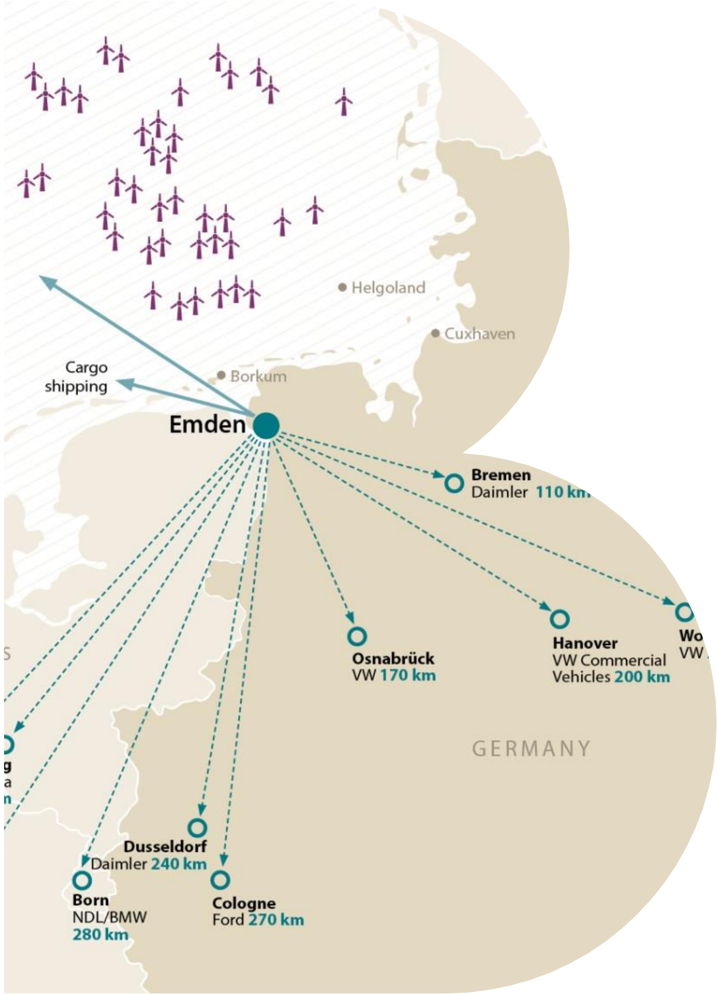
Roland Berger



Site analysis battery cell production for region of Emden

Project documentation

ZUKUNFT EMDEN

Emden, February 21, 2017

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A. Development of xEV market and battery cell demand analysis

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The powertrain electrification market forecast is a quantification of the dominant factors - both push and pull factors for xEVs

Driver for global powertrain electrification1)

Push side (OEMs)

Forcing OEMs to supply a significant number of EVs and PHEVs with…

- Regulations on new car sales
  - ZEV sales targets (CARB)
  - CO_2 fleet emission targets (EU)
  - Fuel efficiency targets (CAFE)
- R&D support for xEV technologies
- Corporate emission/fuel consumption targets

EXPECTED MARKET DEVELOPMENT FOR EVs AND PHEVs

Pull side (end customers)

Making EVs and PHEVs attractive for end customers by fulfilling customer needs for…

- Mobility
- Reasonable costs over use time (TCO)
  - Fuel/battery prices
  - Taxes/incentives
- Image/comfort requirements
- Automated driving enabling new business models (robocabs)
- (City) access limitations (e.g. London, Paris)
- ICE registration bans (e.g. Norway, Netherlands)

Regionally dominating factor: 🇪🇺 🇨🇳 🇺🇸 2)

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1) Both dimensions existing in all three regions, however, with different emphasis 2) Push is dominating factor in CARB Section 177 States

Source: Roland Berger

Emission regulations force automotive OEMs to introduce an increasing share of xEVs from 2020 onwards

Passenger car GHG emissions/fuel consumption [g/km] and toxic emission regulations

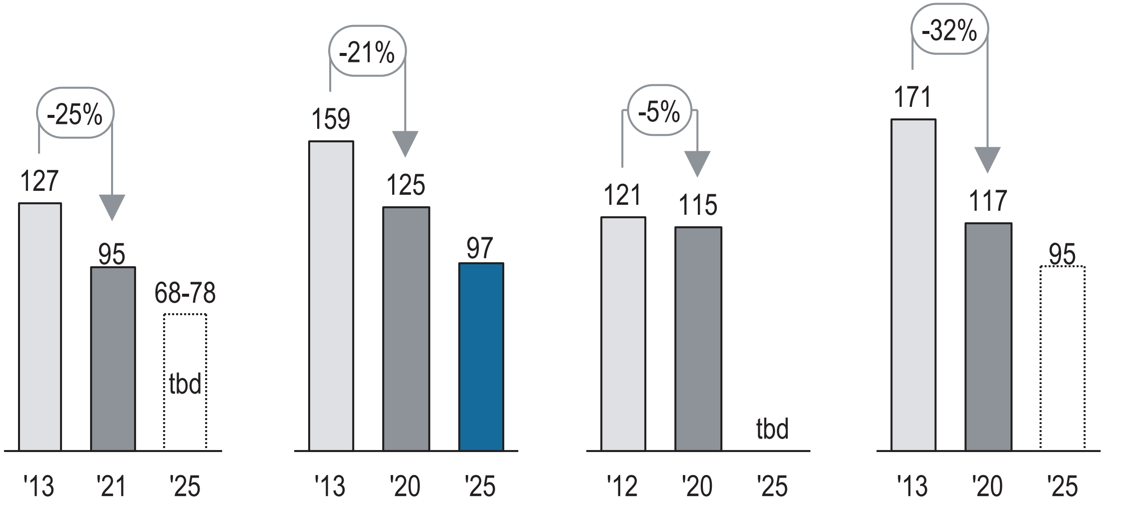
GHG emissions/fuel consumption (CO_2)

🇪🇺
- > CO_2 emissions target[1]

🇺🇸
- > CAFE[2]
- > Additional ZEV regulation CARB

🇯🇵
- > Fuel efficiency targets[3]

🇨🇳
- > CAFC[4] (ph. IV)
- > Add. potential fleet xEV target share



Toxic emissions (NO_x, PM, HC, …)

🇪🇺
- > 2014: Euro 6b
- > 2017: Euro 6c w/ RDE, additionally WLTP

🇺🇸
- > 2015: CARB LEV III
- > 2017: EPA Tier 3 Standards

🇯🇵
- > 2009: Post new long-term JC08 mode cycle
- > 2018: Post-PNLT (PPNLT)

🇨🇳
- > 2016: China 5 and Beijing 5

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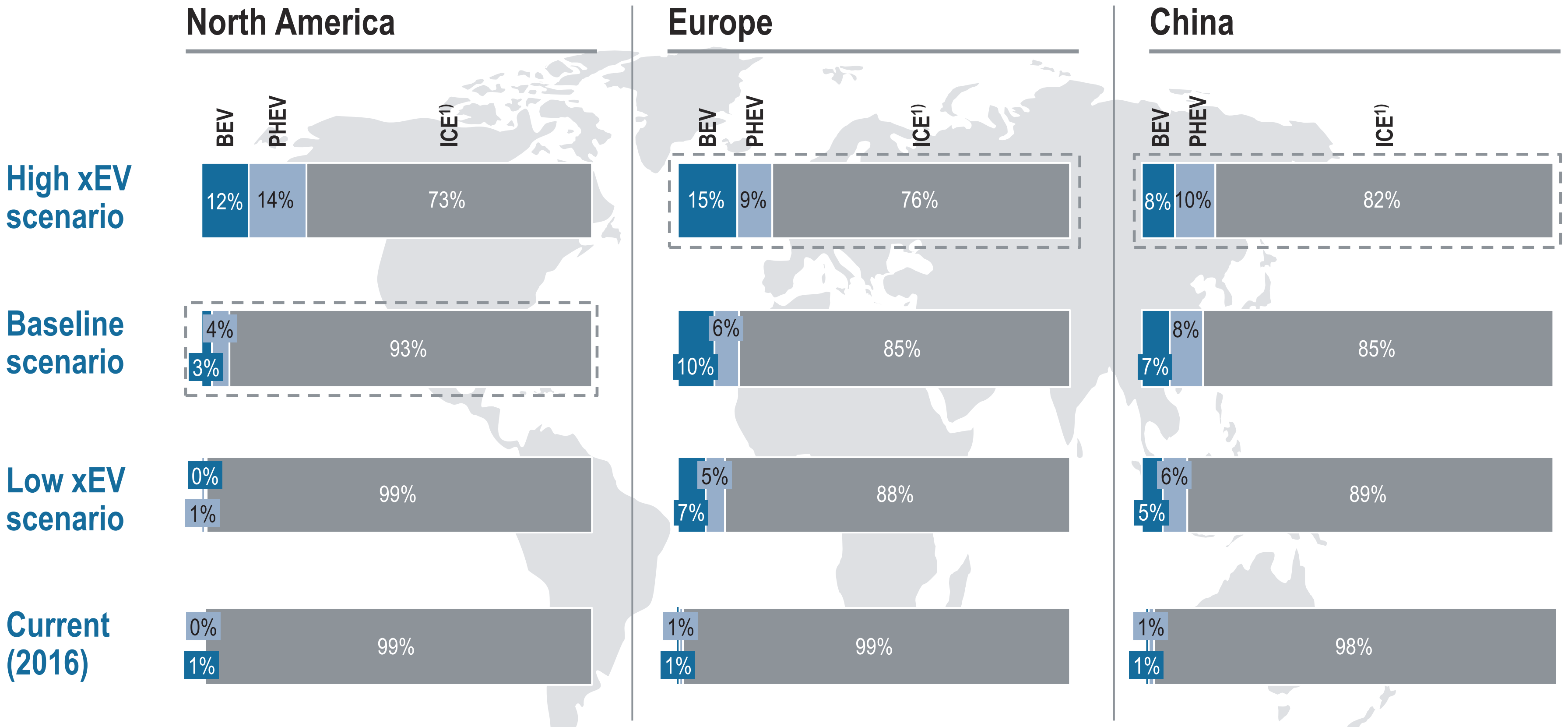
1) Weight-based corporate average 2) Footprint-based corporate average; converted to NEDC 3) Weight-class based corporate average; showing JC08
4) Weight-class based per vehicle and corporate average

Source: Press research; ICCT; Roland Berger

The xEV share in all major markets will grow significantly after 2020 – High uncertainty about long term regulation requires scenarios

Powertrain split, 2025 [% of sales]



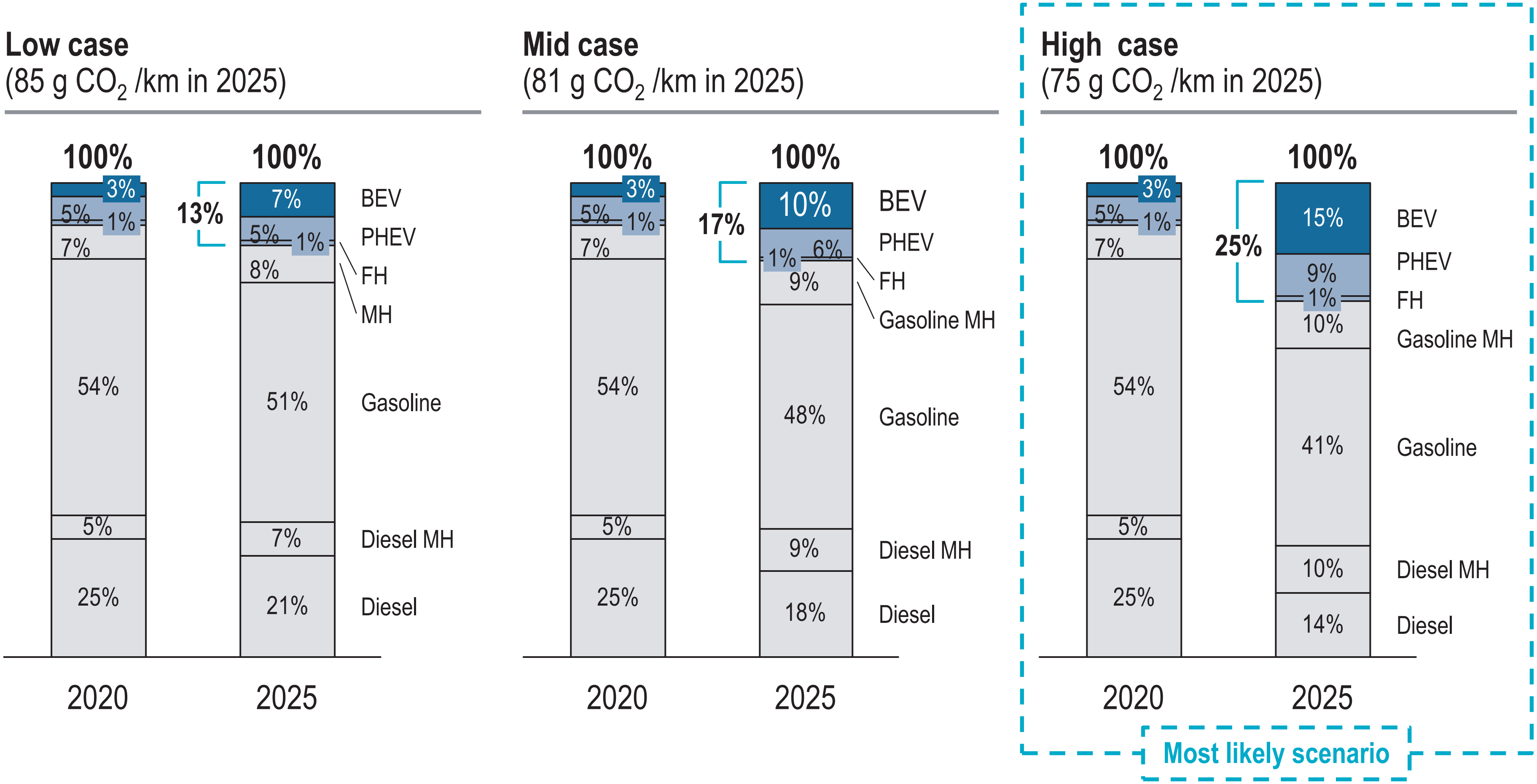
▯ Most likely scenario based on current development of framework conditions

1) Including fully, mild and micro hybrid vehicles

Source: Roland Berger

Depending on the scenario, the powertrain electrification may vary between 13% and 25% in Europe in 2025 – High case most likely

EU propulsion share 2020/2025 [% of sales]



Source: Roland Berger

Regulatory push is the driving force in all scenarios in Europe in 2025, until then customer pull will likely not become powerful

Drives for EU electrification scenarios

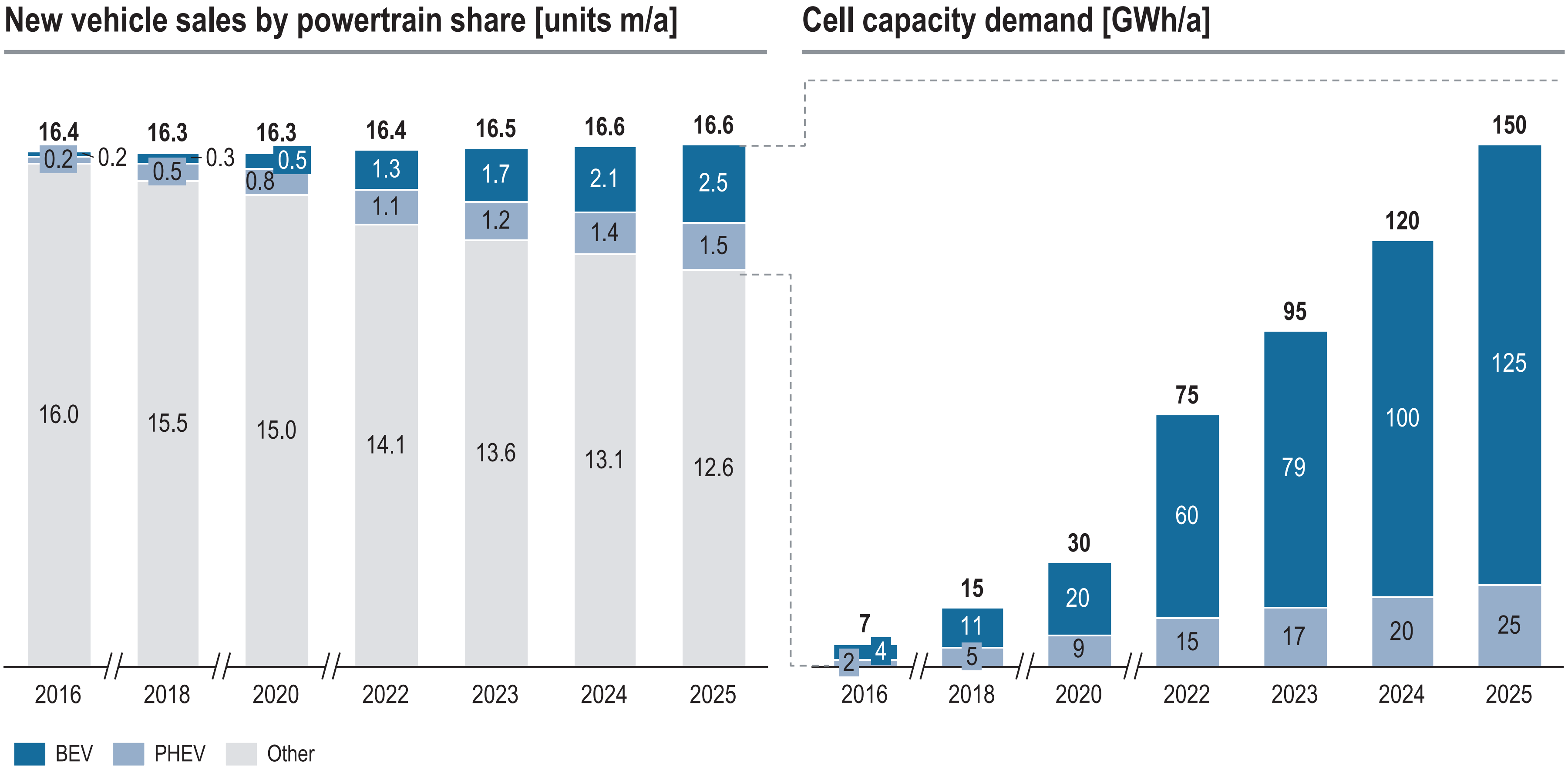
		2016	2021	2025
High case	**Regulatory push**	○ > 130 g corporate CO_2 target	● > 95 g corporate CO_2 target	● > 75 g corporate CO_2 target
	Customer pull	◔ > Subsidies in a selected numbers on countries	◔ > Limited subsidies > First city access limitation s for ICE	◕ > Many metropolis regions with access limitation for ICE > ICE ban in Norway
Mid case	**Regulatory push**	○ > 130 g corporate CO_2 target	● > 95 g corporate CO_2 target	● > 81 g corporate CO_2 target (100% vehicle with 75g target in 2027)
	Customer pull	◔ > Subsidies in a selected numbers on countries	◔ > Limited subsidies > First city access limitation s for ICE	◑ > Few metropolis regions with access limitation for ICE > ICE ban in Norway
Low case	**Regulatory push**	○ > 130 g corporate CO_2 target	● > 95 g corporate CO_2 target	◕ > 85 g corporate CO_2 target (75g target in 2030)
	Customer pull	◔ > Subsidies in a selected numbers on countries	◔ > Limited subsidies > First city access limitation s for ICE	◔ > Only small cities access limitation for ICE > No ICE ban

● Very strong driver for shift towards E-Mobility

Source: Roland Berger

European xEV sales will significantly grow until 2025 and will cause a large scale local production of battery cells

Vehicle sales and related energy capacity [units m/a, GWh/a]

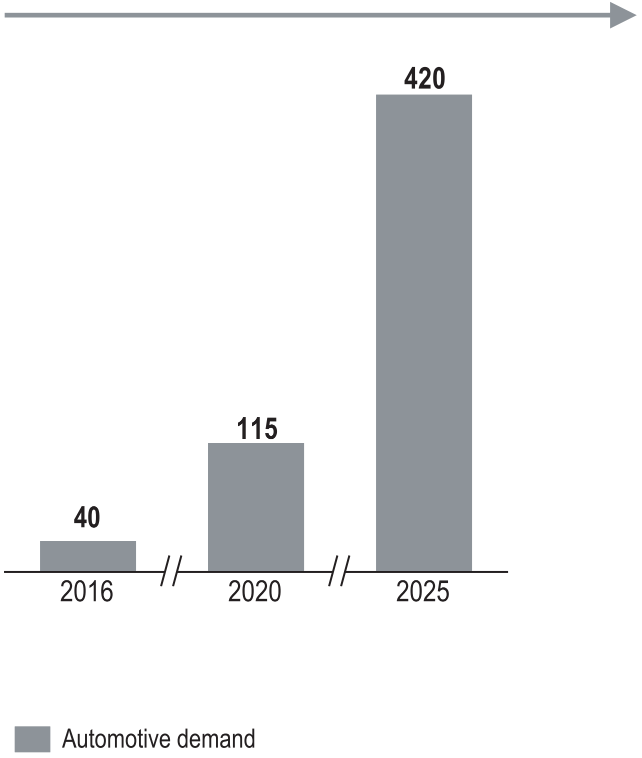


Source: Roland Berger

Battery cell manufacturer announced large scale capacity increase, but a capacity gap min. 130 GWh need to be closed until 2025

Global LiB demand and production ramp-up of battery cell manufacturer[1)] [2016-2025]

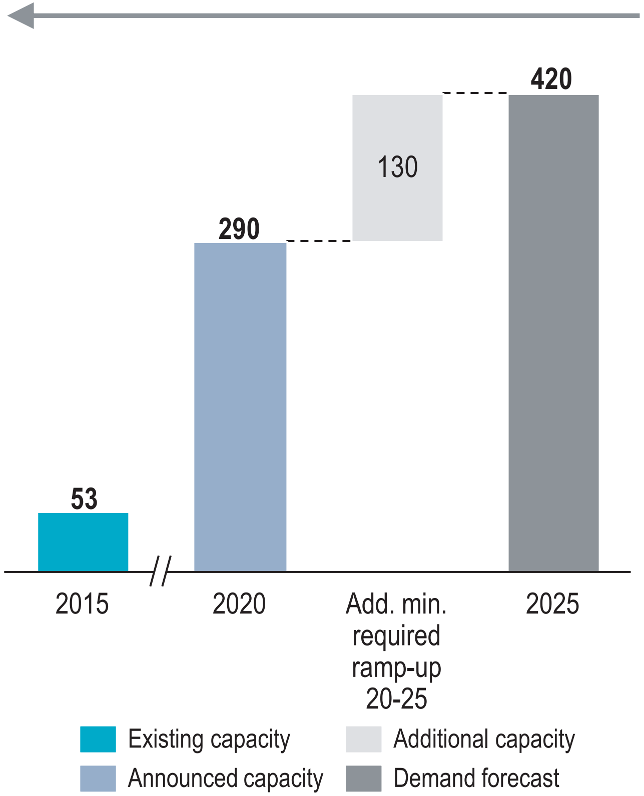
Large format LiB demand[2)] [GWh/a]



Besides current expansion plans, battery **cell manufacturer need to build up even more capacities**

Additionally, **not all** announced capacities **are yet linked to a specific location**

Production ramp-up of cell manufacturer [GWh/a]



1) Capacities as announced by cell manufacturer or as published by public sources without any adjustments

2) Incl. 18650 and successor formats for automotive or e-bus applications

Source: Bank of America, B3, company information, press research; Expert interviews, Roland Berger

Thus Europe gets into spotlight of global cell manufacturer and OEMs, as such the race is on for potential future manufacturing locations

Selected industry quotes

"We will turn the **Poland EV battery plant into a mecca of battery production for electric vehicles** around the world. As LG Chem's Poland EV battery plant is the first large-scale automotive lithium battery production plant in Europe, it will play the role of vitalizing the electric vehicle industry **across the whole Europe.** We will put all our efforts into making the plant into a main production hub for EV batteries."
UB Lee, President of Energy Solution Company, LG Chem – Oct. 6th 2016

"By launching construction for the plant in Hungary, […] we can especially **provide higher quality services to European customers in Europe** by generating synergy with SDIBS."
Jeong SehWoong , Executive Vice President & Head of Automotive division, SDI – Aug. 31st 2016

"There's **no question** that long-term **Tesla will have** at least one – and maybe two or three – **vehicle and battery factory locations in Europe**. This is something that we plan on exploring quite seriously with different locations for very large scale Tesla vehicles, and battery and powertrain production – essentially an integrated 'Gigafactory 2."
Elon Musk, CEO, Tesla Motors – Nov. 8th 2016

"**If more than a quarter of our cars are to be electronic vehicles** in the in the foreseeable future then we are going to need approximately three million batteries a year. Then **it makes sense to build our own factory**."
Matthias Müller, CEO, VW Group – Nov. 21st 2016

Source: Press research

B. Battery technology and cost analysis

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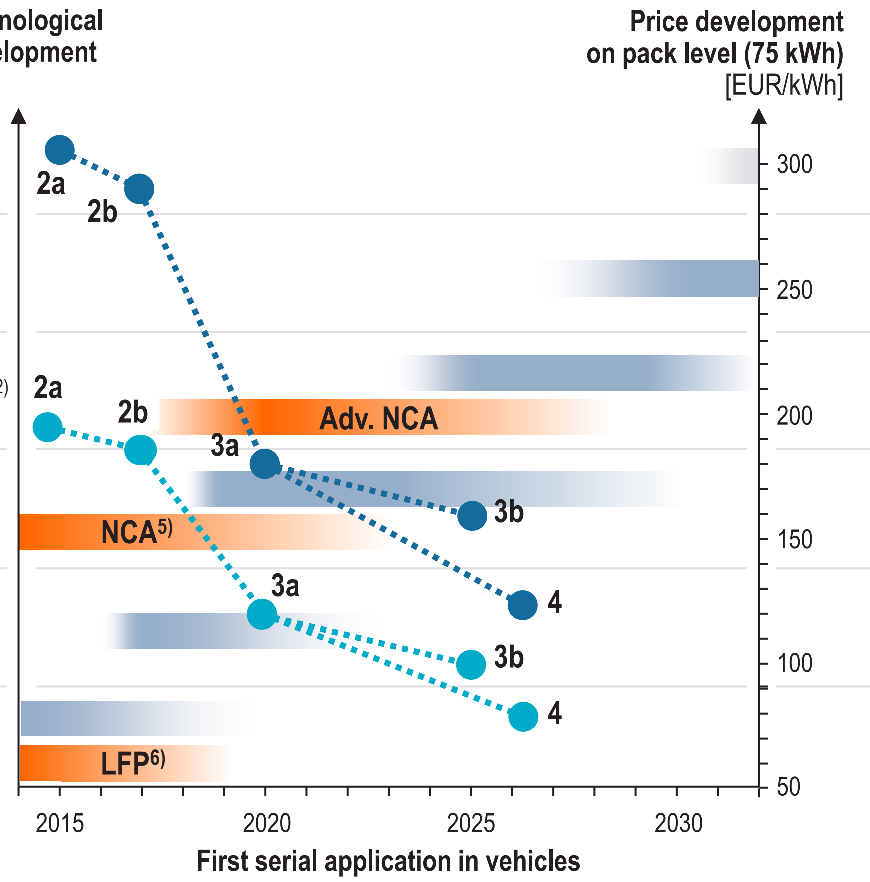
Battery cell chemistries will focus on Ni-rich NCM- and NCA-based cathodes causing a significant decrease in manufacturing costs

Roadmap for Lithium based cell technology and expected price development



	Volumetric energy density[1] [Wh/L]	Gravimetric energy density[1] [Wh/kg]
Gen 5 Li/O_2 (Li air)	-	>500
Gen 4 Solid-state with Li-anode	>1,000	400->500
Gen 3b Cathode:NCM811, HE-NCM, HVS, Adv. NCA[2] Anode: Silicon/Carbon	600-800	250-320
Gen 3a Cathode[3]: NCM622 …NCM811; NCA Anode: Graphite + Silicon[4] (5-10%)	350-600	180-280
Gen 2b Cathode: NCM523 …NCM622 Anode: 100% Graphite	220-400	150-180
Gen 2a Cathode: NCM111 Anode: 100% Graphite	220	150

▨ Expected timeframe of application

— Price development on pack level
— Price development on cell level

1) Energy density on cell level 2) Ni-rich NCA up to 90% Ni-share 3) Incl. NCA-NCM blends 4) No stable 5-10% Silicon formulation available
5) NCA as CAM in configuration used by Tesla 6) LFP in average configuration for CAM on cell level, in future more likely for starter batteries

Source: NPE AG 2 - Roadmap integrierte Zell- und Batterieproduktion Deutschland, BASF; Expert interview, Roland Berger

Roland Berger battery cost model is considering trends in cell and production technology as well as selected location depending costs

Selected key assumptions for battery cost analysis

Location independent assumptions

> **Cell technology**
- Cell size and chemistry
- Pouch format type

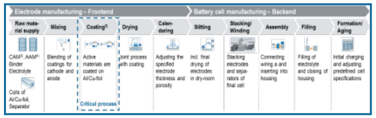
> **Production layout/concept**
- Production layout and size
- Production output
- Work stations
- Utilization of equipment

> **Investment and material costs**
- Invest for frontend, backend, building
- Electrode materials
- Other cell material costs

Battery cost model

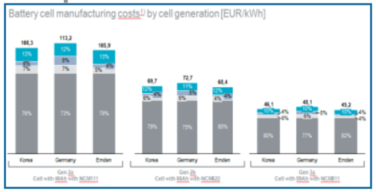
Input

Modeling



Electrode manufacturing – Frontend					Battery cell manufacturing – Backend				
Raw material supply	Mixing	Coating[2]	Drying	Calendaring	Slitting	Stacking/ Winding	Assembly	Filling	Formation/ Aging
CAM[1], AAM[1] Binder Electrolyte Coils of Al/Cu-foil, Separator	Blending of coatings for cathode and anode	Active materials are coated on Al/Cu-foil Critical process	Joint process with coating	Adjusting the specified electrode thickness and porosity	Incl. final drying of electrodes in dry-room	Stacking electrodes and separators of final cell	Connecting wiring a and inserting into housing	Filling of electrolyte and closing of housing	Initial charging and adjusting predefined cell specifications

Output / Calculation


Battery cell manufacturing costs[1] by cell generation [EUR/kWh]

Location dependent assumptions

> **Electricity costs**
- Key sources: City of Emden, Eurostat, KEPCO

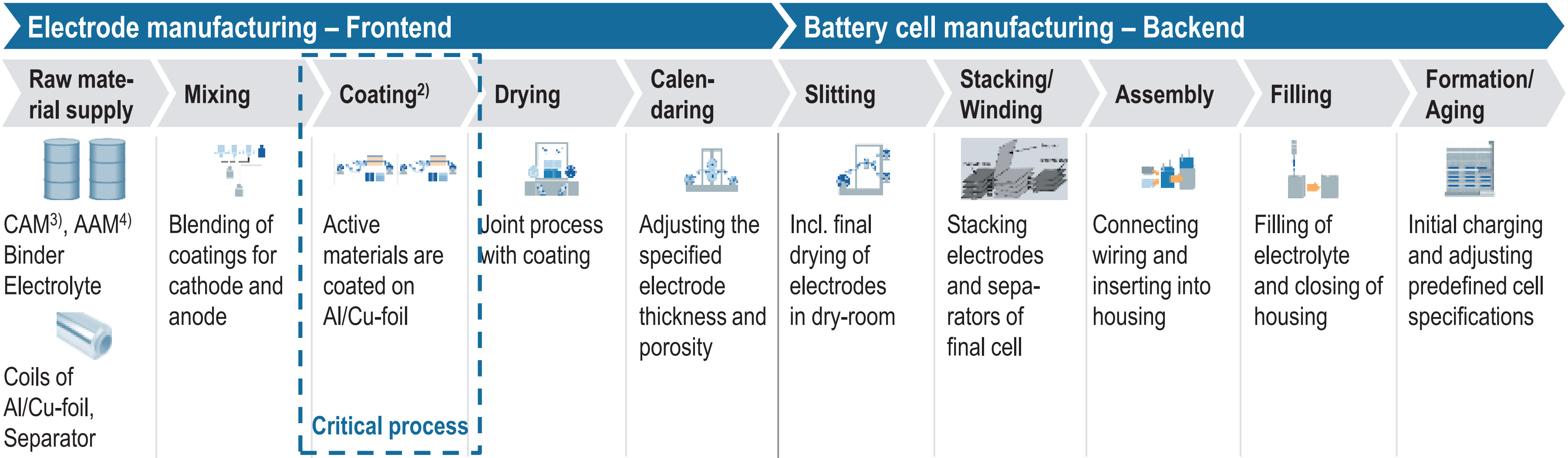
> **Natural gas costs**
- Key sources: City of Emden, Eurostat, KOGAS

> **Employer costs**
- Key sources: City of Emden, Eurostat, Economist Intelligency Unit

Source: Roland Berger

Battery cell production is based on continuous processing and thus is commonly run 24/7 with large scale coating equipment

Wet-coating process chain for LiB cell production



Electrode manufacturing – Frontend					Battery cell manufacturing – Backend				
Raw material supply	**Mixing**	**Coating[2]**	**Drying**	**Calendaring**	**Slitting**	**Stacking/ Winding**	**Assembly**	**Filling**	**Formation/ Aging**
CAM[3], AAM[4] Binder Electrolyte Coils of Al/Cu-foil, Separator	Blending of coatings for cathode and anode	Active materials are coated on Al/Cu-foil Critical process	Joint process with coating	Adjusting the specified electrode thickness and porosity	Incl. final drying of electrodes in dry-room	Stacking electrodes and separators of final cell	Connecting wiring and inserting into housing	Filling of electrolyte and closing of housing	Initial charging and adjusting predefined cell specifications

Equipment CAPEX: approx. EUR 50 m for 13.7 m cells/a[1]
Manufacturing Output: 40 m/min @ 1.2 m width (OEE 83%)

Equipment CAPEX: approx. EUR 200 m for 13.7 m cells/a[1]
Process specification: Electrode winding

- **Profitability of cell manufacturing is determined by degree of equipment utilization and size of manufacturing capacities. Due to this a manufacturing site needs to have a large supply base of vehicles.** Manufacturing equipment always needs to be state of the art to gain economies of scale on investments and depreciation costs

- The labor demand depends on the number of production lines
- A future factory size for 15 GWh/a (about 50 m cells) output requires about 3 k skilled workers + overhead

Energy demand for a 15 GWh/a (about 50 m cells) output

- Electricity: ca. 1,000 - 1,200 GWh/a
- Natural gas: ca. 25,000 - 30,000 t/a

---

1) 13.7 m cells/a net output @83% OEE with electrode thickness of 50µm cathode and 59µm anode 2) 2 coating lines required 3) Cathode active material 4) Anode active material

Source: Siemens; Expert interview, Roland Berger

Manufacturing costs are highly influenced by material costs. Thus additional criteria become relevant for a location choice

Bottom up battery cell manufacturing costs[1)] [South Korea = 100]

Gen 2a
Pouch cell with 40Ah with NCM111

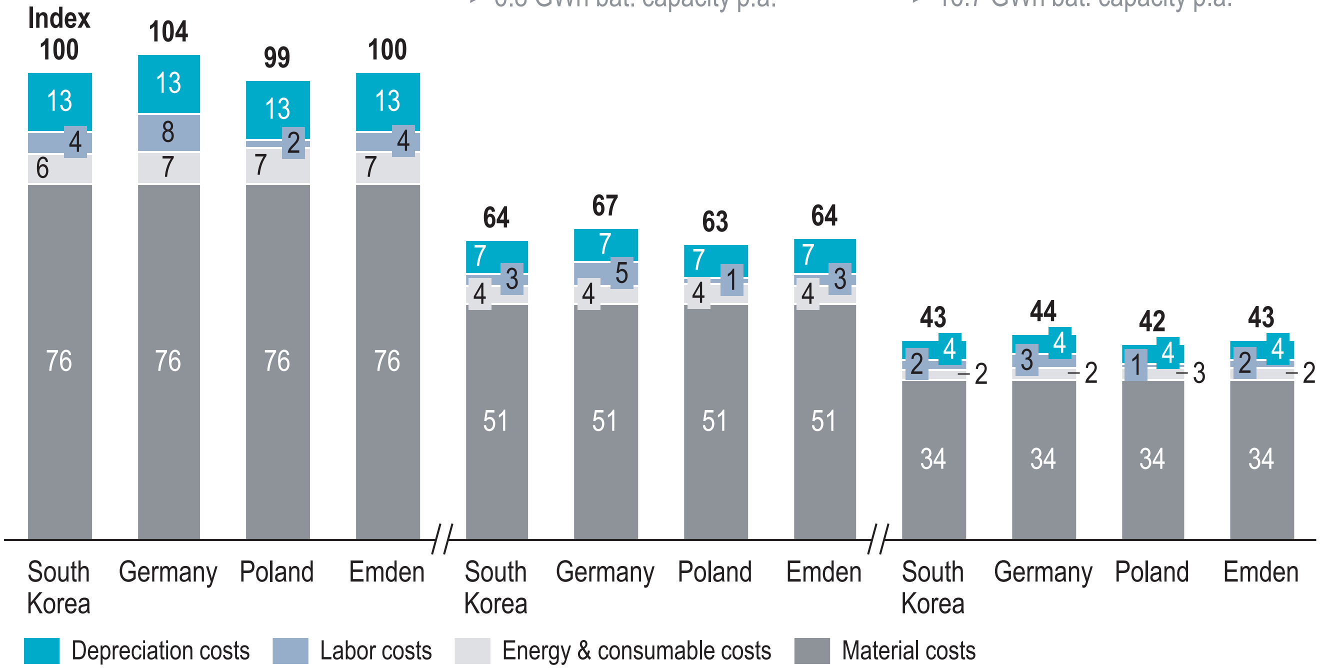
- Small production: 22 m cells p.a..
- 3.3 GWh bat. capacity p.a.

Gen 2b
Pouch cell with 66Ah with NCM622

- Mid size production 28 m cells p.a.
- 6.8 GWh bat. capacity p.a.

Gen 3a
Pouch cell with 89Ah with NCM811

- Large scale production: 50 m cells p.a.
- 16.7 GWh bat. capacity p.a.



1) Excl. logistic costs – From South Korea approx. 1.5-2 EUR/kWh

Source: City of Emden, Eurostat, KEPCO, KOGAS, Economist Intelligence Unit, Roland Berger

Insights

- A Gen 2a production with about 22 m cells per year in South Korea is set to 100 as index

- A battery production will base worldwide on the same process and materials inputs.
- Thus material costs and depreciation for machines are per technology choice on the same level.

- Electricity cost are in general highly volatile and influence approx. 7 % of battery costs
- Since Emden has direct access to renewable energy power generation, there is no need for an electricity transfer and a low carbon footprint can be achieved

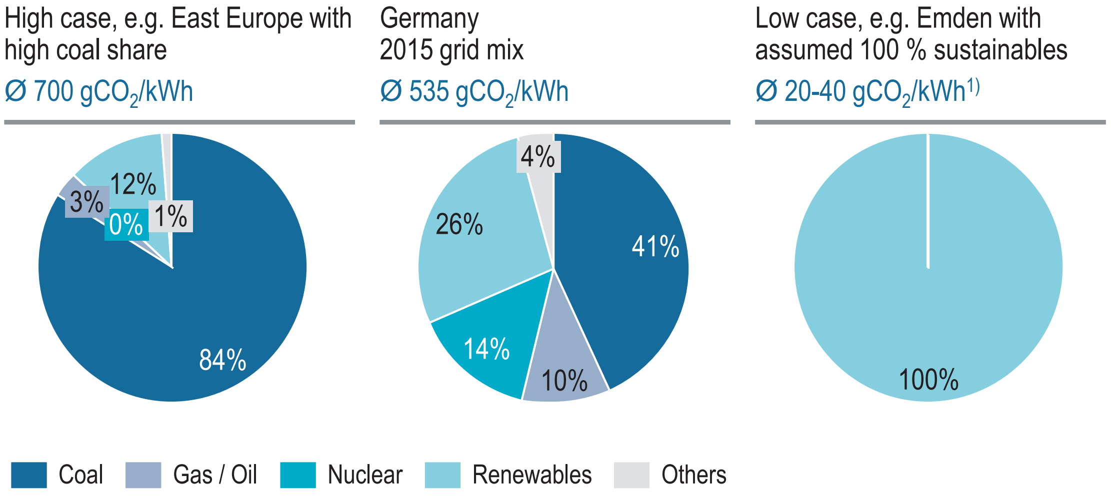
- Labor costs are cheapest in East Europe
- Emden is slightly less cost intensive than Germany

Emden's industry ecosystems provides access to sustainable energy and thus guarantees a low carbon production footprint

Exemplary calculation for a large scale battery cell plant

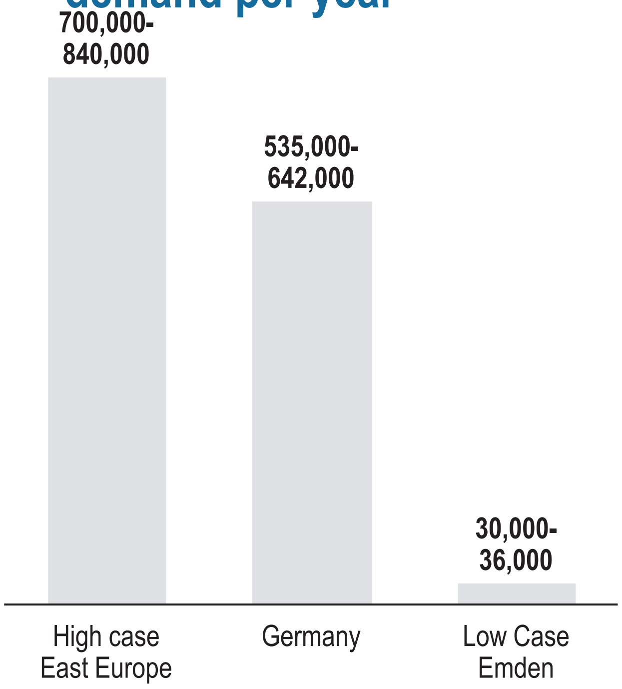
Energy demand and grid mix by region

- A mass production line with today's production standards for an output of **15 GWh/a** battery cell storage capacity **needs ca. 1,000 - 1,200 GWh of electricity per year**. Expected advancements in production technology should significantly reduce the energy needed
- Therefore the grid mix of the electricity is essential for a sustainable carbon footprint of electric vehicles



Carbon Footprint

t CO_2 from electricity demand per year



1) CO2 equivalents for wind energy and water power generation

Source: Eurostat, Enerdata, UBA, Roland Berger

A low carbon production footprint of electrified vehicles is important to actually be green on the road

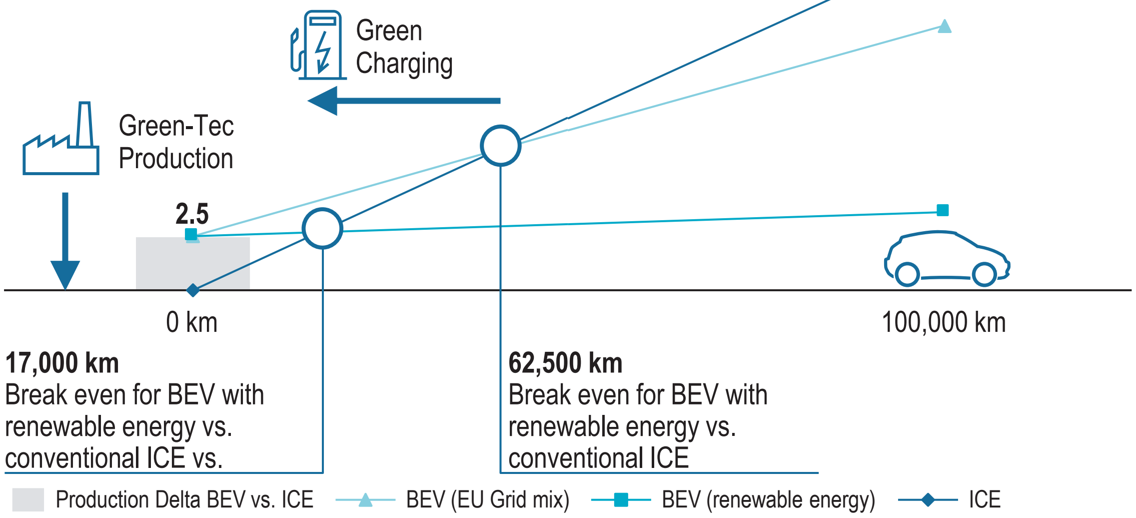
Exemplary Calculation [t CO_2 equivalent]

Life Cycle Perspective on BEV

Compared vehicles (Exemplary choice)

- 100 kW ICE, 1.6 l gasoline, manual gearbox, 160 gCO_2/km real driving emission
- 100 kW BEV, 55 kWh battery pack, 120 gCO_2/km (EU grid mix), 12 gCO_2/km (renewables mix)

Production > **Usage** > **(End of Life)**



17,000 km
Break even for BEV with renewable energy vs. conventional ICE vs.

62,500 km
Break even for BEV with renewable energy vs. conventional ICE

Source: Roland Berger

- The life cycle emission of an electric vehicle consist of all phases including production and end of life
- Thus, there are multiple ways to optimize the carbon footprint of an xEV:

Green-Tec

- A reduction of CO2 emission in the production can be achieved e.g. by using renewable energy for electricity and/ or power to gas

Green-Charging

- During the usage phase, the vehicle should be recharged with electricity from renewable energy

- The high energy demand for a Green-Tec production will require a localization of battery cell manufacturing close to renewable energy generation

C. Benchmarking of Emden in site analysis

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But besides sole cost drivers, also plenty of non-cost factors influence companies decision for a new manufacturing location

Roland Berger standard criteria set for site criteria

Basic country data

Political stability [Index]

Ease of doing business (rank 2015)

Corporate tax rates, 2015 [%]

Custom regulations

Energy prices [Ct./kWh]

Labor statistics

Labor costs [EUR/month]

Universities[1] [# of institutions]

Secondary/tertiary educ. [% of population]

Unemployment [%]

Manufact. employment [% of employees]

Population density [Inhab./km²]

Availability of workforce

Infrastructure data

Motorway density [km/1,000 km²]

Airport distance [km]

Power outages [Outages per month]

Industrial parks [#]

Political environment

Aid intensity [% maximum aid]

Local experience with industrial settlement

Location image

Industry specific statistics

Distance to relevant assembly plants [km]

Logistic infrastructure for sea, road and rail

Regional supplier base (raw materials/precursors, maintenance, contract workers

Average costs of new constructions of industrial facilities in the past

Presence of competitors or other automotive supplier

Focus of further discussion hard facts [quantifiable] soft facts [qualitative description]

[1] With technical focus

Source: Roland Berger

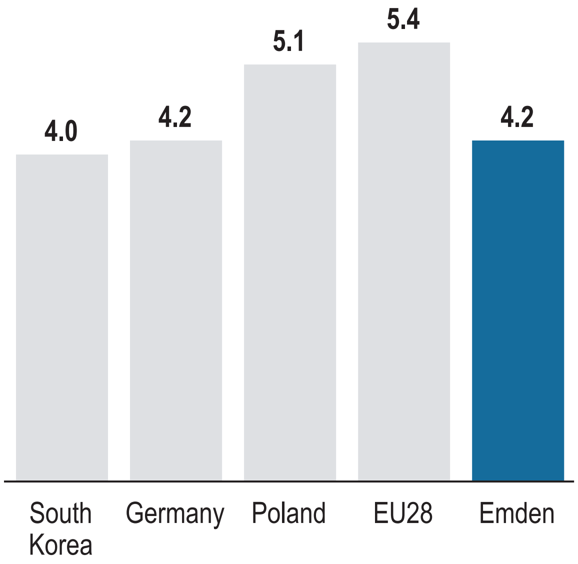
Energy prices are on a European competitive level and average labor costs on a slightly advanced level

Comparison on location specific energy and labor costs

Energy prices are highly volatile

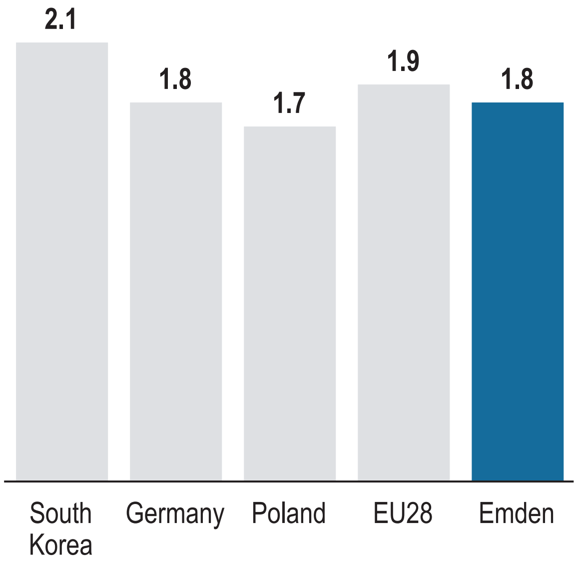
Ø Electricity prices [EUR ct/kWh][1)]

Consumer group IG: >150 GWh

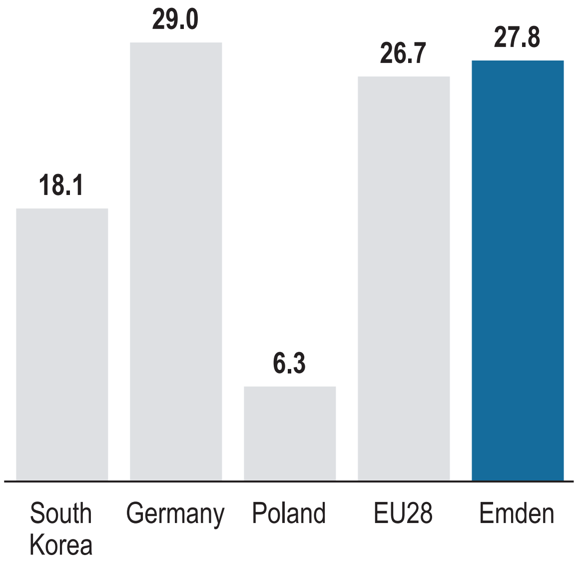


Ø Natural gas prices [EUR ct/kWh][1)]

Consumer group I4: 100 TJ – 1 PJ



Ø Employer costs [EUR/h]



- > Energy prices are highly volatile. Regional taxes and levies do apply for industrial consumers but could be dropped as an incentives for specific companies to create working places in a region
- > Prices for industrial large consumers are usually based on complex models and are individually negotiated

- > Average wages per hour cover all industries, as such industry specific differences might occur

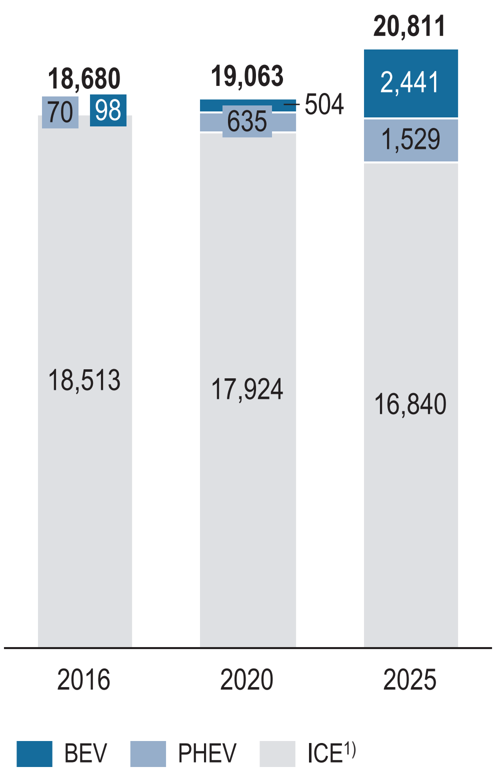
1) Base prices incl. network charges for Q1/2016 without taxes as a reference for comparison

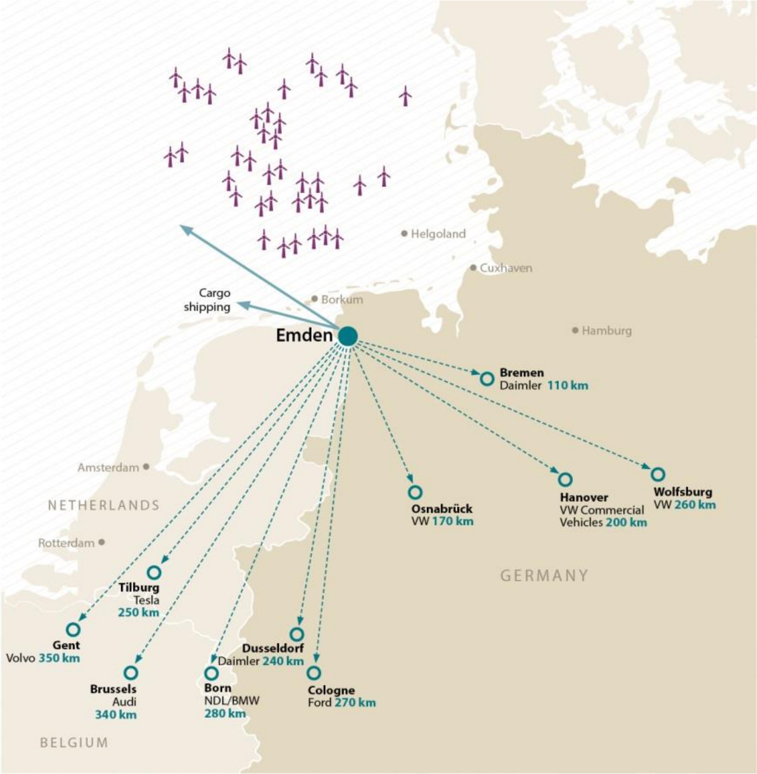
Source: KEPCO, KOGAS, WEO, Eurostat; Oxford Economics Global Economic Database

With its central European position, Emden can target up to 13 % of the European vehicle production as hub for battery cells

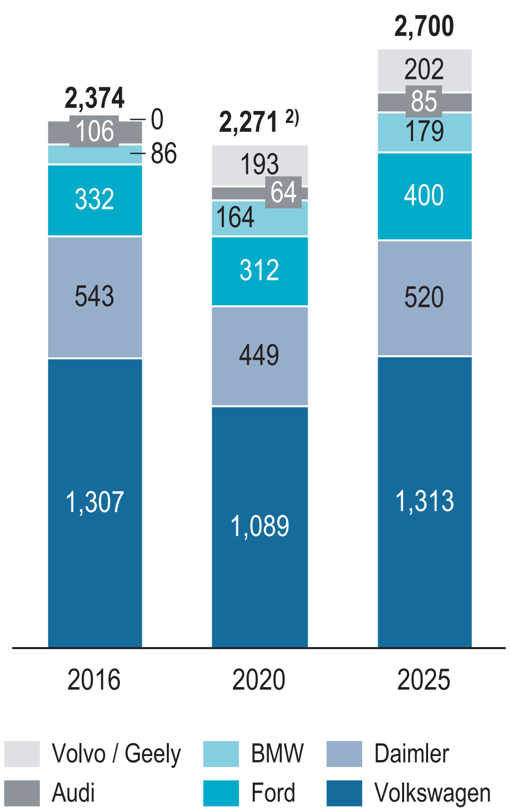
European vehicle production [2016-2025; '000 units p.a.]

Vehicle production in EU28





Target production from Emden



1) Incl. Full hybrids and mild hybrids 2) Decrease in volume due to vehicle model change in production plants

Source: IHS; Roland Berger

Its central European location and access to renewable energies make Emden an ideal place for low emission battery cell production

Soft factors supporting industrial localization in Emden

GUARANTEED SUSTAINABILITY

Up to 300 GWh/year energy consumption can be supplied by 100% renewables

Renewable energy sources already cover all of Emden's electricity needs – and will continue to do so in future. Links to **offshore wind farms** in the North Sea deliver a reliable and sustainable supply of electricity from wind power.

Future potential:

CARBON-NEUTRAL GAS SUPPLY

600 tons gas supply per year is available in Emden

The Norpipe plugs Emden straight into what is easily Europe's largest reserve of natural gas in Norway. The Norwegian Europipes 1 and 2 likewise end in neighboring Dornum. A gas supply of up to 50 tons a month is thus possible by the local high-pressure grid. **In addition, optional CO2 certificates allow gas to be consumed with a zero carbon footprint.**

Source: City of Emden

Roland
Berger