2024

P3

Guide to the Industrialization of Lithium-Ion Batteries in the Automotive Industry

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PEM | RWTH AACHEN UNIVERSITY

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P3/PEM Insights

In the last few years, many companies have started initiatives for battery production, but several of them have run into challenges that have led them to miss their planned SOP dates. These challenges frequently call for external support. Through numerous successfully finished industrialization projects, coupled with its vast knowledge in the field of battery technology, P3 Group and PEM RWTH Aachen University position themselves to excel in the area of industrialization of battery productions.

P3 is a leading international consulting, engineering, and software development services company boasting a growing team of over 1,800 experts. Established in 1996 with its roots in Stuttgart, P3 Group was originally founded as a spin-off from the Fraunhofer Institute. This origin enriches the company with a strong foundation in academic excellence and technical expertise. P3 specializes in a variety of sectors, including automotive, energy, and the public sector. Through its EMIND division—a word combination of E-Mobility and Industrialization— P3 merges expertise in E-Mobility products and technology with insights into the industrialization of production and processes.

The Chair of Production Engineering of E-Mobility Components (PEM) of RWTH Aachen University conducts research in many areas including battery production, electric motor production, and the manufacture of fuel cell systems and components. Its numerous publications as well as scientific input to widely acclaimed works such as the Battery Monitor and the Battery Atlas have established the institute as one of the leading sources of information in the battery industry.

P3/PEM Insights

1. Industrialization projects of LIBs in the automotive industry are each unique but generally follow a similar pattern based on the same underlying principle.
2. The industrialization timeline can be reconstructed based on a few key milestones.
3. The essential key milestones of industrialization are: Determination of Premises, BREI, SOP.
4. At the BREI milestone, product development aligns with factory planning.
5. There is a critical path of interdependent processes, and this path is responsible for the length of the industrialization process.
6. The critical path's duration adds up to a total of ~58 months. (This duration is independent of and separate from the OEM's vehicle project.)

Current Situation in the Battery Market

The demand for batteries is escalating, driven by heightened public awareness of climate issues, the increasing availability of electric vehicles, and the impending ban on ICE in the EU from 2035.[1] As depicted in Figure 1, the battery sector continues to grow with an anticipated CAGR of 34%. This growth trajectory is expected to lead the market demand to 4,917 GWh by 2030, which is an increase from 2022 levels of over 500%.[2]

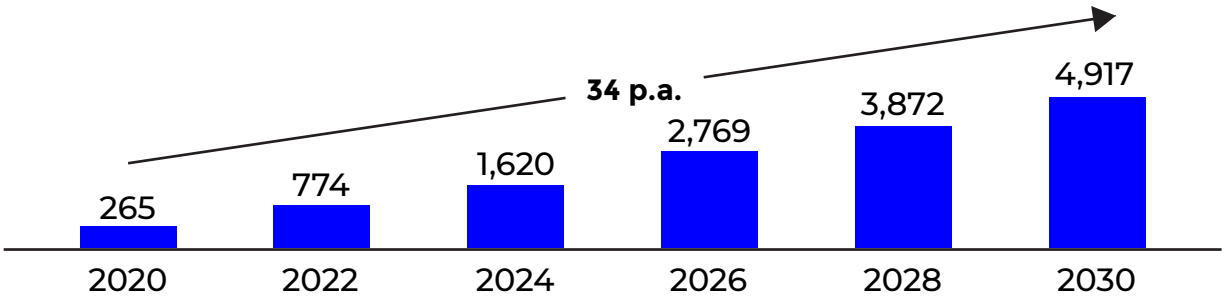

Figure 1: Global demand for batteries2

To meet the rising demand, approximately 40 industrialization projects are actively in progress across Europe. These projects are depicted in the widely recognized chart shown in Figure 2 from Battery-News.[3] However, many of these projects are experiencing delays ranging from a few months to several years. The goal of the guide is to help mitigate these delays and provide greater certainty in planning.

Battery Production as of June 2023

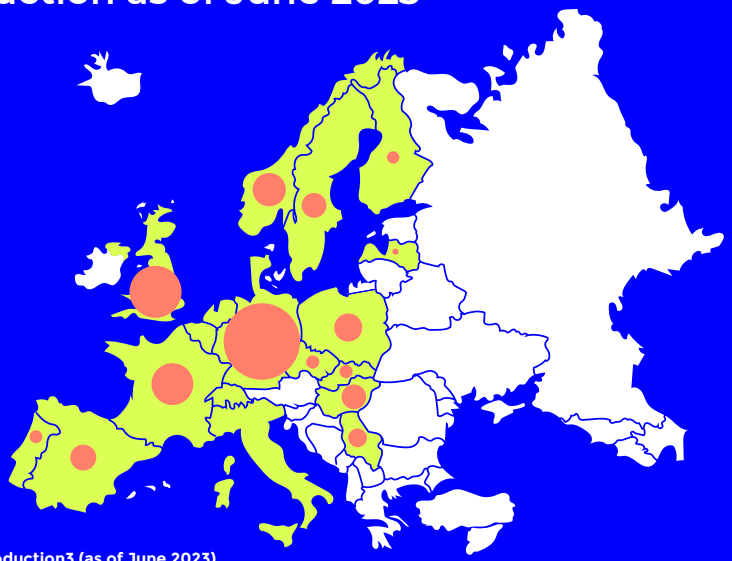

Figure 2: European Battery Production3 (as of June 2023)

Extract from recent delays

No.	Location	Capacity	Initial planned SOP	Delays	Actual SOP
Example A[4]	Central Germany	14 GWh	Q1 2022	<1 year →	Q4 2022
Example B[3,5]	West Germany	24 GWh	Q4 2023	<4 years →	Q1 2027
Example C[6,7]	Central Germany	200 GWh	Q1 2023	>1 year →	TBA

1: https://shorturl.at/FTVW2
2: https://shorturl.at/hmBGR
3: https://shorturl.at/cfitR
4: https://shorturl.at/frtNY
5: https://shorturl.at/ntyL6
6: https://shorturl.at/aBE05
7: https://shorturl.at/dKMZ8

Key Findings of the Industrialization Analysis

The analysis of projects successfully completed in the past and the current market situation has revealed that industrializations of lithium-ion batteries(LIB) in the automotive industry generally follow a similar pattern based on the same underlying principle. This analysis has determined that due to the dependencies and relationships among key milestones, an essential timeline can be constructed using three fundamental milestones.[8]
These are:

1. Determination of premises:

In the determination of premises, company goals and conditions are initially analyzed to determine project-specific requirements. This is followed by the determination of factory and project goals, which include the definition of key performance indicators (KPIs) as well as setting timelines and budget parameters. The milestones also involve the determination of various aspects concerning the product and the production premises, such as the product line, project organization, location selection, schedule planning, pre-supplier selection, and scope of nominations.

2. BREI:

The “Building Ready for Equipment Installation“ (BREI) milestone signifies that a facility and its associated infrastructure are constructed and have obtained regulatory approval. This allows for the installation of machinery and equipment. At BREI, product development aligns with factory planning. To reach BREI status, it's essential to finish building roads and structures, complete roofing and flooring, as well as MEP (mechanical, electrical and plumbing) installations.

3. SOP:

The Start of Production (SOP) is the commencement of serial manufacturing, marking it the main goal of the industrialization process. This milestone indicates the successful completion and readiness of product and production process preparations, ensuring their maturity for large-scale production.

The core timeline was reconstructed using a combination of comprehensive review of relevant literature, an in-depth analysis of P3 Group’s successfully executed projects, and the current market situation. The resulting framework of milestone relationships and durations of phases was refined and validated by experts to ensure its applicability. The result is a detailed timeline for the industrialization process, showing all key activities from the determination of premises until the SOP. These processes are illustrated in Figure 3.

Furthermore, a critical path was identified that is responsible for the duration of ~58 months for the whole industrialization. The activities integral to this critical path are highlighted in light blue, distinguishing them as crucial steps within the timeline. This path can be segmented into four core phases: planning of infrastructure, permits, construction, and installation & ramp-up.[8]

Planning assumptions:

Overall, it is challenging to estimate the duration of processes in the absence of fixed premises. There is a need to adapt all processes to specific project conditions and requirements for each individual project. In order to enable a certain degree of comparability, assumptions have been defined. Future unstable market conditions, such as the availability of personnel, contracting, or construction companies, are not taken into account.

- The product concept and specification exist (high maturity of product and process).
- The planned production site is located in central Europe (especially Germany).
- Cell manufacturer with existing battery production expertise.
- Machinery supplier mainly in Asia.
- Staff is sufficiently trained and available on time.

8: Master Thesis Dau, 2023

Deep Dive: Critical Path

The timeline of industrialization processes is presented in Figure 3. It is aligned along two axes: The X-axis on the left side lists all relevant activities, while the Y-axis represents the timeline in years and months. The SOP is the central point of time origin, with the timeline extending to the left to indicate time before the SOP and to the right to indicate time after the SOP. The lengths of the individual bars correspond to the durations of the respective processes.

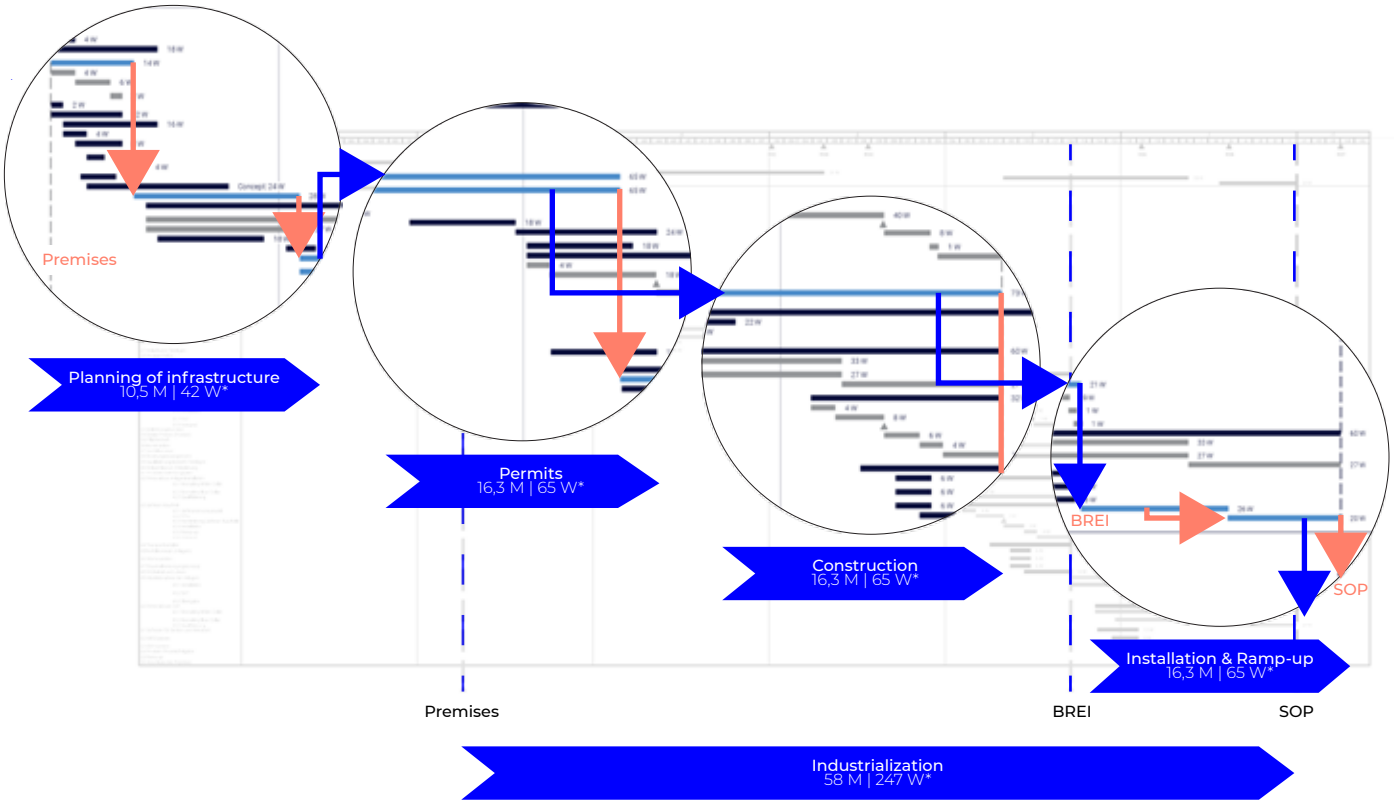

Figure 3: Extract from the Industrialization Guide8

Hereafter, the paper will delve into an analysis of the four outlined phases. This process will include a breakdown of these phases into smaller sub-packages. Following this breakdown, the phases will be compared and benchmarked against relevant industrial projects, which are listed in the following table.

No.	Location	Planned SOP	Planned yearly capacity
Example 1[9]	Central Germany	2025	16 GWh
Example 2[10]	West Germany	2025	13 GWh
Example 3[11]	Central Germany	2022	14 GWh

9: https://shorturl.at/asuK6
10: https://shorturl.at/aiB59
11: https://shorturl.at/fikmJ

*Simplification for durations: 4 W = 1 M

MISES **PREMISES** PREMISES PREMISES PREMISES

1. Planning of Infrastructure

Determination of premises

Determination of locations

Building and infrastructure plans

2. Permits

Construction permit

Imission control act

(Bundesimmis-sionsschutzgesetz)

3. Construction

Infrastructure

Buildings

Phase 1:

The initial Planning of Infrastructure phase starts immediately after the Determination of Premises, encompassing the selection of sites and the development of the building and infrastructure plans. The guide allocates a duration of 42 weeks (W) or 10.5 months (M) for this phase.
Figure 4 shows the comparison to industry projects. Hereby, a high level of conformance is observed. An exception is Project 2 which exceeds this timeframe by 65%. Potential reasons include a delayed start following the Determination of Premises which is supported by a late nomination of the general planner and potential issues with the construction site due to contamination.[12, 13, 14]

Planning of infrastructure	10.5 | 42 W*	Delta
Example 1[12]		+1W | +2%
Example 2[13]		+27W | +65%
Example 3[14]		+4W | +10%

Figure 4: Comparison of actual vs. proposed guideline duration for the first phase

Phase 2:

In this phase, the focus is predominantly on securing approvals, including construction permits and federal permits for emissions (BImSchG). Here, the most significant discrepancies are observed.
These processes, however, are not managed by the companies themselves but are handled by local, public authorities. Applications for Project 1 and Project 3 were submitted to public authorities on March 30th, 2020, and April 30th, 2019, respectively. These timelines collided with the peak of the COVID-19 pandemic in Germany, which likely affected the timeline due to the challenges faced during that period.[15, 16, 17]

Permits	16.3M | 65W*	Delta
Example 1[15]		+75W | +115%
Example 2[16]		-1W | -2%
Example 3[17]		+84W | +78%

Figure 5: Comparison of actual vs. proposed guideline duration for the second phase

Phase 3:

During the third phase, following the approval of construction permits, the focus shifts to the construction of infrastructure and buildings. In this phase, several significant deviations can be observed.
In example 2, the projected duration by the company was 35 Weeks. However, deviations arose due to miscalculations in planning. The date for the laying of the foundation stone was initially planned to be October 2023. Yet, as of January 2024, this milestone has not been reached. This reflects on an underestimation in the time needed for securing permits and completing construction.[19]

12: https://shorturl.at/fwO68
13: https://shorturl.at/bxFSX
14: https://shorturl.at/dhtJ6
15: https://shorturl.at/efhEO
16: https://shorturl.at/quzCN
17: https://shorturl.at/mpqvS
18: https://shorturl.at/xBK12
19: https://shorturl.at/otKNW

*Simplification for durations: 4 W = 1 M

In example 3, the construction with the foundation stone laid on October 18th, 2019, the timeline again collided with the peak of the COVID-19 pandemic in Germany.[20]

Construction	18M | 73W*	Delta
Example 1[18]		-7W | -10%
Example 2[19]		-37W | -51%**
Example 3[20]		+56W | +78%

Figure 6: Comparison of actual vs. proposed guideline duration for the third phase

BREI BREI BREI BREI BREI BREI

4. Installation & Ramp-up

Commissioning of machinery

Product and process validation

Ramp-up

Phase 4:

Following the BREI, the last phase begins with the commissioning of machinery and equipment. It then progresses to product and process validation, leading to a ramp-up and then finalizing in the SOP. In this phase, deviations occur in all three examples.
In example 1, challenges emerged from a lack of transparent public information, possibly leading to wrong assumptions about the BREI and installation stages. Despite this, the project closely adhered to the guide's timeline, with a minimal deviation between the Purchase Order and SOP milestones.[21]
In examples 2 and 3, the projects involved replicated productions. These prior experiences could lead to more efficient processes in the current projects due to learning effects gained by previous factory setups at different locations.[22, 23]

Installation & Ramp-up	16.8M | 67W*	Delta
Example 1[15]		+19W | +30**%
Example 2[16]		-34W | -54**%
Example 3[17]		-27W | -42%

Figure 6: Comparison of actual vs. proposed guideline duration for the fourth phase

SOP SOP SOP SOP SOP SOP

Conclusion and User Guidance

Phase 1-4

In Figure 8, the industrialization process is outlined based on the guide and the examples. The first row represents the guide, while the subsequent rows illustrate examples 1–3. Moreover, all four phases and the three fundamental milestones are showcased. Within this comparative framework, the duration of the first and third project extends beyond the guide's timeline whereas the execution of the second project is shorter.
The comparison distinctly reveals that the theoretical sequential arrangement of all phases is not always conducted in practice. It is observed that the construction phase starts as soon as possible and before full approval of all permits is granted.
This approach can carry inherent risks. Premature construction can be problematic, as in the event of a rejection of federal permits for emissions (BImSchG), the structures or infrastructures already erected may not be authorized. This leads to potential adjustments afterwards. In the worst-case scenario, a regulatory halt to construction could be imposed, recalling to the situation encountered in a recent project in Grünheide.[24]

20: https://shorturl.at/eIT17
21: https://shorturl.at/byCRV
22: https://shorturl.at/ipGJ4
23: https://shorturl.at/cqtFZ
24: https://shorturl.at/AGIL1

*Simplification for durations: 4 W = 1 M
** Planned date, event not occurred yet

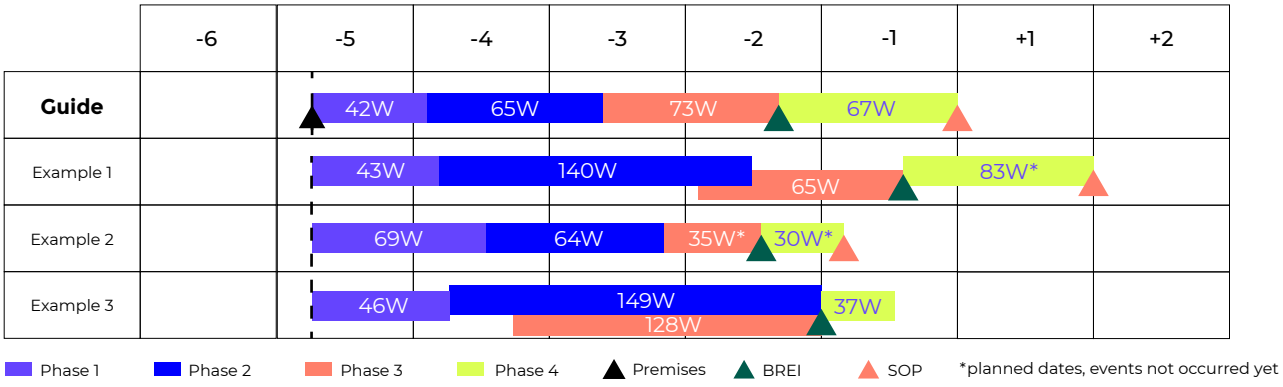

Figure 8: Comparison of all phases

Conclusion

Industrialization projects are characterized by their high complexity and the involvement of numerous stakeholders. These projects span over several years and encounter a variety of challenges. The key difficulties lie in the long lead times and the dependencies of various individual processes, which require careful planning and alignment to meet the SOP.
Despite the complexity and diversity of each project, the analysis has shown that industrialization projects follow a consistent pattern. The sequence of the core milestones is identical: Determination of Premises, BREI, and SOP. The total duration for LIB industrialization in the automotive industry is typically 58 months. By employing a systematic approach, delays can be minimized, and a higher level of planning reliability can be achieved.

How to use the Industrialization Guide now?

Integration of the guide into project planning

- Alignment of project planning with the process outlined in the guide.
- Use the guide as a checklist and roadmap to maintain an overview and ensure important steps are not missed.

Adaption of the guide to specific project conditions

- The guide provides general guidelines for processes and durations.
- There is a need to adapt these processes to specific project conditions and requirements for each individual project.

Using the guide as a communication tool

- Employ the guide to communicate with stakeholders (customers, vendors, authorities, etc.).
- Illustrate the whole progress of the project and the next steps.

List of Abbreviations

Abbreviation	Definition
BImSchG	Bundesimmissionsschutzgesetz
BREI	Building Ready for Equipment Installation
CAGR	Compound Annual Growth Rate
EMIND	A word combination of E- Mobility and Industrialization
EU	European Union
GWh	Gigawatt-hours
ICE	Internal Combustion Engine
KPI	Key Performance Indicators
LIB	Lithium-Ion Battery
M	Months
MEP	Mechanical, Electrical and Plumbing
OEM	Original Equipment Manufacturer
SOP	Start of Production
TBA	To Be Announced
W	Weeks

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Source directory

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