Report

Roland Berger

MUNICH / GERMANY

Rising opportunities for battery equipment manufacturers

BOOM IN ELECTRIC CARS AND LI-ION BATTERIES SHIFTS MANUFACTURING EQUIPMENT INTO OVERDRIVE

PEM | RWTH AACHEN UNIVERSITY

Roland Berger

MANAGEMENT SUMMARY

While the Covid-19 pandemic has apparently parked conventional automotive technology in a dead-end, demand for electric vehicles continues to rise steadily. The breakthrough of electric vehicles – and strong demand for the lithium-ion batteries they use – will open up lucrative opportunities for European equipment suppliers in the years ahead.

Asia still dominates today, with China alone boasting more than 70% of the world's cell production capacity. Yet the European market for lithium-ion cells is already growing faster thanks to brisk demand mainly from automotive OEMs. In the next five years, Europe's production equipment volume should thus nearly double to a market share of 15% and a volume of over EUR 3.1 billion.

European battery manufacturers keen to participate in this growth must focus primarily on reducing both initial investment outlays and ongoing production costs. They can do this in four main ways: by innovating in process engineering to cut the cost per GWh; by scaling up to gigafactories to exploit economies of scale; by improving cell chemistry to boost energy density (thus producing more energy per cell); and by boosting overall equipment effectiveness, which is still low compared to other industries.

To rise to the challenge of Asian dominance, European equipment suppliers also have a hard road ahead. Focusing sharply on equipment for battery production, they must leverage the experience they have gained in other process industries. Efforts to build up production in Europe can draw on the benefits of local support for battery manufacturers (emphasizing their experience on the ground in Europe, which few Asian players possess), deliver high-quality equipment and offer an attractive total cost of ownership. The scale effects afforded by gigafactories can also be turned to their advantage, provided they commit to greater horizontal integration, accumulate references, foster the ability to deliver turnkey systems at competitive prices – and slash their delivery times.

Looking further ahead, all-solid-state batteries (ASSBs) could become a game changer over the next decade, gradually substituting for lithium-ion batteries and massively changing production methods in the process. Volume production is likely only realistic as of around 2030, but market players must position themselves early to reap the potentially substantial rewards.

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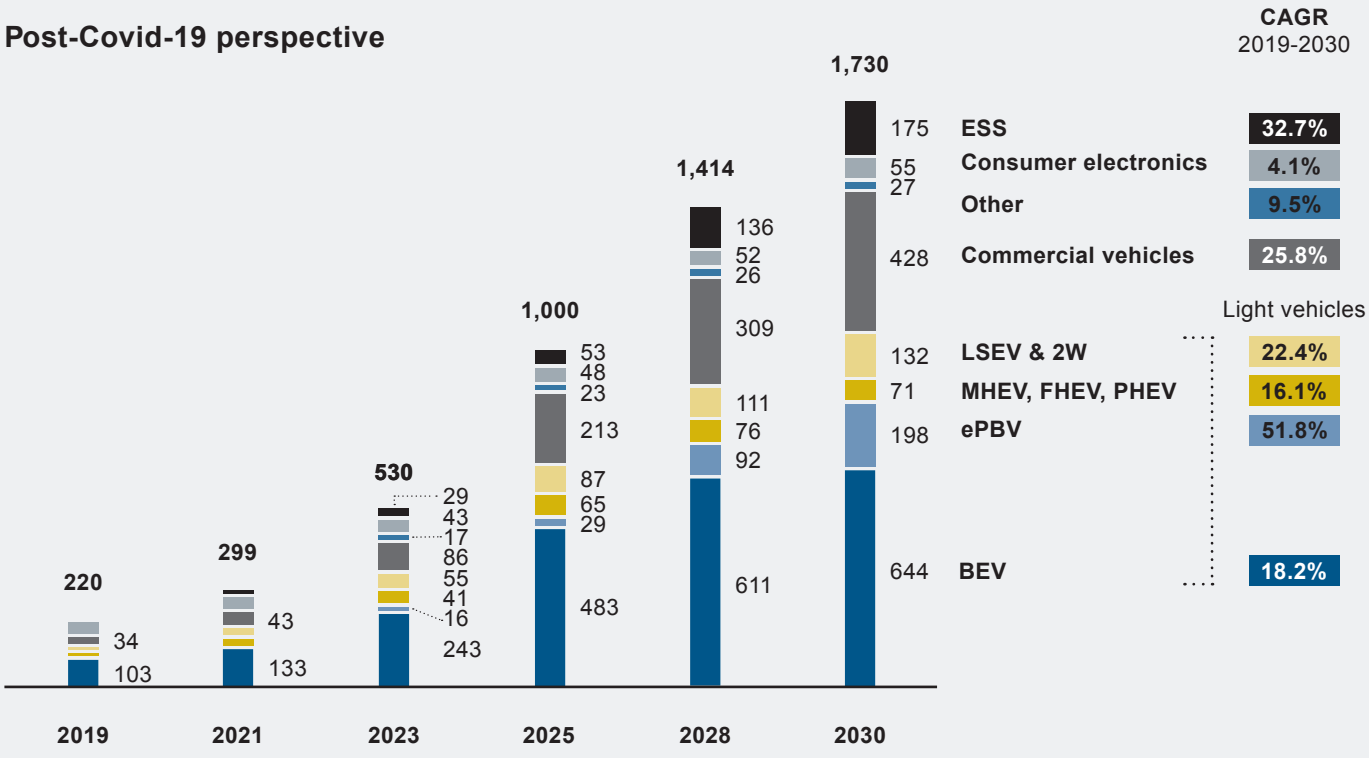
1 / Lithium-ion batteries on the rise: Key takeaways from the 2020 equipment study

The growing popularity of electric vehicles will fuel vast demand for lithium-ion batteries in the coming years. Battery production in Europe is on the verge of a serious breakthrough, with production capacity of almost 500 GWh/a to go on-line by 2025.

The global market volume for the high-quality production equipment needed to set up numerous gigafactories will grow by 34% per annum through 2030. As the market volume increases more than tenfold – from EUR 1.7 billion today to as much as EUR 20.9 billion by 2025 – European equipment suppliers in particular stand to reap handsome rewards. Though currently occupying only 8% of the market, Europe will become the second-largest market for production equipment by 2025, with a market share of 15% and a volume of over EUR 3.2 billion.

A / Market demand for lithium-ion batteries, by application [GWh]



Abbreviations: ESS – Stationary energy storage system; LSEV – Low-speed electric vehicle; 2W – Electric two-wheeler; MHEV, FHEV, PHEV – Mild hybrid, full hybrid and plug-in hybrid electric vehicle; ePBV – Electric purpose-built vehicle; BEV – Battery electric vehicle

Source: Avicenne, Fraunhofer, interviews, Roland Berger

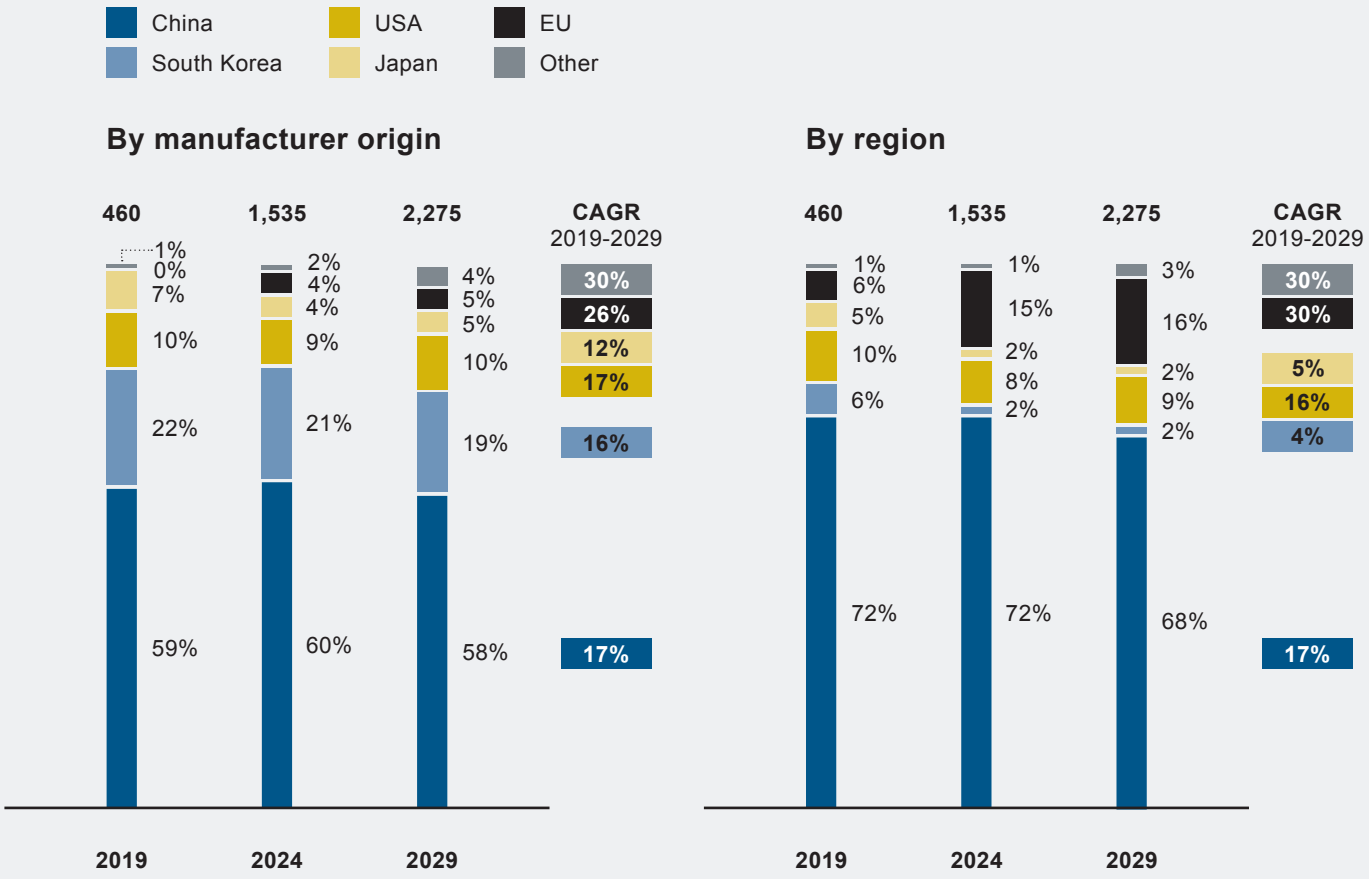
¹ Projected market demand in 2030 before Covid-19

2/ LiB market growing rapidly despite Covid-19, with demand for xEV as a driver

Having fallen off a cliff in 2020 in the wake of the Covid-19 pandemic, demand for passenger vehicles is not expected to fully recover until 2030. Despite lower demand overall, however, electric vehicles are continually adding to their share of the market. If further political incentives are forthcoming, the current crisis could actually become a catalyst that sees electric cars finally move into a new dimension. The resultant sharp rise in demand for electric vehicles is already pushing up the need for battery cells.

Accordingly, demand for these cells is expected to reach the TWh range by 2025 and should rise to 1,700 GWh/a by 2030. Most batteries will be installed in battery electric cars (BEVs), which – with an annual growth rate of 18% – will account for more than a third of the market volume. → A

B / Lithium-ion battery manufacturing capacity projections [GWh]



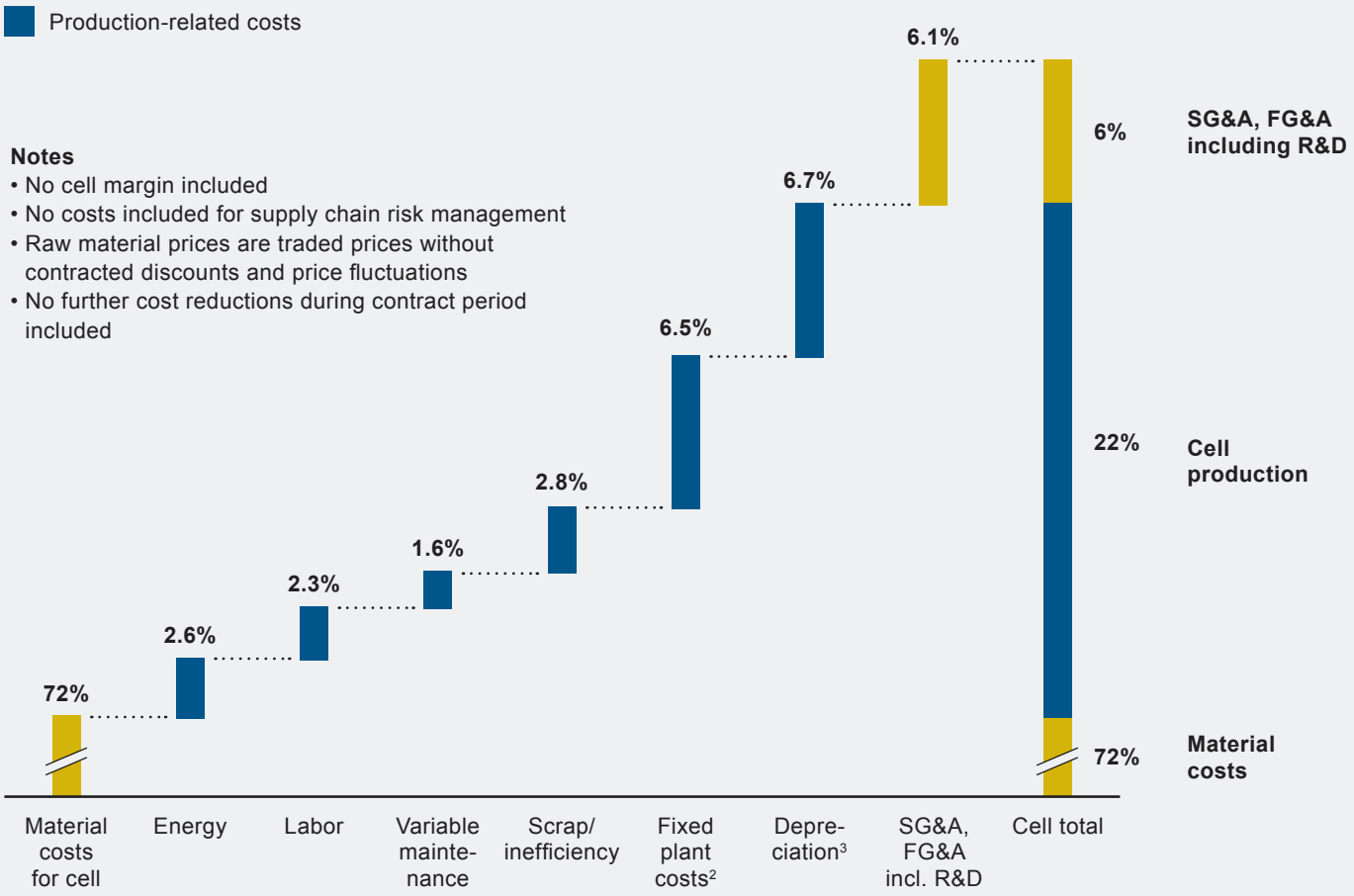
Notes: “Captive players”: Tesla, BYD and JVs between OEM and cell suppliers. USA: mainly Panasonic working with Teals, Panasonic HQ in Japan

Source: Roland Berger, Benchmark Minerals

Asia will remain the epicenter of cell production capacity. With a market share of over 70%, China will continue to be the dominant market in the years ahead, although Europe's importance as a venue for battery manufacturers will also increase. Strong demand from automotive OEMs indeed makes Europe the fastest-growing market for lithium-ion cells. Cell capacity of over 450 GWh/a is expected to be built here by 2025. → B

Right now, however, it is mainly Asian manufacturers who are producing battery cells on a large scale in Germany and/or Eastern Europe. Announcements by new manufacturers with a European background (e.g. Northvolt, Automotive Cells Company, Freyr) provide a ray of hope for authentically European production, but they are nowhere near able to meet automotive industry demand. Suppliers from Europe will therefore continue to play a subordinate role in the coming years and will probably not make it above a market share of about 5%.

C / Cost breakdown for the NCM811 cell[1] [EUR/kWh]



[1] Prismatic cell production in China
[2] Fixed plant costs, including facility management, insurance and imputed interest
[3] Depreciation refers to the investment costs for plant (10-year amortization period) and buildings (25-year amortization period)

Source: Roland Berger battery cost model, PEM RWTH Aachen University

3/ Cell costs must come down

For most battery manufacturers, production in Europe is uncharted territory. Quality requirements are higher, and OEMs expect the battery price to drop significantly with increasing volume. To mitigate the risks involved, contracts with OEMs are often concluded for five to ten years at cell prices that can only ever be profitable in the long term. It is therefore vital for battery manufacturers to further reduce the costs of cell production with a view to their long-term market positioning.

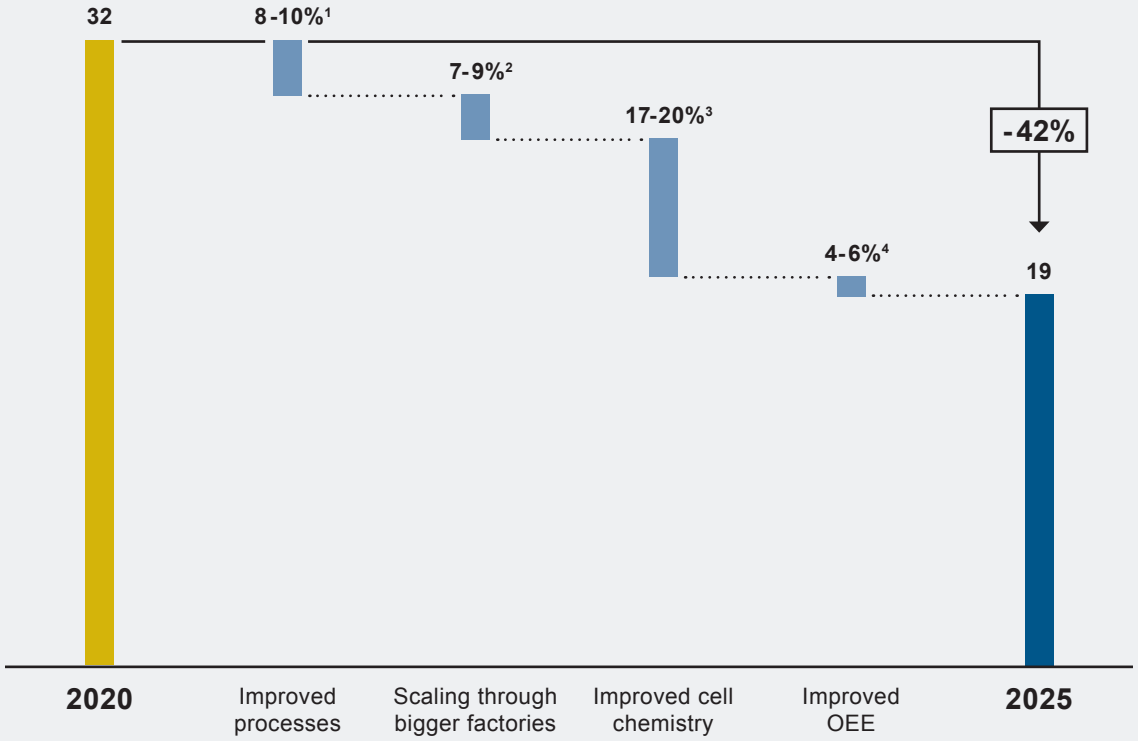
Material costs are the largest single cost block (72%) and will be difficult to curb in the future despite improved cell chemistries. Production costs, which also account for a significant share of 22%, thus represent the most promising lever for progressive cost reduction and it is here above all that equipment suppliers can make the difference. The primary focus here will have to be on depreciation and the fixed costs of plants. → C

Initial investment costs of approximately EUR 100 million for 1 GWh production capacity in 2020 constitute an opportunity for cost reduction, but also – and above all – a major source of risk for cell manufacturers. To reduce this risk, attempts are being made to raise production efficiency, generate more output at the same cost and improve/homogenize the quality of battery cells. The cost of production equipment is one of the biggest drivers for the investment costs and can be cut in this context primarily through:

- **Improved processes**
- **Larger factories**
- **Higher volumetric energy density**
- **Superior overall equipment effectiveness (OEE)**

> *"The success story of lithium-ion batteries in mobile applications has just begun and will play a central role in future value creation. Everyone is well advised to think intensively about how they can participate in this development."*
>
> **Prof. Achim Kampker**
> Professor at Chair of Production Engineering of E-Mobility Components (PEM)
> RWTH Aachen University

D / Equipment investment costs per GWh [EUR/kWh]

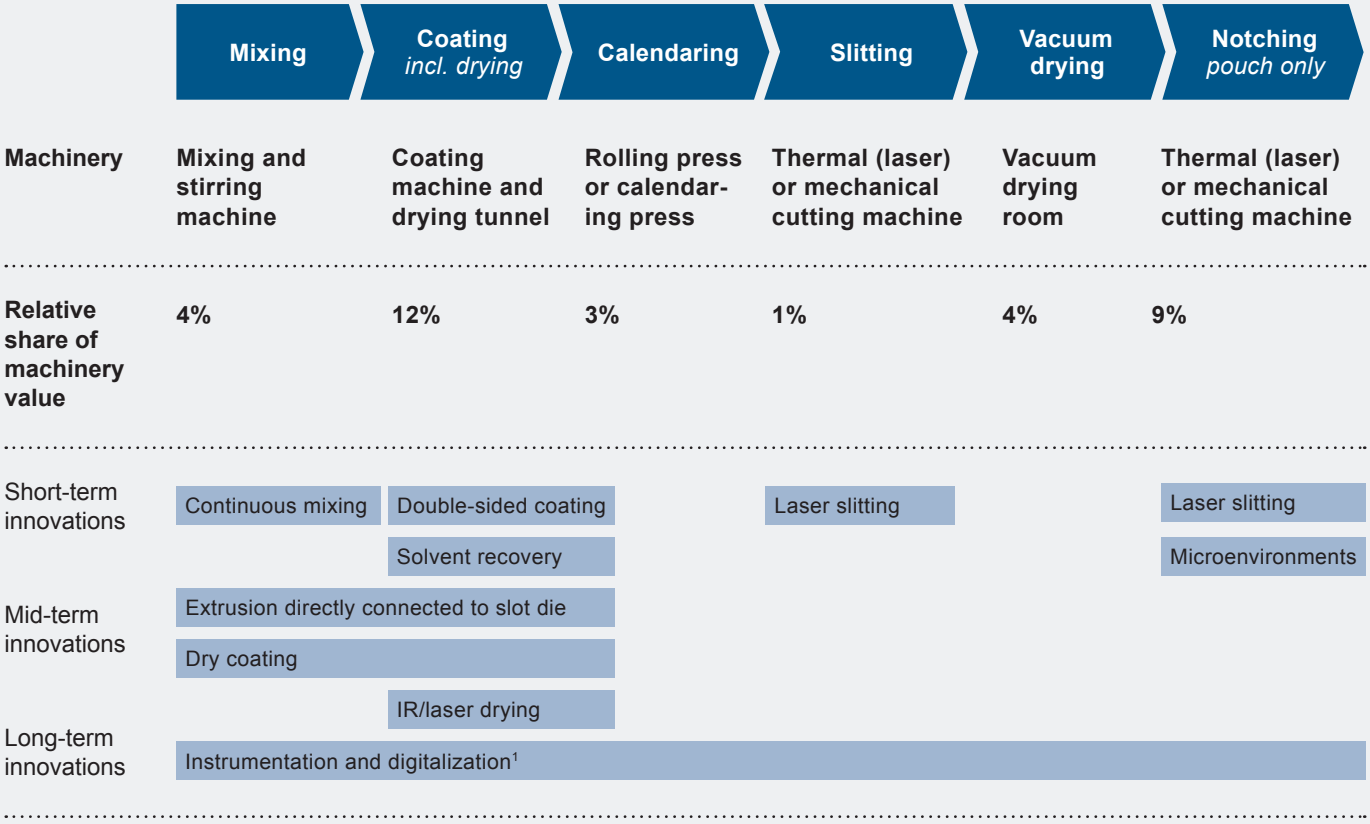


[1] Based on an average 2% increase in output through process improvements [2] Calculation of the scaling factor for midsized and large factories according to their market share [3] Calculation of the increase in energy density increases with the cell format share [4] Constant increase in the OEE from 74% to 80% by 2025

Source: Expert interviews, RB market model for lithium-ion battery production equipment, PEM RWTH Aachen University

It is realistic to expect the current investment cost for production equipment for one GWh of production capacity to fall by as much as 42% by 2025. Improved cell chemistry and the associated higher energy density in battery cells will be the biggest drivers of cost reductions, with a share of 17 to 20%. Production line output will be further boosted by process innovations and volume improvements. By 2030, throughput rates of up to 20 GWh/a on individual production lines are realistic and play a large part in slashing investment costs per GWh. → D

E / Process improvements in electrode manufacturing



[1] Includes machine learning, smart in-line quality control and Industry 4.0

Source: PEM RWTH Aachen University

3.1 / Improved processes

In the area of process improvement, it is mainly innovations in electrode production and cell finalization that will contribute to increased output. By 2025, costs per GWh should already be over 9% lower than today.

The greatest potential for innovation here is in the mixing and coating process and in formation and aging. In electrode production, the wider use of extruders will reduce investment costs by delivering very high throughput and enhanced quality. In the future, mostly double-sided coating will take up less space and halve the coating time. Dry coating is expected to be ready for mass production in 2024. This will not only eliminate the need for expensive and environmentally harmful solvents (NMPs), but will also cut investment costs as increasing energy density facilitates higher output, and as the need for drying is eliminated. → E → F

F / Process improvements in cell assembly and cell finishing

	Stacking *pouch*, winding *cyl. & pris.*	Packaging	Filling, sealing	Forming	Degassing, sealing *pouch only*	Aging & grading
Machinery	**Vacuum gripping, roll-to-roll and other handling technologies**	**Pick & place, ultrasonic or laser welding, impulse or contact sealing**	**Electrolyte filling system with injection lance and vacuum sealing**	**Storage system with contact springs for charging, charging system**	**Vacuum sealing and folding machine**	**Storage and handling, impedance tester**
Relative share of machinery value	**8%**	**16%**	**5%**	**29%**	**5%**	**4%**
Short-term innovations	Microenvironments			Recuperation	Hermetically sealed cells	
	Lamination	High energy laser	Roll pressing			
Mid-term innovations	Continuous stacking	Scanner welding		Fast forming		On-demand aging
	High speed stacking			Automated forming	AI for early quality assurance	
				Parallel forming		
Long-term innovations	Instrumentation and digitalization[1]					

[1] Includes machine learning, smart in-line quality control and Industry 4.0

Source: PEM RWTH Aachen University

Process innovations in cell assembly are expected primarily to concern cell stacking and packaging, where single-sheet stacking (including lamination) will increasingly be used. This technique will also become an alternative to winding in the case of prismatic cells, as it permits much higher volumetric energy densities. In packaging, scanner laser applications require much heavier investment but promise throughput times that are 3 to 4 times faster. Cell finalization can be improved mainly by digitalizing the equipment and improving formation protocols. By completely digitalizing the equipment and collecting information about each individual cell, conclusions can be drawn about cell classifications prior to finalization. It is then possible to adapt cell finalization to the specific cell. Especially in the formation and aging process, both time and footprint can be reduced significantly.

3.2 / Scaling through bigger factories

Scaling effects also play a considerable role in further reducing investment costs. Initially, gigafactories are often set up and tested with only a single production line. This line is then copied "as is" to scale up to planned capacity levels. Given the lack of standardization in battery production, most equipment is tailored to specific customer requirements. It therefore makes sense to purchase several similar units for different production lines: Since the unit only has to be designed once, significant savings can then be realized on engineering costs. In addition, costs can be further reduced thanks to higher purchasing volumes for materials and components.

These economies of scale can be leveraged to save up to 6% at midsized factories (in the 620 GWh range) and as much as 14% in the case of large factories (upward of 20 GWh). This explains why more and more larger factories with capacities of up to 100 GWh/a will be built, and why existing factories will be scaled up in the coming years. The comparatively small market share of 20% possessed by large factories in 2020 should surge to almost 60% by 2030. Between now and 2025, economies of scale will already shave over 8% off the average investment cost per GWh.

3.3 / Better cell chemistry

The biggest lever in reducing capex per GWh is to improve the cell chemistry. By increasing the volumetric (Wh/l) or gravimetric energy density (Wh/kg), more capacity can be produced per cell, thereby increasing the output from production lines.

NMC622 cell chemistry, still the most commonly used chemistry for pouch and prismatic cells, delivers an average volumetric energy density of up to 500 Wh/l but is expected to be displaced by the NMC811 cell in the years ahead. The trend here is to dispense completely with the use of cobalt, which is costly and difficult to access. By 2030, the introduction of all-solid-state batteries and nickel-rich cathodes should pave the way to cells with a volumetric energy density of over 1,000 Wh/l. Increases in energy density can be realized mainly in pouch and prismatic cells. Average growth of 5 to 6% per year is assumed in this segment, indicating that the volumetric energy density of the pouch cell will increase by 75% through 2030. Prismatic cells will see a gain of 65% in the same period. In the case of round cells, an improvement of no more than about 14% can be expected by 2030, as utilization levels are already very high.

That said, better cell chemistry can reduce the investment costs per GWh across all cell formats by an average of 18% between now and 2025.

3.4 / Superior OEE

In battery production, overall equipment effectiveness (OEE) tends to compare poorly with other industries due to the complex electrochemistry involved. Average OEE for large cell manufacturers is about 76%, while leading suppliers reach levels of about 82%. The scrap rate for unusable cells is very low at around 1 to 3%, as cells with poorer quality characteristics can also be sold in different classifications. On the other hand, material wastage is high at 10 to 15%, especially in the process steps of mixing and coating. These low OEE rates are often the result of a failure to fully utilize production facilities. Due to cracks or breaks in the electrode foil, production lines often cannot run at full speed and effectively have far less capacity than was initially planned. Similarly, when new equipment is introduced or cell chemistry is adapted, the ramp-up phase can lead to substantial scrap rates.

In the years ahead, superior quality measurement and system digitalization will be the principal ways to boost overall equipment effectiveness. Digital solutions for the simulation of new cell chemistries and the digital imaging of complete production lines should further diminish the scrap rate. Continuous improvement of the OEE rate to an average of 83% is therefore expected by 2030, resulting in a further 5% saving on investment costs per GWh.

4/ Full steam ahead for already dominant Asian players

As home to the world's dominant manufacturers and a venue for the bulk of production, Asia also leads the market for production equipment. The mainly Japanese and Korean plant manufacturers who pioneered the development of equipment for battery production just a few years ago are today flanked by Chinese suppliers whose equipment is deployed in many gigafactories. Their situation contrasts sharply with the current position of European suppliers, whose lack of projects to date has given them little experience with battery production and only slack sales of machinery abroad. Though many of them possess a wealth of process expertise from related industries, they are not yet able to deliver end-to-end systems for cell production. Leading Asian suppliers such as Wuxi Lead, Yinghe and mPlus, on the other hand, cover as many process steps as possible and supply turnkey solutions for entire production lines. A further challenge to European equipment suppliers stems from the flexibility and fast delivery times that are expected of them due to very short innovation cycles. To compete in the international arena, delivery times after design freezes should not really be longer than six months.

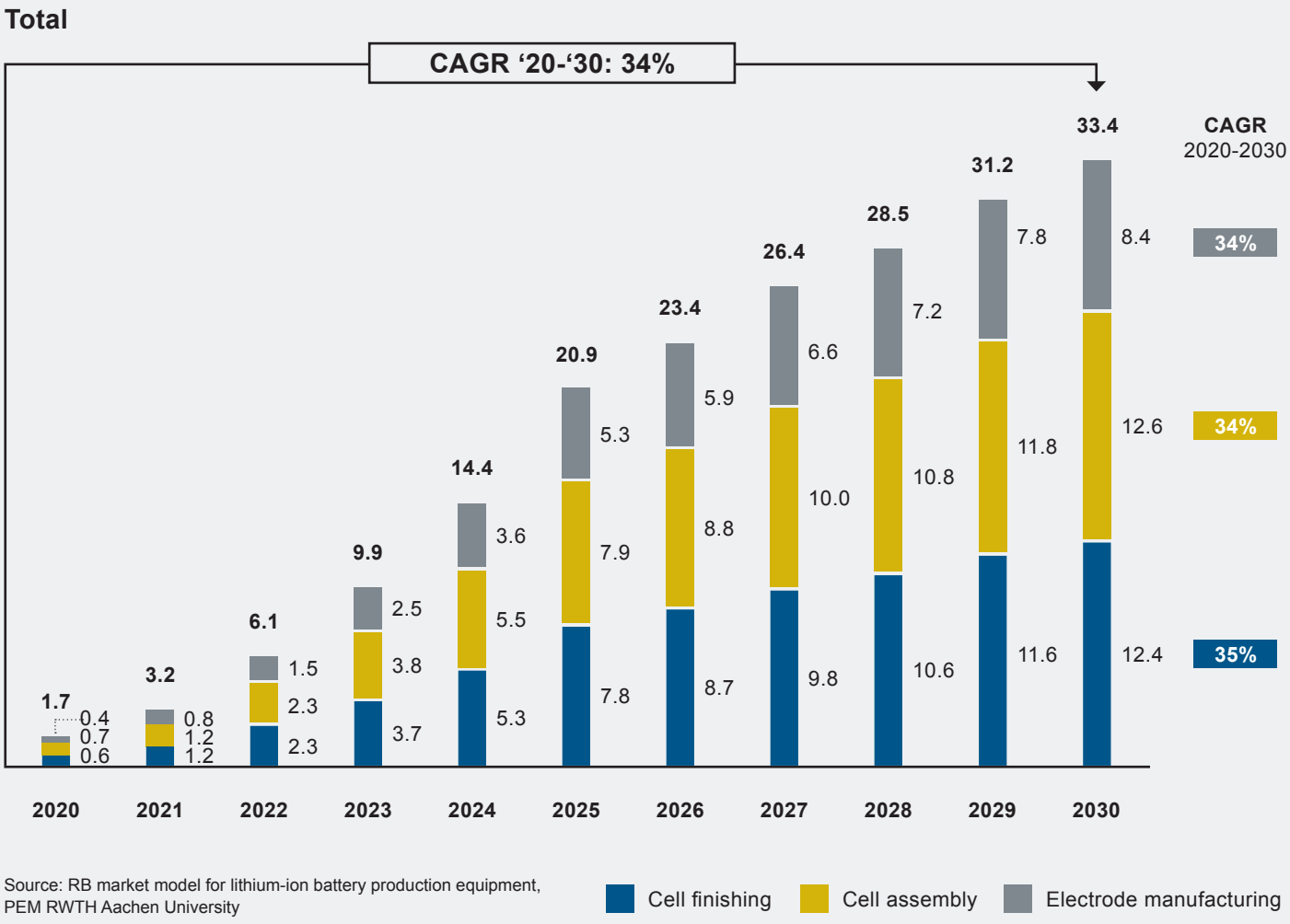
4.1 / Battery production driving profitability and growth

Many equipment suppliers have already profited from an upswing on the back of buoyant demand for electric vehicles. Over the past five years, companies with a strong focus on battery production have expanded by an average of 27% per annum. During this period, Chinese suppliers such as Wuxi Lead and Yinghe have further benefited from close cooperation with similarly fast-growing battery manufacturers such as CATL and BYD.

Players with a sharp focus on battery production have also returned profits of approximately 13% – significantly above the industry average of 10%. In light of developments across the market as a whole, equipment suppliers in the battery cell production space should see growth accelerate in the years ahead.

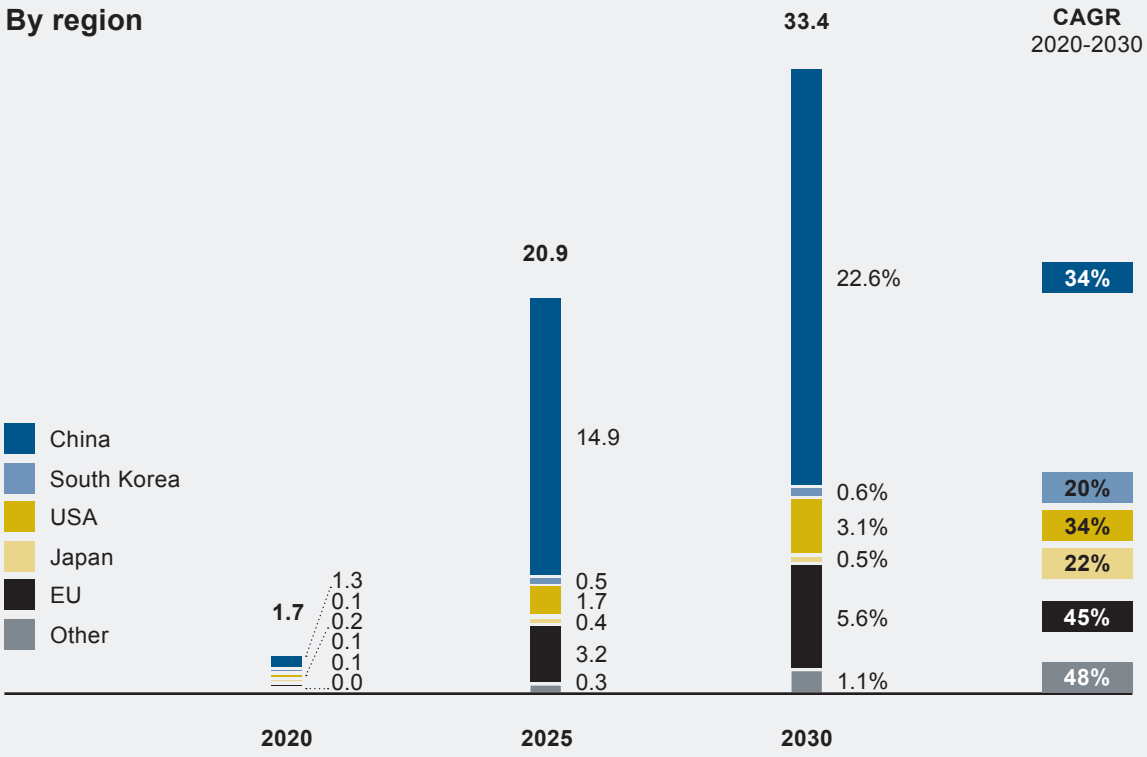
As investment costs fall, the market for production equipment will grow by an average of 34% per annum. That will swell the current market volume of EUR 1.7 billion to EUR 20.9 billion in 2025 and EUR 33.4 billion in 2030. → G

G / Market demand for lithium-ion battery production equipment [EUR bn]



Source: RB market model for lithium-ion battery production equipment, PEM RWTH Aachen University

H / Market demand for lithium-ion battery production equipment [EUR bn]



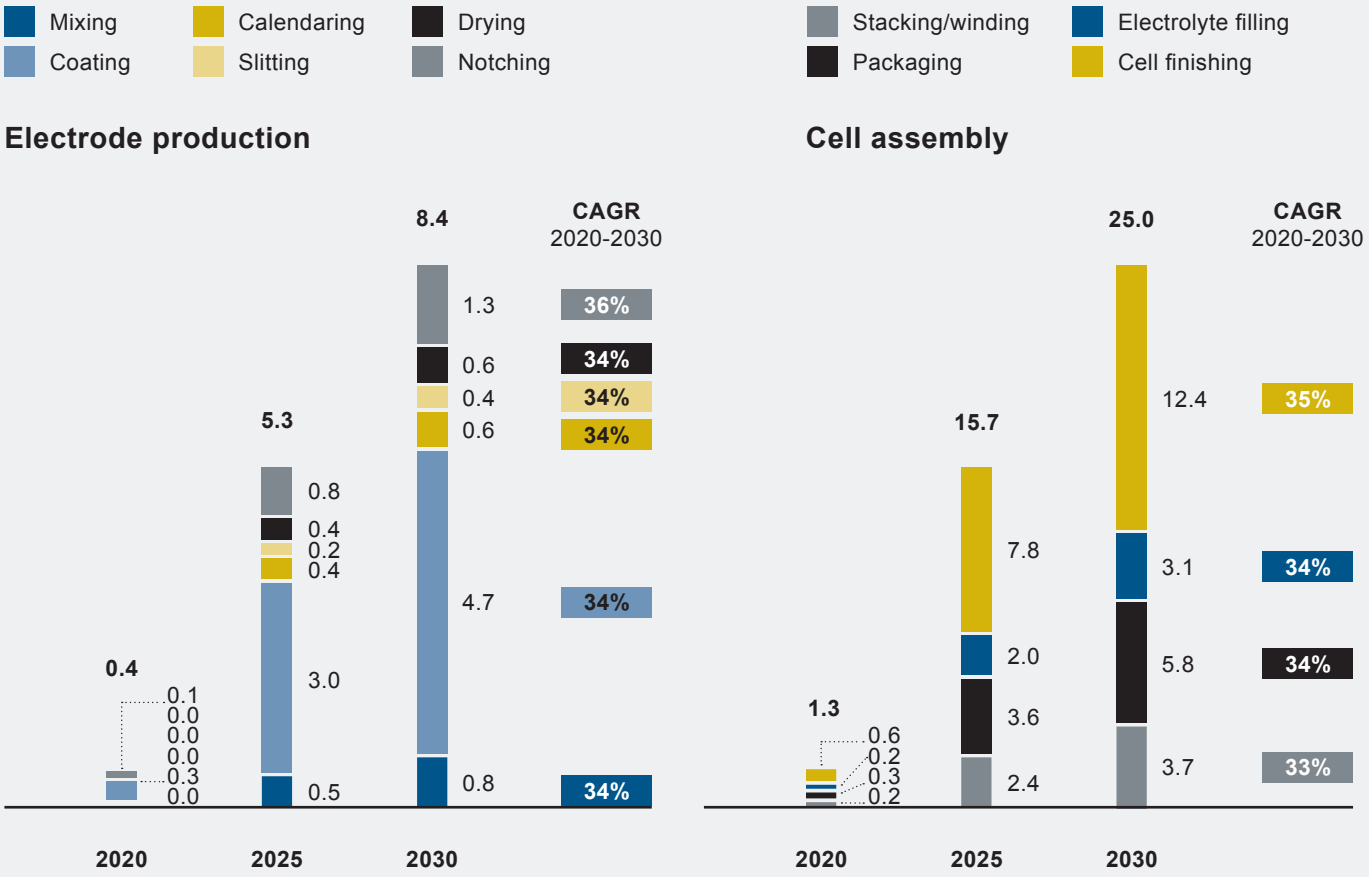
Source: RB market model for lithium-ion battery production equipment, PEM RWTH Aachen University

While the Chinese market will remain by far the largest, vigorous demand for lithium-ion batteries will see the strongest market growth occur in Europe. By 2025, demand for equipment will thus be worth EUR 3.2 billion in Europe, making this the second-largest market for production equipment. → H

Coating, cell assembly and cell finalization will be the process steps that unfold the greatest potential. → I

Such a rapidly growing market creates attractive opportunities for European equipment suppliers. On the other hand, expanding to Europe could present a stiff challenge to Asian suppliers in general and Chinese suppliers in particular. The likes of Wuxi Lead have so far generated only about 2% of their sales overseas, so they have little or no experience with production in Europe. This lack of experience on the ground in Europe could therefore be a decisive factor for the successful positioning of local plant manufacturers.

I / Market demand for lithium-ion battery production equipment, by process step [EUR bn]

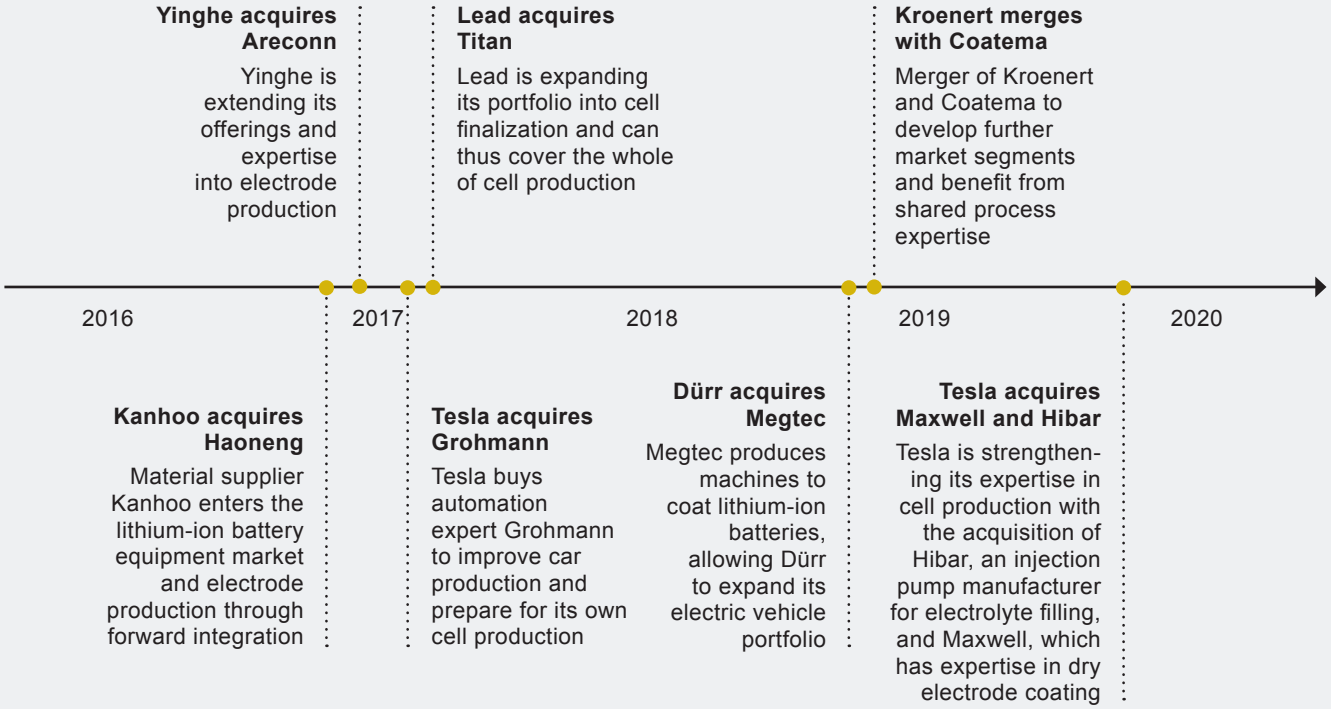


Source: RB market model for lithium-ion battery production equipment, PEM RWTH Aachen University

4.2 / Horizontal integration and turnkey systems – Two key drivers of M&As

Companies' desire to offer turnkey solutions and cover multiple process steps has been reflected in M&A activities in recent years. Equipment suppliers are clearly trying to advance horizontal integration and/or increase the depth of value they add. European equipment suppliers have also lately become active in this context, underscoring their ambition to enter the emerging European market. The same trend is mirrored in stepped-up cooperation with Asian suppliers. This latter strategy allows European plant manufacturers to benefit from the experience already gained by their Asian partners and, in return, makes it easier for Asian partners to expand into Europe. → J

J / Selected M&A activities in the battery equipment industry



Source: Desk research, Yinghe, Kanhoo, Lead, Kroenert, Dürr, CGIS Research, Tesla

Our study identified different drivers of M&A activities and cooperative ventures. Besides covering further process steps and deepening their knowledge of existing process steps, joint ventures are an approach favored especially for automotive OEMs and battery manufacturers. Heavy investment costs can thus be shared and the risk to the battery manufacturer reduced. In return, automotive OEMs secure the supply of battery cells and can adapt production to individual needs. Tesla is so far the only OEM that also invests directly in equipment suppliers: Its acquisition of Hibar, Maxwell, Grohmann and most recently ATW (subsidiary of ATS) is a clear statement of the intent to drive forward in-house cell production and become fully independent of both battery manufacturers and equipment suppliers.

> *"Given the fast growing NEV volume share in the global key markets until 2030, it is expected that we see more innovations and technology development as well as a manufacturing excellence push by OEMs, equipment manufacturers and battery suppliers."*
>
> **Ron Zheng**
> Senior Partner, Roland Berger

4.3 / The all-solid-state battery – A technological game changer

It is safe to say that lithium-ion batteries will remain the dominant battery technology for the next ten years. That said, they could well find themselves gradually being replaced by all-solid-state batteries (ASSB). Conventional lithium-ion battery technology will reach its limits at a volumetric energy density of about 900 Wh/l, whereas ASSB could push this ceiling up as high as 1,300 Wh/l. By eliminating both liquid substances and the possibility of escaping gases, the risk of fire can be reduced and the safety of batteries significantly increased. Charging times too will be shorter as the likelihood of dendrite formation will be greatly attenuated.

The all-solid-state battery's breakthrough is more than just an important lever for further electrification, however: It will also massively change the way batteries are produced. Especially in electrode production, competencies can be transferred only to a limited extent, so new concepts and equipment will be needed. Steps such as drying, electrolyte filling and degassing will be rendered superfluous by the new technology, while cost-intensive processes such as formation or aging can be simplified.

Although ASSB offers clear advantages over the conventional lithium-ion battery, there are still some hurdles to be overcome before mass production can begin. Realistically, all-solid-state batteries could be produced on a small scale as of 2025 but are unlikely to go into mass production before 2030. A great deal of research will therefore be required in the coming years, and companies will need to position themselves early in the production of these potentially game-changing batteries.

> *"Production of automotive traction lithium-ion batteries is one of the key growth markets of the coming years. That's a huge opportunity for equipment suppliers – including the European ones. Scrap rates and OEE are key cost and efficiency drivers. Those who can offer superior equipment to help their customers improve in terms of scrap and OEE will be the winners."*
>
> **Dr. Philipp Schmitt**
> Principal, Roland Berger

5/ Conclusion and recommendations

In the battery market, fierce competition rages not only between battery manufacturers but also among equipment suppliers. Barriers to entry – in terms of technological and process expertise – are high. As things stand, Asian companies often have an advantage thanks to the experience they have already gained and their existing relationships with battery manufacturers.

European equipment suppliers have some catching up to do in the next few years if they are serious about positioning themselves on the European market in particular. It is important to collect references and adapt to the specific requirements of battery production. Key targets must include reducing delivery times, fostering the ability to provide equipment for mass production and delivering turnkey solutions.

In the initial constellation of factories in Europe, European suppliers will have a hard time getting their equipment installed. Manufacturers keen to build up production capacity will try to avoid the risk of using "new" equipment and will most likely prefer the Asian equipment they already know and trust. However, OEMs' pressure for high-quality battery cells and secure production lines will also increase demand for quality equipment. And it is here – as well as in total cost of ownership – that European equipment could have the edge. Often, European-made equipment has lower energy costs and requires less maintenance and repair due to its robust quality, all of which can lead to lower costs over the entire production lifecycle.

Beyond that, battery manufacturers want and need local support for their systems. Unplanned machine downtimes can quickly translate into painful losses due to high output volumes, so quick repairs are vital.

There is therefore a clear need for European plants plus a fast-growing market harboring considerable potential. To stake their claim in this lucrative market, equipment suppliers must position themselves more strongly in battery production, accumulate references and adapt to market requirements. To do so, they must slash delivery times, offer turnkey solutions and – above all – be able to compete on price.

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12.2020

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Publisher:
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RB_REP_20_012