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Deficits Of Innovation Management In The Application To The Disruptive Battery Industry

Achim Kampker[1], Heiner Heimes[1], Jessica Schmied[1], Paul Lingohr[1], Henning Clever[1], Benjamin Dorn[1]

[1]*Chair of Production Engineering of E-Mobility Components (PEM) of the RWTH Aachen University; Aachen, Germany*

Abstract

With the electrification of the automotive industry and the resulting demand for batteries, Gigafactories are increasingly established by battery cell manufacturers or new players, especially in Europe, and North America. When planning Gigafactories, there are various planning challenges due to the high and long-term investments. In particular, the variety of innovations and short innovation cycles creates uncertainty in the planning process. Reviewing the background provided, the application of existing approaches from innovation management to the current battery industry was assessed in this paper. For this, the environment of battery production was first examined in more detail, resulting in the identification of the relevant requirements for an innovation management method. Based on this, standard methods of innovation management were examined and evaluated based on the derived requirements. The evaluation showed that standard methods of innovation management only partially fulfil some of the requirements, highlighting the necessity of a dedicated method for the battery industry. In conclusion, the deficits and potential levers for successful innovation management are discussed.

Keywords

Battery Production; Electrification; Innovation Management; Disruptive Industry; Planning Methods

1. Navigating market demand and technological innovation

The battery industry is highly dynamic and evolving rapidly, driven by a growing demand for sustainable technologies, especially in Europe, where electrification of the automotive sector is surging [1]. To meet diverse customer needs like longer range, faster charging, and enhanced safety, constant innovation is essential. Yet, with innovations and advancements like dry coating and laser cutting emerging, the planning of costly Gigafactories is a long-term and challenging process [2, 3]. Market demand and technological advancement interact, creating a dynamic and uncertain environment for technology selection. To navigate this uncertainty, a strategic approach to innovation management is crucial. This involves identifying and managing risks, as well as ensuring the right resources are available [4, 5].

This paper aims to explore the various innovation management approaches and assess their suitability for the dynamic battery industry, along with the necessary requirements for successful implementation. Overall, the battery industry requires careful management and planning to thrive. By adopting a strategic approach to innovation, companies can stay at the forefront of technological advancements and meet evolving customer demands [4]. This paper offers a scientific perspective on the importance of effective innovation management in battery production. It contributes to our understanding of ongoing and potential developments in the battery production field. While Gigafactories and global competition, especially from economically competitive Chinese facilities, pose significant challenges for European companies, the

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imperative for further research in this field remains evident. Research efforts are currently constrained, given the early stages of the European industry, which has announced a capacity of 2,014 GWh, a notable increase compared to the existing 120-150 GWh production capacity in Europe [6,7].

2. Structure of the paper reviewing innovation management

Following the methodological structure of a literature review, this paper performed the steps: *Definition of the research topic, identification of relevant literature, analysis, and synthesis, as well as presentation of the results and discussion* [8, 9].

This paper reviews standard methods of innovation management in battery production. Conventional methods were analysed and reviewed for their suitability. Relevant articles on innovation management were considered, with a focus on established approaches. The current state and challenges of battery production are examined in detail, leading to the identification of criteria for successful implementation of innovation management. In total, 14 methods were analysed and evaluated based on the criteria. The applicability of each method to battery production was determined, highlighting specific deficits and potential areas for improvement. The conclusion summarizes the results and outlines future research plans.

3. Deriving evaluation criteria from the dynamic battery industry

In this following section an overview of current market trends and their direct and indirect effects on battery production management are compiled. Furthermore, five criteria for a possible method to effectively manage future battery production were derived.

3.1 A global pivot towards e-mobility creates growing demand

The transition to electric transportation relies on electric batteries, a key driver of global mobility [10]. Electric vehicle performance depends on battery technology, leading to increased demand. To meet this demand, global battery production capacity is expected to increase by over 50% by 2030 [11], with a focus on mobility applications [10]. However, European and United States (US) battery manufacturers must reduce costs to compete. As of 2021, production costs were approximately \$177/kWh and \$155/kWh in Europe and the US, respectively, which is around 60% and 40% higher than their Chinese counterparts [12]. This cost difference could significantly impact the market share of European and US manufacturers in the battery industry, particularly considering the growing importance of batteries in the global mobility transition.

3.2 High innovation rate for both product and production

In today's rapidly evolving market, characterized by a high innovation rate in both product and production, companies face significant challenges. Traditional decision-making processes like the product development process are too slow to keep up with Industry 4.0's mid-term uncertainty and the rapid substitution of existing technologies with innovations [12]. Innovation spans materials and products, like fourth-gen batteries and metallic Li-Anodes, and process-level improvements, such as dry-mixing, laser drying, and separator-lamination [13]. As these innovations mature, manufacturers must quickly adapt to realize cost and performance benefits [13]. New entrants, particularly OEMs, contend with the substantial capital requirements, technology complexity, and uncertainty associated with building Gigafactories.

To address these challenges effectively, companies must adopt a strategic and flexible approach to innovation management, prioritizing agility, and adaptability to navigate the dynamic market to maximize the leveraging of emerging opportunities, it is crucial to engage in calculated risks and undertake assertive actions. In conclusion, in the context of the high innovation rate in both product and production, forward-thinking innovation management is vital for staying competitive, fostering risk-taking, agility, adaptability, and embracing emerging technologies and production methods. This positions companies as industry leaders poised to seize opportunities in the rapidly changing market [10].

3.3 Production complexity creates increased planning difficulties

The manufacturing of batteries is a complex process that involves a diverse range of technologies, which can make effective management a challenging task [12]. The battery production process consists of multiple steps, from electrode manufacturing to cell assembly and finishing, each requiring specialized technologies and innovations [13, 14], as depicted in Figure 1. In Figure 1, a subset of the innovation examples presented in Chapter 1 is depicted to enhance clarity. The primary emphasis of this paper centers on delineating methods for managing innovations, rather than delving into the innovations themselves. With the increasing diversity of technologies involved, there is an increased likelihood of bottlenecks and inefficiencies, which can adversely affect the overall production process. To address these challenges and improve the efficiency and effectiveness of battery production, different strategies have been employed. However, due to the complexity of the process, it is difficult to optimize all parameters simultaneously. For instance, reducing the duration of a specific operation could potentially lead to increased idle times of other machines [15]. Thus, managing the entire production process in a holistic manner becomes crucial. However, the increasing diversity of technologies involved in battery production makes it challenging to develop a standardized approach that can be applied to all manufacturing processes. As new technologies emerge, they may require modifications to existing production processes, which can result in additional costs and delays.

Furthermore, advancements in a particular technology can render certain process steps, like dry mixing, unnecessary, potentially making all technological developments in the drying process, such as laser drying, redundant [5]. To manage this complexity effectively, battery cell manufacturers need a management tool that can guide their decision-making by considering the interdependencies of technologies along the production line.

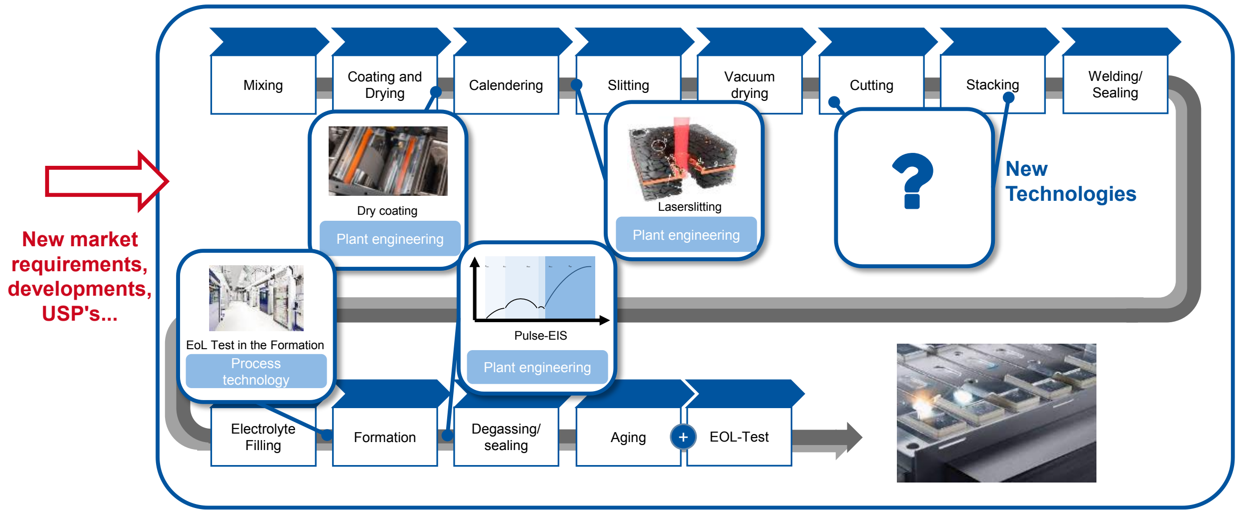

Figure 1: Battery production process chains and exemplary innovations [5]

3.4 The critical need to implement Industry 4.0

Industry 4.0 adoption and readiness is a recommended strategic focus point for most companies in the general manufacturing industry [16], and the same should apply to battery cell manufacturers. However, while most companies fail to move beyond the pilot phase when investing in big data analytics, AI, or 3D printing, a select group of leading organizations is showcasing how to generate new value when deploying advanced manufacturing at scale [17]. Despite the difficulties in scaling up digital transformations, it can provide significant cost and energy reductions, throughput increase, and quality improvements [16, 17] all of which are helpful to meet the before-mentioned increase in demand. Manufacturers must avoid the pitfall of implementing the latest technological advances by default, and instead be value-driven in their decision making [16]. In conclusion, digitalization measures offer promising cost, energy and quality improvements for battery cell manufacturers [18] while simultaneously generating their own challenges in deployment.

3.5 Resulting criteria for innovation management methods

Addressing the market dynamics and the intricate manufacturing processes in battery production (see chapters 3.1-3.4), it is essential to establish clear criteria for effective innovation management. The following qualitative characteristics have been identified to gauge the success of innovation management methods following the previously mentioned challenges:

Bifocal technology foresight: This involves performing simultaneous technology foresight for both process and product innovations. By doing so, companies can effectively evaluate and plan for the latest advancements, ensuring that they remain competitive and stay ahead of the curve, especially in battery production process for electric vehicles. Keeping track of the latest product and process technological advancements, particularly those related to sustainability, energy efficiency, and safety is crucial.

Complexity management: The innovation management method should be capable of handling multi-technology evaluation to effectively manage the complexity of battery cell manufacturing and its potential for factory-scale use.

Industry 4.0 relevance: The innovation management method should emphasize awareness of the latest digital advancements, particularly those related to automation, data exchange, and artificial intelligence. These advancements differ from the first criterion (bifocal technology foresight) in that they are only relevant at the factory level (and not on a single-process or product specific level). Embracing Industry 4.0 technologies allows battery cell manufacturers to enhance efficiency, quality, and safety while reducing costs and waste.

Flexibility and adaptability: The method should facilitate later changes in production processes and the introduction of newer technologies. Given the rapid evolution of the battery production industry, a rigid approach may hinder growth and competitiveness. Flexibility and adaptability are essential for remaining agile and responsive to changing market needs and technological advancements.

Implementation planning: Effective implementation planning should be a core aspect derived from the methodology, encompassing both long and short-term considerations while aligning with the identified criteria. Implementation planning plays a pivotal role in ensuring that the battery production process remains efficient, cost-effective, scalable, and socially responsible.

4. Results: Identification and evaluation of relevant approaches from innovation management

As mentioned in chapter 2, a thorough literature review has been performed. In total, 14 methods addressing the mentioned topics in chapter 3.2 were selected and analysed in detail in regards to their compatibility for battery production. The selected methods can be categorized in four clusters: 1) General methods, 2) Assessment methods, 3) Portfolio methods and 4) Roadmaps.

4.1 General approaches for innovation management

In the context of this paper the Patent-/ and Publication analysis, Scenario analysis and S-Curve Analysis, can be assigned to the application area of general methods on the basis of their overarching function. The underlying assumption is that the number of publications in a given research area is indicative of the level of research activity in that field. For applied research areas, patent data is utilized, whereas publication data is used for basic research areas. The approach is limited by data availability, but nonetheless enables the identification of general manufacturing or product (criterion bifocal technology foresight) as well as Industry 4.0 and digitalization trends and research priorities in the field of battery production [20]. The second general method is the scenario analysis. The overarching goal of this analysis is to generate prescriptive action recommendations for the present by analysing several potential future scenarios that are both flexible and resilient, while accounting for a diverse range of possible outcomes. This process involves identifying potential future risks and opportunities, aligning with the primary objective of early technology identification [21, 22]. Accordingly, scenario analysis is an appropriate method for informing decisions related to (battery) technology strategy but lacks the application towards complexity management and implementation planning since these are mostly out of scope of the method. The S-curve concept describes the development course of a technology's performance as a function of the cumulative R&D expenditure [23]. The concept follows the principle that technologies inevitably reach their technological performance limits during constant advancement. Recognizing the right time to replace one technology by a superior technology is essential for companies. The comparison of several technology developments in this S-curve concept can sensitize and support assessments regarding the remaining further development potential of existing technologies and the development of new technologies [19, 24] and is therefore suited in terms of the bifocal technology foresight and relevant for Industry 4.0 solutions. This methodology allows for a certain degree of foresight in flexibility and adaptability; however, this method does not map the interactions of the various technologies or the complexity of battery cell manufacturing.

4.2 Evaluation-based methods for innovation management

The next section includes the return on investment (ROI) ratios, cost-benefit analysis, argument balance, utility analysis and checklist method. The method of ROI figures, which calculates the financial return of an investment, can be used to compare different technologies from a financial perspective [25]. However, it is not an appropriate innovation management method in the field of battery production because it focuses solely on financial gains and may not account for other important factors, such as technical feasibility, market demand, and complexity management. The cost-benefit analysis compares the costs for the realization of the project with the future benefits achieved [26]. An attempt is made to make non-monetary variables (e.g. reliability) comparable by converting them into monetary values. With the cost-benefit analysis, the net benefit can be used to evaluate different alternatives. This is calculated from the difference between the monetary benefit and the costs of the investment project. The choice should then be made for the alternative with the highest net benefit [19, 27]. One of the biggest challenges of the cost-benefit analysis is the often difficult transformation of benefits into monetary values [26]. For this reason, the practical benefit is often lower than it appears theoretically possible. For qualitative assessments the argument balance, checklist method, and utility value analysis can be used. The argument balance represents a simple method for comparing the advantages and disadvantages of alternative technologies in list form. It can be used especially in early consideration of innovations [28]. However, this allows only a qualitative comparison of one technology without quantifying the effects. The checklist method offers another tool for qualitative comparison of multiple technologies based on predefined criteria and therefore enables complexity management on a small scale [29], but also lacks the quantifiability. The utility value method allows for the evaluation of soft criteria, which are standards that are difficult to measure. The method allows the quantified comparison of various alternatives and the assessment of their advantageousness. For this, a set of target criteria are defined and weighted by pairwise comparison. For each of these criteria the performance of the various alternatives is evaluated using an absolute conversion function. Finally, the multiplication of the criteria weights and the sum of the partial utility value generates a total utility value for each alternative allowing their comparison [19, 29]. The utility value analysis offers a structured approach comparing alternatives but is limited to identification of the optimal alternative.

4.3 Portfolio-based methods for innovation management

As part of strategic technology management, technology portfolios are used to systematically evaluate technologies and derive investment decisions. A variety of portfolio approaches exist in the literature, and each of them addresses different characteristics and dimensions. The most relevant portfolios from ARTHUR D. LITTLE, PFEIFFER, and MCKINSEY are examined in more detail below.

The portfolio approach from ARTHUR D. LITTLE aims to derive a technology strategy, considering the different technology and business unit life cycles [19, 30]. It is based on an analysis of the technology and competitive positions of the strategic business areas and the life cycles of the technologies and the respective industry. In one dimension the technology life cycle curve provides an estimate of future technology potential. The second dimension of the relative technology position indicates, in comparison to competitors, which qualifications, such as patents and production technology, the company has [30, 31]. Considering the Research and Development (R&D) risk, the portfolio approach from ARTHUR D. LITTLE is particularly suitable for deriving directions (see criterion implementation planning) for action based on the consistency of technology and market strategy. In the context of battery production innovation management, such portfolio approaches can serve as a basis for evaluating technology readiness and aligning it with market dynamics. Specifically, the 'Bifocal technology foresight' and 'Flexibility and adaptability' criteria can be assessed by leveraging the technology life cycle curve to identify emerging battery technologies with the potential for sustainability, energy efficiency, and safety. The relative technology position dimension can help gauge a company's competitive edge in these areas.

The technology portfolio by PFEIFFER considers both the generation cycle preceding the market cycle and the observing cycle for the strategic analysis process via the two dimensions of technological attractiveness and resource strength [31]. The attractiveness of the technology describes the economic and technological advantages that can be strategically achieves by further developing a particular field. The resource strength compares the company's resources to realize the technological potential with those of the competitors. When considering the 'Complexity management' criterion in battery production innovation management, PFEIFFER's approach can be adapted to evaluate the resource strength needed for implementing complex manufacturing technologies. Based on the positioning in the portfolio the approach recommends to invest or disinvest in certain technologies to achieve an innovator positioning assuming that the innovator generates more revenue than the imitator [19, 31, 32]. Nevertheless, the PFEIFFER's approach only derives R&D priorities and is limited to the technology portfolio, as detailed planning and implementation is not specified.

The integrated market and technology portfolio by MCKINSEY offer an analysis option to target the investment of internal resources. The basis of the MCKINSEY portfolio is the S-curve concept [33]. The technology and market portfolio provide a mapping of the relevant technologies comparing the company's position with the market and technology attractiveness. The following comparison and subsequent integration of the technology and market portfolio into an integrated portfolio with the dimensions market and technology priority enables the analysis of technology-strategic factors [19, 33]. Regarding 'Industry 4.0 relevance' and 'Flexibility and adaptability' criteria in battery production innovation management, MCKINSEY'S integrated portfolio can be used to assess the alignment of technology priorities with Industry 4.0 advancements. It provides a structured approach to incorporate digital technologies like automation, data exchange, and artificial intelligence into the innovation management strategy. Moreover, it can help in identifying the flexibility and adaptability needed to respond to changing market dynamics and technological advancements. However, MCKINSEY's portfolio serves primarily as a formal instrument for structuring the strategic planning process and for visualizing the strategic position and problems of business areas.

4.4 Roadmapping methods for innovation management

The technology roadmap visualizes technologies and their links over time. The roadmap illustrates the path from a current state to a future targeted status, which ensures that the required resources for fulfilling the targeted objectives are deployed at the right time. Thereby, the technology roadmap serves as a tool for the specification of the technology strategy and implementation [34, 35]. Nevertheless, the main benefit of the technology roadmap is the time-based and graphical representation for the development, representation, and communication of strategic plans regarding the coevolution a development of technology, products, and markets. The roadmap enables continuous support of the technology planning process and the alignment of planning levels. As a variant, explorative technology roadmaps offer the consideration of scenarios and forecasts about technological developments. As a procedure for creating the roadmap, a future scenario is defined and broken down to the current status quo through intermediate scenarios [34]. To translate technology roadmaps into operational measures, balanced innovation scorecards (BIC) can be used. It uses the strategy captured in roadmaps, concretises it in its four perspectives and thus translates the roadmap into clear and measurable goals, key performance indicators, measures, and the persons responsible [35]. In the context of evaluating innovation management methods for battery production, all considered roadmapping methods are especially effective in 'Implementation planning', providing suitable frameworks for translating innovation strategies into actionable plans. When assessing their performance in other criteria, roadmaps integrated with balanced innovation scorecards emerge with a slight advantage due to their ability to combine foresight with performance measurement, manage complexity, and integrate digital advancements makes them slightly more advantageous for addressing the multifaceted challenges of innovation in battery production.

4.5 Summary and evaluation of approaches

In summary, none of the methods presented fully meet all the evaluation criteria. In particular, there are still major deficits in the areas of implementation planning and flexibility and adaptability in production. The evaluation results are shown in Figure 2.

Existing approaches	Evaluation-criteria	Bifocal technology foresight	Complexity manage-ment	Flexibility and adapt-ability	Industry 4.0 relevance	Implemen-tation planning
General	Patent / Publication analysis	●	○	◑	◑	○
General	Szenario analysis	◕	◔	◑	◕	◔
General	S-Curve analysis	◑	◔	◔	◔	◑
Evaluation	Key return figures	○	◔	○	◑	○
Evaluation	Cost-benefit analysis	○	◔	○	◑	○
Evaluation	Argument balance	○	○	◑	◔	○
Evaluation	Utility analysis	○	◔	○	◑	○
Evaluation	Checklist method	○	◑	◑	◔	○
Portfolios	Portfolio method (A. D. LITTLE)	◑	◔	◑	◑	◑
Portfolios	Integr. portfolio (MCKINSEY)	◑	◔	◑	◑	◔
Portfolios	Tech. portfolio (PFEIFFER)	◑	○	◑	◑	◔
Roadmap	Roadmapping (general)	◔	◔	◔	◑	●
Roadmap	Expl. Technology-Roadmaps	◕	◑	◑	◕	●
Roadmap	BIC with Roadmaps	◑	◑	◔	◑	●

Degree of consideration : Full consideration ● ◕ ◑ ◔ ○ No consideration

Figure 2: Evaluation of existing approaches in innovation management assessed by criteria from battery industry

Summarizing, the general approaches such as the scenario technique or patent analyses mainly offer possibilities for early technology identification, but only insufficiently fulfil the simultaneous evaluation of different technologies and the planning of implementation. The evaluation methodologies primarily enable the prioritization of individual technologies or various technology alternatives, but do not consider aspects such as implementation or bifocal technology foresight. The portfolio approaches are mainly used for visualization and support the derivation of strategic measures. However, implementation and complexity management are only considered superficially. The roadmap approaches, such as the explorative technology roadmaps, fulfil the criteria to a certain extent, but have deficits in the multi-technology evaluation and in the consideration of flexibility and later adaptability of the planning. The results show that the application of the respective standard innovation methods to battery production addresses only a fraction of the problems. For this review standard methods from innovation management were focused and assessed for their applicability to battery production. These methods are established in industry and are generally applied for solving specific tasks. However, the review also showed that a combination of all approaches does not meet the requirements of the current battery industry. This highlights the lack of a holistic method addressing the current innovation challenges in battery production.

5. Conclusions and Outlook

The assessment of innovation management methods within the context of battery production indicates that existing approaches have their limitations. None of these methods offers a comprehensive solution to the multifaceted challenges in this field. Each method demonstrates strengths in certain aspects while falling short in others. Future research aims to address these limitations, develop a holistic method, and expand the scope of approaches through an extended literature review. This will enable successful innovation management in battery production. Achieving this goal requires understanding the unique challenges and opportunities in the battery industry, collaborating across disciplines, and considering factors like regulations, market trends, and societal expectations. By adopting a multidisciplinary approach and holistic method, the battery industry can navigate its dynamic landscape and ensure long-term success.

Nevertheless, there are several critical considerations and promising opportunities for future investigation. One such consideration is the development of a tailored innovation framework that specifically addresses the complexities of battery production. This framework should be capable of effectively handling issues related to implementation and adaptability. Additionally, exploring the potential advantages of integrating multiple innovation methods and customizing them to better suit the industry's requirements is essential. Such an approach could yield more comprehensive and holistic solutions. Interdisciplinary collaboration among experts from diverse fields is also of paramount importance. Experts in materials science, engineering, and business management, among others, must work together to generate new perspectives and innovative solutions. Lastly, the potential benefits of knowledge transfer and best practices from related industries, such as energy storage or semiconductors, should not be overlooked. Adopting these insights could help overcome current limitations and accelerate progress.

In conclusion, as battery technology continues to advance, the role of innovation management remains critical in shaping the future of sustainable energy solutions and in harmonizing the integration of product and process advancements in battery production. Innovation will drive progress, efficiency, and sustainability in this dynamic field.

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Biography

Achim Kampker (*1976) is head of the chair “Production Engineering of E-Mobility Components” (PEM) of RWTH Aachen University and known for his co-development of the “StreetScooter” electric vehicle. Kampker also acts as member of the executive board of the “Fraunhofer Research Institution for Battery Cell Production FFB” in Münster. He is involved in various expert groups of the federal and state governments.

Heiner Hans Heimes (*1983) studied mechanical engineering with a focus on production engineering at RWTH Aachen University. From 2015 to 2019, he was head of the Electromobility Laboratory (eLab) of RWTH Aachen University. From March 2019 to 2023, he was PEM's Executive Chief Engineer before being appointed Professor.

Jessica Schmied (*1995) is research assistant at the Chair of Production Engineering of E-Mobility Components (PEM) at RWTH Aachen University. She studied mechanical engineering with a specialization in production technology at RWTH Aachen University.

Paul Lingohr (*1993) is research associate at the Chair of Production Engineering of E-Mobility Components (PEM) at RWTH Aachen University. He studied industrial engineering with a specialization in production technology at RWTH Aachen University.

Henning Clever (*1992) is research associate at the Chair of Production Engineering of E-Mobility Components (PEM) at the RWTH Aachen University since 2019 and was group lead for the research group Battery Production Management from 2021-2023. He studied mechanical engineering specializing in production engineering at the RWTH Aachen University.

Benjamin Dorn (*1990) is research associate at the Chair of Production Engineering of E-Mobility Components (PEM) at the RWTH Aachen University since 2018 and chief engineer for Production Technology & Organization since 2021. He studied business administration and engineering specializing in mechanical engineering at the RWTH Aachen University.