Sphere

Powering Sustainability

Green strategies to reduce the environmental impact of the battery industry

Establishing sustainable value chains and product life cycles for batteries

In the era of climate consciousness and sustainable technological advancement, batteries have emerged as one of the key enabling technologies. These compact reservoirs of energy are crucial for the transition towards renewable energy integration and the electrification of transport and other sectors. However, the ascendancy of batteries comes along with environmental challenges along their whole life cycle, spanning from procurement up to end-of-life management.

This whitepaper delves into the complex landscape of environmental sustainability within the battery industry, shedding light on the challenges and opportunities that lie ahead. From future recycling ambitions to immediate actions that can be taken today, strategic imperatives for stakeholders along the entirety of the battery value chain are explored.

The urgency of sustainable practices and adequate assessment standards

There were times when the Li-ion battery technology was seen as the flawless answer when it came to powering tomorrow's mobility sector in an environmentally friendly way. However, along with the (more-than-justified) boost in recent years, critical voices have been heard from time to time questioning this product's industry-wide claimed sustainability aspect. In contrast, several studies showing that leaving the combustion engine behind is the right way (at least in large parts of the mobility sector), have been published recently.

Total relative carbon emission of electric vs. combustion engine cars

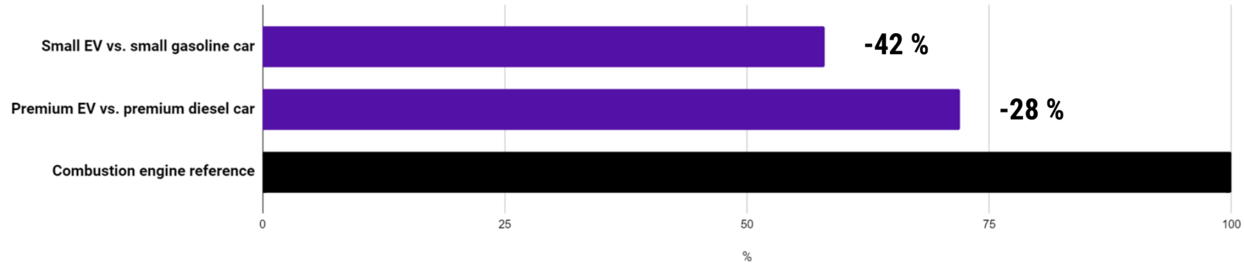

Figure 1: Average relative greenhouse gas emissions savings of EVs vs ICEs (German grid mix). Source: Fraunhofer, 2019.

And yet, even for supposedly green technologies like the battery, especially as the main driver for sustainability of an EV, there must be room for questions targeting these general sustainability claims. The environmental footprint of the battery industry is multifaceted, encompassing issues such as carbon emissions, resource depletion, or waste management.

While the mining and extraction of critical materials for battery production often involves environmentally destructive practices, the cell manufacturing process itself significantly contributes to greenhouse gas emissions. Moreover, the disposal of batteries presents a tough challenge - with improper handling not only leading to pollution but also loss of valuable resources.

A representation of average carbon emissions along the whole life cycle of a battery utilized in an EV, again in direct comparison to ICEs, is given below. While there is an additional impact in the drive-train production, this is overcompensated when looking at the whole lifetime of this specific battery end application product.

Carbon footprint impacts along the EV life cycle (incl. battery production steps)

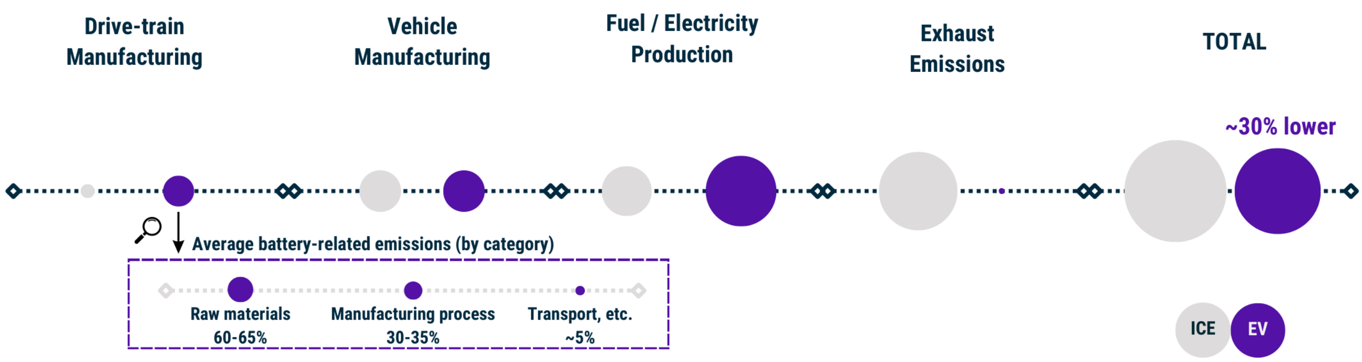

Figure 2: The split of carbon footprint impact along the life cycle (without end-of-life) of an EV, with a separate focus on the battery pack.

With average numbers of clearly speaking in favor for battery-enabled mobility, there are significant differences among similarly performing battery cells when it comes to their sustainability - due to various material compositions, manufacturing processes, and underlying supply chain structures. Above all, there is a need for clear assessment criteria, bringing transparency (to the highest extent possible) into this rapidly growing and evolving field. It should no longer be accepted to hide behind the industry's general sustainability claims and slogans. Instead, companies who come forth with ambitious but realistic (!) sustainability strategies and a clear commitment should be rewarded for these actions in an adequate way.

The term “sustainability” is covering a broad area and spans from social aspects to economic considerations to environmental factors - while the latter is going to be the focus in the following sections. Especially the carbon footprint is seen as one of the most important considerations when assessing the sustainability of batteries, as its importance is well underscored by several global political efforts.

Global warming potential (also greenhouse gas (GHG) emissions or carbon footprint) describes the sum of emissions of any greenhouse gas along the value chain of a certain product and is usually given in equivalents of CO2 emissions, e.g. kg of CO2eq. Main contributors in the life cycle of batteries include energy sources used within the extraction and production processes, or electricity consumption during a battery's use phase.

The narrowed focus herein is solely for the sake of simplification and current geopolitical relevance, and does not imply that other aspects of environmental sustainability, such as resource depletion, water consumption, soil or atmospheric pollution, or social sustainability topics such as. human right discussions in the context of cobalt mining in the Democratic Republic of the Congo, are less important.

Besides globally relevant regulations, there are several **location-specific directives,** often targeting varying areas of the overall sustainability aspects. One prominent example is the announced European **PFAS restriction**. While there are still loopholes, it might be required to have processes compatible with PFAS-free binders, and first players, like E-Lyte, have actively pivoted their R&D focus.

Challenges of a truly environmentally sustainable battery production

Gigafactories - the place where our battery cells are produced, one after the other continuously flowing off the production line. As we think, a great starting point to begin asking the right questions about the sustainability of the whole industry. Recently, gigafactory operators have been the main addressees when questions about the sustainability of battery cells were raised. Within these facilities, dozens of raw material streams come together, are processed in several complex steps, and eventually transformed into the well-known end product - battery cells in various sizes and form factors. With sound connections to suppliers (at least tier one) and first-hand decision power about the production process itself, these players have a deep understanding and a decisive role in the sustainability assessment of battery cells.

Given sufficient information on supply chains and production processes, life cycle assessments allow for a quantification of the sustainability impacts, such as CO2 footprint and beyond. Thus battery cell manufacturers are well capable of performing such assessments - as seen in the recent past.

More and more battery manufacturers are having carbon footprint targets in place

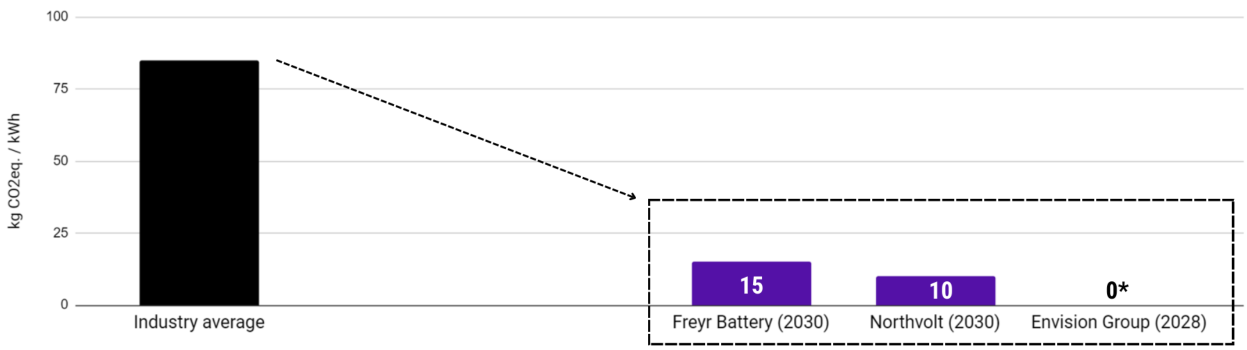

Figure 3: Current industry average vs. publicly announced carbon emission targets (target year in brackets).
**Group-wide ambition of becoming CO2-neutral, partly thanks to carbon offset agreements.*

With a large variety within the level of detail and selected system boundaries, these targets and underlying assessments are not always comparable one to one, of course. Overall, traceability of raw materials, preferably beyond tier one suppliers, is crucial to ensure an accountable and meaningful sustainability statement of a battery - at least up to the gates of the gigafactory (cradle-to-gate boundaries), in a first step.

Whereas having an impact on the whole supply chain can seem out-of-reach in the very short term, the process of cell manufacturing in gigafactories on the other hand, can be adjusted rather easily. Given the high energy consumption of cell production, the main contributor to carbon footprint usually is the energy converted within these factories - leaving the carbon footprint of the underlying energy sources as one of the main adjustment levers in that regard. While natural gas and other fossil fuels have a similar carbon footprint no matter where they are sourced and consumed, the CO2 emissions of electricity grid mixes can vary by order of magnitudes - depending on the underlying source(s). Thus, low-carbon electricity can effectively help mitigate the carbon footprint of battery cell production. A simple access strategy consists of building your factory in a country/region with low-carbon electricity grid mix (e.g. Iceland, Norway, Sweden, France, Switzerland, Costa Rica, Canada, etc.). Another option is to purchase certified low-carbon electricity - whereby there is an ongoing discussion about the true power of such certificates, especially in the short term. Further decisive factors within a gigafactory include the handling of scrap and the desire to decrease rejection rates, which however, is already well-addressed by the overall pressure of economic optimization.

Upstream of the factory's scope, a conscious selection of sustainable suppliers is key to further drive down the carbon emissions of batteries. An effective option is to exert vertical integration steps, as demonstrated e.g. by the Swedish battery manufacturer Northvolt. This strategy also goes hand in hand with current political directives targeting local supply chains (see box below). Joint ventures or, in an even simpler sense, long-term supply arrangements are one way to guarantee arrangements that allow for good sustainability monitoring. Mutual definitions of targets and working towards them in a joint matter are well possible in long-lasting supply relationships despite the fast-changing pace of the overall Li-ion battery industry.

Further down the road beyond the gigafactory gates, when including the product's life cycle, the use phase (incl. potential second life application) and end-of-life treatment strategies are decisive factors for the overall carbon footprint of a battery cell/pack.

Cell manufacturers' endeavors to vertically integrate go well along with the ambitions to localize supply chains - a common target of governments and political organizations all over the world. Newest regulations like the **Inflation Reduction Act** allow for a financially simplified restructuring of existing supply chains and will probably lead to a new global balance of power. Against the background of a more local industry setup, impacting and monitoring upstream processes is becoming more straightforward and less resource intense. Guaranteed financial support for IRA-compliance will allow innovative newcomers to stay competitive and potentially foster the setup of new ecosystems - with new core values such as truly sustainable practices.
Another stepping stone for a sustainable battery industry is the new **EU Battery Regulation "Batt2"**, asking for e.g. minimum waste collection rates of batteries utilized in light means of transport, or minimum threshold values of recycled content in new batteries (of key materials such as cobalt, lithium, and nickel). This actively supports a circular battery economy, a topic which is also touched later within this report.

What about different battery cell chemistries and the variety of end applications?

So far, we treated Li-ion battery cells as the same product - which by far does not do justice to the various products out there. Simply said, Li-ion batteries can be categorized into their (cathode) chemistries, where the most prominent groups are NMC, LFP, and NCA.

These batteries are all based on different raw materials, which leads to e.g. a generally higher carbon footprint of a kg of NMC battery compared to the same mass of an LFP battery. However, there are further aspects to be considered. If the comparison unit is switched from "kg of a battery" to a functional unit (more appropriate) like "kWh capacity of a battery", the energy density is taken into account too. Sustainability scores and comparisons thereof can thus be put into the right context despite some batteries having a lower gravimetric capacity. To address further differing specifications of battery types, other factors like longevity of the batteries should be taken into account as well to make a holistic statement about sustainability. A battery with a longer lifespan will contribute to consuming fewer resources when considering a cradle-to-grave approach.

This aspect further complicates the matter of providing a single comparable footprints for each cell. Different life cycle scenarios with varying battery use phases, preferably based on real-life application scenarios, would be required to fully mirror a life cycle and assess a battery's sustainability. Here, a standard set of use phases for common applications would be required to allow for comparability within sustainability assessments. As a player with experience in application-specific performance of various battery cells, Sphere Energy already keeps a standard set of these at hand and is happy to discuss potential industry-wide standards with other players.

Next-generation chemistries might have a significant impact on sustainability, as e.g. **Na-ion batteries** are prone to solve resource depletion challenges, relying on readily available elements solely. However, decrease the initial (cradle-to-gate) CO2 footprint, challenges with high energy demanding hard-carbon production have to be solved.

Similar hopes are for upcoming **all-solid-state batteries**. However, only in-detail assessments of fully scaled supply chains and manufacturing facilities will shed light on the exact advantages.

A battery's end of life: An opportunity for improvement and regression at the same time

If one had the assignment of drawing up a prime example industry to discuss all aspects of a circular economy, chances are high that it would strongly resemble today's Li-ion industry - with opportunities to extend the product life through second-life applications and a wide desire for recycling due to scarce and costly raw materials. Unfortunately, the battery is a fairly complex product with non-transparent and fragmented global supply chains, making the whole industry quite complex.

With EVs as the biggest end application market for Li-ion batteries, their life cycle becomes heavily dependent on the use phase of such a vehicle - which to this day is expected to be shorter than the one of a battery itself. Assuming that the battery still has the required power/energy capacity after its first life cycle in an EV, there is a theoretical way of its usage in a second vehicle. Otherwise, if the performance is lowered but still sufficient for another "lower-demand" application, the application of stationary energy storage looks predestined. From a resource-technical point of view, such further utilization phases are more than welcome and should be implemented wherever possible - given that the product's performance is still considered sufficient to last for a substantial period of utilization in the second lifetime, of course.

While there has been a lot of buzz around the topic of second life lately, large-scale implementation still has to be proven. Challenges such as health determination, uncertain lifetime, configuration of a new BMS, or warranty need to be figured out today to assess the feasibility of this business model for times when such end-of-life batteries will be readily available.

At the very end of its life cycle, a battery essentially goes one of two ways: Recycling or disposal. Currently available sophisticated recycling process of a battery cell are rather complex due to the many different materials present. Further, each battery pack is built differently, making the process even more difficult. Nevertheless, battery recycling is emerging as a future-proof and generally profitable business model (highly dependent on raw material prices) - which is great news for the sustainability of batteries.

Again, there are key differences between battery cell chemistries. While the recovery of carbon-intensive materials such as NMC is expected to have a greater environmental benefit, the carbon emissions associated with the energy and materials consumed during the recycling process itself are closer to the "retrieving benefit" for lower-carbon-intensive battery types such as LFP. Still, recycling is also considered to be worthwhile for such batteries from a GWP perspective. Similar reasoning is true for the economic aspects - while for a battery with high-value materials (e.g. NMC), the break-even point is reached significantly easier, cost-effective recycling of batteries with more low-cost material components (e.g. LFP) is harder to achieve.

Are regulations the right way to ensure sustainability?

Legislators do not have an easy task at the moment - while many countries primarily want to localize the value creation associated with this industry, some further initiatives and regulations want to influence the economic (and social) sustainability of this sector. The European Union is trying to take the lead in categorizing and comparing battery cells in terms of sustainability. However, to guarantee the desired effect of such measures in the end, several market trends and potential scenarios have to be taken into account.

Although the fact that Li-ion batteries are generally treated as one and the same product category, there is a constant battle for dominance between cell chemistries within the market. Due to the previously mentioned environmental and economic dynamics, recycling ambitions and opportunities are highly dependent on the (cathode) raw materials utilized. Given that in China there is a trend away from the (globally still leading) NMC chemistry towards cheaper LFP-based batteries, the possible impact of a similar pattern projected on the rest of this global market needs to be considered. Such an increasing adaptation of lower-cost batteries could severely dim the prospect of battery recycling profitability.

To avoid leaving the fate of battery recycling to purely economic considerations, minimum recycling targets could be set. Common rationales, as seen in the EU, include minimum percentages of recycled content among key battery materials. However, caution is required with such measures as batteries that are past their first life cycle within an electric vehicle may find themselves in a competitive environment between second-life application and recycling. Too ambitious minimum recycled share targets for new batteries, coupled with rapidly growing cell production (requesting lots of recycled material), can hurt a potential second-life market and thus should be carefully considered.

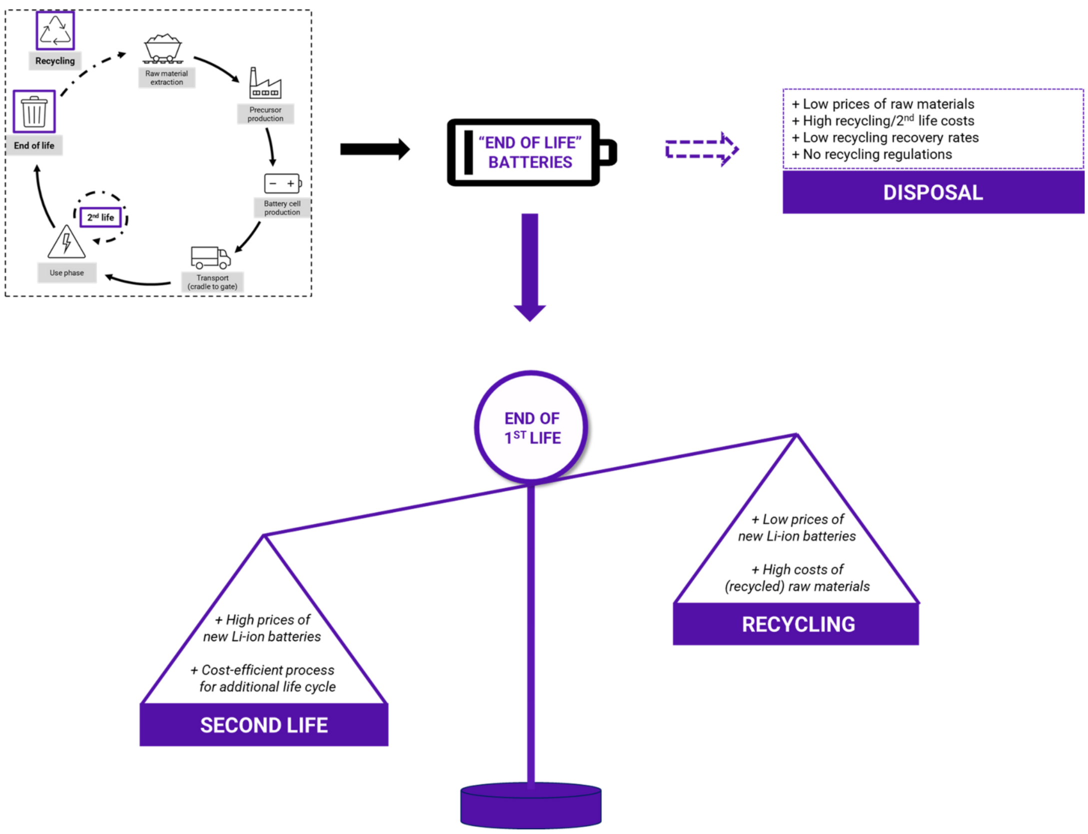

Figure 4: Highlighting the most important economic considerations of different end of life scenarios for Li-ion batteries.

Upcoming regulations should first target the recycling of factory scrap - usually done out of economical considerations anyways - which helps in setting the right conditions for an eventual ramp-up within this sector. At an appropriate stage (when a large-enough mass of "first generation" battery cells has reached end of life), minimum recycling requirements should be expanded. As mentioned before, too ambitious recycling targets will threaten the potential use case of second-life batteries as OEMs and/or battery manufacturers are forced to recover the material of batteries as soon as possible, no matter the costs - and alternatives.

The available battery substance for recycling is still limited, lagging far behind the equivalent of battery manufacturing capacity. This is due to the rather new and fast-growing nature of the battery manufacturing industry. Currently, most of the recycling substance is coming from gigafactories' manufacturing scrap. For end-of-life batteries, there is a certain time shift between their initial manufacturing and availability for recycling. This time shift depends on the (first) lifetime of a battery as well as the potential acceptance of second life application use cases and their duration. The overall lifetime in EVs has usually been estimated at a minimum of ten years. However, this might be subject to change with i) nowadays' slowing electric vehicle adoption rate, leading to long initial periods between battery production and start-of-use in an electric vehicle, and ii) the above-covered potential extension of the overall battery life cycle through second life applications.

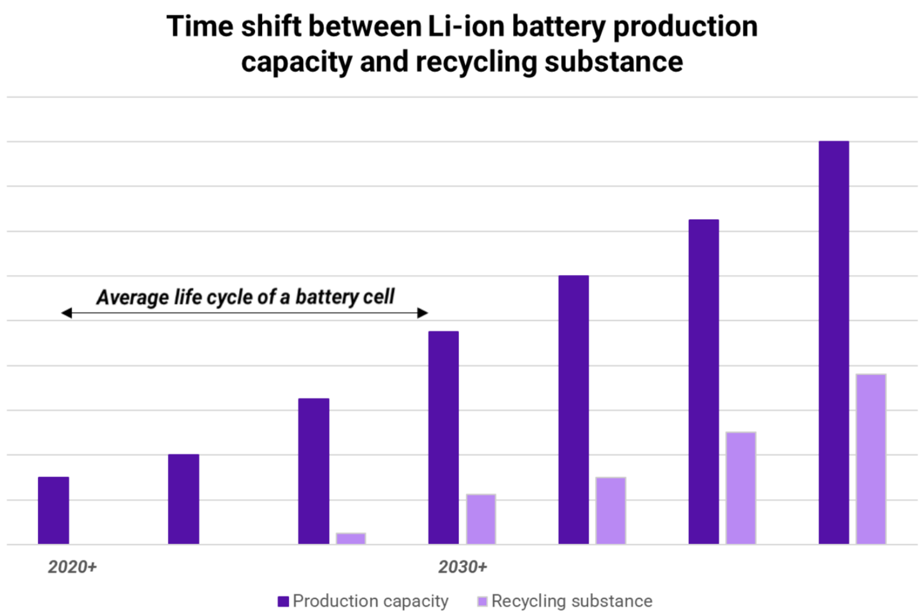

Figure 5: Concept of the hysteresis in Li-ion batteries available for recycling causes (factory scrap recycling not included in here). The exact timeline is strongly dependent on the average lifetime of a battery.

Overall, recycling of batteries will be one of the key enablers of a circular and sustainable battery industry. However, significant proof of concepts and measurable impact are still quite far away, asking for more short-term oriented measures.

Immediate actions - who needs to take responsibility along which part of the value chain?

With ongoing allegations of supply-chain-related pollution and harming local people's health, the importance of keeping track of your whole supply chain is vital for renowned companies. With increasingly complex supplier networks, transparent procurement is becoming more and more important - while at the same time more and more difficult. Before the conclusion of long-term contracts, a fundamental analysis of sustainability issues such as carbon-intense production techniques should have become standard by now. Against the background of upcoming regulations, such practices become even more essential.

Further, the desires and demands from end-users have remarkably shifted within the last decade, with sustainability as a much more appreciated differentiation factor - especially in the automotive industry. End consumers who see the Li-ion battery and all associated end products as a truly sustainable solution may be put off by only few disreputable news about the negative environmental (and human) impacts of this product. To prevent this, there needs to be a collective awareness in society and industry as well as a pursuit of industry-wide transparency.

As always in complex globalized markets, it is not easy to assure sustainability straightforwardly. Above all, there are multiple players involved in building a battery pack, which implies that the responsibility for the product and the associated individual process steps cannot be assigned to one party alone. Ultimately, it takes an interplay of several players, possibly even organized in the form of collaborative partnerships, combined with the right foundation of regulations and industry standards that create effective incentives.
For the different players in the battery industry, sustainability needs to be incorporated differently into their specific business models - but for all, it could turn out to be one of their core future selling propositions.

How can industry players prepare for it and eventually win?

Gigafactories

These players have one of the main roles when it comes to ensuring the sustainability of battery cells. The right strategy in raw material sourcing or in-house production can mitigate a huge amount of pollution. Thus, gigafactories are asked to identify the most effective areas within their operations and channel their resources into these. By remaining flexible in the manufacturing process itself, they can ensure easy adaption of innovative sustainable manufacturing technologies or future battery cell chemistries and strengthen a long-term positioning as thought leaders - especially in the topic of sustainability.
With a complex supply chain, keeping track of managing partners is quite a demanding task. However, defining common sustainability targets in long-term contracts can play out as beneficial for both parties. Another option to assure long-term access to sustainable raw materials is the vertical integration of e.g. key precursor production steps in case that sustainable sources are spare.
In the product development step of battery cells, simple recycling should be kept in mind already in the beginning of the process. In this matter, close communication and knowledge sharing with battery recycling companies and other partners are key.

Suppliers of raw materials/precursors

As the sustainability topics are currently mainly tackled by the gigafactories but start to move up the supply chain, raw material suppliers will eventually be asked to supply sustainable precursors and raw materials. If investments do not want to be tackled alone, these players should look for third-party assistance - as mentioned above, potentially via joint investments or a definition of common targets (e.g. R&D on ecofriendly processes/substitutes) and pre-settled incentives when these goals are reached.

End application manufacturers
Being the link to the end consumer, these companies are particularly important and need good management and communication of sustainability topics. Although most of them are buying battery cells and are not involved in their production directly, these players can have a significant impact on the road to sustainability. Ensuring a long-lasting product to make use of a battery's whole potential or thinking of recycling / second life when designing battery packs and end products are only some of the areas where these players can exercise a positive impact. Guiding regulations such as as the European Batt2, asking for easily removable and replaceable batteries, will reward innovative players focusing on such aspects already early on.

Similar to the relation among raw material suppliers and gigafactories, long-term agreements with end application manufacturers can encourage efforts of cell manufacturers by minimizing their ROI risks of sustainability measures. Lastly, acting as the interface to the end consumer, these players are in a perfect spot to introduce and foster new business models like battery as a service, recycling programs, or refurbishment initiatives for a second life.

Battery recyclers
Battery recycling is one of the newest additions to the battery value chain. With few industrialized players and a growing demand, it attracts a lot of innovative players. However, many questions are still to be answered:
How do these players source battery cells at their EoL? How will they deal with in-homogeneous substances?
To whom are they going to sell their recycled materials to?
The current precursors are mostly produced far away from European battery end users and recycling facilities, which are supposed to be built close to these end users. So, it seems like there still is a missing puzzle piece to fully close the (non-Asian) supply chains and guarantee that there are local buyers for recycled raw materials. However, once set up, this part of the value chain is representing a very important part: An additional source of constant supply of key materials could lead to the overall stabilization of local value chains for batteries while ensuring a truly circular economy.

Legislators
The right regulatory framework can initiate, direct, and drive the transformation of a whole industry. Creating a truly sustainable product and being able to demonstrate this in a well-founded manner requires additional expenses, which cannot be earned back through marketing advantages only. To achieve minimum sustainability targets, regulations that incentivize sustainable practices need to be in place, and, above all, a uniform and reliable method of measuring and comparing impact is crucial. The final target needs to be to ensure strong economic benefits for players who demonstrate sound sustainability performances.

Investors
With targeted investments into "sustainability thought-leaders" within the battery industry, it can be assured that sustainability-targeting projects and initial scaling of new innovative processes are sufficiently backed. It is recommended to have close looks at existing and upcoming regulations, as well as the overall business plan, technology, and quality of the company of course.

Strategic Implementation - "Where ambitions & values meet results"

After discussing a selection of measures for multiple players along the battery value chain above, hands-on impacts on business strategies and implementation steps towards reaching the goal of "sustainability as a core value" are addressed below.

At Sphere Energy, we recommend applying a structured approach to implement sustainability at the core of your battery-driven company:

- Understand key sustainability areas of the industry to deduct the right learnings for your specific use cases
- Process these insights to identify tangible sustainability possibilities within your company (strategy)
- Carry out projects and assessments to examine key drivers and competitive (dis)advantage areas
- Develop a strategy tailored to the company's ambitions with realistic measures and tracking
- Streamline and implement tangible steps within the relevant business departments

Sustainability aspects cannot be viewed detached from other business areas and need to be well aligned with the overall company vision, e.g. the market positioning. Further, they not only need to contribute to the financial targets in the long-term but also work well with the operational structure of the respective company.

Ready to steer the sustainability ambitions within your company? Start your journey of successfully implementing appropriate measures with Sphere Energy's proven sustainability assessment & strategy development process!

Tailored initiatives are to be defined based on the newest industry insights and a detailed company analysis. Besides taking into account internal factors, such as the cost & sustainability impacts, or strategic fit, external factors like local regulations & customer demand are to be incorporated to the same extent.

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