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Future Expert Needs in the Battery Sector

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Content

1. Introduction

Batteries are considered as a core technology for the large transitions in the transport and energy sectors and have a key role in decarbonisation of the transport, enabling the shift from the fossil fuel to a renewable energy-based era and to provide an ubiquitous source for decentral energy. With the emerging global battery economy, production capacities are being built up also in Europe in the coming decade. The global demand for batteries (in particular Lithium-Ion Batteries) has increased from over 20 GWh in 2010 (almost purely for consumer applications) to around 250 GWh in 2020 (with already 50 % demand from passenger EVs and over 70 % from electric vehicles including e.g. commercial vehicles) and is expected to increase to at least 2-3 TWh in 2030 and more than 10 TWh beyond. By then, electric mobility is expected to fully dominate the demand for batteries. The European demand is expected to account for 20–30 % compared to the global demand, which translates to a need for around 400–1000 GWh of battery capacity until 2030 in Europe and an according need to build up battery production capacities.

While there has been a lot of funding for the build-up of knowledge on batteries through publicly funded projects as well as private investment in the past decade, Europe is now facing the challenge to invest into large-scale production facilities for batteries in order to satisfy the upcoming demand and to create a competitive European battery industry or ecosystem. This requires experienced experts, which manage and help to realize these projects and educate the next generation(s) of experts and staff working in battery R&D, manufacturing, integration to applications and finally a fully circular battery economy of the future.

The Strategic Research Agenda for Batteries 2020[1] stresses that the right skills are imperative to develop and strengthen a highly skilled workforce along the entire battery value chain to close the most urgent skill gaps. Such gaps are, for example, reskilling of staff working in industries and fields, which will disappear or be substituted in the future (e.g. around the internal combustion engine), or upskilling of staff in industries, which are working along the battery value chain and face the challenge to integrate digitalisation (e.g. automation, autonomous systems for R&D, processes, production) and a systemic value chain thinking (e.g. to design competitive and sustainable products for a circular economy) to stay competitive. For a future competitive European battery value chain, it will be important to boost growth and employability across transforming industries and sectors as well as across countries, since battery production hot spots will emerge at certain EU countries.

[1] Strategic Research Agenda for Batteries 2020 (December 2020): https://ec.europa.eu/energy/sites/ener/files/documents/batteries_europe_strategic_research_agenda_december_2020__1.pdf

1.1. Motivation – Global and European battery skills needs

In this context, it will be important to identify the concrete skill gaps and implement according measures. It will be important to understand the demand for skilled workforce by number as well as qualification profiles along the value chain. How many people can or will be employed along a future battery value chain or ecosystem and which educational background will be needed? In order to get an understanding of the workforce needed globally and especially in Europe a meta-analysis of studies and estimations from literature provides the following insights:

- According to a number of estimations, the job market impact for establishing a 32 GWh battery production facility is expected to employ between 2900 and 5800 people directly and approximately 3.7–7.5 times more indirectly along the battery value chain.[2,3,4] This translates into **90–180 direct jobs in battery production per GWh and 350–1400 indirect jobs** along the battery value chain.
- In other, more recent, up to date studies also **scale effects** of battery production on job creation have been considered. The number of estimated jobs in these studies is **40 direct jobs in the battery cell and module production** per GWh at large scales (e.g. around 1000 GWh production capacity) as expected to be standard in Europe towards the end of the decade (2030 or 2030+).[5,6] For only a few GWh production the calculations performed at Fraunhofer ISI[7] identify max. 90 direct and over 400 indirect jobs, thus connecting with the results and estimations mentioned above. The calculations for a scaled battery production of e.g. 1 TWh around 2030+ (estimated as the European battery demand by then) identify around **250 direct and indirect (upstream) jobs per GWh**.
- In a presentation from Tesla at the Battery Day (September 2020) around 2.8 million jobs are estimated to be created globally in materials, cell and battery (module, pack) manufacturing at a 20 TWh battery production.[8] This breaks down to **140 jobs per GWh** but includes the upstream value chain (i.e. materials production). We would consider a global battery production capacity of 20 TWh to be realistic in the longer term (e.g. towards 2040 or beyond) but the experiences of the past years have shown, that the expansion of the global battery demand has been constantly underestimated. In any case, if further scaling to a 20 TWh global battery industry would be considered, it seems to be logic that, scaling from a global battery production of some 100 GWh around 2020 to some TWh around 2030 and some 10 TWh

[2] Nationale Plattform Elektromobilität: Roadmap integrierte Zell- und Batterieproduktion Deutschland, Jan. 2016
[3] Joint Research Center JRC: EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications – Opportunities and Actions, 2017
[4] Position Paper on Education and Skills (Thielmann A., Maleka D., Dominko R.): Task Force Education and Skills within the ETIP, 2020.
[5] Hettesheimer, T.; Thielmann, A.; Neef, C.: VDMA Kurzgutachten: Beschäftigungsauswirkung einer Batteriezellproduktion in Europa (VDMA), 2018
[6] Batteries for electric cars: Fact check and need for action, Fraunhofer ISI, 2020. https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2020/Fact_check_Batteries_for_electric_cars.pdf.
[7] Calculations include up-to-date data from the BatPac model (https://www.anl.gov/cse/batpac-model-software), data on battery production announced in future as well as scale effects.
[8] Tesla, Battery Day: September 22nd, 2020

beyond 2040, would reduce the number of estimated jobs from 400–600 per GWh in 2020 to 200–300 per GWh in 2030 and 100–150 per GWh in the decades beyond.

- In their 2019 report on a sustainable battery value chain the World Economic Forum (WEF) expects a total of 10 million jobs in the battery value chain to be created around 2030 (at 2.6 TWh battery production mainly for EVs), with more than half of those jobs in developing countries.[9] This would mean around 3800 jobs per GWh (or for comparison: 1 job per 5–10 electric vehicles produced). The total estimate of 10 million jobs would be on the same level of the global automotive industry employment today (i.e. around 1 job per 5–10 vehicles produced).[10,11]

Thus, assuming the total automotive industry to transform from vehicles with internal combustion engine to fully electric vehicles in the long-term future and also assuming that potential job losses can be countered by active labour market policy measures and natural age-dependent job fluctuation, the today`s automotive value chain would in future converge with the battery value chain. The employment would be at the same level as in the "classical" automotive industry today. Although, of course the demand for batteries will increase also beyond electric vehicles, including electric passenger cars and commercial vehicles (like vans, buses, trucks) but also smaller electric mobiles (e.g. e-bikes, motorcycles) to large mobile applications (heavy duty machinery) as well as marine, air transport, stationary, leisure, consumer applications etc. Batteries are expected to be omnipresent in all kind of mobile vehicles (electromobility) or products, portable devices and stationary applications connected to the energy grid. The battery demand from automotive industry will however dominate in terms of GWh or TWh.

We can conclude, that considering the total and manifold value chain from battery materials, cells, modules, packs, systems to end products (e.g. electric vehicles, stationary applications), their use phase and recycling the number of jobs affected can be possibly up to 5–10 times higher than the jobs directly or indirectly connected with the battery (materials, cells to pack) production only. This number of jobs needed in the mid to long-term might be up to 10 million around 2030 and much more beyond 2030. In the long-term (well beyond 2030) there might be 2–3 million jobs globally connected only with battery (materials, cells to pack) manufacturing. Around 2030 up to 1 million (e.g. 3300 GWh x 300 jobs/GWh) jobs could emerge globally and up to 300,000 jobs in Europe (e.g. 1000 GWh x 300 jobs/GWh).

[9] World Economic Forum Report: A Vision for a Sustainable Battery Value Chain in 2030 Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation, 2019.
http://www3.weforum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf
[10] https://www.fircroft.com/blogs/the-automotive-industry-employs-more-people-than-you-think-71462610395
[11] Thereof, in Europe around 3.7 Mio jobs are in the automotive manufacturing industry:
https://www.acea.be/statistics/article/employment

The emerging battery economy in Europe

In the past 10 years battery production capacities have been built up mainly in Asia (in particular China, Korea, Japan) and the US. With the dramatic increase of the global battery demand however it will neither be practical nor sustainable to transport batteries across the world and battery production hot spots will emerge worldwide. In Europe, the **demand for batteries will increase** from **currently 30–50 GWh to 150–300 GWh in 2025, and 400–1000 GWh around 2030.**[12]

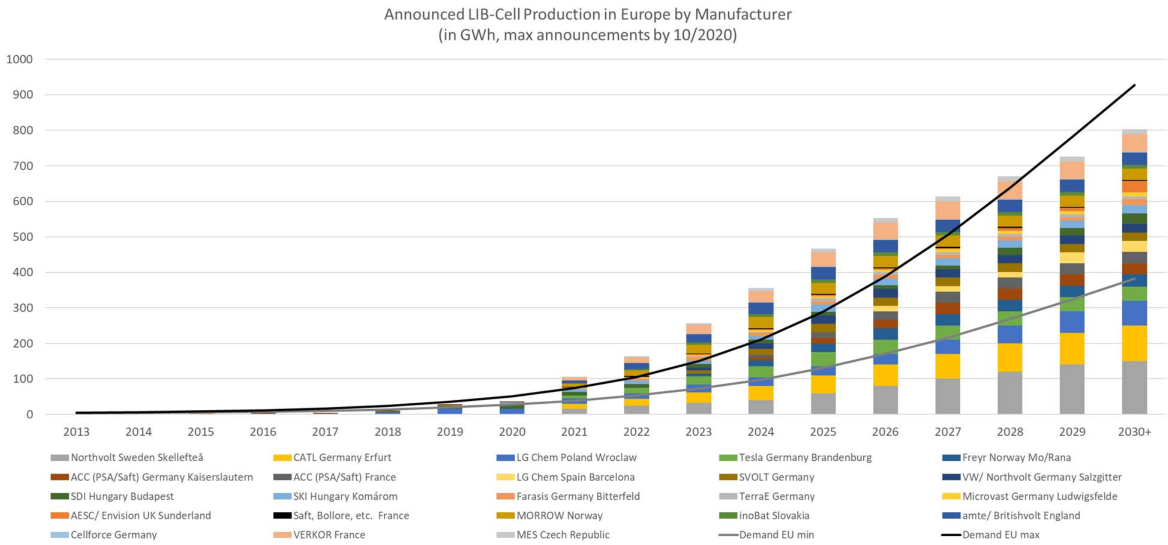
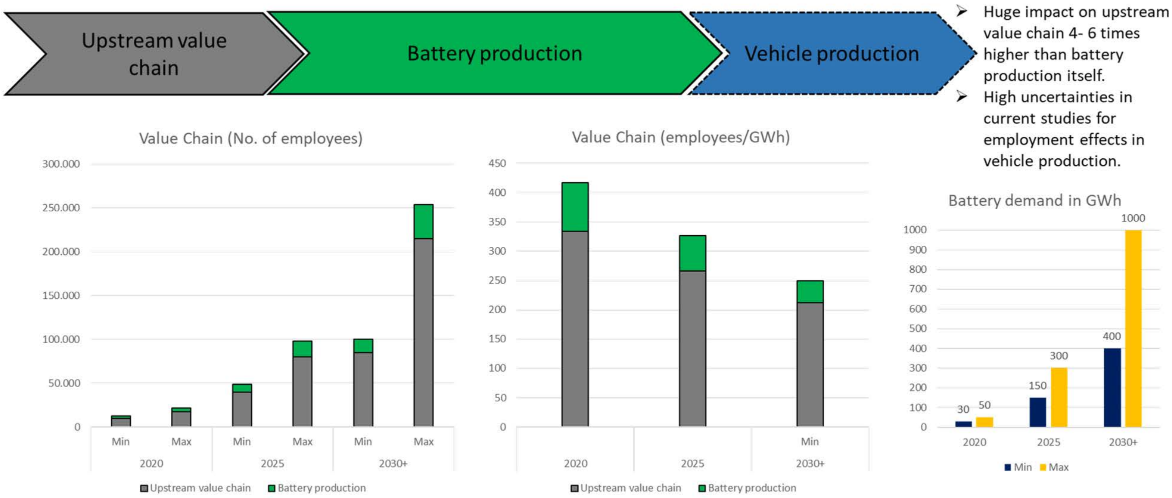


Figure 1: European LIB cell production capacities announced (large Po/Pr, cyl.) by leading cell manufacturers: Source: Fraunhofer ISI (own representation 10/2020) published in VDMA Roadmap Batterie-Produktionsmittel 2030 (Update 2020).

In contrast to the battery demand there have been battery production capacities announced to be built up across Europe which are constantly updated and expanded. These announcements meanwhile sum up to 800 GWh until 2030 (see Figure 1) and even potentially 1.2–1.8 TWh if the recently announced 1.2 TWh from CATL and 3 TWh from Tesla are also assigned to European production locations. Taking into account the dynamic and stepwise expansion and potential delays along the time as well as the fact that factories are not producing at full load and also the yield is not 100 % due to scrap, the real production is expected and also has to hit the demand in order to follow the supply demand curve.

[12] VDMA Roadmap Batterie-Produktionsmittel 2030 (Update 2020), https://battprod.vdma.org/viewer/-/v2article/render/59579372

Employment effects and emerging expert needs



Source: Own calculations based on BatPac Model (ANL) & Hettesheimer et. al (2018): Employment effects and value chains in the battery machinery and plant engineering industries VDMA/Fraunhofer ISI (10/2018). Battery demand from Position Paper on Education and Skills

Figure 2: Absolute number of employees needed in Europe and employees per GWh connected with the battery (materials, cell to pack) production.

Based on the expected battery demand in Europe, the direct and indirect jobs per GWh needed for materials, cells to pack production and accounting for scale effects with larger battery production factories, we have calculated the absolute number of jobs which is expected to increase from 10–20 thousand to several 100 thousand in the coming decade (see Figure 2). It can be seen that the need for workforce at the upstream value chain is 4–6 times higher than for the battery production itself. Due to the large uncertainties of current studies addressing the employment effects on the downstream value chain (in particular the vehicle production) we do not go into more detail and did not perform calculations for this part. However, as mentioned before also factor of e.g. 5–10 might have to considered in order to identify the full employment effects along the battery value chain (other applications beyond vehicles still not considered).

Focusing on the battery cell and pack production (including the machinery and equipment suppliers), it can be seen that the battery cell production needs the largest number of staff per GWh (declining from around 50 to below 30 workers with scaling up the production). The need for experts from the machinery and equipment industry is also considerable as can be seen in Figure 3. In Figure 4, we break down the employment effects to the electrode production, cell assembly, cell finishing and material handling & quality control. For the electrode production the largest demand for staff is needed and for cell finishing e.g. the demand decreases relatively stronger with up-scaling due to the automation potential.

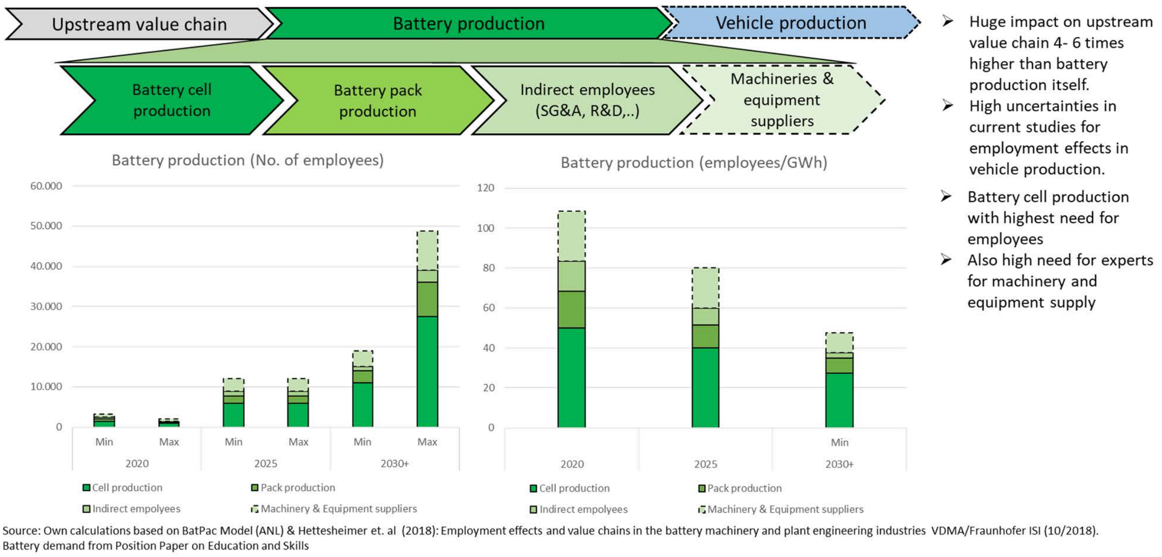


Figure 3: Absolute number of employees needed in Europe and employees per GWh connected with the battery cell, pack production. Also, indirect employment effects and workforce needed in the machine and equipment industry.

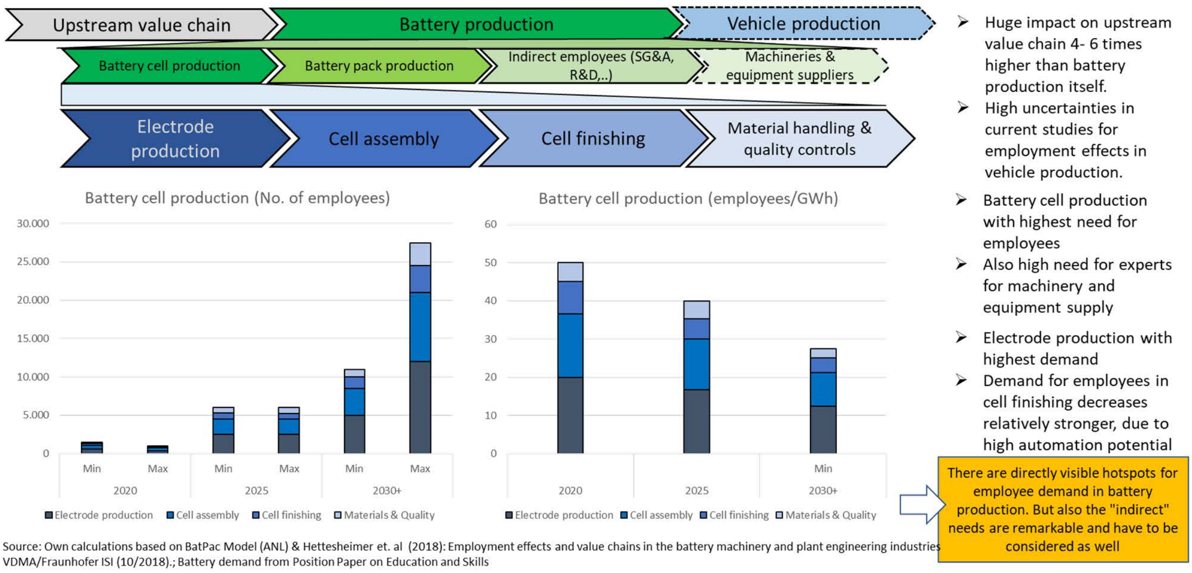


Figure 4: Absolute number of employees needed in Europe and employees per GWh connected with the battery cell production.

We can conclude, that there are certain steps in the production with higher need for workers. But along the battery production and also the full value chain the indirect employment effects are remarkable or can even lead to a demand which is several times larger than the labour need for manufacturing alone. It might be concluded thus, that a competitive battery manufacturing industry in Europe will have much larger effects also on employment and value added than on the battery industry alone.

1.2. Background, scope and approach

Having stressed the enormous need for workforce in order to build up a European battery economy and also having motivated the need to differentiate along the battery value chain we want to explain the background and goal to this report on future expert needs in the battery sector. As we have shown, the pure number of workforces connected with a European value chain will tremendously increase in the next decade and beyond. It can be expected however, that only a smaller share (by number) of the workforce will need very high and long-term experience as well as a scientific background in battery technology. There will be staff needed in a future battery industry with background on different educational levels:

- academic education,[13]
- professional level,[14]
- vocational level,[15]

but there might be also other kinds of needs from the battery industry.[16] By number the largest need for staff is expected to be on the vocational level. But this might vary along the battery value chain. Thus, a main subject of this report is to differentiate the need for experts along the value chain. To keep the analysis differentiated but simple enough we consider the three main steps along the value chain:

- the materials production (including raw materials, active materials to components),
- the battery production (cells, modules, packs and including processes/ equipment), and
- the applications (including 1st life, 2nd life applications and recycling).

For applications electric mobility but also e.g. stationary storage applications are addressed.

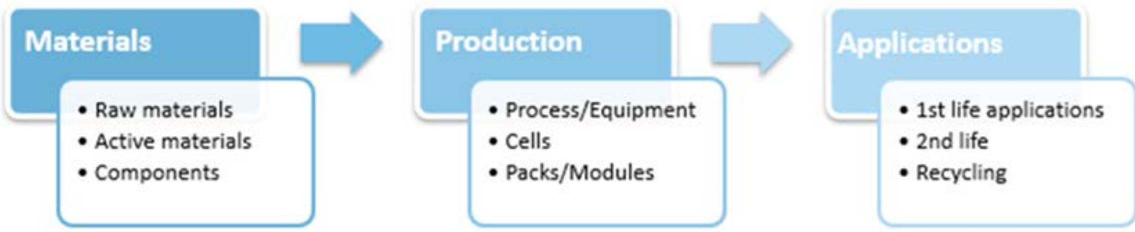


Figure 5: Battery Value Chain (simplified) as considered for the analysis of this report.[17]

[13] This can be e.g. Bachelor, Master, Doctoral, and Post-doc education.
[14] With professional education we refer to any non-academic education, of the existing workforce, with a purpose of professional development and acquirement of specific competences for professional practice. This might e.g. address staff in upper management.
[15] With vocational education we refer to both initial and continuing vocational training i.e. either school or work-based (e.g. technicians).
[16] This could be e.g. the public or end-user who should buy, use, and handle batteries and battery-based products.
[17] see also: Position Paper on Education and Skills (Thielmann A., Maleka D., Dominko R.): Task Force Education and Skills within the ETIP, 2020.

Expert workshop

For the analysis of the expert needs from battery industry Fraunhofer ISI with support of the Fraunhofer Battery Alliance and the Fraunhofer Academy conducted an expert workshop with renowned experts from battery industry across Europe on behalf of EIT RawMaterials.

The workshop has been conducted on October 14th 2020 and was open to experts across Europe (announced via Batteries Europe).[18] The goal of the workshop was to identify battery skills needs and adequate measures to build up a competitive European battery industry and workforce.

Due to different competitiveness along the value chain from battery materials to cell production and system integration into applications as well as the recycling after the end of life, a core issue was to identify the industry needs today and in the short-term (< 2025), in the mid-term (2025–2030) and the long-term (2030+) future along the battery value chain.

At the same time, the potential measures to support companies in order to build up their future workforce have been identified with pointing to relevant players, responsible to implement the measures (e.g. academia, industry, policy or others).

Reporting and background documents

Based on the discussions during the expert workshop Fraunhofer ISI with Fraunhofer Battery Alliance and the Fraunhofer Academy has prepared the present report. The report also takes into account literature research and calculations with respect to the battery production capacities and employment connected to the battery value chain in order to connect the qualitative results with quantitative estimations.

The expert workshop was placed at a time where the "Task Force on Education and Skills" within the ETIP "Batteries Europe" had prepared a position paper[19] which to date is not published but the results of the paper have entered the Strategic Research Agenda for Batteries 2020.[20] Thus, insights from this paper could be used as a starting point.

Furthermore, insights from initiatives and projects aiming to support the growth of a competitive battery industry in Europe could be gathered via some participants of the workshop, which are

[18] https://ec.europa.eu/newsroom/ener/item-detail.cfm?item_id=686973&utm_source=ener_newsroom&utm_medium=Website&utm_campaign=ener&utm_content=Workshop%20on%20the%20future%20skills%20needs%20of%20the%20battery%20industry%20-%20by%20Fraunhofer&lang=en
[19] Position Paper on Education and Skills (Thielmann A., Maleka D., Dominko R.): Task Force Education and Skills within the ETIP, 2020.
[20] Strategic Research Agenda for Batteries 2020 (December 2020): https://ec.europa.eu/energy/sites/ener/files/documents/batteries_europe_strategic_research_agenda_december_2020__1.pdf

connected to or lead those projects, some of them focusing on battery related education (e.g. *Alistore-ERI*, EIT InnoEnergy, *ALBATTS*,[21] Batteries 2030+[22], *Drives*[23]).

Based on these above-mentioned insights it has been clear already that needs and action fields are around the following topics:

- re-/ upskilling existing workforce (especially the reskilling of staff in automotive industries),
- mobilising the future workforce (e.g. internships, exchange between industry and academia),
- education on cross-cutting skills (e.g. digitalisation, cross-sectoral/ -disciplinary/ -value chain knowledge), and
- creating knowledge in large-scale production.

A particular key challenge and focus of the workshop has been on the large-scale production of batteries which defines a missing link to establish a competitive battery value chain in Europe.

2. Future expert needs – State of the art

For the further detailed analysis of the expert needs in the battery sector we start with a discussion on the current situation as of 2020 or 2021. How can the demand for skilled experts be described from the perspective of the industry and what are the educational measures available? Where can the main needs and gaps be identified? In chapter 3 we discuss in detail the future needs along the battery value chain and in chapter 4 we identify measures to address these needs. Chapter 5 summarises the all over findings.

2.1. Qualification needs from industries

The battery community in Europe has strongly grown in the past 10 years through large, continuous and intensive funding programmes but also private investments from industries which are positioning for the emerging battery markets. Experts with academic education have been built up and made available to industry (e.g. for R&D in industry typically a PhD is a must have). But industry has also trained the own staff (e.g. in case of technicians or upskilling of staff towards battery specific skills). However, in the coming years battery (materials, cell to pack) manufacturing will be ramped up in Europe and knowledge and skills with respect to large-scale production will be needed. It will be needed in terms of very deep insights (e.g. on processes, quality control,

[21] https://www.project-albatts.eu/en/home
[22] https://www.battery2030.eu/drives
[23] https://www.skills4automotive.eu/

automation, machine learning for an industry 4.0 battery production) but also in terms of pure numbers of workers due to the economies of scale.

Thus, there will be an increasing demand for battery experts with very high qualification and additional skills (e.g. digital, cross-disciplinary) for R&D and production, long years of experience in industry when it comes to large and complex projects and invests and according management and decisions to be taken. The larger need by number however will be on staff with vocational education (e.g. technical personnel for machine operation). This personnel will have to be trained in larger number e.g. via preparatory training for onboarding in the battery factories of the future.

The European Qualifications Framework (EQF) makes national qualifications across Europe better to understand and translates between different educational degrees, e.g. to promote the mobility and exchange of qualified experts across countries. The EQF levels 7–8 include the PhD and master levels. EQF 6 includes the bachelor degree and EQF 5 relates e.g. to technicians levels. EQF 4 relates to adult education and the upper secondary level. For this report we do not translate into EQF levels and mainly use the degrees PhD, master, bachelor or speak of technical training and courses (e.g. specialized physical or online courses). Especially massive open online courses (MOOC) and small private online courses (SPOC) have gained importance not only for life-long learning for working professionals. Those courses are growing fast with new demands on specialized knowledge, need for fast and high throughput/ training and especially in the current situation with the COVID-19 pandemic.

For companies such courses are increasingly relevant if an in-house training gets too time and cost intensive or special external knowledge is needed (e.g. on digital skills, certain academic topics which might require a more intensive cooperation with universities or the transfer of skills to an increasing number of "next generation" staff).

With respect to the battery (cell) manufacturing industry within the EU funded project *ALBATTS*[24] different job offers and descriptions have been analysed (e.g. from Panasonic, Northvolt, etc.) in order to understand the qualifications which are needed in battery production. There are jobs offered at different qualification levels:

Common lower-qualification jobs (e.g. EQF 4) address the need for e.g. machine operators or material handler. Technicians (e.g. EQF 5) are needed for e.g. maintenance, measurement, quality management or cell inspection. Also, there are some specific "battery"-labelled jobs (which might refer to EQF 6), e.g. battery engineers for battery assembly or formation. However, there are also job titles which refer to the need for digital skills in an Industry 4.0 such as ASRS engineers (automated storage and retrieval systems) or production engineer vision systems. With respect to high level qualifications the job profiles express the needs for production (line) management (e.g.

[24] https://www.project-albatts.eu/en/home

plant manager/ director of production, upstream/ downstream production area manager, process block area managers dry/ wet electrode/ formation/ cell assembly). With respect to the criticality of large-scale production aspects like maintenance, quality control, etc. gain importance and lead to the need for according engineers and technicians.

2.2. Education measures from academy

In contrast to the needs of the battery industry the educational system already today makes highly skilled battery experts available. Battery scientists and engineers educated at research centres, universities (or e.g. innovation clusters) today have background in fields like electrochemistry, crystal chemistry, advanced characterisation, battery monitoring, multiscale modelling, simulation, safety, etc.

The curricula at universities are often adapted to the needs of the local environment (e.g. industries nearby) but do not always cover the current needs from industries. As these needs are also changing or getting more concrete the curricula or courses, seminars during the academic education will have to be adapted.

Looking at the battery relevant measures/ offers from the educational system the current state of the art has been analysed in the position paper on education and skills.[25]

On the **master level** some programmes available are e.g. the MESC – Erasmus Mundus Joint Master Degree (a 2-year programme in materials science and electrochemistry in collaboration of universities and research centres), the EIT InnoEnergy Master's in Energy Storage (a 2-year programme in Energy Storage delivered by EIT InnoEnergy in collaboration with three universities) and of course dedicated battery relevant master programmes at universities. Examples for master programmes relevant for industry are e.g. on electrical vehicle engineering. Courses and programmes in the field of batteries are more and more available but the teaching capacity is still limited, e.g. there is still a lack on specific subjects such as large-scale manufacturing.

Regarding measures and programmes available on the **PhD level** the EU mechanisms offer possibilities for different doctoral programmes (e.g. European Training Networks like Polystorage, COFUND projects like Destiny, H2020 projects, Alistore-ERI etc.) The programmes allow a high mobility and secondments at different universities, industrial partners, and knowledge institutions and the students can obtain broader knowledge and additional working experience. With these programmes universities provide highly skilled researchers and professors with background in electrochemistry material science, engineering, etc. However, the number of experts available for

[25] Position Paper on Education and Skills (Thielmann A., Maleka D., Dominko R.): Task Force Education and Skills within the ETIP, 2020.

industry is still limited and leads to an increasing competition between academia and industry as well as across companies.

With respect to the **professional education** the main challenge is to reskill and upskill personnel along the value chain, especially in the automotive industry. Large companies typically face this challenge by in-house training (e.g. for engineers, technicians) and education on the job (e.g. business-related aspects). Online courses for example, are mainly providing a basic level of knowledge on the topic and are not specific enough. They are suitable for professionals interested in understanding the field but not to specialise. Specialised paid-for training opportunities are often more useful for companies (e.g. bespoke trainings between the company and external provider on topics such as cell design, electrode engineering, assembly, etc.).

Measures and programmes available for **vocational education** are generally limited across Europe and rather very localised programmes in the local language. This might be due to the fact that industry is often and if possible training the staff in-house. However, since member states (like Sweden, France, Germany, etc.) are expecting local hot spots with the announced battery production sites, specific programmes e.g. for onboarding in production will gain importance. With this, also the local public (young people) might have to be better informed about future job opportunities and educational offers. Future programmes for vocational education will thus have to be practically and locally relevant with emphasis on skills related to e.g. battery production, integration, operation, safety in order to train e.g. machine operators and material handlers.

The example of local hot spots and need for people working in the growing up battery industry (not only battery production but also battery integration at OEM) illustrates the need for information campaigns which might need to be also locally with certain focus on the industry and companies nearby.

3. Future expert needs - Towards 2030+

The needs of the battery industry can be different depending on the area along the battery value chain, which we have defined for this chapter along three pillars: materials (including raw materials, active materials to components), production (including processes/ equipment and cell, module, pack production) and systems/ applications (including first life applications, 2nd life and recycling). In the industry expert workshop conducted in October 2020 we have discussed with experts from battery industries about their view with respect to the industries' needs for skilled personnel. In concrete the questions discussed have been:

1. Which staff is needed (e.g. what would be the job description)?
2. Which qualification is needed (background, e.g. academic, vocational education, discipline)?
3. How urgent is the need (1 = low, 2 = mid, 3 = very urgent) and why?
4. What will change in the mid-term (2025-2030)?
5. What will change in the long-term (2030+)?

In the following we summarise the needs identified and formulated for each part of the value chain.

3.1. Needs in materials industries (raw materials, active materials to components)

In the past 10 years (since around 2010) tremendous funding, R&D and investment has been undertaken to build up a battery community in Europe and dedicated countries. Before 2010 the battery community or experts have been pre-dominantly located in Asia (in particular, Japan, Korea and China). Thus, the few battery experts across Europe have been working very much in an academic environment and a focus rather on materials and/ or more fundamental research than application oriented as the situation has changed until today.

Therefore, from a materials industries perspective it might be understandable, that today there is not a bottleneck to get good people from academia. Due to the funding programmes and investments over the past decade **academic experts** working on electrochemistry are available for the materials/ chemical industry today. However, the demand will not stagnate and therefore the offer of **(a) electrochemists** at the market should not be less in the future. For R&D, in this industry a PhD is typically standard and required for according positions. What remains important is the need for chemistry/ materials experts with deeper electrochemical understanding (e.g. how to make/ process electrodes). In concrete, a lack of **(b) inorganic materials scientists** (experts that are familiar with inorganic syntheses) is identified. In addition, and more into the future, it will be important to permanently perform research and development on **(c) new and emerging (battery) material trends**, e.g. which direction does the material technology market take? This includes the comparison of Lithium-ion (LIB) and all solid-state (AASB) batteries as well as further/ alternative battery chemistries. With the battery chemistry and system also requirements on material scientists might change (e.g. glass/ ceramics expertise for ASSB).

Besides academic staff also with respect to **technical workers** a **deeper electrochemical understanding and system know-how** is getting more and more important. Since requirements from applications (e.g. on energy densities, cycle life, charging time) translate back from the system to cell and finally material level, the system view (and transfer along the value chain) is needed for designing, synthesising and processing battery materials and components. Larger companies typically train people by themselves (e.g. in 2-3 years training programmes). Technical workers are getting more important by weight and number with respect to academic staff in materials industry when approaching the materials production (including e.g. processes, machine handling, etc.). Especially when it comes to pilot plants and scaling up production there is still a gap with respect to process engineering experts. With the expected market ramp-up over the next decade this need will not only increase in terms of qualification but also by number. Since the need for technical experts also along the entire value chain will increase, there might be an increasing competition across sectors as well. In contrast to academic experts for R&D, production and complex management tasks, the larger number of technical experts however can be trained in a few years programmes and thus in a shorter time frame.

Another target group, where a bottleneck for the materials industry can be identified is the upper management. Especially in Asia, usually the **upper management** has been grown up in the battery industry and is very familiar with all the details of batteries. This is different in other parts of the world (e.g. Europe), where the upper management typically has not yet **detailed battery knowledge**. This knowledge gap between the mid- to upper-management level has to be addressed since the coordination of complex and large projects or taking (investment) decisions decides upon the direction and market success of a company. The issue however has to be addressed by the company itself by training or upskilling highly educated academic staff in these positions with management skills rather than educating managers in electrochemistry.

In contrast to the skilled workforce with high seniority and facing the future increasing demand for workforce in the battery materials industry, it will be important to **motivate younger people to study electrochemistry** (e.g. PhD students interested in inorganic materials, new battery materials, synthesis, characterisation, processing, etc.). This addresses not only the awareness and attractivity in the research but also the **mobility of people**, since the locations of the battery R&D as well as production facilities will expand across Europe, i.e. also in countries which might not have been funding battery programmes at the same level as e.g. Germany, France, Spain, England, etc.

Most of the staff needed will be technical workers, which require vocational training (VET level). With an expansion of production sites (not only cell production but here also material, component production) not only a massive number of people needs to be trained but also will have to move to locations across Europe. Thus, maybe especially younger people are targeted, which still are open and interested in moving to other countries and regions. With respect to the according cities and regions however it will be necessary to **make those locations attractive**. Especially when a new company or new location opens typically a few hundreds of people are needed with according qualifications and interest to work in the battery industry. Companies might have to land certain programmes to be attractive and hire staff, which might be easier for large companies compared to SMEs.

A cross-cutting need which is of importance for research same as for production and also along the value chain from materials to cells and applications is **digitalisation or the digital mindset**. For material science e.g. data analytics is extremely important. In the materials industry typically, scientific staff with electrochemistry or material science background rather upskills or extends qualifications in simulation, modelling, machine learning etc. than educate an IT-specialist in electrochemistry. Thus, this issue is typically addressed from companies by themselves, in hiring academic staff with those qualifications or interests and/ or by implementing the digital thinking into their lab teams. This can be done by creating teams of material scientists, theoretical chemists, etc. with e.g. pure data scientists as council to the lab team. In future, the knowledge and data generated in this way might serve as a data-back bone for the companies and also define it´s USP.

A recent and prominent example for digitalisation in battery materials research in a funded programme is the project Big Map,[26] which is aiming at finding new materials accelerated through the use of artificial intelligence (AI) and high-performance computing. But digitalisation will be needed also in other fields (e.g. battery cell design, production, battery life, 2nd life, etc.) along the value chain. With respect to battery materials production and manufacturing digitalisation is relevant e.g. with respect to automation, data analytics, machine learning when scaling up production. AI is becoming more and more important in this context. Digitalisation should therefore be in a standard curriculum of a chemist but also be part of training programmes for technical staff.

A further cross-cutting need is the **understanding of the whole battery system** (not only materials, components, cells, etc. but the whole battery system) in order to develop new materials and processes addressing the battery systems requirements in their according application. The requirements from the battery pack to the requirements on the cell level have to be translated to the requirements on component level and finally on the material properties. Not only chemical knowledge but also engineering knowledge (e.g. electrical engineering in particular) is needed for this understanding (this is relevant e.g. also for pack design, system integration etc.). Academic education and staff (e.g. chemists) as well as technical staff (e.g. engineers) with interdisciplinary background from materials to systems and engineering is thus needed. Academic staff in industry can be further upskilled with respect to the aforementioned qualifications but ideally already brings along the right qualifications from chemical/ material science education. Technical staff will be needed to be trained typically in house but as well vocational training programmes implementing the systemic aspects/ thinking might be set up concretely. It can be summarised that there is no lack of experts in the different individual fields, but a lack of experts who can overview the entire

[26] With the development of the Battery Interface Genome – Materials Acceleration Platform (BIG-MAP), a radical paradigm shift in battery innovation is proposed, which will lead to a dramatic acceleration of battery discovery, achieving a 5–10-fold increase relative to the current rate of discovery within the next 5–10 years. BIG-MAP relies on the development of a unique R&D infrastructure and accelerated methodology that unites and integrates insights from leading experts, competences and data throughout the battery (discovery) value chain with Artificial Intelligence (AI), high- performance computing (HPC), and autonomous synthesis robotics. (https://battery2030.eu/research/research-projects/big-map/)

value chain and translate the different requirements across the value chain and disciplines working on the different steps/levels.

This also includes the need to qualify or sensibilise people in having **soft skills** in the sense of translating intercultural languages in the case of people from different world regions and countries working together but also across disciplines and along the value chain. The way of understanding and solving problems, the technical and non-technical background etc. are typically different across disciplines. Thus, it is necessary to be able to speak a common language to solve a problem. As an example, electrical engineers are sometimes not able to understand chemists and vice versa.

The product is very much influenced by the processes for the production. Thus, **process engineers** are relevant and needed already in materials production. In order to connect and transfer knowledge along the value chain the urgency here is very high and will remain on this level until its standardisation.

Recycling, remanufacturing but also business models for 2^{nd} life and finally building up a circular battery economy are important issue in the future. This includes building up knowledge not only in large-scale production but also the future large-scale remanufacturing at low cost and energy consumption. Concepts of “design for recycling” but also business models will be needed to derive at an economic and sustainable (green) circular economy. Staff and knowledge far beyond academic and technical know-how will be needed (e.g. including disciplines such as economists, environmental experts, etc.).

Table 1: Overview of the needs in the battery materials industry.

Short-term (< 2025)			Mid-term (2025-2030)	Long-term (2030+)
1. Which staff is needed?	2. Which qualification is needed?	3. What are the most urgent needs (1 = low, 2 = mid, 3 = high)?	What will change?	What will change?
Needs in the battery materials industry				
1 Qualified academic battery materials experts (a) Electrochemists fine (b) (inorganic) material scientists (c) new material trends	academia	(a): 1*; but should not be less* (b): 2*; managed to live with, but needed* (c): 2*; see b*	should not be less (increase with diversification of technology)	continues to be important, especially with dev. of new battery systems
2 Technical staff with deeper electrochemical knowledge and system view	technical	2–3	increasing importance	continues to be important
3 Upper Management with detailed battery knowledge (along the value chain - VC)	management	1*; to be addressed from/ in industries*	same importance (to be addressed in industries)	needs to be standard
4 Motivated young people/ students to study electro-chemistry (esp. PhD students)	academic education	2	increasingly relevant with number needed	increasingly relevant with number needed
5 Mobility of people and attractiveness of new locations	academia/ technical (cities/ regions)	2	increases with increasing facilities	increases with increasing facilities
6 Establish a digital mindset (e.g. data analytics, simulation, AI, etc.). Put into standard curriculum.	academia/ technical (cross-cutting)	2–3	becomes very important (today only limited look into industrial applications)	to be standardised
7 System view and understanding along the value chain	academia/ technical (cross-cutting)	3	more and more important	to be standardised
8 Soft skills (also intercultural)	academia/ technical/ management (cross-cutting)	2–3	more and more important	to be standardised
9 Product by processes (**process engineering**).	academic/ technical	3	remains important	to be standardised
10 Recycling/ Remanufacturing	beyond academia/ technical (e.g. environment, business, etc.)	2	increasingly important	increasingly important with development of battery ecosystem

3.2. Needs in the production industries (process/ equipment, cells/ modules/ packs)

For the production industries including equipment manufacturers as well as cell, module, pack manufacturers the aforementioned needs are very much the same in many aspects. Here, we point to the differences, which are characteristic for the battery production industries.

Currently, a lot of innovations are taking place in production processes (e.g. in order to fully automate and control production processes, to reduce scrap and energy consumption in production steps such as dry coating, etc.). In the same way as the chemical or material industry needs to observe new materials trends for the production industry changing or even **disruptive production technologies** have to be observed. Also, for novel battery systems e.g. towards solid-state batteries, production processes and equipment might change and new or different know-how from R&D to scaled production might be needed at equipment manufacturers same as in cell production. Thus, academic as well as technical staff is addressed. However, such changes will have to be observed and in the short- to mid-term at least it is not expected to have a change in large-scale production to other battery technologies than Li-ion batteries.

In any case broader, cross-cutting and more in-depth know-how of the **technical staff** will be needed with increasing importance. Especially, engineers with systemic understanding from the materials that are processed to the functionalities (KPI) of the later cells in order to optimise production processes accordingly. Compared to disruptive developments which are much more an R&D topic the technical staff controlling the equipment and working in large-scale facilities is close to the market and the according qualification need is ranked much higher.

But also, with respect to the managers of pilot lines and larger production facilities there is an important need to find **project managers with experience in handling complex and large projects.** The investment in such GWh factories are on the level of billions of Euros (for pilot lines e.g. several hundreds of thousand Euros) and a misplanning and management is accordingly a financial risk. Managers thus should have gained already experience in e.g. pilot lines to later on manage GWh facilities. Also, the need is not only restricted to managing complex projects but also to deeply understand the processes and products (like cells, modules, packs). Project managers with experience with the automotive industry would therefore be a further need or benefit. Since we are facing a huge expansion of factories in the next decade (by number but also invest and size) the urgency already today is quite high and will be higher by qualification as well as demand for the number of people in the next years.

Especially the battery equipment and production industry will face a large expansion in the next 5–10 years with often entirely new staff needed (as compared to chemical or e.g. automotive industry, where people are rather upskilled or reskilled accordingly). The staff does not necessarily always have to come from battery industries (e.g. also other production sectors can transfer staff to the battery production). However, since staff will be needed along all disciplines (R&D, production, software engineers, process engineers, electrical engineers, sales, etc.), it is expected that there will be an increasing competition with OEM or industries having skilled staff at other steps along the value chain. The urgency for **experts to move into the battery business** is already quite high today and will be increasingly relevant with establishing an EU wide battery ecosystem.

This directly transfers into the need to **mobilise people** and to be attractive as industry but also as location. An increasing number of skilled people will be needed in future to move to the cities and regions, where new production sites are built up. This concerns technical and academic staff in particular with respect to the number and qualification needed. Again, the urgency is ranked quite high already today and will further increase in the future. Cell manufacturers such as Northvolt already today are headhunting and hiring people from all over the world (especially Asia) in the search for personnel with the right qualification. Young people living nearby may then be trained as forthcoming generation.

The increasing need for staff with **digital skills, systemic understanding and soft skills** are cross-cutting needs also for the equipment and production industries and thus also cross-cutting along the value chain. It seems that especially for mid-sized companies it is difficult to convince IT-specialists or data scientists (e.g. software engineers) to move to the battery industry. A reason might be that the challenges in battery production are not so attractive fields for highly qualified IT-/data-science experts and those kinds of experts are highly needed across all thinkable sectors. The competition here is thus extremely high. The qualification profiles needed include skills for automation and control of the production. In future, the needed number of operators keeping the machinery running will increase. In addition, machine learning and artificial intelligence for production will be a further topic which might develop to a USP or core competence of a production facility as it should increase efficiencies in processes, quality of the product and reduce energy consumption, scrap etc. and thus reduce the running costs. This will require not only digital skills but also a more in-depth understanding of processes, products and industrial applications (e.g. a systemic understanding).

Skilled process engineers are needed in the near future. Today, already many process engineers are working on improved process steps, new technologies. Thus, trained process engineers are expected to be available in equipment and production industry in the near future. However, the number has to grow. The assessment is thus, that there is rather a lack of people in the next 5–10 years but not of the knowledge. The profile in need is mechanical experts, process experts, etc. working in (cell) production, e.g. in the area of cell design and application. Also, a re- and upskilling need with respect to quality aspects has been identified.

Large-scale production puts a stronger challenge on expanding a qualified team and full traceability with respect to processes and the same kind of qualification and understanding across the team. The split and profiles of experts needed seems to stay the same also with economies of scale. However, with more and more projects coming up there is a need for more and more people and teams to develop solutions. The majority (e.g. around 80 %) of the staff is trained in 1–2 years and the rest is highly qualified academic, technical and management staff. The battery production industry is still focusing fully on Lithium-ion batteries but smaller teams are typically also preparing for the next technological step. A transfer of knowledge and people will be needed in future also for next technical steps in battery production. The challenges for the future European battery production industry will thus be to build up a large number of qualified experts with academic and technical background as well as to prepare those new and increasingly large teams for the competition from Asia as well as the US (e.g. Tesla). The competition is permanently preparing to further develop and adapt processes and equipment while the USP is the knowledge gained around the production. Once, processes are standardised the training of technical staff typically is done in relatively short-time as engineers are in supporting functions. The R&D personnel is needed e.g. to optimise the cell design. The additional staff needed in existing equipment and production industries is often estimated to be around 50 % more compared to today. For the longer term still no estimates are expressed.

Table 2: Overview of the needs in the battery equipment and production industry.

Short-term (< 2025)			Mid-term (2025-2030)	Long-term (2030+)
1. Which staff is needed?	2. Which qualification is needed?	3. What are the most urgent needs (1 = low, 2 = mid, 3 = high)?	What will change?	What will change?
Needs in the battery equipment and production industry				
1 Disruptive development might change the need for know-how and education	academic/ technical	1	to observe	to observe
2 Technical staff with cross-cutting knowledge and system view	technical	2–3	increasing importance	continues to be important
3 Project manager with knowledge in big projects as e.g GWh	management	2–3	more managers needed with increasing nr of facilities	needs to be standard
4 Experts to move into battery business (competition with OEM), not necessarily only from battery side	academia/ technical	2: *General need for staff in all disciplines (R&D, SG&A, ...)*	Increases with increasing facilities/ ecosystem	increases with increasing facilities/ ecosystem
5 Mobility of people and attractiveness of new locations -	academia/ technical (cities/ regions)	2	increases with increasing facilities	increases with increasing facilities
6 Establish a **digital mindset** and need to find software engineers.	academia/ technical (cross-cutting)	2-3	becomes very important	need large no. of staff with these skills
7 System view and understanding along the value chain	academia/ technical (cross-cutting)	2-3	more and more important	additional skill to the profiles
8 Softs kills (also intercultural)	academia/ technical/ management (cross-cutting)	2-3	more and more important	additional skill to the profiles
9 Process engineers (e.g. more people needed in cell design area and application)	academia/ technical	1: *Already trained in academia and applied research.*	just lack today – 5 or 10 years.	lack of people not knowledge
10 Large scale production, full traceability, fulfilled within the team. But with growing demand also the number of jobs grow.	academia/ technical	2: *Economies of scale might change a bit, but the split might stay similar.*	increasing with no. of projects (focus LIB, preparing smaller team on next technical step)	update a realistic planning (scale effects, Asia-EU competition etc.)

3.3. Needs of system integrators (1st life applications, 2nd life, etc.)

For system integrators (OEM) and especially the automotive industry massive upskilling and in particular **reskilling projects** will be needed with very high urgency. The full transport but also the energy sector are in a transition phase. E.g. for the automotive industry external hiring is rather difficult with a large workforce already working there in fields around cars with internal combustion engine (ICE) and the workforce thus will mainly have to be reskilled for the requirements of electric mobility. Most Tier 1 companies might have according trainings already which will have to fully rolled out to the technical staff and management in the future. The academic staff might often rather directly enter the industry after a battery related education (electrochemists, battery engineers, etc.).

With respect to the **technical staff and engineers** also towards the applications an understanding of the machinery and production at OEM will be increasingly needed. This needs to be applied to specific areas and new battery applications (broad electromobility applications, stationary storage applications, etc.). Since the market development and diffusion is progressing especially in the next 5–10 years it is increasingly important to speed up and train the staff until a broader market diffusion will be reached and job profiles as well as education or training are standardised.

Also, for OEM large projects and facilities are rolled out for the serial production of electric vehicles, the installation of large battery storage, etc. Projects with several 100 million Euros invest and teams of 100 to several 100 people will be more and more common in the future and experienced people, i.e. **project managers,** will be needed which today are hard to find. Since those experts are needed right now the urgency is ranked quite high and will increase in the future with the number of projects and market diffusion of battery-based applications.

The need for **experts to move into the battery business** as well as the needed **mobility of people** and attractiveness of production locations is of relevance also for OEM which are more and more competing in hiring skilled personnel with battery knowledge with the other sectors and industries along the value chain. The urgency is assessed here as well as quite high and increasing in future.

The cross-cutting need for staff with **digital skills, systemic understanding and soft skills** are assessed of high relevance and increasing urgency as before. The relevant skills for OEM are e.g. module and pack assembly including battery management systems (BMS), battery control and system integration, battery testing, battery application, handling of batteries and safety. Towards end of life e.g. also the re-use and recycling are relevant. With respect to digital skills experienced staff doing simulations on cell, pack to system level (e.g. aging, electrical properties, …) is needed. The discussion with and integration of the customer on the application side is becoming more relevant and addresses several battery systems, products, applications and profiles of use over the product lifetime. Software specifics skills needed are e.g. functional safety and cyber security.

There is a need for software and electrical engineers accordingly. It is assessed that very often rather an upskilling of the given staff is useful than education IT-experts in engineering and the application but this might be decided case by case.

The systemic view might be of relevance especially on the level of the application and the battery integrated in the product, system, etc. For optimising the battery use, safety, handling, etc. a profound understanding of the battery cell and chemistry, the performance down to the material is needed. Interdisciplinary teams combining the knowledge along the value chain might be a solution as well instead of expecting the full knowledge in one expert. This requires even more soft skills, translating across the different understanding and languages of different disciplines etc.

Towards the start of production (SOP) of certain products and applications there is a need of **application engineers**. These are typically senior experts (e.g. electrical engineers) with 5–10 years experience, good soft skills (especially communication skills), a good network, with technical skills and people who have internationally travelled (e.g. for tests at different locations and customers across the EU or globally). For this reason, the jobs are very often internal. The experts need to be trained in troubleshooting in a short time frame. Application engineers will be quite urgently needed but this depends on the concrete application, closeness to the customer, etc. In any case the relevance increases the closer the work is to the SOP. With increasing market diffusion and broad applications more application engineers will be needed.

In particular there seems to be a lack of staff with focus on industrial applications (traction solutions, UPS, etc.). This may stem from the high need for experts in automotive industries in the last years. But now other application fields are maturing and getting closer to the market or are going into market diffusion. Concerning the needed profile, experts have to know about the application and about the battery including a system perspective. For stationary applications (e.g. grid stabilisation) electrochemical and application engineers (e.g. electrical engineers) are needed. These experts need to have an additional education to know about the application (application mode) but mainly the electrochemical background (Li-ion battery knowledge) is very often missing. The standardisation of batteries for batteries in specific/ special applications is a further issue to be solved or addressed. Currently, there is only a low number of experts on European level and thus mostly experts from Asia (especially on ESS applications) are hired and work in these fields.

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Table 3: Overview of the needs of system integrators (OEM) for battery applications.

Short-term (< 2025)			Mid-term (2025-2030)	Long-term (2030+)
1. Which staff is needed?	2. Which qualification is needed?	3. What are the most urgent needs (1 = low, 2 = mid, 3 = high)?	What will change?	What will change?
Needs of system integrators (OEM) for battery applications				
1 Reskilling staff from ICE to EV. Most Tier1 might have those trainings.	technicians, management	3	later less or ongoing	full transition
2 Understanding of machinery and of production at OEM	technicians, engineers	2: *Basic understanding exists and can be applied to specific area*	increasing import-ance to speed up (therefore education needed)	standardised education/ training
3 Project manager with knowledge in handling huge/ complex projects	management	2–3: *(high need of experienced experts/ managers)*	increases with number of projects (market)	needs to be standard
4 Experts to move into battery business (competition along VC)	academia/ technical	2	increases with increasing market	increases with increasing market
5 Mobility of people and attractiveness of new locations	academia/ techn-ical (cities/ regions)	2	increases with increasing market	increases with increasing market
6 Establish a **digital mindset** (e.g. data analytics, simulation, AI, ...) Put into standard curriculum.	academia/ techn-ical (cross-cutting)	2–3	increases (relevant along full VC)	increasing relevance, standard needed
7 Systems engineer seeing all aspects of parts of battery system. Awareness of different „languages“	engineers as project managers (cross-cutting)	3	more and more important	to be standard
8 Soft skills (also intercultural)	academia/ techn-ical/ management (cross-cutting)	2–3	more and more important	to be standard
9 Application engineers (trained in troubleshooting in short time frame). Jobs are very often internal (due to needed experience).	Disciplines: electrical engineering for packs	2: *Depending on application, how close to customer, etc.*	increasing relevance with market entrance. (more important coming to SOP)	increasing need of number with diffusion of market(s), applications
10 Industrial application: Lack of staff with focus on industrial application (traction solutions, UPS, ...). People have to know about the application and about the battery (i.e. to have system perspective)	**electrochemical and application engineers** needed (electrical engineers)	2	increasingly needed know-ledge on how to operate systems	increased no. of EU experts needed (today rather Asian experts)

4. Measures – Towards 2030+

Based on the industry needs along the battery value chain in a next step we formulate measures which should be undertaken in the next years. In the expert workshop the following questions have been discussed:

1. What are adequate measures to address the most urgent needs?
2. Who would be responsible to initiate the measures?
3. How urgent are the measures (on a scale from 1 = low, 2 = medium, 3 = high urgency)?
4. What will change in the mid-term (2025-2030)?
5. What will change in the long-term (2030+)?

Besides the measures identified, the cross-cutting skills needs, that have been identified already as relevant needs for the industry across the full battery value chain with partly different concrete meaning, show up to be integral and relevant practically for all measures. This means the need for

- soft skills,
- understanding of the system perspective, and
- digital skills (e.g. simulation skills, data analytics, etc.)

should be considered along all measures which are formulated and explained in more detail in the following.

1. Identify the concrete needs of the battery industry (with a focus on SMEs): For the emerging European battery economy a large workforce will be needed with qualified people on academic, professional and vocational level. Large companies are hiring staff with the adequate skills and is active to further educate and skill the own staff in house with respect to the companies needs. However, with the transformation of the battery industry from materials to cell, module, pack production and product integration (e.g. in EVs, ESS) the number of staff needed in industries will expand and lead to more and more competition along the value chain and across industries to get the best talents with the right qualifications. SMEs might be more threatened as they typically do not have the time and capacity to express their concrete needs and to engage in education and skilling people. There is a number of different projects (e.g. *ALBATTS*, Batterie 2030+) on EU level trying to identify the concrete needs for education and skills for a future battery economy. Those and further/ upcoming initiatives should consider also SMEs as target group. In those initiatives e.g. workshops, roadshows are instruments to identify, discuss and figure out the needs of the battery industry. In oder to include SMEs also instruments like interviews, surveys, direct/ bilateral discussions would be needed to identify on a more conrete level their needs and develop according measures.

- <u>Responsibility:</u> The educational system will be needed to react to the industries needs and educate people with the right skills to adress those needs. For identifying the needs and adequate measures analysts in the field of education, e.g. via dedicated projects as mentioned before, would need to conduct such studies.

- Urgency (3 = very high): This measure is needed urgently and right now in order to avoid the risk of a undersized workforce with needed qualifiactions in the next 5–10 years.
- Change (mid-/ long-term): Once identified the needs, the most adequate measures have to be in place in the next years. In the longer term changing needs could be observed but this measure will be accomplished.

2. Roll out interdisciplinary educational programmes and initiatives: A logical next step is to support the educational system to react to the identified and expressed needs which are cross-cutting along the battery value chain and interdisciplinary with respect to the academic and vocational education needed. E.g. the typical chemistry or engineering academic eduation might have to integrate further programmes, courses, exchange with industries and also a dedicated vocational education (typically e.g. 1–2 years training) might have to be specified.

- Responsibility: The educational system (e.g. programmes, national, EU educational agencies) would be responsible and would need support from or cooperation with industries and according funding. An example would be the Erasmus+ programme.
- Urgency (2–3 = high): The need to implement/ adapt measures to the battery industry needs is of importance for the near future.
- Change: Once established in the mid- to long-term programmes might be adapted to changing needs or intensified for certain measures which turn out to be useful (e.g. support for the mobility of students, strategic partnerships, support of early-career researchers, etc.).

3. Adapt curricula: For classical disciplines such as materials science, chemistry, physics, engineering, etc. battery specific needs of industries along the value chain should be adressed by adapting the curricula in order to better address the qualification profiles required from industries. Relevant aspects are interdisciplinarity along the battery value chain. Examples are energy curricula (e.g. geo science, chemistry, physics, electrical engineering with interdisciplinary aspects) or the implementation of digitalisation skills (e.g. with respect to data analytics, to handle big data on e.g. electrochemical information). A concrete example might be the need for a material scientist and an electrical engineer also to understand how to build and produce a battery cell.

- Responsibility: Academia would be responsible and the main target groups would be (1) electrochemists for materials, (2) engineers for production, (3) engineers for applications.
- Urgency (2–3 = high): The need for adapting curricula is especially of high relevance with respect to implement aspects like digitalisation (e.g. data analytics). But industries (especially large indsutries) are currently also upskilling staff in-house and might be satisfied with qualified personnel educated in classical disciplines with high interest in learning further skills.

- Change: Adapted curricula should be standardised with time and known/ accepted across EU countries and world regions for academia and industries.

4. Courses and specific seminars for industry (digital): Industry is using courses and specific seminars for re-/ upskilling the own staff, if courses are detailed enough and adding an added value to concrete skills of relevance to the industries. For electrochemistry e.g. currently such courses are not always detailed enough and more in-depth offers for different topics are needed. This might be specialised courses and seminars on electrochemistry, characterisation methodology, battery manufacturing, battery management or battery system integration. Especially offering such courses to other/ complementary disciplines across the value chain to support the cross-disciplinary knowledge transfer. For battery production knowledge on large-scale production is increasingly important. Towards applications and end use such courses might cover cells and battery packs behavior, testing and measures towards safety precautions, etc. With increasing knowlegde on a circular battery economy technical courses could be developed in the future. Also courses addressing cross-cutting topics like digitalisation (e.g. data analyics, simulations, AI, ...), a systemic view or soft skills might be adapted towards the battery industry. With respect to courses for industries online-lessons and virtual seminars with limited or no physical attendance on-site might have a higher relevance, since employees have very limited time to upskill in parallel to the current job (e.g. a few days courses). In contrast, for more academic education more extensive and longer term courses (e.g. several weeks online-trainings) might be more relevant. With respect to vocational training and e.g. for battery manufacturing plants, several-weeks course packages might be useful to train, e.g. machine operators or material handlers.

- Responsibility: Academia (e.g. universities, applied research centres) but also private education centres and public/private infrastructures (e.g. pilot lines) already partly today provide such courses. These will have to expand towards (large-scale) production relevant aspects, concretise topics and exand in number and throughput with increasing staff needed in the battery industry.
- Urgency (3 = very high): The need for such courses (especially online-courses for upskilling personnel at industries) is very high. Probably, especially for SMEs.
- Change: More established and standardised offers (including in-depth topics, adapted formats to target groups, etc.) will be needed. With changing topics the offer needs to be adapted and extended. In the long-term the number and throughput needs to be expanded.

5. Specialised and standardised online courses: In contrast to the aforementioned courses for industries (physical or online) also in the acadmic education the offer of online courses, virtual seminars and learning methods (e.g. adaptive learning to optimise individual learning/ education) with battery relevant content might be extended. Especially, with COVID-19 the educational system is adapting to digital education and this might develop to a trend (e.g. also facing current limited mobility across countries and regions).

- Responsibility: As before the educational system but also (research, pilot) infrastructures might offer such courses to students preparing to work in industries (e.g. production facilities) after studying. In contrast, to the offer for industries courses for students will need a format of rather several-weeks.
- Urgency (2 = medium): The urgency for industry is not considered as high as courses for the own staff. However, it is indirectly relevant with respect to qualifying students which later apply for jobs in industries.
- Change: The offer of online courses in adacemia might need to be adapted to the academic education and programmes offered there. If such courses should be offered also across universities, with facilities, industries, etc. and across countries a standardisation and scaling of the offer would be needed.

6. Hiring and upskilling of staff in industry towards new needs: The industry is training (and thus upskilling) the own staff typically in-house (e.g. with onboarding plans and trainings for 1–2 years). However, this takes time and cost and it would be preferable to directly hire/ employ people with the required skills. With respect to cross-cutting skills (digitalisation, system view including cross-disciplinary knowledge transfer, soft skills, etc.) probably only (mostly) large companies might be able to deal with.

- Responsibility: Industry itself is active in this field and running own programmes (by itself or e.g. together with external providers). Industry hires staff from universities, job fairs or raises awareness there for the companies needs. Training is then provided for the staff hired.
- Urgency (1–2 = lower): Since industry typically is already active it is an ongoing activity.
- Change: Besides the ongoing activities, the industry is often using more and more social media and networks (including different content in the channels). The number of followers is increasing and relevant for the human ressource (HR) market. For SME such activites in social media might be different. In the future it is expected that industry will icreasingly need to headcount people, since with the increasing demand for skilled personnel across the value chain, there will be an increasing competition for best talents.

7. Up- and Reskilling for production and automotive industry: Along the value chain, there are however differences in the urgency of re-/ upskilling of the personnel. For materials industry rather an upskilling of personnel with new skills (e.g. data analytics) is of relevance. For cell production e.g. new staff has to be hired and trained with new skills relevant for large-scale production. With respect to the automotive industry external hiring is rather difficult with a large workforce already working there but in fields around vehicles with internal combustion engine (ICE). Reskilling people for electric mobility in this case is an issue in addition to upskilling people the aforementioned cross-cutting (digital, system view, soft skills, etc.) and other specific skills. The industry recruits from universities but for production lines (cells, modules, packs, etc.) also hires from other markets/ industries, since it is easier to train/ skill people from other market (production sectors) than newly train people. SMEs are additional partners for inline measurements, sensors, digitalisation to adapt to production lines and there is a need for training for those companies to integrate their products in production lines and accordingly also people to fulfill the requiered skills.

- Responsibility: Here, concretely the system integrators (OEM) and in particular automotive industry needs to reskill the existing workforce in order to avoid too many people loosing their jobs.
- Urgency (2–3 = high): The urgency is high since the market diffusion of EVs is progressing in the next 5–10 years.
- Change: Reskilling programmes have to be completed in parallel with the transformation of the transport sector to e-mobility.

8. Internships for transfer from academia to industries and vice versa: Internships are voluntary but for industry they are increasingly important, as they also link to the training of people on the job. Internships e.g. at (public) production infrastructures could be open for all universities and further link between academia and industries via the infrastructure/ facility as a kind of nucleus and public centre for exchange.

- Responsibility: The industry needs to be active and exchange with academia to provide the possibility for interships. At facilities the production infrastructures would be responsible.
- Urgency (1–2 = medium): The measure is already known and established in principle but could increasingly be used from industries to get access to and attract later potential staff. For production facilities it could be a measure in general for skilling a broad workforce, transfer knowledge and/or prepare the onboarding to a factory.
- Change: The measure could be further adapted by the industry itself according to their needs and by the emerging (public and private) facilities when developing their concepts and with their implementation and expansion.

9. Platform projects are identified as very efficient and favorable measure for the exchange between industry and academia. Examples for such platform projects are industry days (e.g. organised in the frame of running large, funded projects, clusters, networks, initiatives), where certain topics are discussed between academia and industries. For industries it is a good possibility to get into contact with less experienced people from university (students, PhD, post-Docs) as potential employees. Talented people can be proactively informed about job opportunities at the industries. Also it is possible for industries to place smaller projects and to solve problems. The transfer from expert to expert (1–2 day seminar), e.g. on topics like solid-state batteries, new production, module/ pack integration, functional safety, aging, system architectures, future material trends, etc. is regarded as very beneficial for industries. The concrete technology, topic and the industry needs might change over time and the measure might constantly have to be adapted in order to adress the needs of the industry. Although such industry days are restricted to a certain community they could or should be more broadly open, e.g. to SME. However, a question is to get the information on activities. This can be done e.g. via project websites, platforms of funding agencies, etc. it could be also part if information campaigns as further measure.

- Responsibility: Academia is organising such platform projects in cooperation with industry, e.g. via funded projects. Also, exisiting platforms (e.g. hubs, regions) and networks, associations, etc. (e.g. including EIT) are already organising such industry days and could do so also in the future.
- Urgency (3 = very high): There is a high benefit expressed from industries and thus it would be urgent to maintain and/or further align and standardise those activities along the needs of the industries.
- Change: Standardised formats and changing topics also for next generation topics are and will be relevant for the industry.

10. Foster the attractiveness of a future battery economy for less experienced people (students): Young academic people are the potential future workforce in a battery economy. Already today in some industry fields which might not be attractive since they might dissapear in the future or do not enough address the work on products supporting decarbonisation goals and environmental aspects observe that young people are shifting their interests to emerging industries, e.g. focussing on fields like artificial intelligence, environmental engineering, etc. Younger people are getting more and more political and have a sustainable thinking and behaviour. This can be positive for a future „green" battery economy but there are many other industries and sectors in need for talented and motivated workforce. Especially for the next years with the increasingly large number of experts needed measures informing about the sustainability and importance of a battery economy and the potential working fields and qualifiaction needs with a focus on younger, less experienced people and students should be set up.

- Responsibility: The educational system (e.g. universities) but also industry would need to proactively advertise and inform about those future job opportunities, the benefit and importance (e.g. in addition to job fairs). Policy and (social) media should support accordingly with objective and fact based information, e.g. negative and one-sided press releases, broadcasts, etc. on environmental problems due to lithium production in Chile, cobalt mining in the Congo or a CO_2-intensive battery production are counterproductive.
- Urgency (3 = very high): A positive but fact based image clearly addressing the future potentials and ongoing challenges which are worth working in the battery industry is of high importance already since the past decade.
- Change: A broad awareness, acceptance and interest from young/ less experienced people should be reached in the future to build up a large skilled workforce of next generation experts.

11. Mobilise experts and strengthen battery locations: The industry is very international, i.e. the way of interconnecting actors and people is difficult since there is no one only battery hot spot. However, the demand for skilled personnel especially at cell production facilities will increase in the next decade. Not only the job profiles but also the locations need to be attractive options for experts. This might be easier for younger/ less experienced experts which still are open to settle down at new cities, coutries, regions. But the mobility might include both (1) first measures to connect and exchange across battery hot spots (e.g. for a certain time, via online concepts, etc.) and (2) second measures to **strengthen certain locations** by creating hot spots through a broader industrialisation of industries along the value chain and also by providing and expanding private offers and attract people (e.g. large cities, cultural offers, nature nearby, etc.).

- Responsibility: The industry and in particular production facilities would be responsible to offer attractive job opportunities but regions, cities, the local government would need to support industry with providing an attractive environment, e.g. also through benefits for people working at the facilities.
- Urgency (2 = medium): The urgency is quite high already today but will increase with the expansion of battery hot spots.
- Change: In future the number of factories and locations will increase and there might be a stronger competition among those locations especially with respect to young people and battery experts which are open or undecided where to move and live.

12. Preparation for onboarding in factories: A preparatory study or education connected to the onboarding in large-scale factories will be important for highly efficient and competitive production facilities. Such a preparation might be realised via dedicated courses but also internships or work experience at production research facilities, pilot lines, small-scale production in other locations. Also, large-scale factories will most probably set up their own onboarding measures.

- Responsibility: The (large-scale) factories will have the leading role but might be supported by other facilities (e.g. public research production infrastructures). For example, a European wide network of production facilities is currently built up and might have such a role for transferring experts between those facilities in the future.[27] The importance on vocational education might be higher in terms of number of staff but with respect to the management e.g. it could be a must in future to have gained experience at several production sites.
- Urgency (2–3 = high): The urgency is already high and increases with the expansion of production sites and size of the factories.
- Change: Onboarding measures will have to be set up and might need to be harmonised across facilities which would be clearly a task for such networks like *LiPLANET*. In the longer term this needs to be broadly established and standardised. The measures are also relevant production beyond cell manufacturing (i.e. materials production, module, pack production, production of electric vehicles and other battery based products or recycling plants).

[27] LiPLANET's objective is to create an European innovation and production ecosystem bringing together the most relevant European Lithium battery cell pilot lines and the main stakeholders of the battery sector: https://liplanet.eu/

13. Managing complex projects and large infrastructures: Especially for the management of thoses infrastructures it is needed (a) to train people to handle complex projects and (b) to have experts with knowledge about the product and process. Both aspects are needed at the same time. A first step is to implement education with focus on managing complex projects in the academic education (e.g. need for internships in production facilities) and especially professional education (i.e. experience by long years working and managing smaller to larger projects). In Asia battery experts are experienced and grew up with managing very large and complex projects as there is already an exisiting industry. This knowledge will be needed also in Europe.

- Responsibility: Again, the production facilities will be mainly responsible (e.g. the *Forschungsfertigung Batteriezelle* in Müster (Germany), pilot lines, facilities in industries with additional focus to teach project manager). The aforementioned network *LiPLANET* might be an example, where exchange and job markets for management but also specialised staff with different/ alternative/ supplementary skills and background might be organised.
- Urgency (3 = very high): The urgency is very high because the requirements are very high and long years experience is needed. Thus, according measures have to be implemented already now. Examples like Northvolt show that as long as there are not enough experienced experts in Europe also hiring experts from Asia might be the best way. This is e.g. how Chinese and Korean industries have learned from the Japanese industry in the last 20 years.
- Change: The knowledge about arising difficulties when building up large infrastrutures (e.g. cell production) is urgently needed in the next few years. Later, more and more people with this experience will be needed. Additional measures will be necessary (e.g. coaching among managers of different facilities). It can be expected that there will be a market across at least European infrastructures and production facilities for upper management staff.

14. Access to infrastructures for target groups: Pilot lines and other research production infrastructures should be integrated and functionalised in the academic and professional education network, recognising their educational role, acting as a nucleus for exchange between academia and industry. But also other stakeholders like policy or the public will need to have access to those production infrastructures. The target is to transfer knowledge not only on manufacturing but also on the later product integration, use and recycling. Due to the limited space available (since the production is at the core of the facilities) such an access might be restricted to parts of the facilities, realised via showrooms or a smaller test-production environment but also digital tools (digital twin) like virtual-reality production, online guided tours, seminars etc. might be used.

- Responsibility: The infastructures, especially public or publicly funded research infrastructures, would be responsible but would need to be supported by industry and academia to concretise the content to be offered. A funding or financial support would be needed to establish concepts and to implement the access to the target groups. Networks of those facilities are of importance in order to benchmark and learn from other facilities and concepts in terms of experiences and best practice.

- Urgency (2 = medium): The urgency is maybe very high at the beginning in terms of demonstration to the public. With respect to other facilities and industry along the value chain an early exchange is needed and direct business models for joint cooperation have to be assessed. With respect to establishing standardised forms of access the urgency certainly increases with the establishment of the facilities.
- Change: In the longer term there should be standardised concepts in information on the access. Lessons learned and best practices across infrastrucutres might help to harmonise but also to differentiate business and access models for different target groups.

15. Access to infrastructures for SME: Small and medium sized enterprises are a special target group since those companies typically do not have the means to build up own infrastructures. They might be a target group to provide access to research or pilot production (e.g. smaller material, component developer, system integrators beyond automotive industries) but they might also be a relevant target group as client or co-developer (e.g. cooperation with producers of sensors and automation equipment, etc.).

- Responsibility: Research and pilot infrastructures (public/ private) are responsible. They would have to identify the concrete SME needs to establish business or cooperation models. In case of a role to just inform SMEs an additional funding or finance would be needed according to the concrete concept.
- Urgency (2–3 = high): The urgency might be higher compared to broader or other target groups due to the special need and role of SMEs (especially in Europe).
- Change: After having identified the more concrete needs of SMEs with respect to access, use or contribution to the infrastructures cooperation or business concepts would be needed to establish. In the longer term standardised forms of access would need to be established.

16. Train the trainer: All along the battery value chain there will be a need for an increasing number of personnel. As the numbers in chapter 1 of this report have shown every decade the workforce needed increases by a factor of about 10. It is clear that the people which are educated today at universities, research centres or in industry will have to act as multipliers and educate or train the next generation of experts. This will require standards for training and educational programmes for future teachers in this field.

- Responsibility: This adresses the full battery value chain but with respect to educational measures and concepts the educational system would have a key role.
- Urgency (2 = medium): The urgency will increase with the workforce.
- Change: In the long-term „train the trainer“ or „teach the teacher“ programmes will need to be established.

17. Information campaigns: A full battery ecosystem can evolve only if there is a broad acceptance and support in the society. The public or end user has to experience the benefits of battery based products. E.g. in the past years there have been campaigns and demonstrations e.g. to drive an electric vehicle. With an increasing number of electric vehicles and charging infrastructure, etc. the public is experiencing the change towards electric mobility. But also for other applications and products it is needed to better inform the public. For example, there is still a lack of knowledge or understanding on devices in household such as powertools (e.g. vacuum cleaner and drilling maschines) and wearables (laptops, tablets, …) that utilise batteries concerning basic aspects related to optimal/ safe conditions (e.g. how to extend life cycle, how to minimise fire risks, etc.). The same holds for electric cars and bikes. The proper disposal of battery waste is another issue. When getting more and more familiar with those issues also the awareness and interest in battery applications will increase with the effect that also the motivation to work in a future battery industry will increase.

- Responsibility: Such campaigns might be pushed forward from policy and media but support by industry and academia.
- Urgency (2 = medium): The urgency will increase with the market diffusion.
- Change: In the long-term living with and handling battery products needs to be normality.

Table 4: Overview of the measures.

Short-term (< 2025)			Mid-term (2025-2030)	Long-term (2030+)
1. Measures	2. Responsibility	3. Urgency	4. Change	5. Change
1 Identify the concrete needs of the battery industry (with a focus on SMEs)	educational system, analysts	3	develop adequate measures	done
2 Roll out interdisciplinary educational programmes and initiatives	academia (supported by industry, policy)	2-3	establish	potential adaptation to new needs
3 Adapt curricula	academia	2-3	standardise	established
4 Courses and specific seminars for industry (digital)	academia, industry, private business/ consulting	3	more in-depth topics, adapted formats	higher number and throughput
5 Specialised and standardised online courses for academic education	academia, industry, private business/ consulting	2	adapt to educational system	standardise

6 Upskilling of staff in industry towards new needs	battery industry along value chain	1–2	ongoing	ongoing
7 Up- and reskilling for production and automotive industry	automotive industry	2–3	increasing with diffusion of e-mobility	reskilling completed with transformation
8 Internships for transfer from academia to industries and vice versa	academia with industries	1–2	increasing use of the measure	adapted to new cooperation formats and facilities
9 Platform projects	academia with industries	3	align platform projects with industry needs	standardise networks and exchange
10 Foster the attractiveness of a future battery economy for young people (students)	academia, industry, policy, media	3	broad awareness and acceptance	large number of skilled workforces
11 Mobilise experts and strengthen battery locations	industry (production facilities), cities/ regions, policy	2	attractivity, increased number	battery ecosystem with hot spots
12 Preparation for onboarding in factories	facilities (with academia and industries)	2–3	specified, harmonises concepts	standard (also other production than cells)
13 Managing complex projects and large infrastructure	industry, facilities (experienced selected experts)	3	long year experience needed	more managers needed
14 Provide access to infrastructures for target groups	facilities (supported by industry, academia, policy)	2	establish concepts	standards
15 Access to infrastructures for SMEs	facilities (supported by industry)	2–3	identify needs, concepts	standards
16 Train the trainer	along value chain (prob. support from educational system)	2	increases with workforce	"train the trainer" programmes
17 Information campaigns	policy, media (supported by academia, industry)	2	with market diffusion	broad acceptance (normality)

5. Conclusions

After 10 years of ramping-up battery know-how and preparing industries for the emerging battery markets, in particular electric mobility, stationary, industrial but also other applications, the European battery industry is facing a transition towards a European circular battery economy in the next 10 years and beyond. While 10 years ago battery production capacities in Europe have been on a level below 1 GWh, the plans for the next 10 years sum up towards meanwhile around 1000 GWh or 1 TWh. In the years 2030 to 2050 the European battery economy might reach a battery demand of even several TWh. With around at least 100 direct and 300 indirect jobs per GWh along the entire battery value chain at scaled production, the European workforce needed in the future will be on a level of several hundreds of thousands to above 1 million jobs.

European players along the value chain are now trying to position within global and highly competitive markets. For Europe, a large-scale battery cell production still defines the missing link and a gap that should be closed in the coming years. At the same time Asian players like CATL, LG Chem, Samsung SDI, etc. but also Tesla as US battery and electric vehicle manufacturer are building up battery production capacities across Europe. Those companies are competitors but suppliers, customers, cooperation partners and employees at the same time.

Against this background, Fraunhofer ISI with support of the Fraunhofer Battery Alliance and the Fraunhofer Academy conducted a study and a “battery industry expert workshop” on behalf of EIT Raw Materials, in order to identify battery skills needs and adequate measures to build up a competitive European battery industry and workforce. The companies workforce is the backbone for a competitive industry in the future. Due to different competitiveness along the value chain from battery materials to cell production and system integration into applications as well as the recycling after the end-of-life, a core issue was to identify the industry needs today, in the near to mid-term (2025) and long-term (2030+) future along the battery value chain. At the same time, the potential measures to support industries in order to build up their future workforce have been identified with pointing to relevant players, responsible to implement the measures (e.g. academia, industry, policy or others). Skills needed in industries can be e.g. on an academic, professional or vocational level.

It can be concluded, that in the last 10 years a battery community has grown-up already, especially in the materials industry and at system integrators (OEM), but also in the equipment and production industry, where in the next years the highest demand for additional staff could be identified. There is available expertise in universities and research centres etc. - but the issue and challenge for the future will be to continuously adapt and develop skills toward future needs which are in parts different along the value chain and to upscale the number of workforce.

In general, at the R&D level there is always a higher weight on academic degrees needed and e.g. in chemical industry a PhD typically is a must have. Towards production, there is an increasing weight on vocational education needed (e.g. for operating machines). This is typically staff, that can be trained within 1–2 years. Towards applications and end-products the number of non-academic but also non-technical personnel is increasing (e.g. for marketing, sales, etc.). The all over split of 20 % academic *vs.* 80 % technical to non-technical staff is typically pronounced from industry experts. Still this would lead to an estimated need for experts at the order of e.g. 100–200 thousand with academic background and longer-term experience in the battery field across Europe and in the long-term future. In total, this indicates and increasing or at least ongoing demand for educating battery experts in the educational system as well as scaling-up (vocational) training for technicians.

Four action fields could be delimited with 10 needs of industries across the value chain and 17 measures are formulated corresponding to the needs, including cross-cutting measures (see Table 5).

Re-/ Upskilling the existing workforce: The largest number of staff will be needed with vocational education (e.g. 1–2 years training). Typically, industry itself is training, re- & upskilling the staff (e.g. technical staff in chemical industry to have deeper electrochemical knowledge, in production to application industry to have a more systemic understanding and knowledge of large-scale production machinery). In chemical industry academic personnel needs to understand upcoming material trends and to have special software skills, e.g. in data analytics. In production, besides large-scale production and quality aspects also digital skills (e.g. automation, artificial intelligence (AI)) and R&D in future production technologies is needed. Concerning the applications, especially in the automotive industry reskilling of personnel which today is working around vehicles with internal combustion engine is an urgent issue. But also, the upper level management at all stages of the value chain needs to have battery knowledge, experience in large and complex projects (e.g. for large-scale production), since investments at this stage are enormous and the projects are too large to fail. On the academic level educational programmes adapted to these needs and adapted curricula, the more targeted use of internships but also platform projects with industry days for the exchange of industry with academia are identified measures with benefit to the industry. Towards vocational education (online) courses and specialised/ standardised seminars (later with larger number of topics offered and higher throughput) are of help for re-/upskilling the workforce beyond the own capacities of the industry. However, still a lack has been identified to define specific subjects for such courses and seminars based on the industry needs. Thus, especially the needs of SMEs should be understood on a more concrete level to properly design such measures. The level of courses needed is typically on a topic such as cell design, electrode engineering, assembly, functional safety, aging, etc. but might also integrate cross-cutting topics and skills in need (see below).

Mobilise the future workforce: Besides considering the existing staff additional staff will be needed especially in equipment and production industry (e.g. around 50 % additional staff in the next years and more in the longer-term). This will have the effect of an increasing competition along the value chain for skilled personnel. With respect to next generation experts, young people need to be aware of the upcoming transition and perceive electrochemistry, cell production, the battery business in general as an attractive future field. They also need to be open to move to production sites which are ramped-up across Europe. But also, the transfer of experts across industries along the value chain will be increasingly relevant, not only as threat for certain companies but also as chance to establish a battery community with cross-cutting skills and understanding.

Cross-cutting skills: In order to keep the pace with the global (in particular Asian) competition and to speed up innovation a more and more complex, systemic and digital mindset will be needed in the future. Digitalisation (e.g. automation, data analytics, simulation) will be relevant to drastically increase the speed and efficiency of R&D, production but also use and circulation of products like battery cells, electric vehicles, etc. AI, e.g. for autonomous production, quality control as well as in high-efficient and accelerated R&D, etc. will become a more and more concrete USP. Different disciplines (e.g. IT-specialists, electrochemists, engineers, mechanical experts, etc.), experts on different educational level and experts along the value chain will have to work more and more together and understand the different perspectives and background of scientific disciplines, educational levels, as well as cultures (e.g. working with experts from Asian countries). This also requires soft skills. With this cross-cutting character of the needs they basically have to be implemented across all measures identified (i.e. in the educational system, curricula, courses, seminars for vocational training, in the mind of students to experienced managers as well as the broad public).

Scale to a circular battery economy: The todays workforce will train again the next generation to deal with the large amount of people needed in the future. Not only educational and training concepts, formats will need to be adapted but also the throughput of students and trainees. A focus will be on the vocational education with highest demand by number of staff. Also, the large-scale production is a bottleneck for a future European battery economy. Here, public (and private) R&D infrastructures, pilot lines, production lines are identified to have a special role. E.g. those infrastructures could prepare experts for onboarding in large-scale production factories, educate an increasing number of process engineers (with knowledge e.g. in cell design, operation and optimisation of production lines), prepare experienced managers of large projects and facilities (e.g. transfer from pilot to larger scale production). But also, those infrastructures would contribute to a knowledge transfer in providing access to target groups (e.g. SME industry, academia, policy as well as the broader public for information and raising awareness and acceptance).

Table 5: Overview of the measures.

Action Fields	Material	Needs Production	Applications		Measures
Re-/ Upskilling existing workforce	1 Qualified academic battery materials experts (electro-chemists, inorganic materials, new material trends).	1 Disruptive development might change the need for know-how and education.	1 Reskilling staff from ICE to EV. Most Tier1 might have those trainings.	1 Identify the concrete needs of the battery industry	2 Roll out interdisciplinary educational programmes and initiatives. 3 Adapt curricula 4 Courses and specific seminars for industry (digital). 5 Specialised and standardised online courses.
	2 Technical staff with deeper electro-chemical knowledge.	2 Technical staff with cross-cutting knowledge and system view.	2 Understanding of machinery and of production at OEM.		
	3 Upper Management with battery knowledge (along value chain).	3 Project manager with knowledge in big projects as e.g. GWh.	3 Project manager with knowledge in handling huge/ complex projects.		6 Re-/ upskilling of staff in industry towards new needs. 7 Re-/ upskilling for automotive industry. 8 Internships for transfer from academia to industries and vice versa. 9 Platform projects
Mobilise the future workforce	4 Motivated young people/ students to study electro-chemistry (esp. PhD students).	4 Experts to move into battery business (competition with OEM), not necessarily only from battery side.	4 Experts to move into battery business (competition along VC).		10 Foster the attractiveness of a future battery economy for young people (students) 11 Mobilise experts and strengthen battery locations
	5 Mobility of people and attractiveness of new locations.	5 Mobility of people and attractiveness of new locations.	5 Mobility of people and attractiveness of new locations.		
Cross-cutting skills	6 Establish a digital mindset (e.g. simulation data analytics, AI). Put into standard curriculum.	6 Establish a digital mindset and need to find software engineers.	6 Establish a digital mindset (e.g. simulation data analytics, AI). Put into standard curriculum.		Measures 1 to 17
	7 System view and understanding along the value chain.	7 System view and understanding along the value chain.	7 Systems engineer seeing all aspects of parts of battery system. Awareness of different „languages“		
	8 Soft skills (also intercultural)	8 Soft skills (also intercultural)	8 Soft skills (also intercultural)		
Scale to a circular eeconomybattery economy	9 Product by processes (Process engineering).	9 Process engineers (e.g. more people needed in cell design area and application).	9 Application engineers (trained in trouble-shooting in short time frame). Jobs are very often internal (due to needed experience).		12 Preparation for onboarding in factories. 13 Managing complex projects and large infrastructure. 14 Provide access to infrastructures for target groups. 15 Access to infrastructures for SMEs 16 Train the trainer 17 Information campaigns
	10 Recycling/ Remanufacturing	10 Large scale production, full traceability, fulfilled within the team. But with growing demand also the number of jobs grow.	10 Industrial application: Lack of staff with focus on industrial application (traction solutions, UPS, ...). People have to know about the application and about the battery (i.e. to have system perspective).		

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