to improve battery efficiency and lifespan.

- **Enel X** and other Italian utilities are enhancing charging infrastructure and working on energy storage projects using second-life batteries. Enel X is actively engaged in developing innovative solutions for energy storage and sustainable electrification, with a specific focus on the use of second-life batteries. In 2021, the company was awarded funding for three projects under

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the European IPCEI programme, dedicated to the integration of disused batteries into high-power charging infrastructures and large-scale storage facilities, as well as to the sustainable end-of-life management of lithium batteries. At the Storage X-Lab in Catania, Enel X conducts research and experimentation on the use of storage systems to improve the efficiency of the distribution grid, support distributed generation, and encourage a smarter use of energy both in the home and in electric mobility. A concrete example of application is the PIONEER project, implemented in collaboration with ADR - Aeroporti di Roma and financed by the EU Climate Innovation Fund. The initiative envisages the installation of a 10 MWh storage system based on second-life batteries, integrated with a 30 MW solar park at Fiumicino airport, with the aim of significantly reducing the airport's emissions.

- **Comau (FCA Group)**: Comau is a leading developer of advanced systems and products for industrial automation and a single-source supplier in the field of electrification. It supports companies with projects ranging from the assembly of electric motors and batteries to the machining of lightweight structural components.

- **Li-Cycle-Glencore Portovesme**: The project to build a battery recycling hub in Portovesme, Sardinia, is a strategically important initiative in the European landscape of the circular economy and energy transition. Promoted by Glencore, a leading multinational company in the raw materials sector, in collaboration with Li-Cycle Holdings Corp., a company specialising in the recovery of resources from lithium-ion batteries, the project aims to create Europe's largest centre for the recycling of spent batteries. The initiative consists

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of two main phases. Initial Phase: Installation of facilities capable of processing up to 11,000 tonnes per year of 'black mass', the material resulting from the shredding process of spent batteries. This phase is designed to rapidly start the production of lithium carbonate for the battery industry, anticipating the large-scale implementation planned in the next phase. Large-Scale Expansion: Expansion of treatment capacity to between 50,000 and 70,000 tonnes per year of black mass. This expansion will allow the production of critical battery materials, such as lithium, cobalt and nickel, to be increased through advanced recycling processes.

- **Loccioni** is active in the development of advanced systems for the assembly and quality control of key components of electric mobility, including electric motors, inverters and batteries, contributing to improving the efficiency and reliability of production processes in the automotive sector. Among the company's most innovative initiatives is the Nomadic Labs project, a modular system of mobile laboratories powered by renewable energy sources. It is an energy island made up of interconnected containers, integrated in a micro-grid, where the main components of electric vehicles - including axles and electric motors, inverters, modules and battery packs - are tested for some of the world's largest manufacturers (such as Mercedes, Volvo and BMW). The entire system is designed to optimise energy recovery: the energy used for testing is largely regenerated and returned to the company's micro-grid. In addition, the batteries used in testing - including those in their second life - contribute to powering the facility, along with renewable sources such as solar energy and water power from the nearby Esino river. The project represents a

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concrete example of circular economy applied to electric mobility, where technological innovation is combined with energy sustainability.

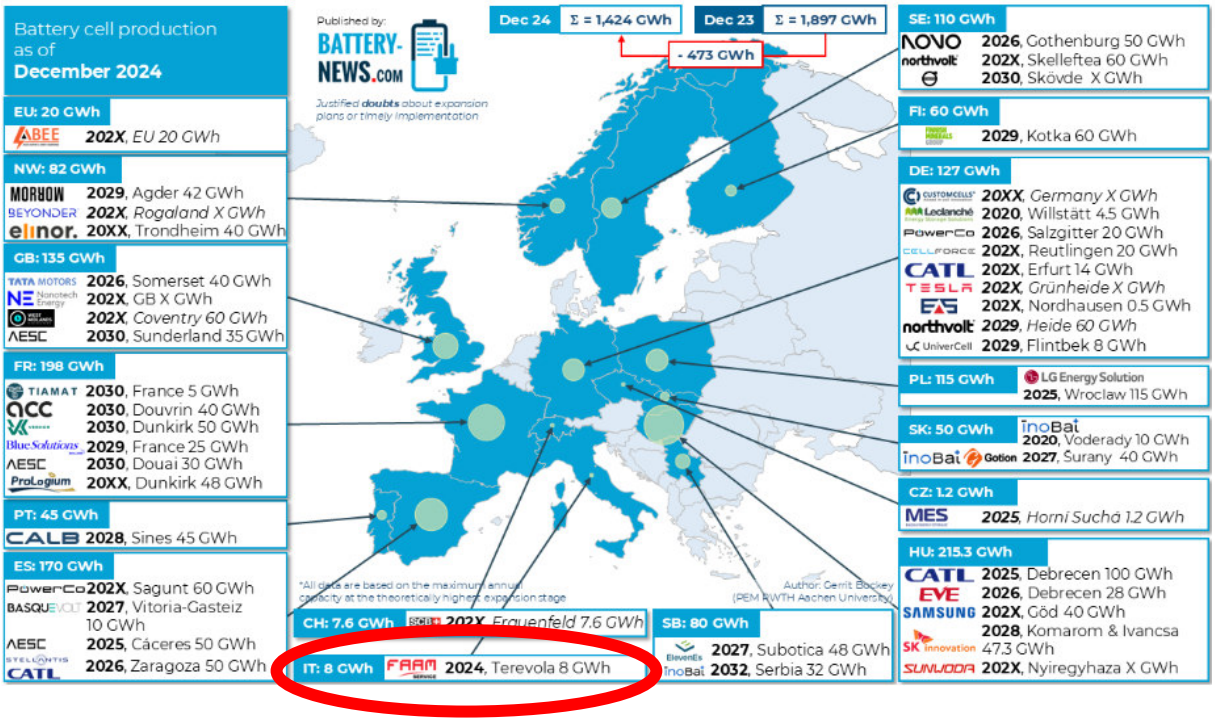

Figure 1: Battery cell production (source: https://battery-news.de/en/europe-battery-cell-production/)

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Figure 2: Machine and Equipment Manufacturer (source: https://battery-news.de/en/elementor-22769/)

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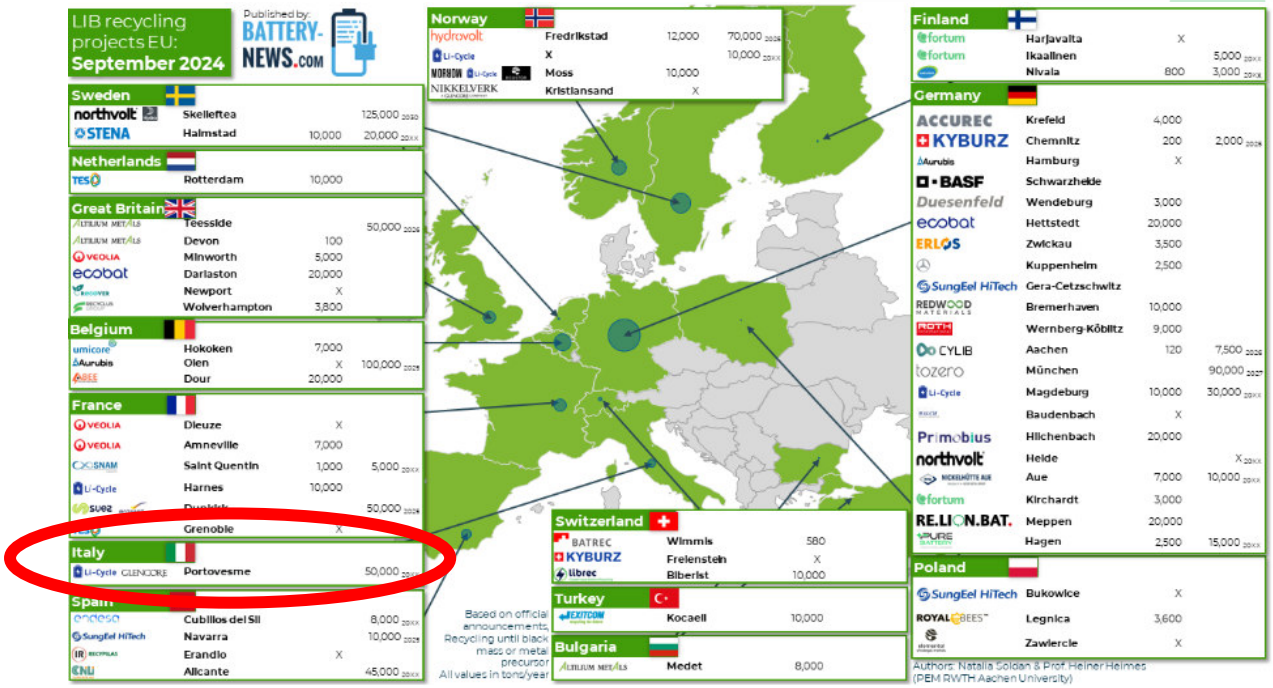

Figure 3: Battery Recycling (source: https://battery-news.de/en/europe-battery-recycling/)

1.2 Automotive Sector and Battery Integration

Italy has played a leading role globally in the automotive sector for decades, thanks to the presence of iconic brands and a consolidated industrial chain. Groups such as Stellantis (which includes the Fiat, Alfa Romeo and Maserati brands), Ferrari, Lamborghini and Piaggio constitute not only a historical and cultural heritage of the country, but also a strategic industrial asset. However, the automotive industry is today in a phase of profound transformation, driven by the transition from internal combustion engines to electric propulsion systems. This change does not represent a mere technological evolution, but a real paradigm shift, involving the entire value chain.

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The increased adoption of electric vehicles (EVs) in Europe, driven by increasingly stringent environmental regulations and growing consumer awareness of sustainable mobility, has led to a strong growth in demand for high-performance batteries. This dynamic has a direct and profound impact on Italian production chains, generating new needs in terms of both production and supply.

One of the most relevant aspects is the need to develop a national battery production capacity, capable of reducing dependence on foreign, especially Asian, suppliers. The localisation of production on Italian territory - through gigafactories and integrated plants - would not only improve the security of the supply chain, but would also represent an opportunity to increase the added value generated internally and foster the country's strategic autonomy in the European context.

A second important element concerns the industrial reconversion of companies producing components for endothermic engines. These companies, which have historically formed the backbone of the Italian automotive supply chain, now find themselves in the need to redirect their know-how towards the design and production of components for electric vehicles: electric powertrains, battery cooling systems, inverters, power electronics and battery management systems (BMS). This transition requires significant investments in technological innovation, personnel training and plant restructuring.

Finally, the progressive electrification of Italy's historic car brands is an emblematic and highly strategic challenge. Brands such as Ferrari and

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Lamborghini are investing in the development of hybrid and electric models, seeking to combine the ecological transition with the preservation of high performance and brand identity. This process involves a sophisticated engineering approach, integrating high-energy-density batteries, lightweight materials and advanced control systems to ensure performance in line with the expectations of the premium and sports segment.

Parallel to the development of electric vehicles, an efficient and widespread charging infrastructure is a necessary condition for the success of electric mobility in Italy. At present, the country has a lower level of recharging station deployment than other EU Member States, such as Germany and the Netherlands, both in terms of density and available power (number of fast and ultra-fast columns).

This infrastructural lag may jeopardise the diffusion of electric vehicles among consumers and is an obstacle to the competitiveness of the national market. However, numerous public and private initiatives are underway, also thanks to the support of the National Recovery and Resilience Plan (PNRR), which envisage targeted investments for the installation of new recharging stations along the main motorway routes, in urban centres and in peripheral areas. The aim is to ensure homogeneous coverage of the territory, reduce 'autonomy anxiety' and promote the adoption of electric vehicles on a large scale.

1.3 Research and Innovation Ecosystem

Innovation is a key factor for the success of Italy's battery industry. Several universities, research centres, and technology companies are working to

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develop more efficient and sustainable solutions. Italy is at the forefront of the development of new batteries for electric mobility. There are in fact numerous research projects for the realisation of a new generation of increasingly sustainable, high-performance, safe and low-cost storage devices.

Key Research Institutions

Politecnico di Milano: A leader in advanced materials research for batteries and energy management systems. The CIRC-eV laboratory - Circular Factory for the Electrified Vehicles of the Future, promoted by the Politecnico di Milano, was set up with the aim of developing a new circular factory model to support the manufacturing industry in the recovery and reuse of components from end-of-life electric and hybrid vehicles, in particular lithium ion batteries, a critical element for sustainable electric mobility. CIRC-eV represents Europe's first laboratory entirely dedicated to the integration of disassembly, testing, reassembly and recycling functions in a single infrastructure, and is proposed as a reference platform for the introduction of new circular industrial models. The project focuses on remanufacturing and second-life cell strategies, favouring the use of remanufactured batteries in stationary applications - such as support for renewable energy plants or domestic storage - and recycling those that are no longer reusable, for the recovery of high-value materials such as lithium, nickel and cobalt.

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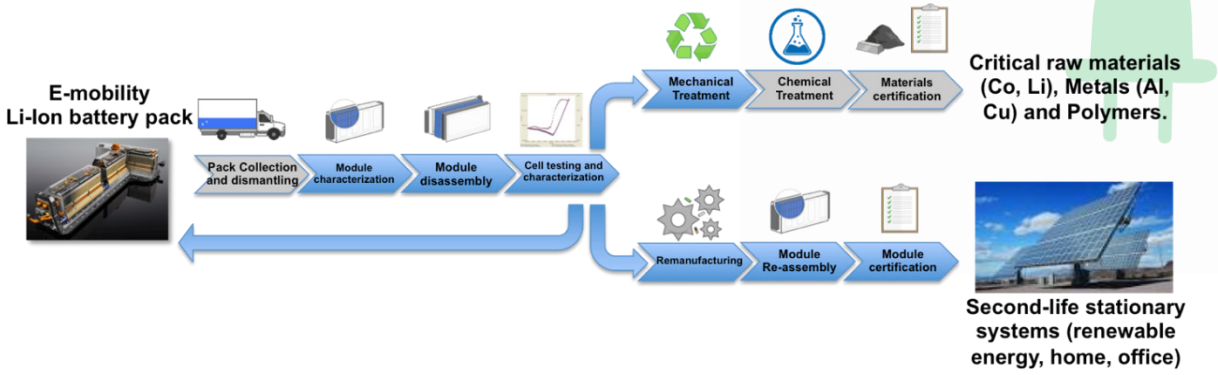

Figure 4: CIRC-eV circular process chain for lithium-ion batteries. The functional steps in blue are integrated in the CIRC-eV laboratory (source: https://www.polimi.it/ricerca/laboratori/laboratori-interdipartimentali/circ-ev-circular-factory-for-the-electrifie

The National Research Council (**CNR**) is heavily involved in the research and development of advanced technologies for the electrochemical storage sector, with activities ranging from the recycling of lithium ion batteries to the exploration of more sustainable alternative solutions . In particular, the Institute of Advanced Energy Technologies (ITAE) in Messina is working on the development of new solid electrolytes for sodium batteries, based on NASICON (NAtrium Superlonic CONductor) materials, with the aim of replacing lithium with sodium in the future, a more abundant, economic and sustainable resource. In addition to these activities, the CNR is coordinating the ORANGEES project, one of the most innovative initiatives in the field of green battery materials. The project, which is entirely Italian and funded with EUR 4 million, aims to develop a new generation of accumulators based on organic and hybrid materials with high sustainability and low cost, also obtained from agro-food industry waste, such as casein, whey, keratin, prickly pear and cellulose. The aim is to progressively reduce the use of critical metals such as lithium and

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cobalt, promoting a circular economy approach and reducing the environmental impact throughout the battery supply chain.

ENEA: ENEA carries out constant research on the development of better performing, cheaper and more environmentally friendly batteries. It is involved in several European and national projects, such as the 'Electricity System Research' project, which addresses the critical issues of batteries (capacity, cost, durability, safety, recharge time, critical materials, environmental impact, recycling). Furthermore, in the European project 3beLiEVe, ENEA is developing innovative third-generation lithium batteries with smart sensors to monitor cell health. ENEA has also patented a system that uses Vinavil glue as a binder for lithium batteries, replacing harmful materials.

Politecnico di Torino: the Politecnico di Torino is developing advanced electrolytes (polymers, ionic liquids, ceramics and their hybrids) for sodium batteries and beyond. The Politecnico di Torino is involved in the European Battery 2030+ project, with the aim of identifying the sustainable batteries of the future and making Europe a leader in the sector. The project focuses on innovations in all aspects of batteries (materials, production, recycling), including the installation of internal sensors for cell monitoring and self-repair. The polytechnic will play a key role in training workers for the battery production of the future4 .

University of Bologna: The Laboratory of Electrical Machines and Drives (LEMAD) coordinates the TIME - Integrated Technology for Electric Mobility project, developing advanced traction systems for native and converted electric vehicles5 . A spin-off of this project is LiBER - Lithium Batteries Emilia

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Romagna, set up to develop process and product solutions for battery packs for automotive and industrial applications, focusing on low cost, high quality, ease of integration, safety and recycling6 . The aim is to set up a pilot line in Bologna for the automatic assembly of battery modules.

Bettery: Bettery is a start-up resulting from research at the University of Bologna that has developed Nessox, a lithium-oxygen flow battery with high energy density, long life, lower costs and fast recharge times by replacing the internal liquid. The idea was born in the Laboratory of Electrochemistry of Materials for Energy of the 'Giacomo Ciamician' Department of Chemistry at the University of Bologna, the entrepreneurial project came to life after years of research thanks to the start-up BETTERY. Nessox consists of oxygen dissolved in a liquid and lithium: this chemistry enables it to provide 3 times the energy density of commonly used lithium-ion batteries. Among BETTERY's next goals is to build a prototype that demonstrates this technology in a real environment, also for application in light electric vehicles.

IIT (Italian Institute of Technology): The IIT in Genoa is developing graphene-based supercapacitors, capable of rapid charging and discharging, and lithium batteries that use silicon as the anode together with a small amount of graphene, promising greater capacity and charging cycles. This is also in collaboration with his start-up company BeDimensional and Varta.

University of Padova: The Department of Industrial Engineering conducts research on electric powertrains with different power configurations (lithium batteries, fuel cells, supercapacitors) . They also develop V2G chargers and

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wireless charging systems, both stationary (V2H) and on-road for moving vehicles.

Innovations in the Battery Sector

Italian research focuses on several strategic areas. These include the development of solid-state batteries and new advanced electrolytes that can guarantee greater safety, efficiency and sustainability. Great attention is paid to alternatives to lithium batteries, such as sodium batteries and redox flow batteries, as well as the use of innovative organic materials, also derived from agro-food waste, to reduce dependence on critical raw materials.

Another priority strand is battery recycling and reuse technologies, through solutions integrating disassembly, diagnosis, remanufacturing and selective material recovery. Research also focuses on battery pack optimisation, with a focus on second-life and stationary applications, and the development of intelligent sensors for real-time performance monitoring. Activities on energy management systems, advanced electric powertrains and intelligent charging infrastructures, including wireless and two-way charging, complete the picture.

Challenges and Opportunities for Italy

Despite encouraging signs of growth and the strong dynamism of the battery industry in Italy, the country faces a number of structural challenges that could limit its long-term development. One of the main obstacles concerns the strong dependence on imports of critical raw materials, such as lithium, cobalt and nickel. The absence of mineral resources on the national territory makes Italy vulnerable to international price fluctuations, complex geopolitical dynamics

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and competition with other European and Asian countries for access to strategic supplies.

A second critical element is the lack of specialised skills in the workforce. In fact, the rapid transition to electro-mobility requires new skills capable of operating in highly digitised, automated and innovation-oriented environments. In particular, advanced knowledge is required in areas such as industrial automation, energy management, battery pack design and recycling systems.

A further difficulty concerns the pace of development of charging infrastructures. Although significant investments are being made, Italy is still lagging behind other European countries in the widespread diffusion of fast and ultra-rapid recharging stations. This limits the spread of electric vehicles and, consequently, domestic demand for batteries, slowing down the entire production chain.

Alongside these critical issues, however, it is possible to identify important opportunities that, if seized, could decisively strengthen Italy's position in the European energy storage technology landscape.

Coordinated action between companies, public institutions and the research world - supported by national incentives and European funds - could significantly strengthen the competitiveness of the sector.

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2. Workforce Challenges and Educational Gaps

Italy's battery and electric mobility industry is growing rapidly, but it faces a significant shortage of qualified professionals. The transition to more sustainable technologies requires a highly skilled workforce capable of operating in an increasingly digitised and automated environment. However, Italy's vocational education system is not yet fully aligned with industry needs, creating skill gaps that hinder the country's competitiveness.

This section analyses the key challenges in the labour market and educational system in Italy, focusing on four main aspects:

1. Technical skills shortages
2. Deficiencies in practical training
3. Gaps in soft skills
4. Regional challenges in the distribution of industrial opportunities

2.1 Technical Skills Gaps

The lack of specialised technical skills is one of the main critical issues for the battery industry in Italy. Many companies report difficulties in finding skilled workers in several key areas along the supply chain. These include CAD-CAM design and electronic engineering, industrial automation and robotics, battery module assembly and the related Battery Management Systems (BMS), and battery recycling and second-life activities.

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In particular, battery design using CAD-CAM tools and related electrical engineering skills are crucial for developing more efficient and lighter batteries; however, companies have difficulty finding engineers and technicians with specific experience in these areas. This shortage of qualified designers limits the industry's ability to optimise module design and introduce innovations in the architecture of storage systems.

These gaps also extend to the production area: many Italian technicians lack sufficient experience with advanced automation systems and industrial robotics, which are now indispensable in modern battery production plants. Similarly, there is a shortage of specialists in the assembly of battery modules and the integration of related energy management systems (BMS), activities that require interdisciplinary knowledge of materials, power electronics and safety regulations.

A further critical area concerns skills related to the end-of-life of batteries. The sustainability of the sector depends to a large extent on the ability to recover valuable materials from spent batteries and the reuse of batteries in 'second life' applications; yet few professionals in Italy have specific training in the recycling of batteries and in the management of their entire life cycle.

2.2 Practical Training Deficiencies

Although Italy can count on a good technical education system, in particular thanks to the network of technical and professional institutes, significant gaps remain in the practical component of training. In a highly specialised sector such as batteries for electric mobility, direct experience in industrial contexts is

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an essential element for the development of operational and transversal skills. However, this training dimension is still undervalued within educational pathways.

One of the main obstacles lies in insufficient laboratory facilities: many Italian technical schools and universities do not have up-to-date equipment or simulated environments that faithfully reproduce battery production and management processes. This deficiency severely limits the opportunity for students to get to grips with tools and technologies in use in the industry, reducing the applicative value of theoretical training.

Alongside this structural limitation, there is still little participation by Italian companies in dual training programmes, internships and apprenticeships. Unlike in countries such as Germany, where school-enterprise collaboration is an integral part of the training model, in Italy these experiences are often sporadic and poorly integrated into the curricula. This results in a limited number of learning opportunities in real work situations, hindering the full transition between training and employment.

A further critical issue concerns the updating of training content. Battery technologies are subject to rapid change and innovation, but school and university curricula struggle to adapt with the same timeliness. The failure to periodically review curricula results in a mismatch between what is learned in the classroom and the skills actually required by the market.

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Preparation of the VET sector on battery energy transition

In order to fill these gaps, it is necessary to promote structured partnerships between companies, schools and vocational training centres, capable of co-designing educational paths geared to the real needs of the sector.

2.3 Soft Skills Gaps

In addition to specialised technical skills, the battery industry requires professionals with strong transversal skills, able to operate effectively in multidisciplinary, technology-intensive and ever-changing environments.

The ability to tackle complex problems, to analyse complex technical situations and to propose innovative solutions - in short, the skills of problem solving and critical thinking - are increasingly in demand throughout the production chain. From the research and development phase to design, from system integration to battery life cycle management, cognitive flexibility and analytical approach are crucial to managing uncertainty and fostering continuous improvement.

In parallel, the spread of advanced digital technologies linked to Industry 4.0 has made the possession of basic and advanced digital skills indispensable. The ability to use data analysis tools, to understand the principles of automation, and to interact with systems supported by artificial intelligence can no longer be considered the exclusive prerogative of highly technical profiles, but represents a widespread competence, transversally required in the production, management and technical-commercial spheres. However, many Italian workers - particularly in SMEs and among profiles coming from traditional educational backgrounds - still have insufficient levels of digital literacy, with negative repercussions on the innovation capacity of businesses.

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A further critical area concerns project management and teamwork. The production and management of batteries requires collaboration between heterogeneous professionals - engineers, chemists, technicians, operators - who must share objectives, deadlines and processes effectively. For this reason, skills such as clear communication, planning, widespread leadership and operational coordination are considered increasingly central but often neglected in technical and university education.

Table of Required Skills in the Battery Sector

Skill Area	Description	Labor Market Demand
CAD-CAM Design	Use of software to design battery components and energy storage systems.	High – Required by manufacturers and research centers.
Industrial Automation	Programming and management of robots for battery production.	Very high – Essential for the digitization of gigafactories.
Battery Lifecycle Management	Monitoring battery performance and maintenance strategies.	Medium – Growing demand with battery adoption in transport and energy.

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Recycling and Second-Life Applications	Recovery of critical materials and repurposing of depleted batteries.	High – Key for sustainability and circular economy.
Data Analytics and AI	Use of artificial intelligence to optimize battery lifespan and performance.	Very high – Crucial for developing more efficient batteries.
Safety Regulations	Knowledge of European and international regulations for battery production and disposal.	High – Required by manufacturers and regulatory agencies.

2.4 Regional Challenges in Italy

The electric vehicle battery industry is assuming a central role in Italy's energy transition, but the distribution of opportunities appears unbalanced between North and South. Most investments, production facilities and research centres are concentrated in the northern regions (especially Lombardy and Piedmont), which are the main industrial hubs. In contrast, the South still has limited and fragmented initiatives, often forcing students and professionals from the South to move to the North to work in the sector, thus accentuating territorial inequalities. This polarisation emerges not only in the presence of factories, but also in the infrastructure and skills available: for example, about 56% of electric car charging stations are installed in Northern Italy, compared to just 23% in the South and Islands, indicating an infrastructural gap that reflects the overall asymmetry in the development of the electric supply chain.

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The south, although starting late, sees the emergence of a number of projects in addition to Teverola and Messina, cited above as best practices of active innovation projects in the sector. In Apulia, some university poles (Bari Polytechnic, University of Salento) have activated courses and laboratories on electrochemical storage and electric mobility, laying the foundations for local expertise. There is no shortage of minor industrial initiatives: for example, battery hubs projects in the Special Economic Zones of the South, reconversion of existing plants (a former Alcoa plant in Sardinia has been hypothesised for the production of anodic/cathode materials, but at an embryonic stage), and investments in battery recycling (Cobat, a collection consortium, is also upgrading recycling plants in the South to support the emerging supply chain).

To address territorial imbalances and stimulate the battery supply chain in an inclusive manner, targeted industrial policies have been put in place at both the Italian and European level. Some of the most relevant instruments include:

- PNRR (National Recovery and Resilience Plan): as part of the post-Covid PNRR, Italy has dedicated significant resources to the green and digital transition. In particular, through the 'Development Contracts - Net Zero Components, Renewables and Batteries' (managed by Invitalia) more than €1.7 billion were allocated to strengthen strategic supply chains linked to the green transitionesg360.it. Of this, at least €205.1 million is reserved for battery projects (e.g. new cell factories, recycling plants, etc.). An important constraint of the NRP is that at least 40 per cent of these resources are used in southern regions. For example, the public financing of Teverola 2 falls under this objective.

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Preparation of the VET sector on battery energy transition

- IPCEI Batteries (Important Project of Common European Interest): a European initiative that coordinates public funding from the Member States for strategic projects along the battery value chain, overcoming limits on state aid. Italy has participated in IPCEI since the first wave (IPCEI Batteries 1) through various companies (FIB-FAAM, FIAMM, Vicenza, for developments on new batteries) and Endurance (Motoritalia Group))

In addition to the production facilities, the territorial gap is manifested in the support infrastructure, the training offer and the employment spin-offs related to the battery industry. A comparison between North and South on these aspects helps to identify the main gaps to be bridged:

- Energy and recharging infrastructure: As mentioned, Northern Italy is well ahead in terms of infrastructure for electric mobility. In addition to a higher density of public charging stations (more than half at Nord), northern regions benefit from a more robust and interconnected electricity grid, an important factor for supporting energy-intensive gigafactories. Many industrial areas in the South suffer from less reliable or undersized electricity grids, necessitating investments in transformer stations and grid storage.

- Educational offerings and skills: The North boasts a concentration of universities and technical institutes that have been training engineers and technicians for years, then employed in the automotive sector and now in electric mobility. In the south, the specific training offer on the battery chain is more limited: some universities have incorporated modules on storage technologies in their degree courses (e.g. in Bari and Naples), and initiatives such as the Consorzio Sud Innovation are considering inter-university masters

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courses on electric mobility. However, a critical mass of dedicated programmes and equipped teaching laboratories is lacking. Many young graduates from the South, in order to specialise in electrochemistry or power electronics applied to batteries, move to the Centre-North or abroad, fuelling the 'brain drain' from the South. This creates a vicious circle: less local skills -> less attractiveness for investors -> less opportunities for skilled work in the South.

- Employment and local supply chain: Today, most of Italy's battery-related jobs (production, R&D, services) are concentrated in the North. Companies such as Lithium Italia, Solith (module assembly in Lombardy), Electro Power Systems (Turin) and the component supply chain (from connectors to thermal management systems) have northern locations. The south, on the other hand, has still small numbers: when fully operational, the two Teverola plants will employ a few hundred highly specialised direct employees, in addition to indirect employees in the local allied industries. A paradox highlighted by the SVIMEZ report is that the south has so far sustained the bulk of traditional automotive manufacturing employment in Italy (almost 90% of the cars produced in the country in the first nine months of 2024 came from plants in the south) just think of Melfi, Pomigliano, Cassino, Atessa - but this workforce risks heavy contractions if the transition to electric power is not accompanied by the creation of new activities in the battery chain. SVIMEZ data show a drop of more than 100 thousand cars produced in the South in 2023-24 (-25%) and point out that the enlarged automotive sector in the south is worth around €13 billion in added value and 300 thousand employees (with Campania and Puglia in the lead). These workers, often with mechanical skills, could in part be retrained towards electric mobility (production of electric motors, assembly of battery

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packs, maintenance of columns, etc.), but only if these activities are set up in the South. In practice, employment in the South can only withstand the transition by bringing the new technology chain there.

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3.Recommendations for Education and Industry Collaboration

Italy's battery industry is expanding, but to ensure sustainable and competitive growth, the gap between required and available skills in the labour market must be closed. Strengthening collaboration between educational institutions and companies is crucial to developing innovative training pathways aligned with industry needs.

This section presents a series of recommendations to enhance workforce preparation and promote the development of Italy's battery sector.

The strategies focus on three key areas:

1. Updating and innovating vocational education and training (VET) programmes

2. Developing partnerships between industry and educational institutions

3. Reskilling and upskilling programmes for the existing workforce

3.1 Updating and innovating vocational education and training (VET) programmes

In order to address the skills gaps in the battery industry in a structured way, it is essential to start a process of reviewing and modernising technical and university education programmes. The rapid evolution of technologies related

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to electric mobility and energy storage requires a continuous adaptation of the educational content, so that it can respond to the real needs of the industry and adequately prepare future professionals.

One of the most urgent actions concerns the integration of specific new disciplines into curricula. Educational programmes, both at secondary and tertiary level, should include modules dedicated to the knowledge of **battery technologies**, delving into the structure, chemistry and functioning of lithium-ion batteries, as well as emerging alternatives such as solid-state and sodium batteries. Likewise, it is crucial to introduce elements of **automation and industrial robotics**, illustrating the operation of advanced machinery used in modern gigafactories.

In the context of Industry 4.0, it is also essential to strengthen **training on artificial intelligence and data analysis**, with a focus on applications in battery performance monitoring, predictive maintenance and production process optimisation. To complement this upgrade, training courses should include modules dedicated to **recycling and sustainability**, addressing technologies and processes for the recovery and reuse of spent batteries, with a view to the circular economy.

In parallel with the revision of the content, it is necessary to invest in the **teaching and technology infrastructure**. Many technical institutes do not have up-to-date laboratories for practical training, a condition that severely limits the effectiveness of learning. With this in mind, we propose the creation of **centres of excellence** equipped with laboratories dedicated to battery assembly and testing, which can offer students experimental training experiences. Universities

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and technology poles should also be strengthened through the acquisition of industrial simulation tools and digital machinery, to bring the educational context closer to the production context.

Finally, the adoption of **active teaching methodologies**, such as *project-based* learning and industrial simulations, can help strengthen students' transversal skills, stimulating their problem-solving ability and attitude to teamwork. Involving students in real research and development projects, in collaboration with companies in the sector, is an opportunity to develop concrete professional skills, while promoting innovation and technology transfer.

3.2 Developing partnerships between industry and educational institutions

One of the most effective tools for bridging the gap between training and the world of work in the battery industry is the strengthening of structured collaboration between companies and educational institutions. A greater involvement of industry in training programmes allows students to come into direct contact with real technologies, processes and organisational dynamics, enabling them to acquire skills that are immediately spendable in the labour market.

A first area of intervention concerns the creation and dissemination **of structured internship and apprenticeship schemes**, capable of offering quality training experiences. In particular, it is desirable for companies to promote **paid apprenticeships** aimed at students from technical institutes and universities, so as to facilitate their gradual insertion in the production context and enhance

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the contribution of the new generations. At the same time, the implementation of **professional apprenticeship programmes**, designed for young workers, represents a concrete opportunity to train qualified figures directly in company contexts.

In addition to the provision of practical experience, companies can make a significant contribution to the definition of training content through the **co-design of joint modules and courses.** The construction of shared didactic paths, with the inclusion of specific contents related to industrial innovation, makes it possible to ensure greater coherence between the skills developed in the classroom and those required in the work context. To this end, it is essential to organise **seminars, workshops and refresher** courses aimed at both students and teachers, directly involving industry experts and company representatives.

A further strategic element concerns the strengthening of **collaboration between universities, research centres and companies**, especially in terms of technological innovation. Italian universities, in particular those with strong competences in engineering and chemistry, can play a central role in promoting applied research on next-generation energy storage technologies. **Joint research projects** focusing on advanced batteries, sustainable recycling or new system architectures foster the development of innovative solutions and the training of highly specialised profiles.

Finally, the creation of **shared laboratories between academia and industry** can facilitate technology transfer, allowing new processes to be tested in controlled environments and reducing the gap between prototyping and industrial application. These spaces, if integrated into territorial ecosystems of

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innovation, can become privileged places for the contamination between research and production.

3.3 Reskilling and upskilling programmes for the existing workforce

The transition to electric mobility and the spread of battery technologies require not only the training of new professional figures, but also a major **retraining (reskilling**) and **updating (upskilling)** of the already active workforce, particularly within traditional manufacturing. Many workers in sectors related to mechanical engineering, combustion engine components or conventional industrial manufacturing risk being excluded from the new value chains if they are not adequately prepared for the changes taking place.

In order to meet this need, it is essential to design **training courses dedicated to professional reconversion**, enabling technicians and operators from traditional industrial sectors to acquire the necessary skills to work in areas such as industrial automation, control of storage systems, traceability of materials or battery safety. At the same time, more qualified technical figures - such as process engineers, quality control operators or production managers - also need specific training in emerging technologies, with a focus on energy management, safety regulations and design for recycling.

In a context characterised by rapid technological change and the need for continuous training, a key role can be played by **online learning platforms**, which are able to offer interactive, flexible courses that are also accessible to already employed workers. The integration of digital tools, such as augmented or virtual reality modules, makes it possible to simulate complex industrial

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environments and to offer training experiences close to practice, even at a distance.

To support the widespread adoption of these programmes, it is essential to provide **financial support mechanisms** for both companies and workers. Recognition of **tax incentives for companies that invest in training their employees**, together with the introduction of **training vouchers for workers in transition** to the battery sector, could facilitate access to refresher courses and increase participation by small and medium-sized enterprises.

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Conclusion

Italy is strategically positioned within the European battery supply chain, thanks to the presence of consolidated industrial skills, technological hubs in the development phase and a constantly evolving production network. Investments in new gigafactories, applied research initiatives and projects focused on the circular economy testify to a growing dynamism, which could translate into a significant competitive advantage in the medium term.

However, alongside this potential, a number of critical issues are clearly emerging that require a systemic and integrated approach. The lack of professionals with specialized technical skills, the delay in updating training courses and the limited diffusion of practical training are factors that risk hindering the development of the sector. Added to this is a territorial fragmentation of industrial and training supply, which could accentuate regional inequalities and compromise the cohesion of the system.

In this scenario, it seems essential to strengthen the structured dialogue between companies, educational institutions and public actors, in order to build training courses that are consistent with technological developments and capable of responding to the real needs of the labor market. It is also necessary to invest in up-to-date educational infrastructures, promote experiential training methods and enhance retraining opportunities for workers in sectors in transition.

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Project Nr.: 2024-1-SK01-KA220-VET-000256192

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BATPOWER: PREPARATION OF THE VET LEVEL ON BATTERY ENERGY

"Slovakia: Industrial Trends and Effects of Mass Application of Battery Technology"

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BATPOWER
Preparation of the VET sector on battery energy transition

Table of Contents

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Executive Summary

Slovakia is at a turning point in its industrial and energy transition, with the battery sector becoming a key driver of economic growth. As a major European automotive hub, the country has attracted significant investments, including the €1.2 billion InoBat Auto & Gotion High-Tech gigafactory, yet faces critical workforce and educational gaps that could slow progress.

Despite the growing demand for battery specialists, Slovakia's VET system lacks specialized programs, leaving graduates unprepared for industry needs. Practical training in battery assembly, testing, and recycling is limited, and workforce reskilling efforts remain insufficient to transition professionals from traditional manufacturing roles into the battery sector.

To address these gaps, VET curricula must be updated to include battery safety, lifecycle management, and recycling techniques. Industry partnerships with InoBat Auto, SGS TECNOS, and major automotive players should provide certifications, internships, and hands-on training. In the long term, regional training hubs and research collaborations will be essential for workforce development and industrial innovation.

By modernizing education, expanding industry collaboration, and investing in reskilling programs, Slovakia can position itself as a leader in Europe's battery industry, securing long-term competitiveness and sustainable economic growth.

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Preparation of the VET sector on battery energy transition

Introduction

Slovakia holds a pivotal position in Europe's automotive sector, being the world's leading car producer per capita. The country hosts major automotive manufacturers, including Volkswagen, Stellantis, Kia Motors, and Jaguar Land Rover, with Volvo Cars planning to establish an electric car plant in the near future. This robust automotive industry significantly contributes to Slovakia's economy and employment.[1]

In alignment with Europe's green transition, Slovakia has been actively investing in battery technology. The nation is a participant in the **European Battery Alliance (EBA)**, an initiative launched in 2017 to develop a competitive and sustainable battery value chain in Europe. The EBA encompasses over 800 participants from both public and private sectors, covering the entire battery value chain. [2]

Domestically, the establishment of the **Slovak Battery Alliance (SBaA)** in 2018 mirrors the EBA's model, aiming to create an ecosystem that integrates Slovak industry, science, and research in the battery sector.[3] Notable investments include the construction of a first-of-its-kind electric vehicle battery technology center and pilot line by **InoBat Auto**, which began in 2021. This facility is designed to integrate research and development with battery cell manufacturing capabilities under one roof. [4]

Despite these advancements, Slovakia faces significant challenges in workforce preparedness for the burgeoning battery industry. A report from **InoBat** highlights the absence of comprehensive education in electromobility and battery business fields within the country. This educational gap underscores the need for targeted vocational education and training Resource programs to develop a skilled workforce capable of supporting the industry's growth.

[1] https://apnews.com/article/slovakia-hyundai-mobis-electric-car-parts-7935a67ef9ed5e2c20f6e78e1babb08c
[2] https://www.eba250.com/about-eba250/network/
[3] https://www.globsec.org/sites/default/files/2021-08/AutoFocus-Slovakia-An-Automotive-Industry-Perspective.pdf
[4] https://www.inobat.eu/newsroom/construction-begins-on-first-of-its-kind-electric-vehicle-battery-technology-centre-and-pilot-line/

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BATPOWER
Preparation of the VET sector on battery energy transition

This report aims to analyze Slovakia's industrial trends in battery technology and identify the educational gaps and workforce needs essential to support this sector's expansion. The analysis will focus on:

Assessing the current state of Slovakia's battery industry and its alignment with European energy policies.

Evaluating the demand for skilled professionals in battery manufacturing, testing, and lifecycle management.

Examining the availability and adequacy of VET programs and higher education courses related to battery technology.

Proposing necessary reforms in Slovakia's vocational education system to align with industry requirements.

By identifying these gaps, the report will provide recommendations for educational interventions to strengthen Slovakia's workforce readiness for the growing battery industry.

This report is structured as follows:

Slovakia's Industrial Trends in Battery Technology – A detailed examination of Slovakia's battery production landscape, key players, and market dynamics.

Impact of Mass Battery Technology Application – An analysis of how the large-scale adoption of EV batteries, energy storage, and recycling initiatives affects the country's economy, energy security, and industrial policies.

Educational Gaps and Workforce Needs – A study of current VET and higher education programs, identifying missing elements in battery-related training and upskilling requirements.

Recommendations for VET Development – Proposed interventions to integrate battery technology into Slovakia's vocational education system, including curriculum enhancements, industry partnerships, and practical training initiatives.

By addressing these aspects, the report seeks to support Slovakia's strategic role in the European battery industry, ensuring that the country remains competitive, innovative, and well-prepared for the evolving demands of battery technology and sustainable mobility.

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1. Industrial Trends in Slovakia

1.1 Battery Manufacturing Investments

Slovakia is rapidly establishing itself as a significant player in the European battery manufacturing sector, leveraging its strong automotive industry foundation. The country's strategic initiatives and substantial investments are positioning it as a hub for electric vehicle (EV) battery production.

A landmark development in this trajectory is the planned construction of a state-of-the-art battery production plant in Šurany, a collaborative effort between China's Gotion High-Tech and Slovakia's InoBat Auto. This joint venture, known as Gotion InoBat Batteries (GIB), represents a significant milestone in Slovakia's industrial advancement. [5]

The Slovak government has recognized the strategic importance of this project, granting it the status of a significant investment. The total investment is valued at €1.2 billion, marking it as the second-largest investment in the country's history. The government has committed to providing investment aid totaling €214 million, comprising a €150 million subsidy and €64 million in tax relief. [6]

This initiative is anticipated to create approximately 1,311 new jobs, offering wages above the regional average. Beyond job creation, the project includes the establishment of a research and development center aimed at enhancing the expertise of workers and bolstering Slovakia's innovation potential.

The Šurany plant is designed to have an initial production capacity of 20 gigawatt-hours (GWh), with the potential to expand up to 40 GWh in subsequent phases. Construction is slated to commence in 2024, with the start of production targeted for the second quarter of 2026 and full-scale operations by 2027.

[5] https://www.inobat.eu/newsroom/gotion-inobat-batteries-gib-has-signed-a-memorandum-of-understanding-with-the-government-of-the-slovak-republic-to-support-the-construction-of-a-battery-gigafactory/
[6] https://www.mhsr.sk/en/press/the-second-highest-investment-in-the-history-of-country-is-coming-to-slovakia-it-is-worth-eur-12-billion-and-it-focuses-on-battery-production

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Preparation of the VET sector on battery energy transition

This significant investment underscores Slovakia's commitment to advancing its battery manufacturing capabilities and aligns with broader European efforts to enhance the continent's energy independence and sustainability.

Case Study: InoBat Auto – The Role of Gigafactories in Šurany and Collaboration with Investors like Gotion High-Tech

InoBat Auto, a Slovak-based innovative battery company, has been at the forefront of developing advanced battery solutions tailored for the automotive industry. The company's strategic collaboration with China's Gotion High-Tech has culminated in the formation of Gotion InoBat Batteries (GIB), a joint venture dedicated to establishing a cutting-edge battery gigafactory in Šurany. Gotion High-Tech, recognized as one of the top-tier global battery manufacturers and a key supplier to Volkswagen, brings extensive technological expertise and manufacturing experience to the partnership. This collaboration is poised to significantly enhance Slovakia's position in the European battery value chain.

The planned gigafactory in Šurany is set to occupy a 65-hectare site within the strategic eco-park known as the Šurany Battery Hub. The facility aims to implement an innovative closed-loop circular value chain, emphasizing sustainability and efficiency in battery production. The Slovak government has demonstrated strong support for this venture, as evidenced by the signing of a Memorandum of Understanding (MoU) with GIB. The MoU outlines commitments from the government to provide subsidies, facilitate land arrangements, prepare the construction site, and ensure connectivity to the electrical grid. In return, GIB has pledged to commence construction in 2024, with production activities beginning in 2026. [7]

This partnership between InoBat Auto and Gotion High-Tech exemplifies the critical role of international collaboration in advancing battery manufacturing capabilities. The gigafactory in Šurany is anticipated to not only bolster Slovakia's industrial landscape but also contribute significantly to the broader European objectives of achieving energy sustainability and reducing carbon emissions.

1.2 Automotive Sector and Battery Integration

[7] https://www.inobat.eu/newsroom/gotion-inobat-batteries-gib-has-signed-a-memorandum-of-understanding-with-the-government-of-the-slovak-republic-to-support-the-construction-of-a-battery-gigafactory/

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Preparation of the VET sector on battery energy transition

Slovakia as a Hub for Automotive Giants

Slovakia has established itself as a significant hub for major automotive manufacturers, hosting production facilities for companies such as **Volkswagen Slovakia, Kia Motors Slovakia, Stellantis Slovakia, and Jaguar Land Rover Slovakia**. In 2022, these four manufacturers collectively produced approximately one million cars. Looking ahead, **Volvo Cars** is set to become the fifth vehicle manufacturer in the country, with plans to install equipment and production lines during 2024 and commence serial production of pure electric next-generation vehicles in 2026.[8]

Demand for EV Battery Production and Its Effects on Supply Chains

The global shift towards electric vehicles (EVs) has led to a significant increase in demand for EV batteries, impacting supply chains worldwide. In Slovakia, this trend necessitates substantial investments in the production of components and batteries for electric vehicles, with an emphasis on supporting the local supply chain. Such investments aim to ensure that Slovak companies can effectively navigate this transition and capitalize on the opportunities presented by electromobility. [9]

However, the country faces challenges in securing sufficient battery production to meet EV manufacturing requirements. A report by Cambridge Econometrics indicates that, to offset potential employment and economic losses from the internal combustion engine (ICE) vehicle supply chain, Slovakia would need to ensure substantially more battery production than currently planned. This would involve significant investments to build new EV production facilities or retrofit existing ICE production facilities, as well as to establish battery production capacity.[10]

Transition from Combustion Engines to Electric Vehicles (EVs)

The transition from internal combustion engine (ICE) vehicles to electric vehicles (EVs) is accelerating globally, driven by policy shifts and market dynamics. In Slovakia's key export markets, 74% have announced bans on ICE vehicle sales by 2035, underscoring the urgency for domestic producers to adapt to remain competitive. This shift presents both challenges and opportunities for Slovakia's

[8] https://www.trade.gov/market-intelligence/slovakia-automotive-electric-vehicles-action-plan
[9] https://seva.sk/en/hubs/transformation/
[10] https://www.camecon.com/wp-content/uploads/2022/03/AutoFocus-report-new-v2.pdf

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automotive industry. Proactive adaptation to these trends could position the country as a leader in EV production, with positive effects on GDP and employment. Conversely, failure to transition could result in significant economic and employment challenges. [11]

1.3 Research and Innovation Ecosystem

Contributions of Local Institutions and Research Bodies to Battery Technology Advancements

Slovakia's commitment to advancing battery technology is evident through the collaborative efforts of its academic institutions, research centers, and private enterprises. A notable initiative is the establishment of the National Battery Centre, a consortium led by the Centre for Advanced Material Application of the Slovak Academy of Sciences (CEMEA). This consortium includes prominent institutions such as the Technical University of Košice, Pavol Jozef Šafárik University in Košice, Slovak University of Technology in Bratislava, and the University of Žilina. The center focuses on key areas like the development of new materials for lithium batteries, solid electrolytes, and alternative battery technologies, aiming to position Slovakia at the forefront of battery research and development.[12]

In addition to academic collaborations, private companies are making significant strides. InoBat Auto, a Slovak company specializing in innovative battery solutions, has successfully produced the first batteries labeled "made in Slovakia." The company has also obtained necessary certifications and initiated production of high-performance cells, marking a milestone in the nation's battery manufacturing capabilities.[13]

Furthermore, a joint research endeavor between Pavol Jozef Šafárik University in Košice, the Technical University of Košice, and the Slovak company INO-HUB Energy led to the development of a revolutionary flow battery. This collaboration resulted in a fully functional 80 kWh flow battery, with plans for

[11] https://www.globsec.org/what-we-do/publications/slovakia-automotive-industry-20-time-now-retool-e-mobility-era

[12] https://www.sav.sk/?doc=services-news&lang=en&news_no=9186&source_no=20&

[13] https://batterytechassociation.org/inobat-announces-first-slovak-batteries-for-e-mobility-and-introduces-a-completely-new-profession-to-slovakia/

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mass production by 2026, showcasing the potential of Slovak research institutions in pioneering energy storage solutions.[14]

Challenges in Scaling R&D into Practical Industry Applications

Despite these advancements, transitioning research and development (R&D) outcomes into practical industry applications presents several challenges. One significant hurdle is the scaling of laboratory materials and manufacturing processes to industrial levels. While innovative battery materials and designs are often successful in controlled laboratory settings, replicating these results on a commercial scale can be complex. Issues such as maintaining material consistency, ensuring process reliability, and achieving cost-effectiveness can impede large-scale production.[15]

Another challenge is the development of a skilled workforce capable of addressing the complexities of battery production. As the industry evolves, there is a pressing need for professionals adept in both the theoretical and practical aspects of battery technology. This includes expertise in materials science, electrochemistry, and manufacturing processes. Educational institutions must adapt their curricula to meet these demands, ensuring that graduates are equipped with relevant skills to contribute effectively to the industry.[16]

Additionally, the environmental impact of scaling battery production poses a significant concern. The processes involved in mining and refining raw materials, as well as the manufacturing of batteries, can have adverse environmental effects. Addressing these issues requires the development of sustainable practices and technologies that minimize ecological footprints while maintaining production efficiency.[17]

[14] https://www.upjs.sk/prirodovedecka-fakulta/en/actuality/revolucna-prietokova-bateria-vysledok-spolocneho-vyskumu/
[15] https://www.batterytechonline.com/design-manufacturing/the-challenges-in-scaling-up-battery-material
[16] https://www.frontiersin.org/journals/manufacturing-technology/articles/10.3389/fmtec.2024.1360076/full
[17] https://leyton.com/uk/insights/articles/battery-technologies-market-drivers-challenges-and-future-rd-opportunities/

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Preparation of the VET sector on battery energy transition

2. Workforce Challenges and Educational Gaps

2.1 Technical Skills Gaps

Slovakia's burgeoning battery industry faces significant technical skills gaps, particularly in areas such as battery lifecycle management, safety training, recycling, fault analysis, and quality control processes.

Insufficient Focus on Battery Lifecycle Management and Safety Training

The rapid growth of the battery sector necessitates a workforce proficient in comprehensive lifecycle management to ensure efficiency, safety, and environmental sustainability. However, current educational programs in Slovakia often lack structured training in these areas. This deficiency can lead to improper handling, reduced efficiency, and increased safety risks.[18]

Safety training is another critical area where current educational programs fall short. The complex nature of battery systems, especially lithium-ion batteries, necessitates specialized knowledge to prevent hazards such as thermal runaway, fires, and explosions. Without adequate safety training, workers may be ill-equipped to handle these risks, potentially leading to accidents and injuries.[19]

Limited Understanding of Recycling, Fault Analysis, and Quality Control Processes

The processes of recycling, fault analysis, and quality control are integral to the sustainable and efficient operation of the battery industry. Yet, there is a scarcity of training focused on these areas:

Recycling: As the demand for batteries increases, so does the need for effective recycling methods to manage end-of-life batteries and recover

[18] https://www.globsec.org/sites/default/files/2021-05/GLOBSEC-Boosting-Slovak-batteries_webinar-outcome-report_14May.pdf
[19] https://nac.naatbatt.org/wp-content/uploads/2022/12/NAATBatt-Edu-Comm-Survey-Results-Overview_Final_Dec-21-2021.pdf

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valuable materials. A lack of expertise in recycling processes can result in environmental harm and loss of resources.

Fault Analysis: Identifying and diagnosing faults within battery systems require specialized skills. The absence of thorough training in fault analysis can lead to prolonged downtimes, increased maintenance costs, and compromised safety.

Quality Control: Ensuring the reliability and performance of batteries hinges on rigorous quality control measures. However, limited training in this area can cause inconsistencies in battery production, affecting overall product quality and consumer trust.

Addressing the Technical Skills Gaps

To bridge these technical skills gaps, Slovakia has initiated several measures:

National Battery Centre: The establishment of the National Battery Centre aims to support the most promising components of the battery industry's value chain. This initiative focuses on research and development in areas such as advanced electrodes, electrolytes, and recycling processes, contributing to the development of advanced batteries and supporting the training of specialists in battery technologies. [20]

Centres of Excellence for Vocational Education and Training: Launched by the Ministry of Education, these centers aim to increase the quality, flexibility, and adaptability of vocational education and training. They focus on providing vocational education to young people and enhancing the skill levels of adults to meet labor market needs, particularly in the context of digital and green transformation.

InnoEnergy Skills Institute: This institute has reached a milestone of upskilling over 50,000 learners to support the growing battery industry. The training courses cover various aspects of the battery value chain, including battery management systems, battery testing, safety, and security.

2.2 Practical Training Deficiencies in Slovakia

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Slovakia's vocational education and training Resource programs face significant challenges in aligning with the evolving demands of the battery industry. Key deficiencies include a lack of hands-on experience in battery assembly, testing, and recycling, as well as misalignment between current VET curricula and industry-specific needs.

Lack of Hands-On Experience in Battery Assembly, Testing, and Recycling

The rapid advancement of battery technology necessitates practical skills in assembly, testing, and recycling processes. However, Slovak VET programs often lack the infrastructure and curricula to provide students with direct experience in these areas. This gap results in a workforce that is theoretically knowledgeable but lacks the practical competencies required by employers in the battery sector. For instance, the production of the first batteries labeled "made in Slovakia" by InoBat highlights the country's potential in battery manufacturing, yet underscores the need for skilled professionals to sustain and advance such initiatives.[21]

Current VET Programs Not Aligning with Industry-Specific Needs

There is a noticeable disconnect between the curricula of existing VET programs and the specific requirements of the battery industry. As the automotive sector increasingly shifts towards electrification, the demand for specialists trained in battery technologies has surged. Alexander Matušek, President of the Automotive Industry Association of the Slovak Republic, emphasizes the importance of supporting the training of specialists for battery technologies to maintain competitiveness. [22]

Example: Contributions and Limitations of the DSA Polytechnic School Programs

The DSA Polytechnic School in Nitra, in collaboration with Jaguar Land Rover, has initiated a four-year course in mechatronics aimed at addressing the skills gap in the automotive industry. While this program represents a positive step towards integrating practical skills into the curriculum, its focus remains broad, encompassing general mechatronics without delving deeply into specialized battery technologies. Consequently, graduates may still lack specific

[21] https://batterytechassociation.org/inobat-announces-first-slovak-batteries-for-e-mobility-and-introduces-a-completely-new-profession-to-slovakia
[22] https://www.sav.sk/?doc=services-news&lang=en&news_no=9186&source_no=20&

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competencies in battery assembly, testing, and recycling, limiting their immediate applicability in the rapidly evolving battery sector. [23]

2.3 Soft Skills Gaps

In addition to technical competencies, the battery industry in Slovakia faces significant challenges related to soft skills among its workforce. Key areas of concern include limited problem-solving abilities, digital literacy, project management skills, and the need for effective cross-disciplinary teamwork among engineers, researchers, and managers.

Limited Problem-Solving, Digital Literacy, and Project Management Skills

The evolving nature of the battery industry demands a workforce adept at critical thinking and problem-solving to navigate complex challenges. However, there is a noticeable deficiency in these areas within the current labor market. A report highlights that companies in Slovakia are increasingly emphasizing the importance of supporting soft skills such as teamwork, communication, and problem-solving, as well as the ability to adapt to new situations and engage in complex projects. [24]

Digital literacy is another critical area where the Slovak workforce falls short. As the battery industry becomes more technologically advanced, proficiency in digital tools and platforms is essential. The OECD underscores the challenge of skill mismatches and shortages in the context of rapid technological advancements, emphasizing the need for improved digital competencies. [25]

Project management skills are vital for overseeing complex battery projects, ensuring they are completed on time and within budget. However, there is a scarcity of professionals equipped with robust project management capabilities, which can lead to inefficiencies and delays in project execution.

Need for Cross-Disciplinary Teamwork Between Engineers, Researchers, and Managers

[23] https://kafkadesk.org/2018/06/06/jaguar-ready-to-kick-off-production-in-slovakia/

[24] https://cdn.ceps.eu/wp-content/uploads/2023/12/D-3.1-I-SKILL_National-Report_-Slovakia_final.pdf
[25] https://www.oecd.org/content/dam/oecd/en/publications/reports/2017/07/getting-skills-right-skills-for-jobs-indicators_g1g7b8c1/9789264277878-en.pdf

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Effective collaboration among engineers, researchers, and managers is crucial for innovation and efficiency in the battery industry. Despite this, there is often a lack of cross-disciplinary teamwork, stemming from siloed working practices and insufficient communication skills. The NAATBatt survey identifies project management as a missing skill in the existing applicant pool, highlighting the need for improved coordination and collaboration across different roles within the industry.

2.4 Regional Challenges in Slovakia

Slovakia exhibits significant regional disparities, particularly between its urban centers and rural areas. These disparities manifest in various socio-economic indicators, including employment rates, educational attainment, and industrial development.

Uneven Distribution of Industrial Opportunities Between Urban and Rural Regions

The western regions of Slovakia, especially the Bratislava area, have experienced substantial economic growth, attracting significant foreign investments and becoming hubs for various industries. In contrast, the eastern regions have lagged, facing slower economic development and higher unemployment rates. This disparity is partly due to the concentration of industries and services in urban centers, leaving rural areas with limited access to similar opportunities. The International Monetary Fund (IMF) notes that regional disparities in GDP per capita, labor productivity, and labor utilization have widened since 2000, coinciding with Slovakia's negotiations for EU accession. [26]

The World Bank emphasizes that slow economic growth and job creation in eastern and central Slovakia, coupled with poor labor mobility, exacerbate these regional inequalities, hindering the country's overall sustainable development.[27]

Case Study: Investments in Eastern Slovakia

To address these disparities, targeted investments in Eastern Slovakia have been initiated to revitalize the region's economy and enhance educational

[26] https://www.elibrary.imf.org/view/journals/002/2024/076/article-A003-en.xml
[27] https://blogs.worldbank.org/en/europeandcentralasia/narrowing-economic-disparities-between-slovakias-regions-essential-economic

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prospects. A notable example is the development of the Valaliky Industrial Park near Košice. This project includes significant investments in infrastructure, such as nearly 16 kilometers of new roads, 10.6 kilometers of railway tracks, and the construction of a new intermodal terminal. These developments aim to attract businesses to the region, thereby creating job opportunities and stimulating economic growth.[28]

Furthermore, the establishment of industrial parks and clusters in Eastern Slovakia can harmonize social, economic, and environmental aspects, contributing to sustainable regional development. By creating new production areas outside traditional city structures, these initiatives can decentralize industrial activities and promote balanced regional growth.

Impact on Employment and Education Opportunities

Investments in infrastructure and industry in Eastern Slovakia are expected to enhance employment prospects and educational opportunities. The OECD highlights that raising the level of schooling outside of Bratislava to that in the capital region could increase productivity by 5–10 percent.

Additionally, the World Bank's support has focused on investing in the quality of secondary vocational education and its better alignment with labor market demands to improve opportunities for young people and contribute to new jobs and industries.

[28] https://www.mdpi.com/2075-5309/13/10/2506

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3.Recommendations for Education and Industry Collaboration

To strengthen Slovakia's position in the burgeoning battery industry, it is imperative to foster robust collaboration between educational institutions and industry stakeholders. This partnership will ensure that the workforce is equipped with the necessary skills and knowledge to meet current and future demands. The following short-term recommendations are proposed to enhance this collaboration:

3.1 Short-Term Recommendations

Update Vocational Education and Training Resource Curricula

Battery Safety and Lifecycle Management

Integrating comprehensive modules on battery safety and lifecycle management into VET programs is crucial. This includes educating students on the proper handling, storage, and disposal of batteries, as well as understanding the complete lifecycle from production to end-of-life. Emphasis should be placed on safety protocols to prevent hazards such as thermal runaway, fires, and explosions. Incorporating case studies and real-world scenarios can enhance understanding and application. For instance, the NESC Academy offers a short course on lithium-ion batteries that covers fundamental concepts, battery safety, and modeling techniques, which can serve as a valuable resource for curriculum development.[29]

[29] https://nescacademy.nasa.gov/video/263eb2771bf34968bba79136b07c851c1d

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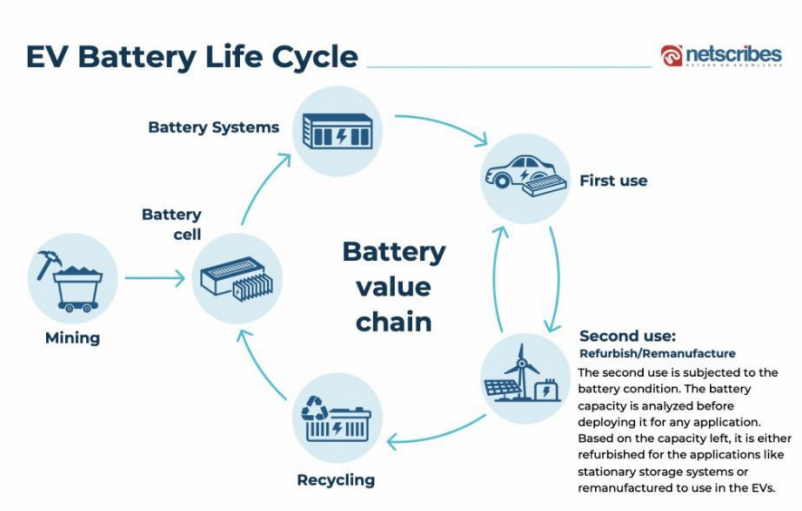

Key Components of Battery Safety Education:

Safe Handling, Storage, and Transportation

Workers must understand proper battery storage conditions, safe transport standards, and emergency response protocols to prevent thermal runaway and chemical hazards.[30]

Battery Chemistry and Failure Mechanisms

Training should cover lithium-ion and next-gen batteries, common failure causes, and risk prevention techniques like thermal imaging and early detection.

Thermal Runaway Prevention and Fire Safety

Workers must be trained in fire suppression techniques, cooling systems, and high-voltage safety measures to prevent battery-related fires and explosions.

Battery Lifecycle Management: Production to Recycling

Education must include battery production processes, maintenance, and end-of-life recycling to promote sustainability and compliance with EU

[30] https://road-safety.transport.ec.europa.eu/specialist/knowledge/vehicle_safety/safety_standards

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Preparation of the VET sector on battery energy transition

environmental regulations. Currently, only 5% of EU battery workers receive formal recycling training, highlighting a critical gap.[31]

Implementation Area	Description
Standardized Safety Courses	Introduce battery safety and lifecycle management courses in Slovakia's VET programs.
Industry Partnerships	Partner with **InoBat Auto, SGS TECNOS, and other industry leaders** for real-world training.
Practical Training Facilities	Equip VET institutions with **battery testing tools** for hands-on experience.
Regulatory Alignment & Certification	Align training with **EU battery safety regulations** and offer **specialized certifications**.

Recycling Techniques and Environmental Protocols

Given the environmental implications of battery disposal, it is essential to educate students on effective recycling techniques and environmental protocols. This encompasses the processes involved in recycling battery components, the importance of material recovery, and adherence to environmental regulations. Practical training sessions can be conducted to provide hands-on experience in recycling processes. The U.S. Environmental Protection Agency provides comprehensive information on lithium-ion battery recycling, including methods and regulatory considerations, which can inform the development of these modules.[32]

Key Aspects of Battery Recycling Education

Understanding Battery Recycling Processes

Recycling lithium-ion batteries involves several **key steps** that must be understood by workers entering the field:

Collection & Sorting – Identifying usable vs. damaged batteries and directing them to appropriate recycling facilities.

[31] https://eit.europa.eu/news-events/news/european-institute-innovation-and-technologys-european-battery-alliance-academy

[32] https://www.epa.gov/hw/lithium-ion-battery-recycling

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Disassembly & Material Separation – Breaking down batteries into anode, cathode, electrolyte, and casing materials.

Metal Recovery & Refining – Extracting valuable raw materials (e.g., lithium, cobalt, nickel) for reuse in battery production.

The European Battery Alliance (EBA) Academy has highlighted that only 5-10% of used lithium-ion batteries in the EU are currently being recycled, indicating a critical skills gap in this area.

The Importance of Material Recovery & Circular Economy

Lithium-ion batteries contain scarce and high-value materials, making material recovery essential for reducing dependency on mining and ensuring the sustainability of the battery supply chain. A strong circular economy model should be incorporated into VET training, covering:

The value of recovered lithium, cobalt, and nickel in future battery production.

Recycling vs. Second-Life Applications – Determining whether batteries should be recycled or repurposed for stationary energy storage.

Environmental & Economic Benefits – Reducing waste production and lowering the cost of new batteries through effective resource recovery.

Regulatory Compliance and Safety in Battery Recycling

Strict EU environmental laws regulate battery disposal and recycling to prevent hazardous waste accumulation. Workers must be trained to:

Follow EU Directives on battery recycling and waste management.

Handle hazardous substances safely, including electrolytes and heavy metals.

Ensure compliance with waste tracking and disposal reporting requirements.

The U.S. Environmental Protection Agency (EPA) provides comprehensive guidelines on safe lithium-ion battery recycling, which can inform the development of these training modules

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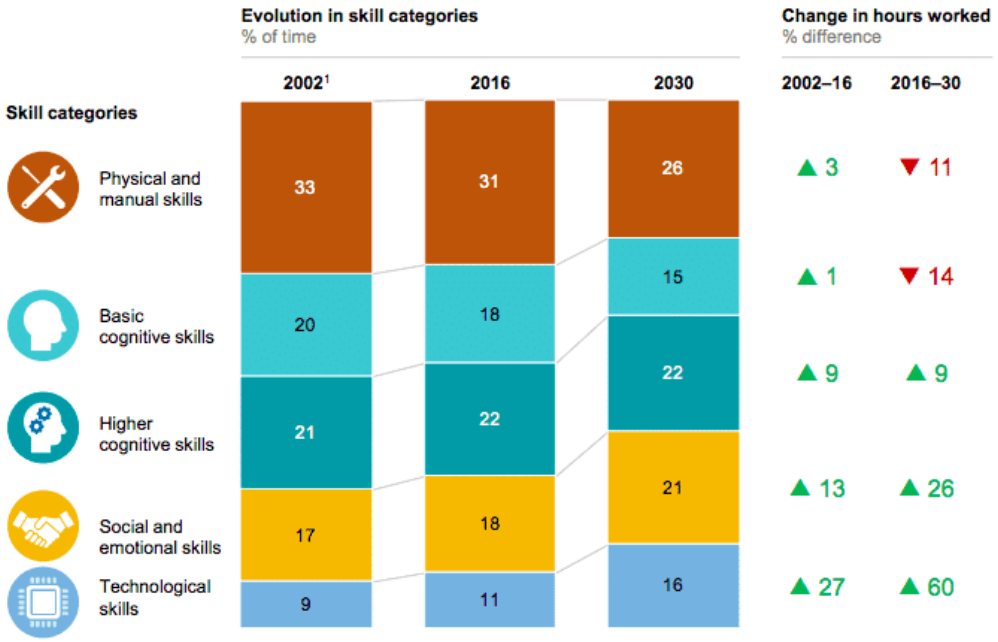

Introduce Certification Courses in Partnership with Industry Leaders

Establishing certification courses in collaboration with leading industry players, such as InoBat Auto, can provide students with specialized knowledge and skills that are directly applicable to the industry. These courses can cover areas such as advanced battery technologies, manufacturing processes, quality control, and safety standards. Partnerships with companies like InoBat Auto, which has pioneered battery production in Slovakia, can offer valuable insights and resources for curriculum development. Additionally, organizations like SAE International, in collaboration with InnoEnergy, offer Battery Academy courses that cover various aspects of battery technology and could serve as models for such certification programs. [33]

3.2 Long-Term Recommendations

To ensure the sustained growth and competitiveness of Slovakia's battery industry, it is essential to implement long-term strategies that foster deeper collaboration between educational institutions and industry stakeholders. The following recommendations aim to build a robust talent pipeline equipped with the necessary skills to meet future industry demands:

[33] https://www.sae.org/learn/professional-development/sae-innoenergy-battery-academy

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Development of Industry-Academic Collaborations

Internship Programs with Automotive Companies and Gigafactories

Establishing structured internship programs in partnership with leading automotive companies and emerging gigafactories is crucial. These programs should provide students with hands-on experience in battery technology, manufacturing processes, and quality assurance. For instance, companies like MAHLE offer internships that allow students to engage in practical tasks and gain insights into the automotive sector.[34] Similarly, ZF Slovakia collaborates with secondary and higher education institutions to organize professional lectures, excursions, and practical training, thereby enhancing students' readiness for industry roles.[35]

Practical Labs Integrated with Real-World Testing Tools

Integrating practical laboratories within educational institutions, equipped with industry-standard testing tools, will bridge the gap between theoretical knowledge and practical application. These labs should simulate real-world scenarios, allowing students to work with advanced battery systems and testing equipment. The National Battery Centre (NBC) in Slovakia aims to enhance the share of domestically produced technologies in cars manufactured in the country, emphasizing the importance of such practical training facilities.[36]

Establish Regional Training Hubs to Address Skills Gaps

Creating regional training hubs dedicated to battery technology and related fields can address existing skills gaps and promote workforce development across Slovakia. These hubs should offer specialized courses, workshops, and certification programs tailored to the needs of the battery industry. The European Battery Alliance (EBA) Academy has initiated programs to provide specialized training for experts and technicians in the battery industry, highlighting the effectiveness of such collaborative efforts. [37]

To illustrate the potential impact of implementing long-term strategies for Slovakia's battery industry, consider the following data:

[34] https://www.jobs.mahle.com/slovakia/en/get-in-contact/students/
[35] https://www.zf.com/slovakia/sk/careers/students/students.html
[36] https://en.univnet.sk/slovakia-to-have-a-national-battery-centre-nbc/
[37] https://sbaa.sk/aktivity-en/the-pilot-eba-academy-programme-under-the-sbaa-has-started

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Projected Employment Changes in Slovakia's Automotive Sector by 2040

Scenario	Employment Change	Number of Jobs Affected
Best-Case Scenario	+18%	+8,000 jobs
Worst-Case Scenario	-4.5%	-85,000 jobs

Resource: https://www.camecon.com/wp-content/uploads/2022/03/AutoFocus-report-new-v2.pdf

In the best-case scenario, proactive measures such as developing industry-academic collaborations, establishing internship programs, integrating practical labs, and creating regional training hubs could lead to an 18% increase in employment within the electrical equipment sector, adding approximately 8,000 jobs. Conversely, failure to adapt to the evolving industry may result in a 4.5% decrease in employment, equating to a loss of about 85,000 jobs.

3.3 Upskilling Existing Workforce

As Slovakia's battery industry continues to expand, it is imperative to facilitate the transition of professionals from traditional manufacturing sectors into battery energy roles. This can be achieved by creating comprehensive reskilling pathways that equip the existing workforce with the necessary skills and knowledge to thrive in the evolving energy landscape.

Creating Reskilling Pathways for Professionals in Traditional Manufacturing Sectors

As Slovakia undergoes a transition towards electromobility and sustainable energy solutions, the demand for a workforce proficient in battery technologies is growing rapidly. Many professionals currently engaged in traditional manufacturing sectors, such as automotive, mechanical engineering, and electronics, possess valuable industry experience that can be leveraged and repurposed through targeted reskilling programs. These initiatives aim to equip workers with new competencies that align with the evolving battery production and energy storage industries, ensuring that Slovakia remains competitive in the European battery market.

A successful workforce transition depends on structured retraining programs that focus on technical expertise, safety compliance, and quality assurance.

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This will allow workers from traditional industries to integrate seamlessly into the battery energy ecosystem, filling critical skill gaps in manufacturing, recycling, and maintenance. The following key areas must be addressed in Slovakia's reskilling efforts:

Technical Training:

One of the most pressing challenges in workforce reskilling is the lack of in-depth knowledge about battery systems, their chemistry, and lifecycle management among existing workers. Many professionals from traditional industries, such as automotive assembly and general mechanical engineering, may have hands-on manufacturing experience, but their expertise does not include battery-specific components such as cell chemistry, module assembly, or energy management.

Reskilling programs should provide comprehensive training on:

Battery Cell Chemistry – Understanding lithium-ion, solid-state, and next-generation battery chemistries, their properties, and performance characteristics.

Battery Assembly – Training in cell-to-module and module-to-pack assembly, including bonding, cooling, and casing techniques.

Energy Management Systems (EMS) – Developing expertise in battery management systems (BMS), thermal control, and charge-discharge cycles.

Battery Integration into Vehicles and Energy Storage Systems – Understanding how batteries interact with electric drivetrains, grid storage solutions, and hybrid systems.

International programs such as the U.S. Department of Energy's Battery Workforce Challenge have demonstrated the importance of building a diverse and skilled workforce in the battery and electric vehicle (EV) sector. This initiative provides hands-on training for technicians, engineers, and skilled trades workers, emphasizing cross-disciplinary knowledge and battery technology specialization. [38]

[38] https://www.energy.gov/eere/articles/us-department-energy-kicks-nationwide-battery-workforce-challenge-program

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Safety Protocols:

Safety in battery production and energy storage is a critical concern, particularly due to the potential fire hazards, thermal runaway risks, and high-voltage exposure involved in handling lithium-ion and solid-state batteries. Workers transitioning from traditional mechanical industries often lack specific training in battery safety, making it imperative for reskilling programs to incorporate detailed safety compliance measures.

Key areas of focus should include:

Safe Handling and Storage – Training on temperature-sensitive materials, flammability risks, and battery aging factors.

High-Voltage Safety – Educating workers on working with high-voltage battery systems, ensuring proper personal protective equipment (PPE) usage.

Thermal Management and Fire Prevention – Understanding heat dissipation strategies, battery overheating risks, and early hazard detection.

Emergency Response Training – Preparing workers to handle battery failures, leaks, and fire suppression methods.

The Battery Workforce Initiative, led by the U.S. Department of Energy, has already established National Guideline Standards for battery machine operators and safety training. These standards ensure that workers receive comprehensive operational and safety guidance when dealing with high-voltage battery systems.[39]

Quality Assurance:

Maintaining consistent quality in battery manufacturing is crucial to ensure the performance, durability, and safety of electric vehicle batteries and energy storage units. Professionals transitioning from traditional automotive and mechanical engineering fields need additional training in quality control methodologies, diagnostic tools, and process evaluation techniques.

Reskilling programs should emphasize:

[39] https://netl.doe.gov/bwi

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Battery Testing and Diagnostics – Training workers in electrical performance testing, durability assessments, and failure analysis.

Defect Detection and Inspection – Introducing automated scanning, infrared testing, and electrolyte leakage detection techniques.

Process Standardization – Ensuring adherence to EU battery manufacturing regulations, such as UN 38.3, IEC 62133, and ISO 9001.

Recycling and Circular Economy – Developing competencies in material recovery, second-life battery applications, and sustainable disposal practices.

Many global battery manufacturers are struggling with workforce shortages due to a lack of specialized quality control engineers and battery diagnostics technicians. In response, training programs like the European Battery Alliance (EBA) Academy and InoBat Auto's Battery Training Programs have introduced highly specialized courses focused on battery quality control and manufacturing process validation.

Training Area	Current Workforce Skills (%)	Required Skills for Battery Sector (%)
Technical Training	30	80
Safety Protocols	40	85
Quality Assurance	35	75
Recycling & Sustainability	25	70
Industry Collaboration	30	90

Resource: https://www.bruegel.org/system/files/2024-01/WP%2001%202024_0.pdf

Key Insights:

Technical Training: Currently, 30% of the workforce possesses adequate technical training in battery technology, whereas 80% proficiency is necessary to meet industry standards.

Safety Protocols: About 40% of workers are trained in safety protocols, but the industry requires 85% to ensure safe operations.

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Quality Assurance: Presently, 35% of the workforce is skilled in quality assurance processes, while a 75% proficiency level is needed.

Recycling & Sustainability: Only 25% of employees are knowledgeable in recycling techniques and sustainability practices, yet 70% is essential for environmental compliance.

Industry Collaboration: Currently, 30% of the workforce engages in industry collaboration, but a 90% engagement level is desired to foster innovation and best practices.

Implementing such reskilling pathways will not only address the skills gap in Slovakia's battery industry but also provide career advancement opportunities for professionals transitioning from traditional manufacturing roles. By investing in the development of a skilled and adaptable workforce, Slovakia can strengthen its position in the global battery market and drive sustainable economic growth.

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Conclusion

Slovakia has established itself as a key player in the European automotive industry, making significant strides in integrating battery technology into its industrial ecosystem. The country's strategic geographic location, strong manufacturing infrastructure, and skilled workforce have made it an attractive destination for battery production investments. The development of projects like InoBat Auto and the Gotion High-Tech gigafactory in Šurany marks Slovakia's commitment to advancing its role in the European battery value chain. However, despite these advancements, Slovakia faces critical challenges in ensuring its workforce is adequately prepared for the demands of the evolving battery sector.

The Need for an Updated Vocational Education and Training Resource System

One of the biggest obstacles hindering Slovakia's progress in battery energy technology is the outdated structure of VET programs. Currently, vocational schools do not offer specialized curricula focused on battery lifecycle management, safety protocols, quality assurance, and recycling processes. As a result, students graduate with a general technical background but lack the specific competencies required in battery production and energy storage industries. Moreover, practical training opportunities in battery assembly, testing, and quality control remain limited. Many students complete their education without direct experience working with high-voltage battery systems or industry-grade testing equipment. This misalignment between education and industry needs creates a significant workforce gap, slowing the adoption of battery technologies in Slovakia.

Addressing these educational deficiencies is essential to maintaining Slovakia's competitiveness in the European and global battery markets. Reforming VET programs, introducing short-term certification courses, and expanding collaborations with industry stakeholders will ensure that Slovakia develops a future-ready workforce.

The Role of Industry-Academic Collaboration

Stronger collaboration between educational institutions and the battery industry is necessary to bridge the existing skills gap. The creation of internship programs in partnership with automotive giants like Volkswagen, Jaguar Land

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Rover, Kia, and Peugeot-Citroën could provide students with hands-on experience in battery technology, allowing them to develop practical skills while still in training. Additionally, regional training hubs dedicated to battery technology and electromobility should be established to upskill the workforce and provide training tailored to emerging industry demands. The European Battery Alliance (EBA) Academy has already initiated training programs across Europe, and Slovakia should leverage similar frameworks to train technicians, engineers, and skilled workers in battery production, maintenance, and recycling.

By integrating practical learning, improving internship opportunities, and establishing stronger ties with industry partners, Slovakia can ensure that students and workers alike receive the training needed to excel in the battery industry.

Long-Term Benefits for Workforce and Economic Growth

Investing in education and workforce development will bring long-term benefits to Slovakia's economy, ensuring that the country remains at the forefront of battery manufacturing and green energy solutions. By aligning VET curricula with industry demands, Slovakia can attract further investments from leading battery manufacturers and create high-value jobs in research, development, and production.Moreover, a highly skilled workforce will enhance Slovakia's competitiveness in the broader EU Green Deal initiatives, allowing it to expand its role in the European energy transition. This will not only help meet the increasing demand for battery experts but also contribute to energy sustainability goals, ensuring that Slovakia becomes a leader in the circular economy of battery production and recycling.

Slovakia has a strong foundation in the automotive industry, but to maintain its position as a European hub for battery production and electromobility, it must take proactive steps to modernize education, enhance industry collaboration, and upskill its workforce.By implementing the recommended interventions, Slovakia can successfully transition from a traditional automotive powerhouse to a leader in battery energy technology, driving both industrial growth and sustainable economic development in the years to come.

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