

# **Analysis of the battery value chains with regard to the German in- dustry and the global context**

**Working paper to the project on “Low-  
Carbon Vehicle Futures for Germany”**

Karlsruhe, 03.07.2016

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**Proposed citation:**

Schade W., Mader S. (2016): *Analysis of the battery value chains with regard to the German industry and the global context*. M-Five working paper on behalf of the ECF and Cambridge Econometrics. Karlsruhe.

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**List of abbreviations**

BEV	Battery electric vehicle
EUROBAT	Association of European Automotive and Industrial Battery Manufacturers
EV	Electric vehicle
HEV	Hybrid electric vehicle
Li	Lithium
LIB	Lithium-Ion Battery
NMC	Li-Ion battery (LIB) with cathode made of nickel-manganese-cobalt in various compositions
NPE	Nationale Plattform Elektromobilität (National Stakeholder Forum on Electric Mobility)
OEM	Original equipment manufacturer of automobiles
PHEV	Plug-in hybrid electric vehicle

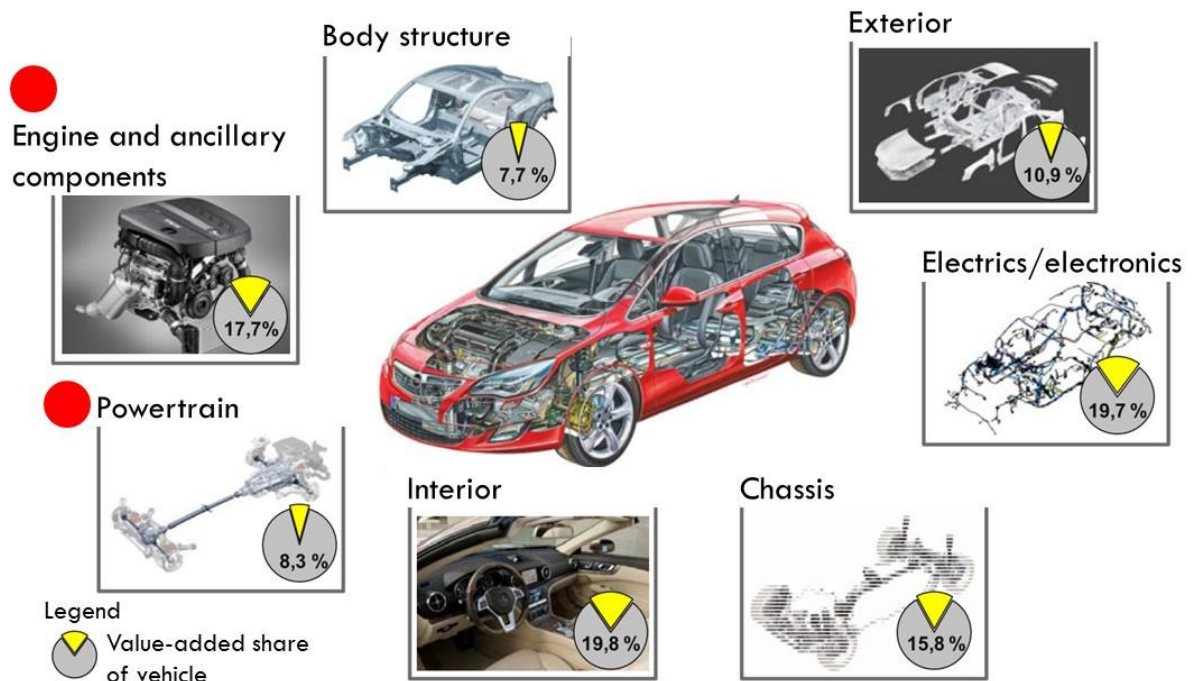
## 1 Introduction

The automotive world is on the verge of a great **transition**. Assisted and fully autonomous driving, new mobility services, partial and full electrification of the drivetrain as well as the demand for sharp reduction of pollutants and greenhouse gas emissions shape this transition. This analysis looks at a detail of the transition process, though of course a decisive issue as well: the value chain of the future battery technologies required for a successful electrification of cars.

This paper was elaborated as part of a larger project assessing the economic impacts for Germany of transitioning towards low carbon cars. The project was coordinated by Cambridge Econometrics teaming up with ElementEnergy and M-Five. It involved a stakeholder forum that provided for feedback and valuable input to the project and this paper.

Two **studies** looked at the future of the automotive industry and in particular on electric mobility in Germany on behalf of the German Parliament in 2013. They concluded that (1) providing R&D support by the government for developing lithium-based batteries, and (2) investing in battery manufacturing in Germany would be important in order to continue the success and the value creation of the automotive industry in Germany (Peters et al. 2013, Schade et al. 2013).

The reason becomes obvious looking at the distribution of **value-added** in Figure 1. Powertrain, engine and ancillary components together account for about 26% of the value-added of a compact car. These are components that are largely manufactured by the major automobile manufacturers themselves, i.e. by the original equipment manufacturers (OEM). Therefore, the OEMs are facing a risk of losing a substantial share of their value-added and consequently also of the employment opportunities that they offer. Besides the OEMs (e.g. Audi, BMW, Daimler, VW), the major suppliers like Bosch and Continental or medium-sized suppliers of e.g. exhaust systems would also be negatively affected, at least with their current business models.



Source: IKA et al. 2014

Figure 1: Distribution of valued-added on major components of a compact car

*But does the argument of potentially losing a substantial share of value-added in Germany due to electrification hold for investing in a battery cell production in Germany?*

The opposite **argumentation** suggests that lithium-based batteries are and will be traded on the world market and that at least three Asian manufacturers from Japan and Korea will compete on this market, so that dependency on a monopoly can be avoided. It is also expected that this situation will provide for sufficient competition to bring down the cost of battery cells. The argument is enhanced by the belief that technological advancement of these manufacturers could not be caught up by any late follower.

A third line of argument was recently raised by the German National Platform for Electric Mobility (NPE) estimating that around 2021 supply will fall short of sharply increasing demand for lithium-based cells, opening up a window of opportunity to establish at least one additional battery cell manufacturer in Germany.

The **following sections** will discuss these arguments, first looking at the different battery technology options confirming the most important role of lithium-based technologies. Secondly analyzing the manufacturing of such batteries, thirdly describing the value-chain of the batteries and fourth providing for potential criteria of selecting a manufacturing site. Finally, potential scenarios for German shares of the battery value-chain in the future will be proposed.

## 2 Battery technology options

Today the dominant **electrical system of cars** with combustion engines operates with a voltage of 12V. The standardized battery connected to such a 12V system are lead-based batteries. However automotive applications requiring higher power and higher energy, like in battery electric vehicles (BEV) or plug-in hybrid electric vehicles (PHEV), require other types of batteries. The Association of European Automotive and Industrial Battery Manufacturers (EUROBAT) identified three alternative **technology options**: nickel-based, lithium-based and sodium-based batteries. Extending the portfolio of battery technologies also technically enables to equip cars with electrical systems with higher voltages of up to 600V, which may be more adequate for additional purposes the electrical system shall satisfy (e.g. auxiliaries, boost, range). Changing the voltage requires adaptation of the auxiliaries of cars that today are optimized to operate with 12V systems.

**Fehler! Verweisquelle konnte nicht gefunden werden.** presents the **preferential use of the four battery technologies** for cars until 2020 with regard to three different drivetrain systems: internal combustion engine without capability to drive electric (class 1), hybrid electric vehicles (HEV) without option for external power supply (class 2), as well as BEV and PHEV (class 3). Nickel-based technologies are expected to play a niche role in HEVs, while sodium-based technologies find their niche role in heavy trucks and buses. Lead- and lithium-based technologies are expected to play major roles in the future: Lithium-based technologies currently constitute the only viable solution for PHEV and BEV for energy density reasons. Lead-based batteries are expected to continue to play a role in all three drivetrain systems, if not as the major battery but then as the auxiliary battery providing power to the board net.



Table 1: Eurobat analysis of battery technology options for automotive uses until 2020

	<b>CLASS 1: CONVENTIONAL VEHICLES (INCLUDING START-STOP AND BASIC MICRO-HYBRID VEHICLES)</b>	<b>CLASS 2: HYBRID ELECTRIC VEHICLES (INCLUDING ADVANCED MICRO-HYBRID, MILD-HYBRID AND FULL HYBRID VEHICLES)</b>	<b>CLASS 3: PLUG-IN HYBRID ELECTRIC VEHICLES AND FULL ELECTRIC VEHICLES</b>
<b>Lead-Based Batteries</b>	Expected to continue to dominate the market as a reliable, cost effective, efficient and proven technology. Expected developments in cycle life, efficiency and power delivery.	Primarily expected to be used as auxiliary battery to support the board-net. Increased industrial potential of advanced lead-based batteries in micro-hybrid and mild-hybrid applications.	Expected to be used only as auxiliary battery to support the board-net and for supply of active redundancy safety mechanism.
<b>Nickel-Based Batteries</b>	Nickel-based batteries are a mature technology but are not expected to be present in the SLI application due to limitations such as the need to oversize to meet requirements for cold cranking, calendar life, and cost compared to lead-based batteries.	Nickel-based batteries are expected to continue in this application although with greater competition from emerging lead and lithium-based technologies.	Nickel-based batteries are a mature technology and are not expected to develop in this application because of their characteristics such as low cell voltage and their significantly higher weight compared to lithium-ion technology.
<b>Lithium-Based Batteries</b>	Energy density and power ability will continue to increase, even at low temperatures. Increased industrial potential and improved techniques for recycling. Increased interest of manufacturers for future developments in this segment (especially as a performance option when weight is the driving factor).	Technology of choice for hybrid applications where significant power is expected from the battery. Increased industrial potential and improved techniques for recycling. Continuous reduction of product cost.	Only viable solution where high power and energy are expected. Increased industrial potential and improved techniques for recycling.
<b>Sodium-Based Batteries</b>	Being mostly a high voltage energy technology, sodium nickel chloride batteries are not expected to be used in the classic SLI application, as they were not developed for this purpose.	Hybrid cars are not today a realistic application of sodium nickel chloride batteries, because the relatively low power to energy ratio is not compatible with the small size of batteries used in hybrid cars. However, they are already used in heavy duty hybrid vehicles such as buses or trucks, where the required energy exceeds 20 kWh or in harsh environmental conditions.	Sodium-based batteries are expected to continue improving in this application, especially for heavy duty vehicles and public transport (buses, trams, etc.). In the future, improved performance, better integration into vehicles, and more sophisticated energy management is expected.

Source: Eurobat 2014

Since electrification is in the focus of this study and the lithium-based batteries have been identified as the most viable solution, the **following sections** provide a deeper analysis of Li-Ion battery manufacturing and their value-chains only.

### 3 Technology and production of Li-Ion batteries

There exist many roadmaps on how the technology of lithium-based batteries would develop (e.g. Thielmann et al. 2012, Thielmann et al. 2015a, b). Discussions of developments of LIB batteries concern the structure and the materials of the cathode, the anode, the electrolyte, the separator, the geometric form of the cells and their production processes. In general, there is seen a sequence of generations of lithium batteries starting with Lithium-Polymer und Lithium Iron Phosphate (LiFePO<sub>4</sub>) followed by:

- Lithium Nickel Manganese Cobalt Oxide (NMC), with different combinations of the three materials:
  - NMC111 with equal share of nickel, manganese and cobalt
  - NMC622 with reduced content of manganese and cobalt
  - NMC811 with a further reduction of the costly cobalt material.
- Lithium Sulfur (Li-S)
- Lithium all solid state (ASS)
- Lithium air (Li-Air)

NMC622 and NMC811 seems to be the most advanced batteries on the market or coming soon on the market, while Li-S and ASS are expected after 2020 and Li-Air after 2030. This list is not exhaustive, but it should provide the most relevant technologies until 2030. Over the last years developments from one generation to the next generation have usually been faster than expected by the various roadmaps developed by researchers and consultants. This also holds for the development of the cost reductions.

Figure 2 presents an overview on the components and the production process of a lithium-based battery. The process is dominated by two issues: the use of **specific materials** for different components and the **automated production** of larger systems from the components. The output of the production process is the battery system.



Source: own representation after Kompetenznetzwerk Lithium Ionen Batterien - KLIB

Figure 2: Components and production sequence of lithium-based batteries (second generation)

The **battery system** consist of the battery pack, the temperature control and the battery management system. The **battery pack** in turn consists of several **battery modules** consisting themselves of single **cells**. These cells are connected in row or parallel. The battery requires a cooling concept that can be based on air or liquid. The battery management regulates the voltage, currents, temperatures and state of charge of the single cells and recognizes and avoids errors (Propfe et al., 2011). Further components exist for the mechanic, electric and electronic linking and for communication. Different cell types require different characteristics of the system, concerning cooling and packaging for example (e-mobil BW GmbH, 2015).

The **market for electric vehicle batteries** is expected to triple by 2020 and to grow by the factor 10 to 30 by 2030. With cell costs reducing by the factor two or more, the global market could grow by the factor five to ten by 2030, compared to the costs in 2015. Of course, these are indications from other studies and the precise development of battery market will depend on the market scenarios developed by the study. Nevertheless, the value added potential of the battery cells over this growth period is expected to decrease significantly due to economies of scale and learning effects.

At the same time, the share of material costs for the production of the components in comparison to the pure cell production will increase. A comprehensive battery and electrification strategy has to include technical change through research and development, production, recycling etc.. These have to be analyzed in their reciprocal technical, economic and chronological dependency. Due to the importance of various raw materials the strategy would have to be accompanied by a sound raw material strategy considering also to attain long-term independence from singular technical solutions and materials (Thielmann et al., 2015).

The **framework conditions** of the production of LIB consist of the raw material criticality, the material efficiency (recyclability), the life cycle energy demand and the technological synergies (Thielmann et al., 2015):

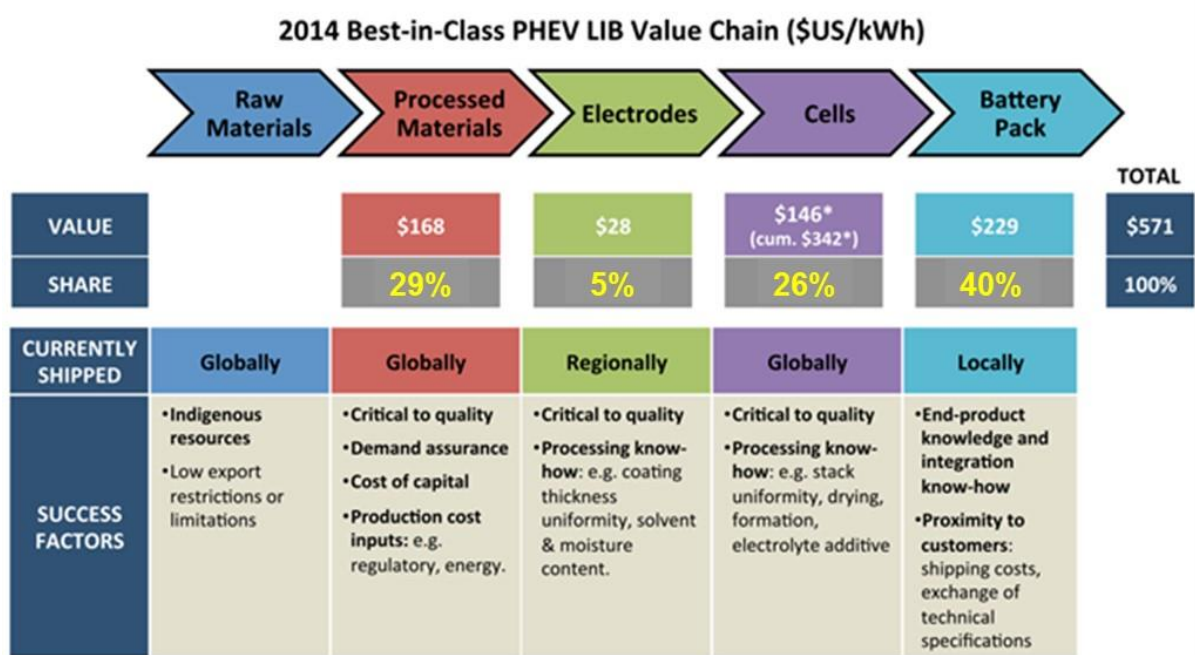
- Concerning **raw material criticality**, the significant share of cobalt in the battery costs is supposed to go back in favor of the need of nickel in the short term (before 2020). In the longer term, rare earths could become critical for electric engines.
- Concerning **material efficiency / recyclability**, pilot plants for the recycling of cobalt and nickel are already being tested. In order to foster the development of cobalt, nickel, copper and aluminum, the battery design will soon have to be adapted on the battery system level. In the longer term (2020), the battery design will have to be adapted for recycling purposes and further materials will have to be recycled in order to reduce material costs.
- Concerning the **life cycle energy demand**, the energy need and negative environmental balance of the production of Cobalt and Graphite are critical already and will remain critical in the long run.

- Concerning **technological synergies**, technology platforms for LIB are already active in several locations in Germany (e.g. Kompetenznetzwerk Lithium Ionen Batterien (KLIB), Innovationsallianz "Lithium Ionen Batterie LIB2015").

In 2007 experts concluded that no relevant manufacturing of lithium-based cells and batteries for automotive applications was existing in Germany.

## 4 Value chain of Li-Ion battery manufacturing

There are different options to describe the value chain of the LIB. Figure 3 splits it similar as we have done it to explain the LIB technology using the value-chain of a best-in-class technology for a PHEV battery of 2014. Raw materials (e.g. lithium, cobalt, phosphate, etc.) and processed materials (e.g. sheets of the materials) account for 29% of the total value-added of the battery, which was estimated at 571 US\$/kWh. 5% account for the manufacturing of the electrodes. Value-added of cell manufacturing amounts to 26% and of producing the battery pack including the intermediate step of producing modules to 40% (Chung et al. 2015).



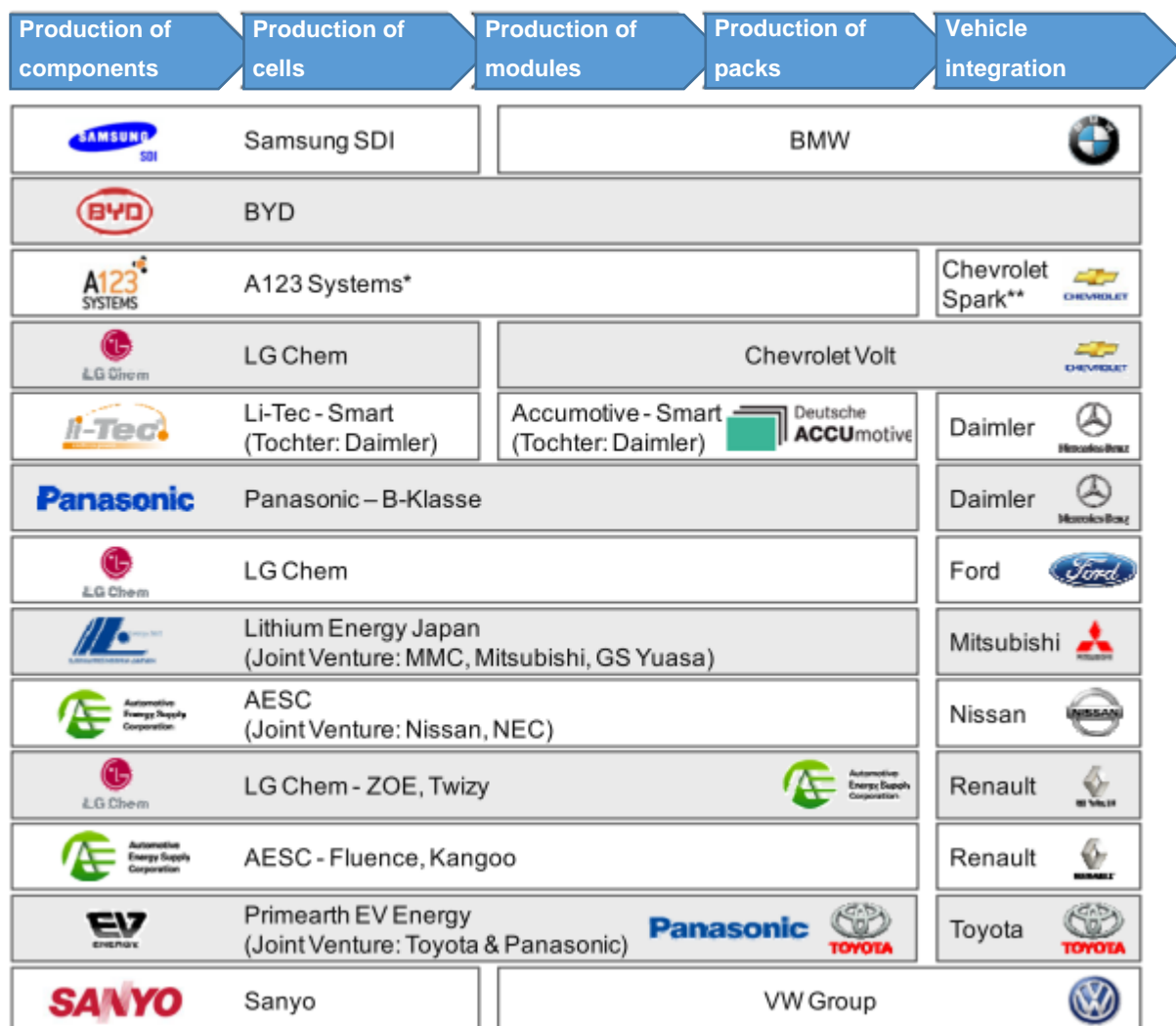
Source: Chung et al. 2015

Figure 3: Aggregate structure of LIB value-chain in 2014

The different steps of the LIB value chain can be spatially organized by different approaches. Due to substantial cost of shipping heavy battery packs and due to the close interaction required for the design and integration of the battery packs into the vehicles it is widely expected that the pack production will be located close to the OEM. High quality electrodes require that no contaminations and moisture affect the materials. Therefore long transport distances and times should be avoided for electrodes such that regional production with shorter transport distances is recommended. For raw materials, processed materials and cells such issues do not emerge. For these three components global distribution

from centralized production facilities with high output are feasible and economical. Nevertheless, as batteries or their components constitute a costly good also the cost of capital should not be neglected that matters in case of long travel times when shipping the components from one manufacturing site to the other.

Due to these characteristics of production and distribution of LIBs the value-chain can be split differently between OEM and their suppliers as Figure 4 shows with regard to vehicles produced by various manufacturers in 2013/2014. All OEMs remained responsible for vehicle integration of the batteries. But for instance, BMW split the chain between cells and modules receiving their cells from Samsung SDI and producing modules and pack by themselves. The same approach was applied by Chrysler with LG Chem as supplier for the Chevy Volt and the VW group with Sanyo as supplier. Toyota and Nissan both established a Joint Venture with a battery manufacturer that provided them the packs, and Daimler had established two daughter companies to produce the cells (Li-Tec) and to produce modules and packs (Deutsche Accumotive). BYD was the only manufacturer that captured the full value-chain of the batteries in their vehicles.



Source: adapted after IKA et al. 2014

Figure 4: Different approaches of OEM to split the value-chain of Li-Ion batteries for manufactured EV models in 2013/2014

A closer look at the value structure of the different components is provided in Table 2 for a BEV battery of 48 kWh for the years 2010, 2020 and 2030. It reveals that the cathode is the most costly component making up about 14% of the battery price in 2010, or even 20% of the battery production cost. The total share of the cell is 45% of the battery price and 66% of the cost estimated by Hettesheimer et al. (2013) for 2010, which is roughly the share indicated by Chung et al. 2015 for 2014.

Table 2: Value structure of lithium-based batteries at different points of time

		High energy battery systems of BEV in 2010 48 kWh, 650 \$/kWh			
	Component	\$	2010	2020	2030
Cell components	Cathode	4.415	14%	22%	24%
	Anode	968	3%	5%	5%
	Elektrolyte	2.117	7%	10%	11%
	Copper deflector	127	0%	1%	1%
	Separator	624	2%	3%	3%
	Cell coat	181	1%	1%	1%
	Binder/Additives	416	1%	2%	2%
	Aluminum deflector	72	0%	0%	0%
	Further materials	127	0%	1%	1%
	<b>Sum components</b>	<b>9.047</b>	<b>29%</b>	<b>45%</b>	<b>48%</b>
Cell production	Labour	5.205	17%	10%	9%
	<b>Sum cell</b>	<b>14.252</b>	<b>45%</b>	<b>55%</b>	<b>57%</b>
		\$	2010	2020	2030
Pack components	Mechanic components	3.421	11%	6%	5%
	Electric components	2.281	7%	4%	3%
	Electric connectors	570	2%	1%	1%
	<b>Sum system</b>	<b>6.272</b>	<b>20%</b>	<b>11%</b>	<b>9%</b>
Pack production	Labour	1.078	3%	3%	2%
	<b>Sum battery pack</b>	<b>21.602</b>	<b>69%</b>	<b>69%</b>	<b>69%</b>
	Guaranty	312	1%	1%	1%
	Margin	9.360	30%	30%	30%
	<b>Total battery price</b>	<b>31.274</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>
	Cost per kWh \$/kWh	652			

Source: Hettesheimer et al. 2013

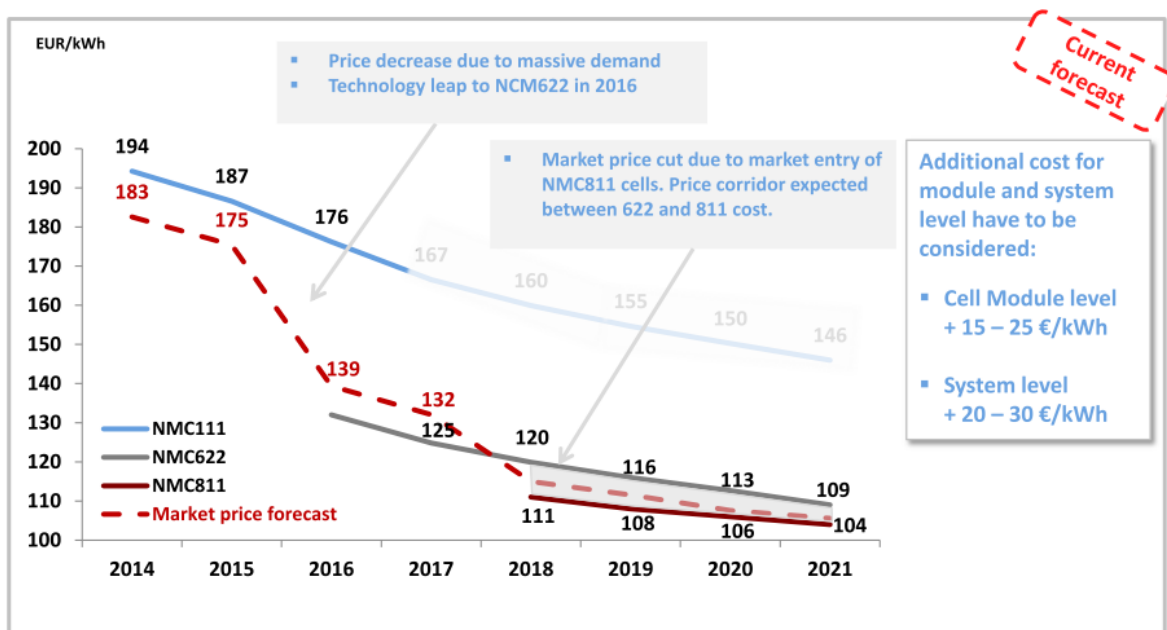
However, for the future years the expectations differ. While Hettesheimer et al. (2013) assume an increase of the value share of the cell on the total battery other authors expect the strongest future cost decreases for the cell manufacturing, which then would reduce the share of the cell cost on the total battery cost. Looking at the definition of scenarios for the study (see section 6) one important question to be answered is if the value is moving



rather upstream i.e. into the cell production or rather downstream i.e. into the pack production and the vehicle integration.

Another relevant question concerns the cost of future LIB batteries. We have pointed out to the different NMC-technologies above. It seems that shifting from NMC111 technologies to more advanced cathode compositions the cost will drastically be reduced by roughly 40% within two years (Figure 5). This should explain why several car manufacturers announce new BEV models for 2016-2018 that should achieve more than 300 km of electric range at prices of 25 to 35 k€ for a new car.

However, as a consequence of that cost drop existing plants producing LIB with previous technologies are facing a substantial risk of not being able to reach the necessary sales volumes to recover their investment cost as demand will shift fast to the new LIB cell compositions. Such examples could enfold impacts in two directions. Either it discourages further investments in cell manufacturing given the daunting example of these sunk cost, or it encourages new investments possibly even by new entrants as it becomes apparent that with choosing the right battery technology leap-frogging the incumbents will be possible in the cell market.

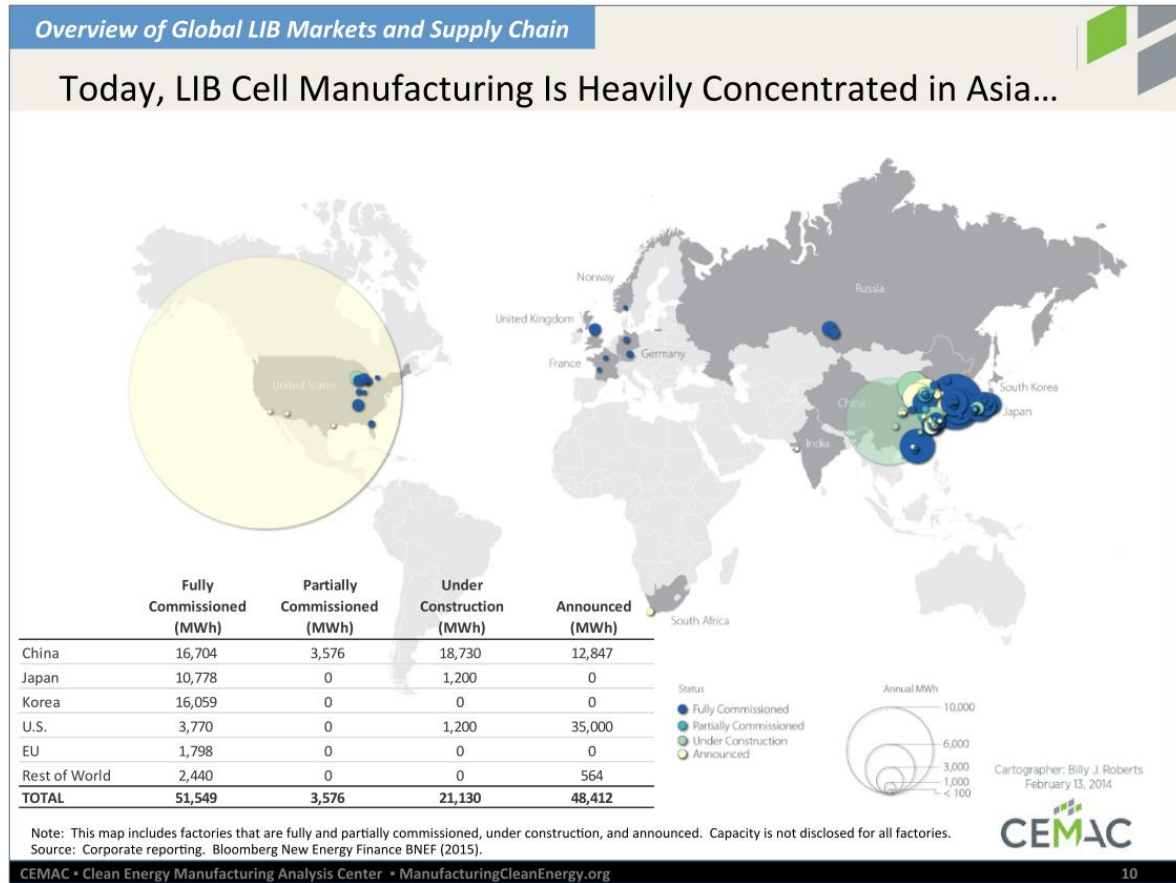


Source: Hackmann/Stanek 2016

Figure 5: Sharp market price decline from 2016 onwards due to new cell materials

Given that the cell manufacturing plays an important role in the LIB value chain the locations where LIB manufacturing takes place are relevant. As Figure 3 reveals the largest existing manufacturing sites exist in China, Korea and Japan in this order, while the US and Europe lag behind. Also in terms of planned extensions as of 2015 mainly China and the US (in particular Tesla Gigafactory) reveal plans to extend their capacities, which is not surprising as the market in 2015 was facing large overcapacity. It should also be noted that

most recently further plans for new capacity were announced including capacities to be established in Europe (see section 4.2).



Source: Chung et al. 2015

Figure 6: Locations of LIB cell manufacturing at global level in 2015

## 4.1 Actors of LIB value-chain in Germany

Following the description of current LIB value chains, expected future cost developments and the locations of global cell production as of today we take a closer look at the potentials to locate battery, modules and cell manufacturing in Germany.

Starting with financial and economic crisis of 2008 and the appearance of the Tesla Roadster on the market electric mobility became a hype topic in Germany, including that through the economic stimulus program substantial funds to develop knowledge and technologies for electric mobility have been made available by the government. This included also alliances and networks cooperating on the LIB technology. Figure 7 provides an overview of stakeholders that have joined forces in the KLIB network and that could cover specific steps of the LIB value-chain. This overview is not exhaustive as there exist further alliances in Germany, but it demonstrates that competencies for all relevant production steps of LIB cells and batteries would be available in Germany.





## 4.2 Extensions of LIB capacity in Europe

This section provides exemplary insights on plans to build LIB cell or battery pack factories in Germany and other European countries. Additional to existing cell manufacturing in Germany e.g. by GAIA in Nordhausen (<http://www.gaia-akku.com/de.html>) and BMZ in Karlstein (<http://www.bmz-gmbh.de/presse/presse-mitteilungen/0,1,4545,1653.html>) or by AESC/Nissan in Sunderland (UK), several plans of further capacity increases have been announced:

- German supplier ElringKlinger is analysing the potential of setting-up a battery module and pack production in Germany (<http://ecomento.tv/2016/04/04/zulieferer-elringklinger-prueft-eigene-elektroauto-batteriefertigung/>).
- Daimler is investing 0,5 billion € in their battery factory in Kamenz to extend the capacity though this might not include cell manufacturing (<http://www.elektromobilitaet-praxis.de/akkutechnik/articles/523611/>).
- Bosch has acquired Seeo a US battery start-up offering solid-state technology, which Bosch has also announced to bring such technology to the market by 2020 ([http://www.pv-magazine.com/news/details/beitrag/bosch-acquires-silicon-valley-battery-startup-seeo\\_100020854/#axzz4D67r09yM](http://www.pv-magazine.com/news/details/beitrag/bosch-acquires-silicon-valley-battery-startup-seeo_100020854/#axzz4D67r09yM)).
- Volkswagen requests that a cooperation between manufacturers is established to build battery cell factory in Germany that in particular is supported by the labor unions ([http://www.focus.de/finanzen/news/wirtschaftsticker/vw-will-zellfertigung-fuer-elektroauto-batterien-in-deutschland\\_id\\_5089762.html](http://www.focus.de/finanzen/news/wirtschaftsticker/vw-will-zellfertigung-fuer-elektroauto-batterien-in-deutschland_id_5089762.html)).
- LG Chem plans to build a battery factory in Poland to be completed in 2018 to produce up to 230.000 BEV batteries (<http://www.reuters.com/article/lg-chem-poland-idUSL3N17H1IV>).
- Samsung is analyzing if a Samsung TV factory in Hungary could be converted into a LIB factory providing the company with production facilities in Korea, China and Europe. Further they acquired the Magna battery division (<http://en.kipost.net/product/Samsung-established-EV-Battery-Factory-in-East-Europe-seeking-Korean-China-East-Europe-triangle/319/>).
- Even rumors are reported that Tesla would consider to build another gigafactory in Germany (<http://www.businessfinancenews.com/26291-tesla-motors-inc-picks-germany-for-its-first-european-gigafactory/>).

This list of LIB factory sites that might become implemented in Germany between now and 2020 provides hints that the stakeholders assume (1) it would be technically possible, (2) it would be feasible from the point of skills and political framework, and (3) it would be commercially viable.

### 4.3 Potentially neglected steps of LIB value creation

So far, we have discussed the LIB value chain from the manufacturing process, only. However, there exist two further steps of value creation by LIBs:

- The so-called **second life of batteries**, which takes place after a battery aged and its capacity declined such that it does not satisfy anymore the requirements for automotive use. However, batteries then may still provide between 50% and 80% of their original capacity, which then can be used as buffer storage for the electricity grid, and in particular to store renewable electricity. Through this storage capacity also value can be created by the LIBs.
- LIB contain expensive raw materials. When LIB demand grows and the number of batteries set out-of-service is increased as well it will become a viable market to shredder the batteries and **recycle the various materials of LIB**, e.g. of today's LIBs in particular cobalt and lithium. Recycling will also provide for value creation in the LIB value-chain.

## 5 Criteria for selection of LIB cell manufacturing site











While it is demonstrated that LIB module and pack manufacturing can be successfully located in Germany it has been questioned if this also would hold for large scale LIB cell manufacturing. This section briefly discusses the criteria, which influence location decisions for new LIB cell factories. The literature lists a number of such criteria which either have been identified to assess the viability of implementing a LIB factory in the US or in Germany (e.g. Chung et al. 2015, NPE 2016):

- Access to raw materials (graphite, lithium, cobalt, nickel, manganese).
- Proximity to machinery suppliers.
- Existing clusters of battery and materials manufacturers.
- Protection of intellectual property, including process innovations.
- Energy cost and environmental legislation.
- Logistical risks and proximity to end-markets.
- Supply chain optimization e.g. degree of vertical integration.
- Access to talented workforce, especially in RD&D.
- Labor cost of RD&D staff and of skilled factory staff.
- Competitive edge of incumbents that can not be caught up anymore.
- Sunk cost of factories that would produce old technologies if new cell technologies were produced by the new factory.
- Discounts provided to regional customers or members of the regional cluster but not to foreign customers.
- Opportunity to generate lead markets or at least export markets.
- Policy and regulatory context.
- Ease-of-doing-business-considerations.
- Brand and reputation.

A few of these criteria would be prohibitive for building a LIB cell plant if these would hold for Germany. E.g. if there would be no access to raw materials or a lack of skilled workforce. However, we do not see this being the case for Germany having developed both a raw materials strategy and an education and research strategy for electric mobility over the past years. Thus from these criteria it will be possible to build LIB cell manufacturing in Germany.

The other decisive question concerns the competitive edge that Asian incumbents have achieved. For today's advanced generation of LIB cells on the market this can not be caught up by a cell manufacturing to be established in Germany. However, technological development is moving fast and 3<sup>rd</sup> or 4<sup>th</sup> generation of LIB cells still also need to be commercialized at large scale by Asian manufacturers, such that for future technologies there will be a rather level-playing field. In addition, incumbents have to consider that they risk to create sunk cost out of their existing plants when developing new technologies too fast; an issue that is not relevant for a potential German cell manufacturers.

The German NPE has made an attempt to integrate many of these criteria into an assessment framework and to evaluate the position of building a LIB cell manufacturing in Germany against globally competing locations in Asia, in the US and in Europe. Figure 8 presents the outcome of this assessment. Under certain assumptions (exemption from the renewable energy surcharge on electricity) a production in East-Germany, an area with low labor costs, will be as competitive as the other leading regions in the future, which are expected to be Korea, Poland and the USA, while China and Japan are expected to be less competitive locations. Particular German advantages are considered with respect to logistics, transparency, innovation system and stability. The result was even achieved with putting a rather high weight on the influence of subsidies (15%), which play an important role in Korea and China.

Weighting (%)												
		DE <sup>4)</sup> "normal case"	DE-NB <sup>5)</sup> "best case"	South- Korea	Japan	Czech Rep.	Hun- gary	Poland	Slova- kia	China	USA	France
Labor	30%	2,8	3,6	2,7	3,3	3,7	2,2	4,0	3,4	3,8	3,6	2,6
Labor cost 2015	10%	1	3	3	3	4	4	4	4	5	3	2
Labor cost forec. 2019	30%	1	3	3	3	4	4	4	4	5	3	2
Workers' availability	30%	3	3	4	2	4	1	5	4	3	4	4
Workers' motivation	30%	5	5	1	5	3	1	3	2	3	4	2
Energy	25%	2,2	4,0	4,6	1,0	3,4	3,0	4,0	3,2	2,0	2,6	4,2
Electricity	80%	2	4	5	1	3	3	4	3	2	2	4
Natural gas	20%	3	4	3	1	5	3	4	4	2	5	5
Logistics	5%	5	5	3	4	2	2	2	1	2	4	4
Subsidies	15%	1	1	5	1	2	4	4	3	4	4	1
Exchange risks	5%	3	3	4	4	1	2	2	3	5	5	3
Economic and financial stability	5%	5	5	4	3	3	1	3	3	3	5	4
Transparency	3%	5	5	2	4	2	2	3	2	1	4	4
Corporate rate taxes	5%	2	2	3	2	5	5	5	4	3	1	2
Innovation ecosystem	7%	5	5	1	3	1	1	1	1	3	5	3
Total	100%	2,8	3,5	3,5	2,4	2,9	2,6	3,5	2,9	3,1	3,5	2,9

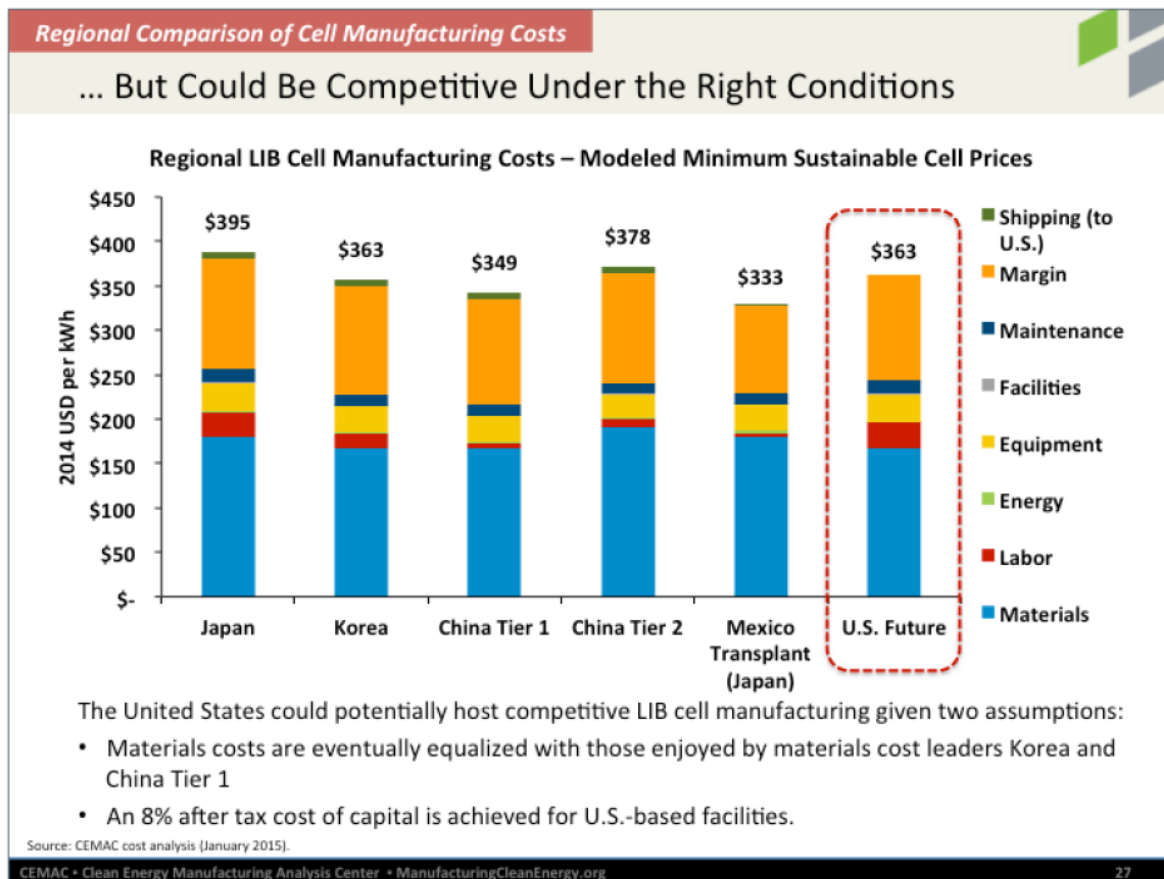
5 = best performer, 1 = worst performer

Source: NPE 2016

Figure 8: NPE assessment of potential locations for future LIB cell manufacturing plants

The NPE analysis thus supports our conclusion that Germany would constitute a potential location for a LIB cell manufacturing. The NPE identified no obstacles for establishing lithium-based battery manufacturing in Germany that could not be overcome. Of course, a joint effort of German stakeholders will be needed to invest into R&D and the manufacturing plants to turn a large scale German cell and battery manufacturing into reality.

Chung et al. (2015) did a similar assessment than the NPE for the US and Mexico against the Asian manufacturing locations, but excluding any European location. They conclude that future US plants will be competitive with Asia (better than Japan, equal to Korea, indifferent to China). The most competitive location would be Mexico due to the lower labor costs. Given the high automation of battery manufacturing this seems to put too much weight on the cost of labor. Nevertheless, it indicates that when considering competition of a potential new LIB cell plant in Germany also the option of potential new entrants from outside the US and Asia should be taken into account.



Source: Chung et al. 2015

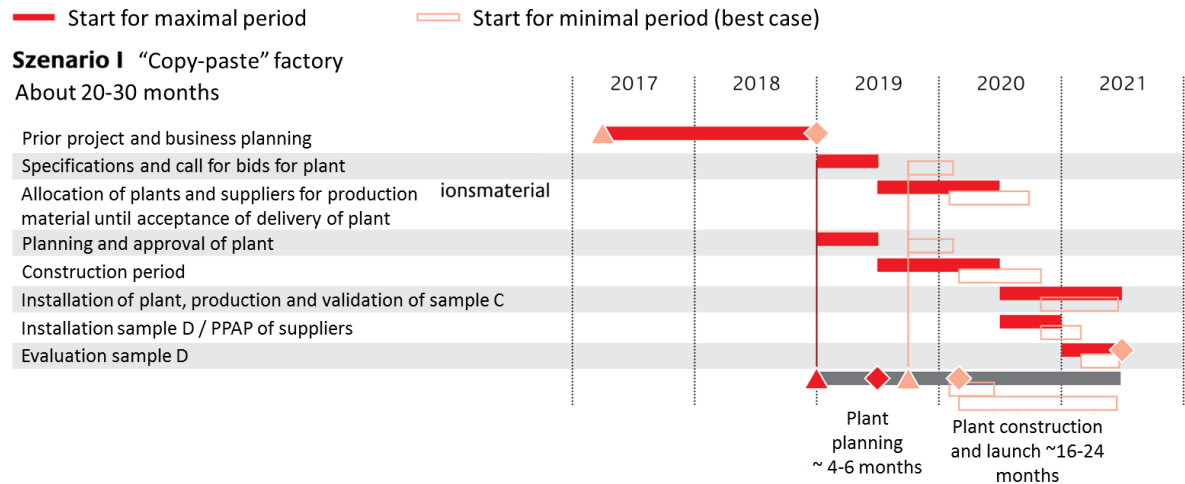
Figure 9: LIB cell manufacturing cost competitiveness of US and Mexico versus Asia

## 6 Scenarios for future manufacturing strategies

The purpose of the value-chain analysis in this study is to discuss and agree on scenarios of future value chains in a world with high penetration rates of electric cars. In practice, the scenarios need to describe the locations of the major value creation steps of LIB manufacturing. Thus the scenarios inform the economic modeling how to reflect the domestic value creation in Germany and the trade structure in the future. The question to be answered is how much of the EV value chain will be produced in Germany, and how big will be the share that has to be imported. A substantial part of the answer to this question depends on how the LIB value chain until 2030 will be spatially distributed between Germany, Asia and America.

The German National Stakeholder Forum on Electric Mobility (NPE) has developed a roadmap how a LIB cell manufacturing could be established in Germany until 2021, which provides valuable insights to develop our scenarios. The roadmap proposes two scenarios how cell manufacturing could be implemented in Germany. 2021 was selected as year of start-of-production (SOP) as it was expected that LIB demand will ramp-up in that year such that globally at least one new cell manufacturer will be required to satisfy demand, while today we see overcapacity of cell production.

In the first scenario (Figure 10) the process is described if a stakeholder disposing of a prototype factory would develop this factory into a mass production facility. This would take 16 to 24 months meaning that the investment should start at the beginning of 2019 to be completed in 2021. In principle, this manufacturer could also start earlier and then would have the plant in operation even before 2020.



Source: NPE 2016

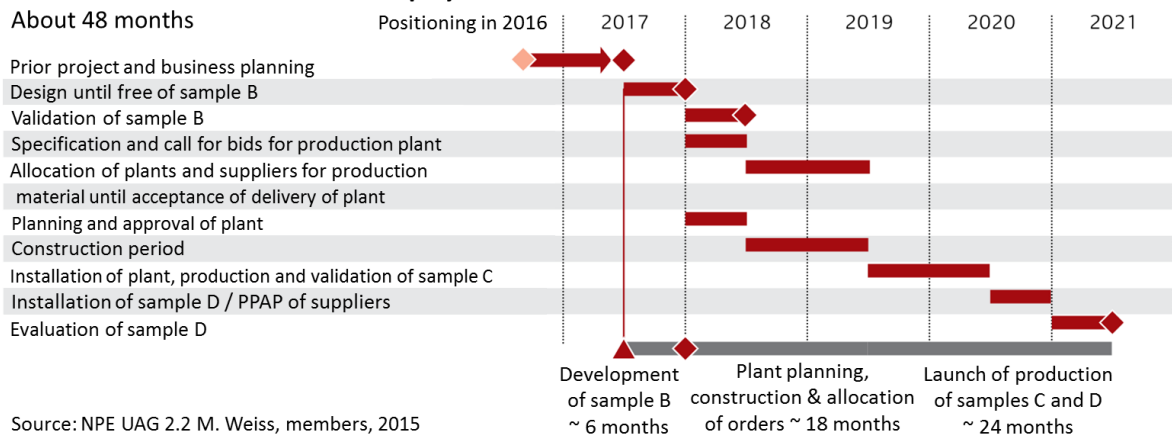
Figure 10: Scenario for battery cell manufacturing in Germany by the NPE – manufacturer with existing prototype production

The second scenario (Figure 11) describes the process for a new entrant to the LIB cell manufacturing market. In this case the new entrant has to go through a learning process to develop the LIB cell samples B, C and D, of which the latter then would go into production. The duration from project start until launch of cell production (SOP) is estimated to be 48 months.



**Scenario 2: Establishment of new player**

About 48 months



Source: NPE 2016

Figure 11: Scenario for battery cell manufacturing in Germany by the NPE – manufacturer starting from scratch

The previous sections have elaborated that LIB value chains can be split into three major value creation steps that thus should shape the LIB production scenarios of the economic study:

- Cell manufacturing.
- Module manufacturing.
- Pack manufacturing and vehicle integration.

Further important steps of value creation for LIB manufacturing that could be considered for defining scenarios would be:

- Production of processed materials.
- Manufacturing of electrodes.
- Manufacturing of machineries for LIB production plants.

Two steps that might additionally be considered for creating LIB related value in Germany are:

- Second life of LIB batteries as part of the renewable energy system.
- Recycling of raw materials of LIB at their end of life.

Having the abovementioned value creation steps in mind plausible production scenarios can be designed to provide the economic model with input on future value chains related to the impact of electrification of cars and the implication on locating LIB manufacturing in Germany versus in other parts of the world. Examples of such plausible production scenarios are:

- Only pack production located in Germany.
- Module and pack production located in Germany.



- Cell (from 2021 onwards), module and pack production located in Germany.
- Pack production and production of processed materials in Germany (e.g. via recycling), where the processed materials would then be exported to Asia.
- Further, time profiles of German shares of cell, module and pack production could be modified between scenarios.

To apply two distinguishable production scenarios we recommend to make the distinction in relation to the location of cell production:

- Scenario A: only module and pack production of LIBs to be implemented in cars manufactured in Germany or nearby neighboring countries would be located in Germany.
- Scenario B: also the cell manufacturing would be located in Germany such that in total cell, module and pack production of LIBs to be implemented in cars manufactured in Germany or nearby neighboring countries would take place in Germany.

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