BUILD-UP OF THE BATTERY INDUSTRY IN EUROPE – STATUS QUO AND CHALLENGES

Electromobility remains the prime driver of growth for the sale of lithium-ion batteries. In line with the record sales of more than 10 million electric vehicles worldwide in 2022, the sales of traction batteries increased significantly by 76%. This upwards trajectory continues in 2023. In order to meet the rising demand, an increasing number of cell production plants and factories for battery components in Europe are starting production. Until the end of 2023, battery cell production capacities could reach 175 GWh/a. This market update highlights the challenges that arise during the development and ramp-up of cell production plants

Electromobility remains on an upward trajectory

As shown in the Global EV Outlook 2023 published by the International Energy Agency (IEA) in April, the sales of electric vehicles (EVs) continue to rise quickly. In the past year, more than 10 million EVs were sold worldwide and reached a share of 14% of the total market. After China with 6 million sold EVs, the second main growth driver is Europe with 2.7 million sold units. Compared to the total car market, the share of EVs in China approaches 30% and equals more than 20% in Europe.

This trend continues in 2023. Despite discontinued political support measures for the purchase of EVs in their main market, China, more than 2.3 million EVs were sold in the first quarter of 2023, which equals an added 25% year-over-year. Until the end of 2023, global EV sales could reach 14 million sold units.

The rising EV sales lead to an increased demand for batteries. According to SNE Research, in 2022 batteries with a combined energy capacity of 690 GWh were sold for the purpose of application in EVs. This growth amounts to 76% compared to 2021. The market leader in battery cell production is CATL followed by LG Energy Solution, BYD, Panasonic, Samsung SDI und SK On. All mentioned companies have their main seats in Asia, but four out of six have production facilities in Europe as well.

Next to electromobility, the market for stationary battery storage systems has been developing particularly strongly. According to SNE Research, 122 GWh in battery capacity were sold globally in 2022, corresponding to a growth of 177%. Due to political measures, the high demand for stationary storage will persist in the future. For example, the Chinese government has stipulated that, along with the buildout of renewable energy generation, energy storage systems have to be installed simultaneously.

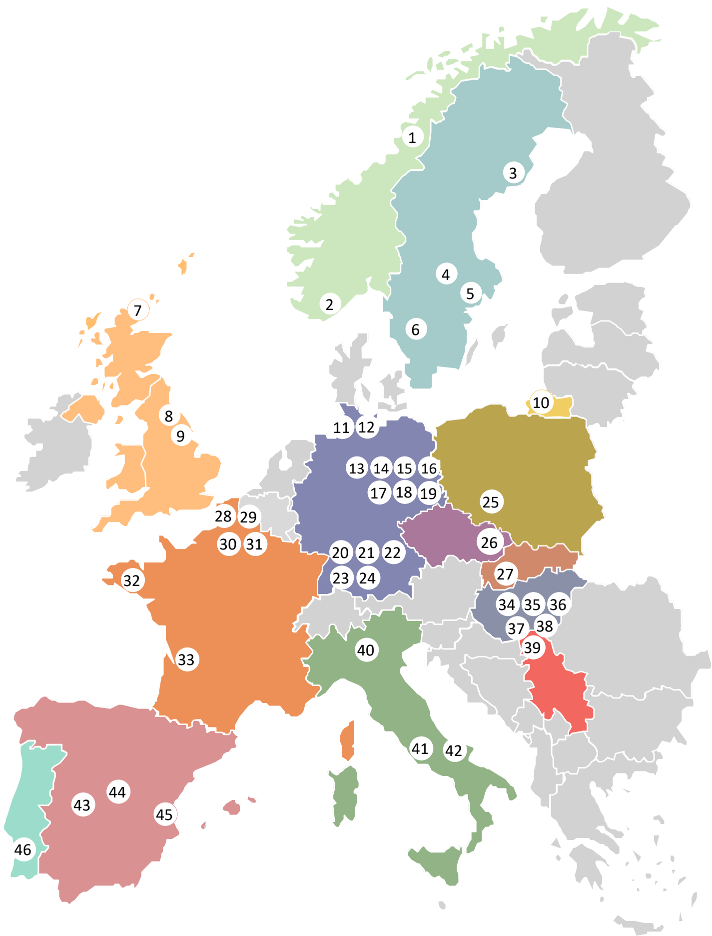
As a result of the increase in EV sales, the growth trend for batteries continues accordingly in 2023. In the first quarter of 2023, according to SNE Research, 133 GWh in batteries for EVs were sold, which corresponds to a year-over-year growth rate of 39%. Thus, the quarter lies above the expected compound annual growth rate (CAGR) of 26%.

New battery cell production facilities start production in Europe

Not only worldwide, but also in Europe the battery cell production is gaining momentum, and an ever-increasing number of factories are starting production. After Northvolt announced the start of cell production in December 2021 and delivery of the first commercial cells in 2022, CATL announced the start of serial production near Erfurt, Germany, in December of 2022. The first buildout phase of Northvolt Ett has a capacity of 16 GWh/a and the CATL factory in Erfurt has a capacity of 8 GWh/a. In May 2023, ACC began battery cell production in Billy-Berclau in Douvrin, France. The company aims to start production before the end of 2023, and the ramp-up is intended to be completed by the end of 2024. In the first

Figure 1: Sites of battery cell production in Europe that are either in planning, under construction, or already in operation.

No.	Company	Start of operations	Capacity (GWh/a) Available	Build-up (Planning 1st phase)	Maximum	Investments in million EUR	Jobs
Norway							
1	FREYR	2024	0.375	29	43	4,500	1,500
2	MORROW	2024		1	43	470	2,000
Sweden							
3	northvolt	i. o.	16	60	60	4,000	2,500
4	northvolt	2025			50	n. a.	1,000
5	northvolt	i. o.	0.35		0.35	750	1,000
6	NOVO	2025			50	2,900	3,000
Great Britain							
7	amte	i. o.	0.1	0.5	0.5	n. a.	215
8	Envision AESC	i. o.	1.9	12	35	1,185	1,650
9	Recharge Industries	n. a.			30	2,960	3,000
Russian Federation							
10	Rosatom	2026		3	12	n. a.	2,000
Germany							
11	UniverCell	i. o.	1.5			n. a.	n. a.
12	northvolt	2026			60	n. a.	3,000
13	国轩高科 Gotion High-Tech	2023		3.5	18	n. a.	n. a.
14	PowerCo	2025		20	40	2,000	2,500
15	QuantumScape	n. a.			21	n. a.	n. a.
16	Tesla	n. a.			n. a.	5,000	2,000
17	CATL	i. o.	8	14	100	1,800	2,000
18	LIACON	i. o.	0.5			n. a.	n. a.
19	SVOLT	2025		16	16	n. a.	n. a.
20	SVOLT	2027		6	24	1,700	2,000
21	ACC	2025		13.4	40	2,168	2,000
22	Leclanché Energy Storage Solutions	i. o.	0.5	1	4	48	n. a.
23	CELLFORCE	2024		0.1	1	n. a.	n. a.
24	VARTA	2026			2	1,000	500
Poland							
25	LG Energy Solution ESS Battery Division	i. o.	70	90	115	2,800	1,800
Czech Republic							
26	MES	i. o.	0.2	1.2	15	38	250
Slovakia							
27	InoBat	2026	0.045	4	10	100	150
France							
28	Verkor	2025			50	1,600	1,200
29	ProLogium	2026			48	5,200	3,000
30	ACC	2023		13	40	2,600	1,700
31	Envision AESC	2027		9	30	800	1,200
32	Bolloré Logistics	i. o.	0.5	1	1	n. a.	n. a.
33	ACC	2021	2	2	0.2	200	n. a.
Hungary							
34	SK innovation	i. o.	18		18	1,500	1,410
35	Samsung SDI	i. o.	40		40	n. a.	n. a.
36	CATL	n. a.			100	7,340	n. a.
37	SK innovation	2024		30	30	1,980	2,500
38	EVE 亿纬锂能				28	1000	1000
Serbia							
39	ElevenEs	2026			48	n. a.	n. a.
Italy							
40	ACC	2026			40	2,000	1,800
41	ITALVOLT	2025			45	4,000	3,000
42	FAAM	i. o.	0.35	8	8.3	505	n. a.
Spain							
43	Envision AESC	2025		10	30	n. a.	3,000
44	Phi4tech	i. o.	0.3	2	10	80	150
45	PowerCo	2026		40	60	3,500	3,000
Portugal							
46	CALB	2025		15	45	n. a.	n. a.
Europe							
	Eurocell	2025			6	2,000	n. a.
	PowerCo	n. a.			140	n. a.	n. a.
	InoBat	2025			32	n. a.	n. a.
		∑	160	405	1,639		



Start of operations

Capacity (GWh/a) *Available / Build-up (Planning 1st phase) / Maximum*

Investments in million EUR

Jobs

For companies without assigned number, the final location within a specific country or within Europe has not been announced yet.

Source: Company announcements, own depiction.

buildout phase, the goal is to produce battery cells of more than 13 GWh/a. All mentioned facilities are intended for further buildout in the future.

Aside from the recently started operations, South Korean manufacturers LG Energy Solution, Samsung SDI, and SK On have been producing battery cells in Poland and Hungary. During its last end-of-quarter presentation of 2022, LG Energy Solution showed that its production capacities in Poland amount to 70 GWh/a and are supposed to expand to 90 GWh/a in 2023. Until 2025, a total production capacity of 115 GWh/a is intended. SK On, the battery branch of SK Innovation, operates capacities of 17.5 GWh/a in Hungary. According to company announcements, another facility is planned to start production in 2024, yielding an additional 30 GWh/a.

Samsung SDI is producing battery cells for automotive applications in a plant in Göd, Hungary. However, the company itself has not revealed its available production capacities. According to industry news, it has approximately 30 GWh/a and is supposed to be expanded to 40 GWh/a. Following the quarterly report by Samsung SDI, this buildout phase was completed in 2022.

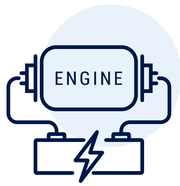
In addition to the listed sites with production capacities of more than 5 GWh/a, there are numerous other facilities producing battery cells on a smaller scale, often for applications other than EVs (Figure 1).

In 2022, the total production capacities for xEV batteries in Europe amounted to approximately 145 GWh/a and might increase to 175 GWh/a by the end of 2023.

Component production to take place in Europe as well

Next to cell production, factories have been and are being built on European grounds that supply the battery cell production industry with the necessary components, such as cathode active material (CAM), separators, and electrolytes (Figure 2).

Among others, BASF and Umicore are producing CAM in Europe. Umicore opened a factory producing CAM in Nysa, Poland, in September 2022. The production capacity of this site is said to reach 20 GWh/a by the end of 2023 and expand to 40 GWh/a in 2024. Ultimately, its CAM production capacity can be increased to 200 GWh/a. Moreover, the CAM plant at BASF Schwarzheide is poised to start production shortly. According to a press release, the site has been in the process of ramping up since the end of 2022 and will reach an initial production capacity of 20 GWh/a.



Separators for lithium-ion batteries are produced, among others, by LG Chem in Poland and by Toray in Hungary. Both companies have announced last year that they have formed a joint venture for the production of separator materials in Hungary. With the formation of this joint venture, the Toray site will be expanded and is intended to reach a production capacity of 800 million m² of separator foil.

SK IE Technology is another company that produces separators in Europe. SK IE owns a facility in Poland which can produce 340 million m² of separator foil per year. Further sites are under development so that up to 680 and 1540 million m² of separator foil can be produced until the ends of 2023 and 2024, respectively.

In Sweden, Senior Technology Materials is running a plant for the production of battery separators. This site is planned in several phases and is intended to reach an annual production capacity of 600 million m² of separator foil until the end of 2024, corresponding to approximately 60 GWh_{eq}.

SEMCORP, another Asian company, plans to open a production facility for separators in Hungary, aiming for a production capacity of 400 million m².

Numerous companies producing electrolytes are already existing in Europe. Due to limited shelf life, electrolyte solutions must be processed quickly, making short transport pathways particularly important. Consequently, electrolyte producers have established themselves in close proximity to cell production facilities, mainly in Poland, Hungary, and the Czech Republic.

Figure 2 summarises production capacities that will presumably be reached by the end of 2023 in the column titled „Capacity Europe 2023e". Those capacities would be able to supply the cell production plants in Europe with sufficient electrolyte. Regarding separators and especially CAM, Europe depends on additional imports. The same applies to anode active material (AAM), which is not depicted in Figure 2, since there are only few, small production plants in Europe. However, a change of this situation is foreseeable because several sites for the production of AAM are currently under development.

Prototypical development of a battery cell production plant in Europe

The challenges that arise during the development of new production sites and especially during planning and build-up of cell production plants are diverse. Reports on the development of battery cell production sites in Europe show that the planning is not always straightforward. During the process, timelines of plans and announcements of milestones can vary, deviate from the original plan, or being stopped altogether. Thus, adaptations to changing circumstances are always considered during planning and operation. Recent examples in Europe have shown that, starting with the **announcement of a factory**, approximately five years pass until start of operations.[1]

The site planning begins with the setting of goals, which encompasses the specific conditions such as strategic orientation, planned products, possible locations as well as the budget and timeframe.[2] In particular, the **search for financial coverage by potential investors** or opportunities for national financial support or funding can have consequences for the choice of location or the size of the planned factory. It has been shown that the EU must create more incentives and simplify its approval processes to stay competitive vis-à-vis the markets in North America and Asia.

Figure 2: Companies that are active in battery cell production as well as component manufacture, and own sites in European countries.

	Capacity Europe 2023e	Sweden	Great Britain	Germany	Poland	Czech Republic	Hungary
Battery cell production	175 GWh/a	northvolt	Envision AESC	CATL	LG Energy Solution		SAMSUNG SDI; SK on
Cathode material	40 GWh_{eq}/a			BASF We create chemistry	umicore		
Separator	120+ GWh_{eq}/a	SENIOR			SK ie technology; LG Chem		LG Chem; TORAY Innovation by Chemistry; SEMCORP
Electrolyte	230 GWh_{eq}/a		MITSUBISHI CHEMICAL GROUP	LANXESS Energizing Chemistry	GTHR; enchem; CAPCHEM	CENTRAL GLASS; TINCI	enchem; soulbrain; Dongwha Electrolyte

Electrolyte: 1 kt ≈ 1 GWh_{eq}; Separator: 1 Mio. m² ≈ 0,1 GWh_{eq}

Only companies that are already producing in Europe or will start production by the end of 2023 are depicted. The secound column shows an estimate of annual production capacities for the end of 2023. Source: Company announcements, own depiction.

1 Northvolt starts production in its battery factory Ett- electrive.net; CATL announces start of battery cell production in Arnstadt- electrive.net

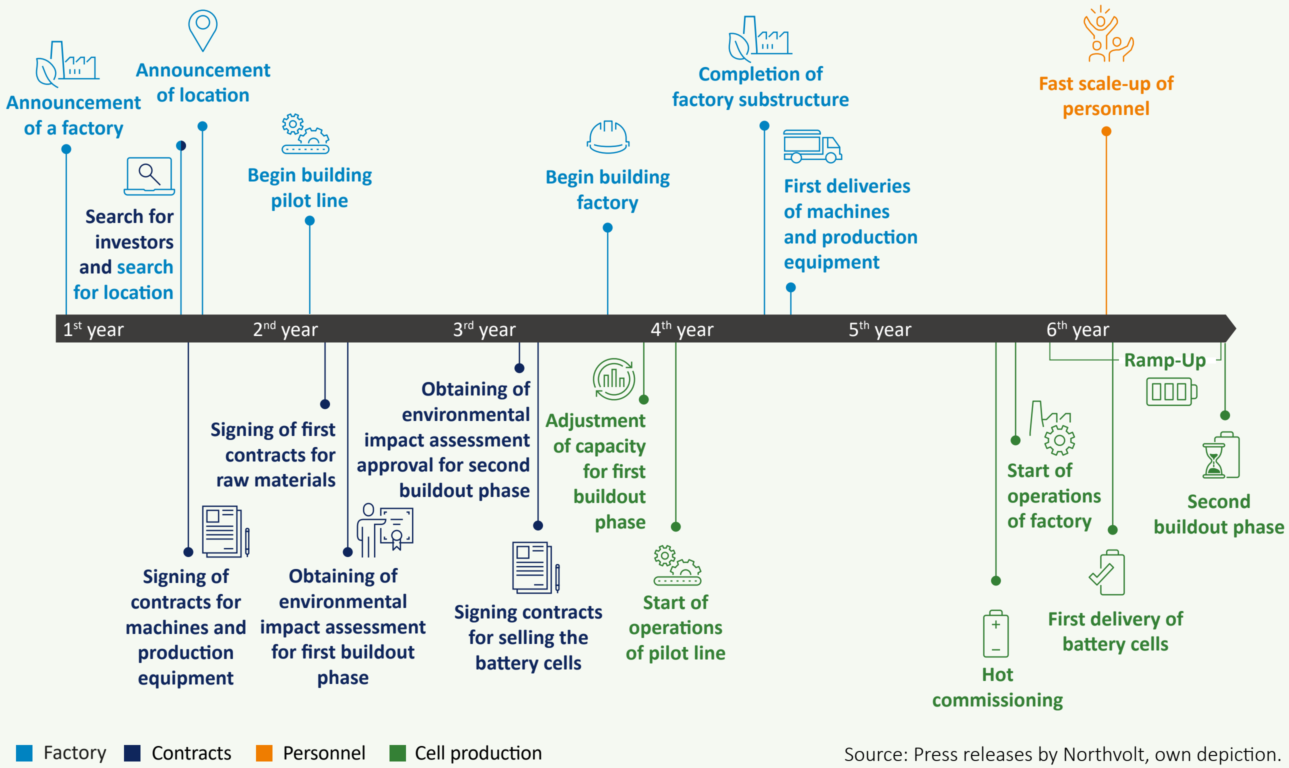
2 VDI 5200 Blatt 1

During the development phase, a **pilot line might be constructed** to serve as a precursor to serial production. This practice is especially implemented by new manufacturers that aim to establish themselves in the battery cell market but do not have access to prior production expertise. In the case of ACC and Northvolt, **start of operation of the pilot line** commenced two to 2.5 years before the actual factory went into operation. By means of the pilot line, the cell production processes are developed and cell designs tested, and the resulting preproduction series – or null series – serve as a basis for the serial production. During preproduction, samples are produced that can be inspected by potential customers. PowerCo designated its first factory in Salzgitter, Germany, as a blueprint in terms of sustainability and innovation and uses it to accelerate the build-up of further factories. According to the VDMA Roadmap Battery Production Equipment, the time from **beginning of construction** until start of operations of a *copy & paste factory* can be one to 1.5 years, whereas a factory with an entirely new production takes four years on average to start production.

The timeline in Figure 3 depicts the build-up of a battery cell plant exemplified by Northvolt Ett. The site is not a *copy & paste factory* but the company's first factory, which was built without prior expertise and whose battery cells and production equipment were developed and tested using a pilot line.

During the concept planning phase of a **factory its location** plays a crucial role. Due to rising energy prices in Europe and the future declaration of the CO_2 footprint, in particular the sourcing of cheap, renewable energy has gained importance. The energy-intensive production becomes especially competitive if the local electricity is sourced to a high degree from renewable sources or can be supplemented by own production from wind and solar. The gigafactory Northvolt Ett in northern Sweden stands out by merit of its green, sustainable production since it uses 100% renewable energy, benefitting from a location with an abundance of cheap wind and water power.

Figure 3: Timeline of the build-up of a battery cell production plant, exemplified by Northvolt Ett.

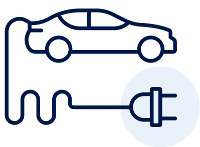


Source: Press releases by Northvolt, own depiction.

The dimensioning of a factory is adjusted over the course of the planning stage and laid out for several **stages of capacity increases**. The larger a factory is, the more opportunities there are for improvement of energy efficiency and material input in order to produce increasingly sustainably. This is an effect of the economy of scale and leads to a lowering of fixed costs. Therefore, factories are expanded or new facilities added in the long run to profit from the existing infrastructure. For example, SK Innovation built a second factory next to its existing one in Komárom, Hungary, in order to add production capacity.

In parallel to location planning, other preparations such as **first contracts for raw materials and production equipment** need to be realised in order to facilitate a smooth start of production. A thorough analysis of the internal value chain helps identifying vertically non-integrated areas. These areas can be served by establishing strategic partnerships within the battery ecosystem and a deliberate choice of location. Spatial proximity to suppliers, buyers, and production equipment manufacturers can yield logistic advantages.

After settling on a location, realisation preparations include the obtaining of permits from official institutions. These permits contain an **environmental impact assessment** – among others, depending on location – such as pollution control, protection of natural reserves, drinking water protection, and forest protection. After **all permits have been obtained**, the **factory build-up process can start**. Press releases from the Samsung SDI factory in Göd, the ACC factory in Douvrin, and Northvolt Ett in Skellefteå show that the basic construction of a factory building takes seven to ten months. After **completion of the factory substructure, first machines and equipment are delivered**, installed, and the individual production lines are set up.



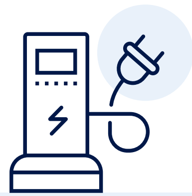
SK Innovation describes how production commenced step-wise on the five production lines in the first factory in Komárom, Hungary, over the course of one year in order to reach the announced capacity of 7.5 GWh/a. The advantage of multiple production lines running in parallel is the possibility to switch between cell formats, chemistries, or other adaptions to current developments.

Although **the start of operations** of the production equipment is tested in pilot lines, scale-up by a factor of 20 (example Northvolt Ett) is far more complex and requires close collaboration between process engineering, quality management, cell design and software. At first, a cold commissioning process takes place during which the equipment is adjusted to the desired operational speed, temperature and pressure without the use of starting materials. During the following **hot commissioning** process, starting materials are introduced into the production lines for the first time. This step is accompanied by intense scrutiny by quality assurance guided by specific parameters. By means of a surveillance system, the products are tested on-line and off-line, which means that sensor equipment is either integrated into the production line or that the products are tested outside the production line. For the early recognition of defective goods, digital twins are currently investigated as a means to better understand causal relationships and quickly adjust unfavourable production conditions. Digital equipment and product twins are relevant data sets that are gathered during production via sensors within the production line and contribute to the optimisation of the production process. For example, the introduction of digital twins is intended for the new ACC factory in France. The better the process steps are optimised during the early stages of production, the lower the final reject rate, which impacts efficiency. Next to minimisation of the reject rate for cost reduction an increase in throughput is also aimed at, which can be realised by precise tuning of automated processes. Until now, the yield of cells in well-tuned production lines lies at approximately 90%, in some cases below, which means in turn that „avoidable“ rejects are produced. Due to the high materials costs the avoidance of rejects is a high priority and offers potential to increase efficiency.

The recruitment of skilled labour in the vicinity of the factory is an aspect that is not to be underestimated. With increasing labour shortage there is high competition for qualified personnel, which has to be taken into account during the search for a suitable location. Shortly after start of operations of its first factory, Northvolt announced a **fast scale-up of personnel** by hiring 150 employees per month, meaning that the number of employees would eventually be quadrupled from 1,000 to 4,000. To make the workplace attractive for the required workforce, a concept for the development of the surroundings should be prepared to ensure that enough living space and infrastructure are present in the vicinity of the factory.

In the case of Northvolt Ett, four months after start of operations, the **first delivery of cells** to customers took place. According to reports, within the first six months the first production line was started up successfully. During the **ramp-up phase** over the following months, more lines came online in order to reach the second buildout phase of 60 GWh/a. As mentioned previously, during the initial ramp-up phase the production is successively accelerated, thus the factory is not assumed to produce the announced capacity immediately but with a delay of approximately one year. The CATL factory near Erfurt, Germany, was announced to have a capacity of 14 GWh/a but produced 8 GWh in 2022 before accelerating its production step-wise. During this acceleration phase, throughput is increased while the desired quality and process stability are reached. Usually, factory utilisation lies below 100%. At around 85% it becomes feasible to consider an expansion of production and thus **further buildout stages**.

The mentioned examples demonstrate that the process of building a battery cell factory is dynamic and must be adapted to current developments. Despite great challenges, European battery cell production is accelerating. In the coming years, more factories will start operations and ramp up capacities, thus the growing demand for batteries will be satisfied from increasingly domestic production.



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