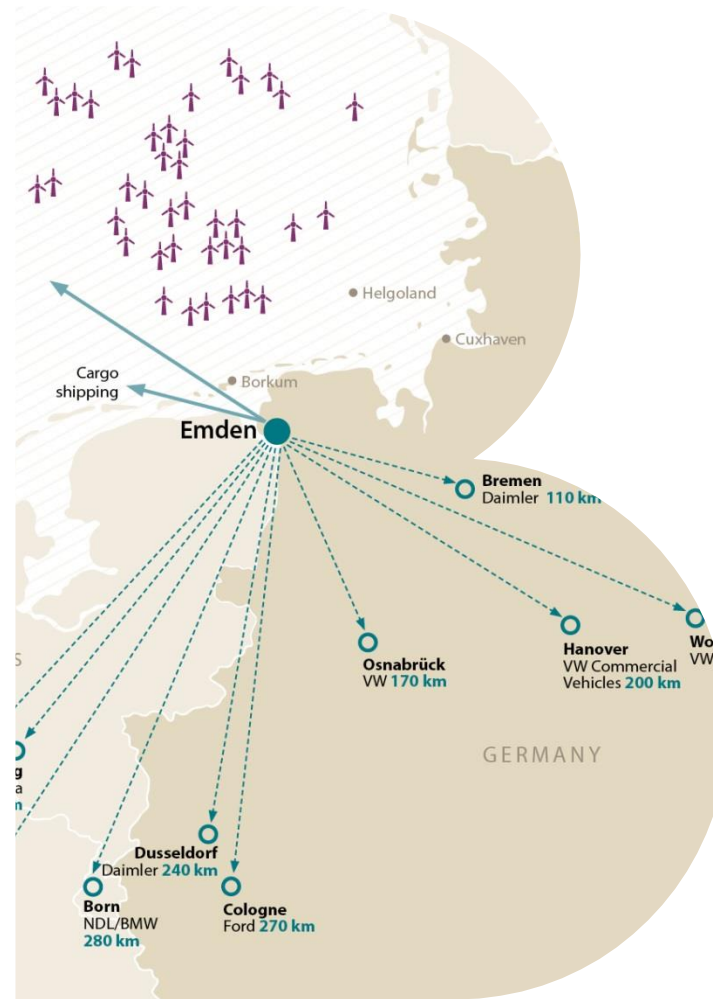


# Site analysis battery cell production for region of Emden

Project documentation

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EMDEN



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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 electrification<sup>1)</sup>

## 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<sub>2</sub> fleet emission targets (EU)
  - Fuel efficiency targets (CAFE)
- > R&D support for xEV technologies
- > Corporate emission/fuel consumption targets

## 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)

**EXPECTED  
MARKET  
DEVELOPMENT  
FOR EVs AND  
PHEVs**

Regionally  
dominating  
factor



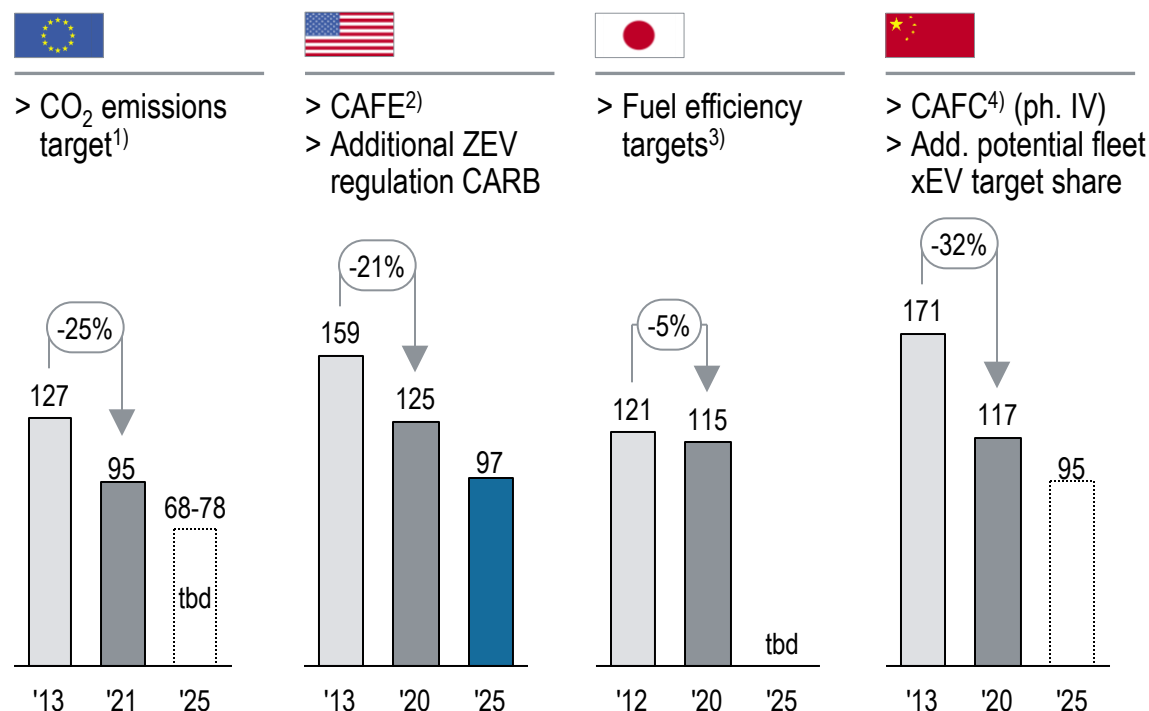
<sup>2)</sup>

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








# 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<sub>2</sub>)



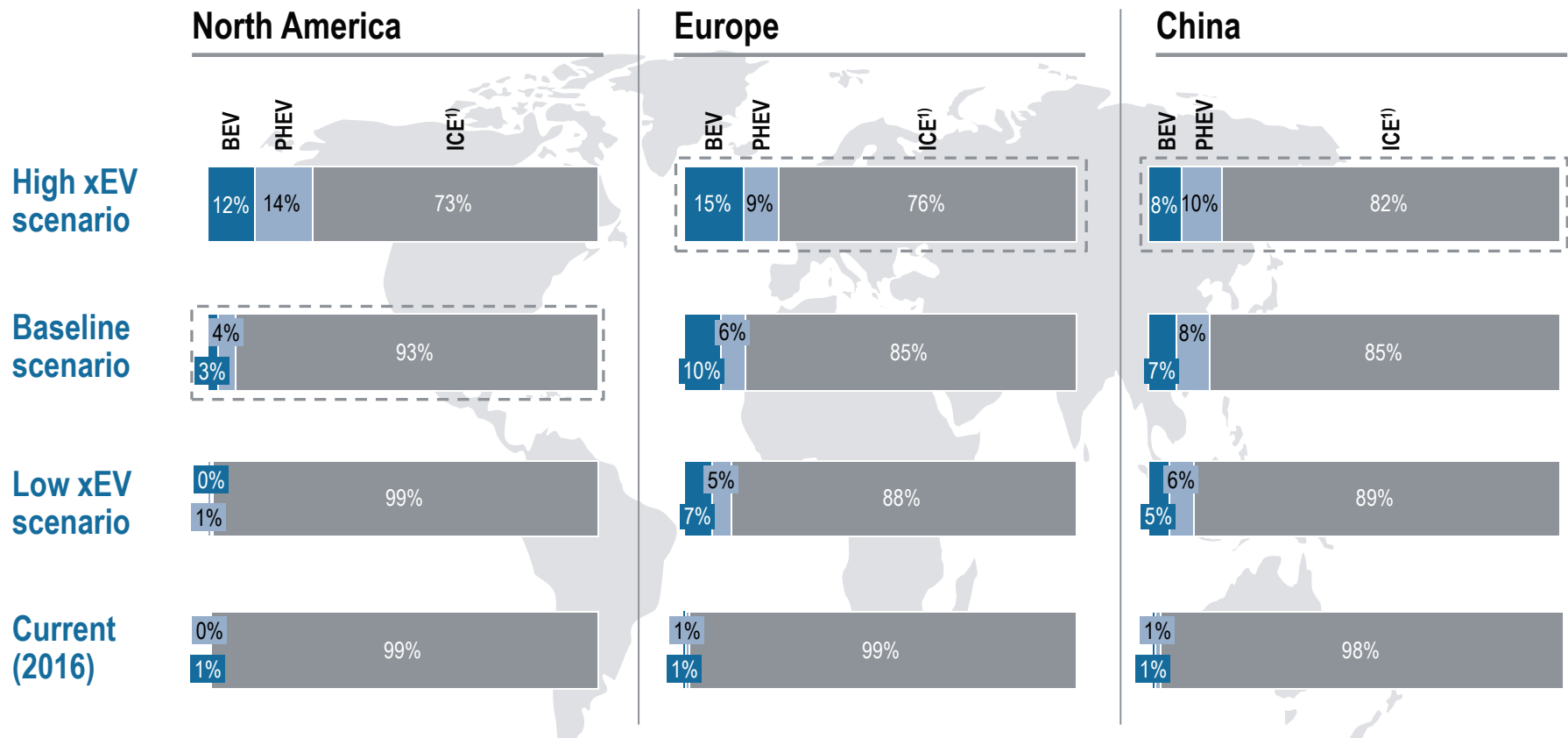
### Toxic emissions (NO<sub>x</sub>, PM, HC, ...)


-  > 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

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

# 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

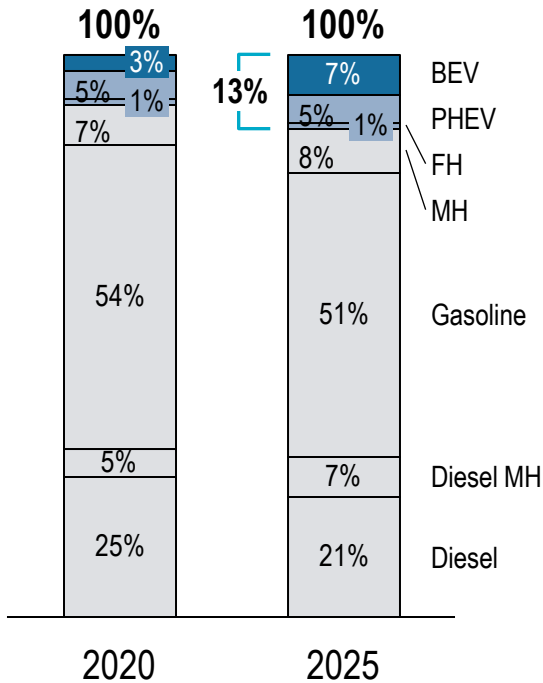
1) Including fully, mild and micro hybrid vehicles

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

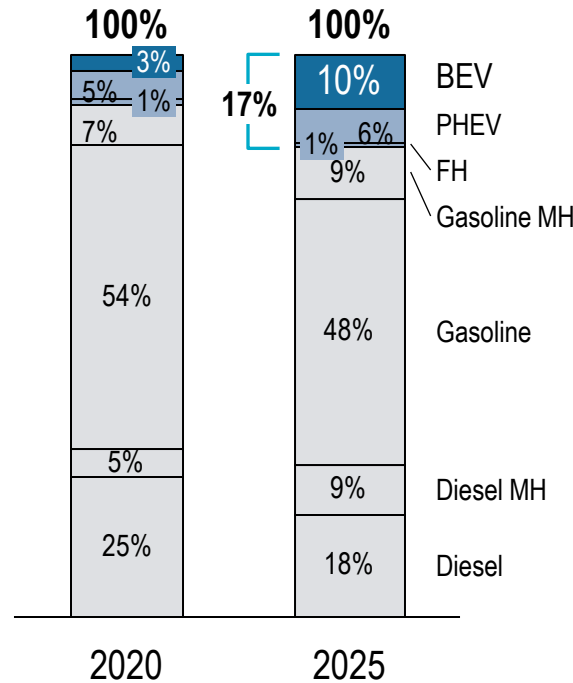
EU propulsion share 2020/2025 [% of sales]



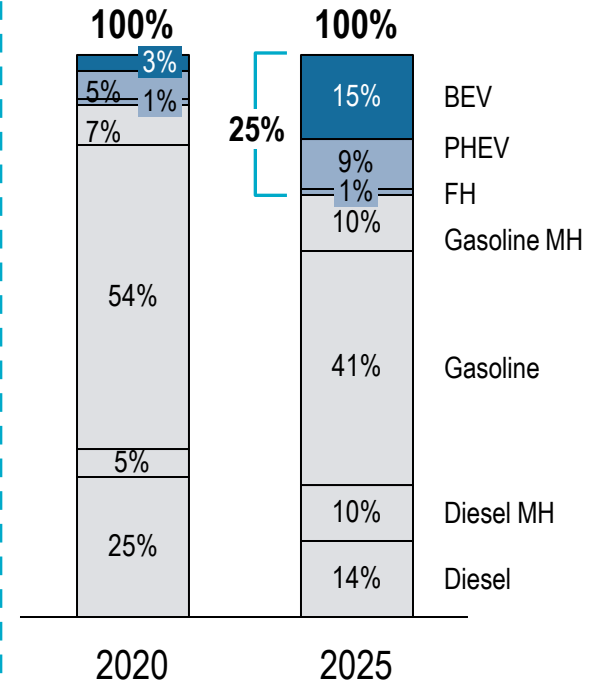
**Low case**  
(85 g CO<sub>2</sub> /km in 2025)



**Mid case**  
(81 g CO<sub>2</sub> /km in 2025)



**High case**  
(75 g CO<sub>2</sub> /km in 2025)



Most likely scenario

# 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 | <b>Regulatory push</b> | ○ > 130 g corporate CO <sub>2</sub> target       | ● > 95 g corporate CO <sub>2</sub> target                         | ● > 75 g corporate CO <sub>2</sub> target   |
|           | <b>Customer pull</b>   | ◐ > Subsidies in a selected numbers on countries | ◐ > Limited subsidies<br>> First city access limitation s for ICE | ◐ > Many metropolis regions with access limitation for ICE<br>> ICE ban in Norway |
| Mid case  | <b>Regulatory push</b> | ○ > 130 g corporate CO <sub>2</sub> target       | ● > 95 g corporate CO <sub>2</sub> target                         | ● > 81 g corporate CO <sub>2</sub> target (100% vehicle with 75g target in 2027)  |
|           | <b>Customer pull</b>   | ◐ > Subsidies in a selected numbers on countries | ◐ > Limited subsidies<br>> First city access limitation s for ICE | ◐ > Few metropolis regions with access limitation for ICE<br>> ICE ban in Norway  |
| Low case  | <b>Regulatory push</b> | ○ > 130 g corporate CO <sub>2</sub> target       | ● > 95 g corporate CO <sub>2</sub> target                         | ◐ > 85 g corporate CO <sub>2</sub> target (75g target in 2030)                    |
|           | <b>Customer pull</b>   | ◐ > Subsidies in a selected numbers on countries | ◐ > Limited subsidies<br>> First city access limitation s for ICE | ◐ > Only small cities access limitation for ICE<br>> No ICE ban                   |

● Very strong driver for shift towards E-Mobility



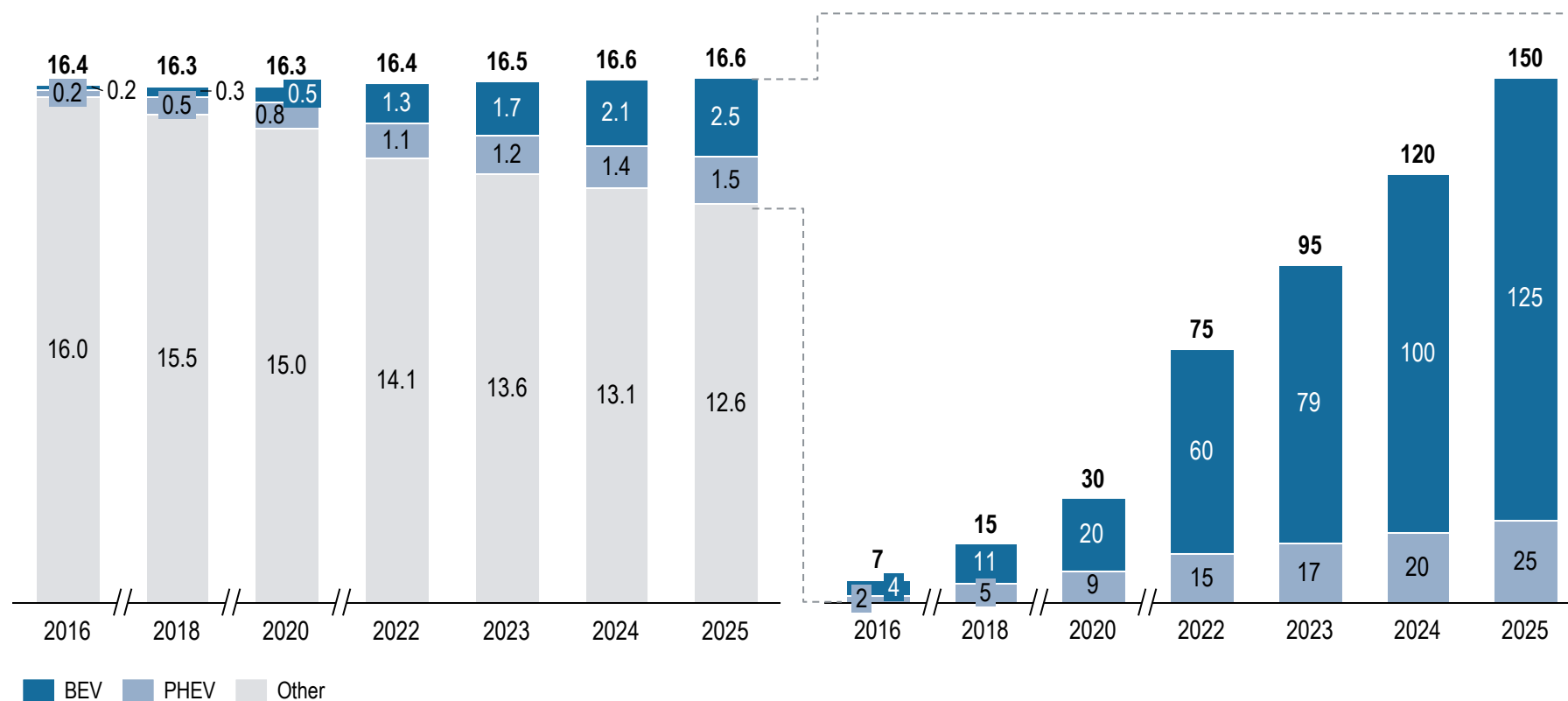
# European xEV sales will significantly grow until 2025 and will cause a large scale local production of battery cells

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



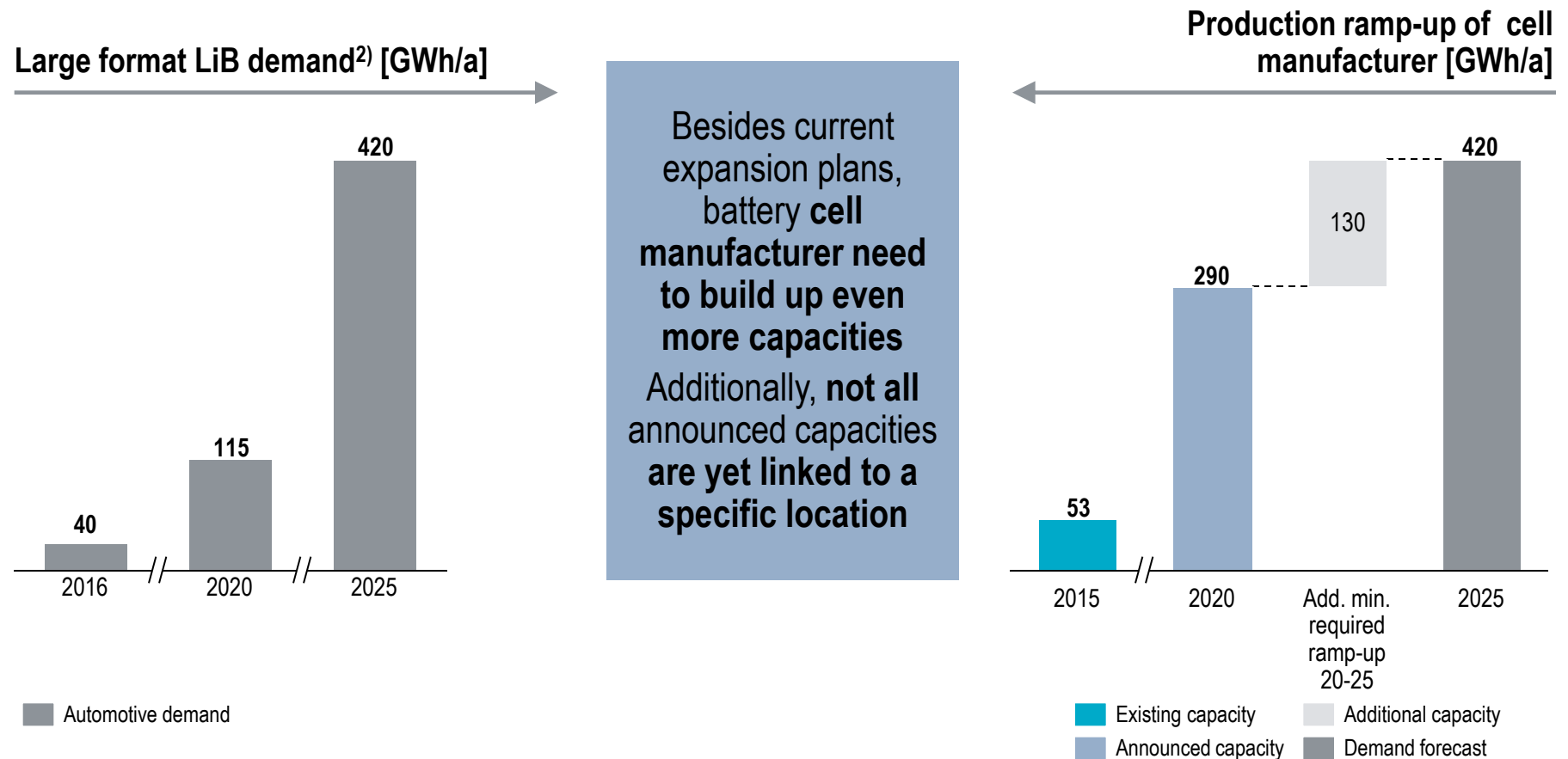
New vehicle sales by powertrain share [units m/a]

Cell capacity demand [GWh/a]



# 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<sup>1)</sup> [2016-2025]



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

# 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*

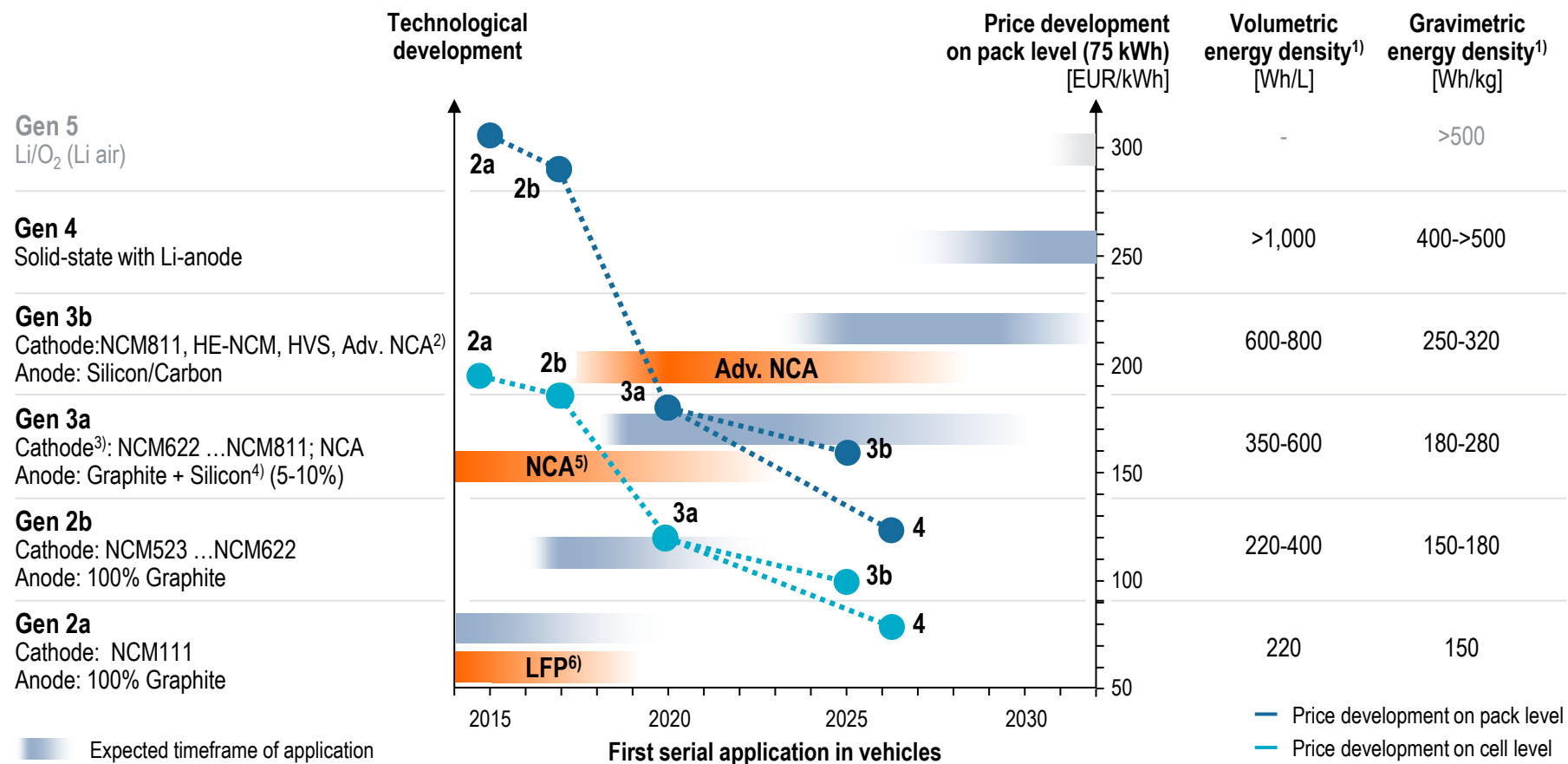
## B. Battery technology and cost analysis

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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



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

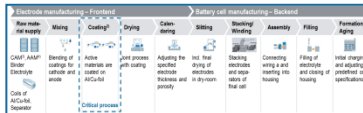
- Invest for frontend, backend, building
- Electrode materials
- Other cell material costs

### Battery cost model

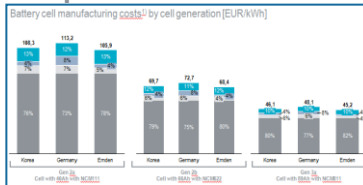
Input



Modeling



Output / Calculation



### Location dependent assumptions



#### > Electricity costs

- Key sources: City of Emden, Eurostat, KEPCO



#### > Natural gas costs

- Key sources: City of Emden, Eurostat, KOGAS

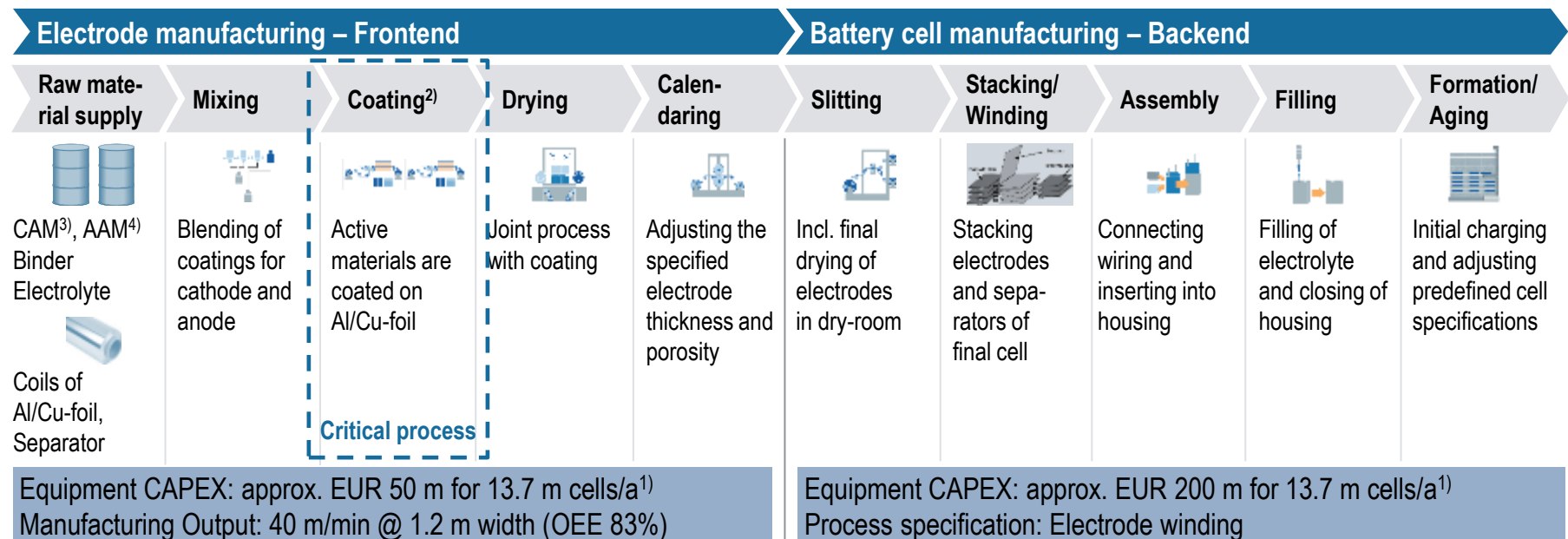


#### > Employer costs

- Key sources: City of Emden, Eurostat, Economist Intelligency Unit

# 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



> **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

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

## Bottom up battery cell manufacturing costs<sup>1)</sup> [South Korea = 100]

### Gen 2a Pouch cell with 40Ah with NCM111

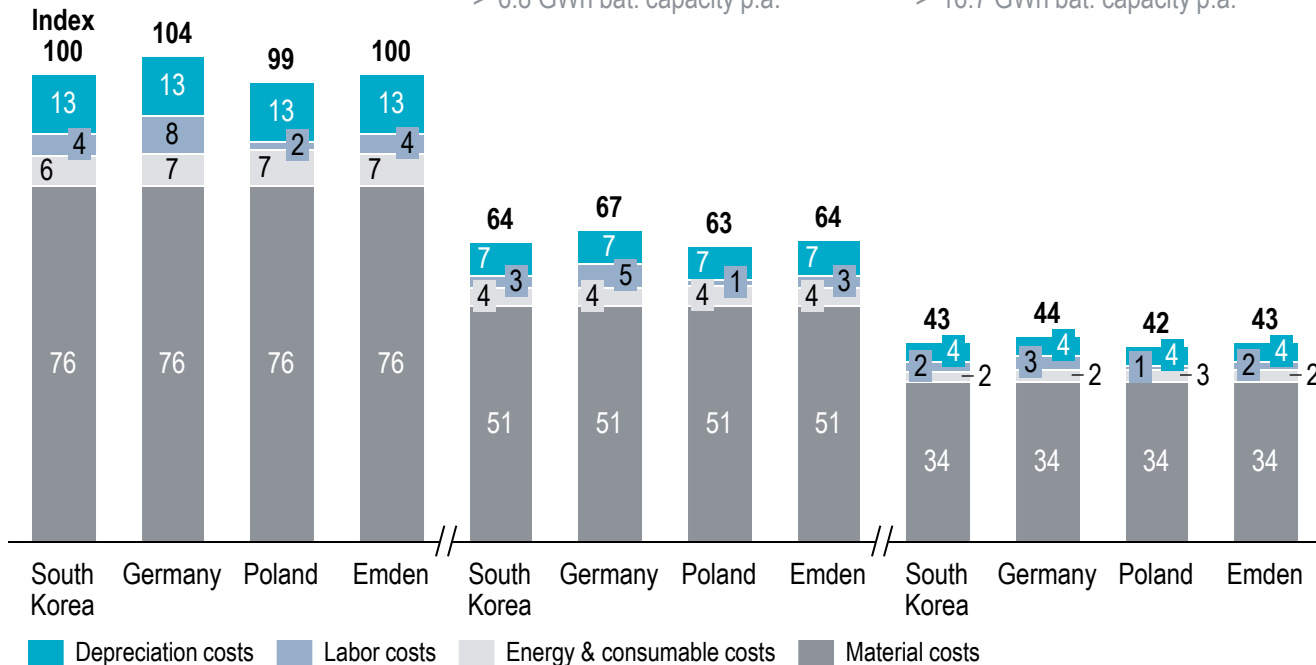
- > Small production: 22 m cells p.a.
- > 3.3 GWh bat. capacity p.a.

### 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.



### 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

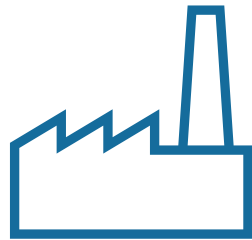
1) Excl. logistic costs – From South Korea approx. 1.5-2 EUR/kWh



# 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

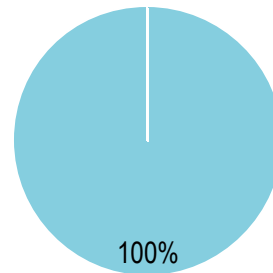
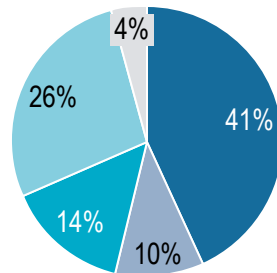
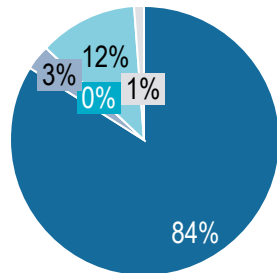


- > A mass production line with today's production standards for an output of **15 GWh/a** battery cell storage capacity **needs ca. 1,000 - 1,200 GWh of electricity per year**. Expected advancements in production technology should significantly reduce the energy needed
- > Therefore the grid mix of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

High case, e.g. East Europe with high coal share  
Ø 700 gCO<sub>2</sub>/kWh

Germany 2015 grid mix  
Ø 535 gCO<sub>2</sub>/kWh

Low case, e.g. Emden with assumed 100 % sustainables  
Ø 20-40 gCO<sub>2</sub>/kWh<sup>1)</sup>



■ Coal ■ Gas / Oil ■ Nuclear ■ Renewables ■ Others

1) CO2 equivalents for wind energy and water power generation

### Carbon Footprint t CO<sub>2</sub> from electricity demand per year



700,000-840,000

535,000-642,000

30,000-36,000

High case  
East Europe

Germany

Low Case  
Emden

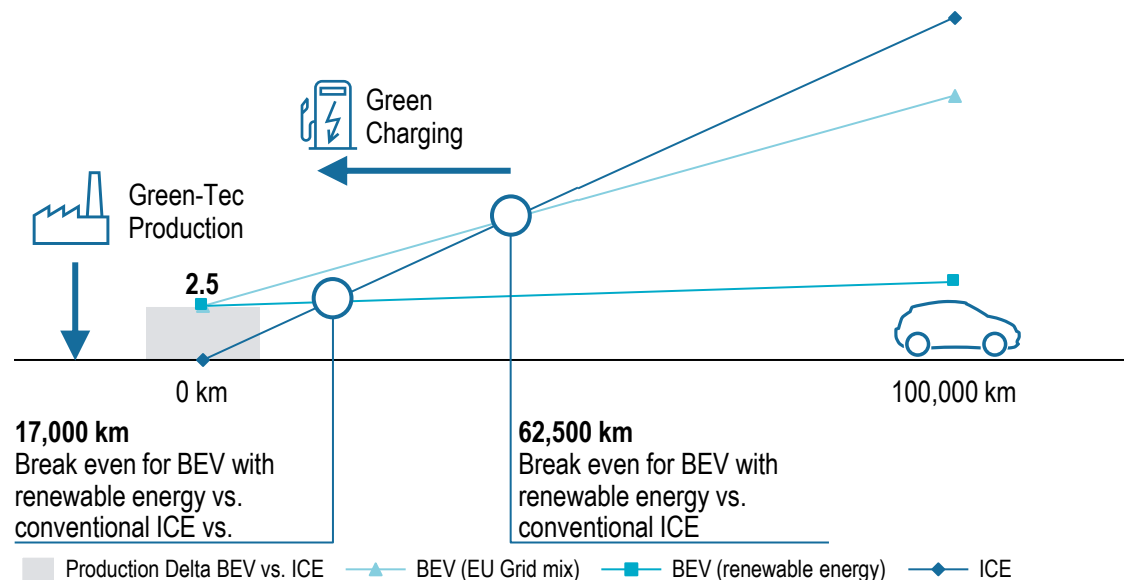
# A low carbon production footprint of electrified vehicles is important to actually be green on the road

Exemplary Calculation [t CO<sub>2</sub> equivalent]

## Life Cycle Perspective on BEV

Compared vehicles (Exemplary choice)

- > 100 kW ICE, 1.6 l gasoline, manual gearbox, 160 gCO<sub>2</sub>/km real driving emission
- > 100 kW BEV, 55 kWh battery pack, 120 gCO<sub>2</sub>/km (EU grid mix), 12 gCO<sub>2</sub>/km (renewables mix)



- > 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 CO<sub>2</sub> 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

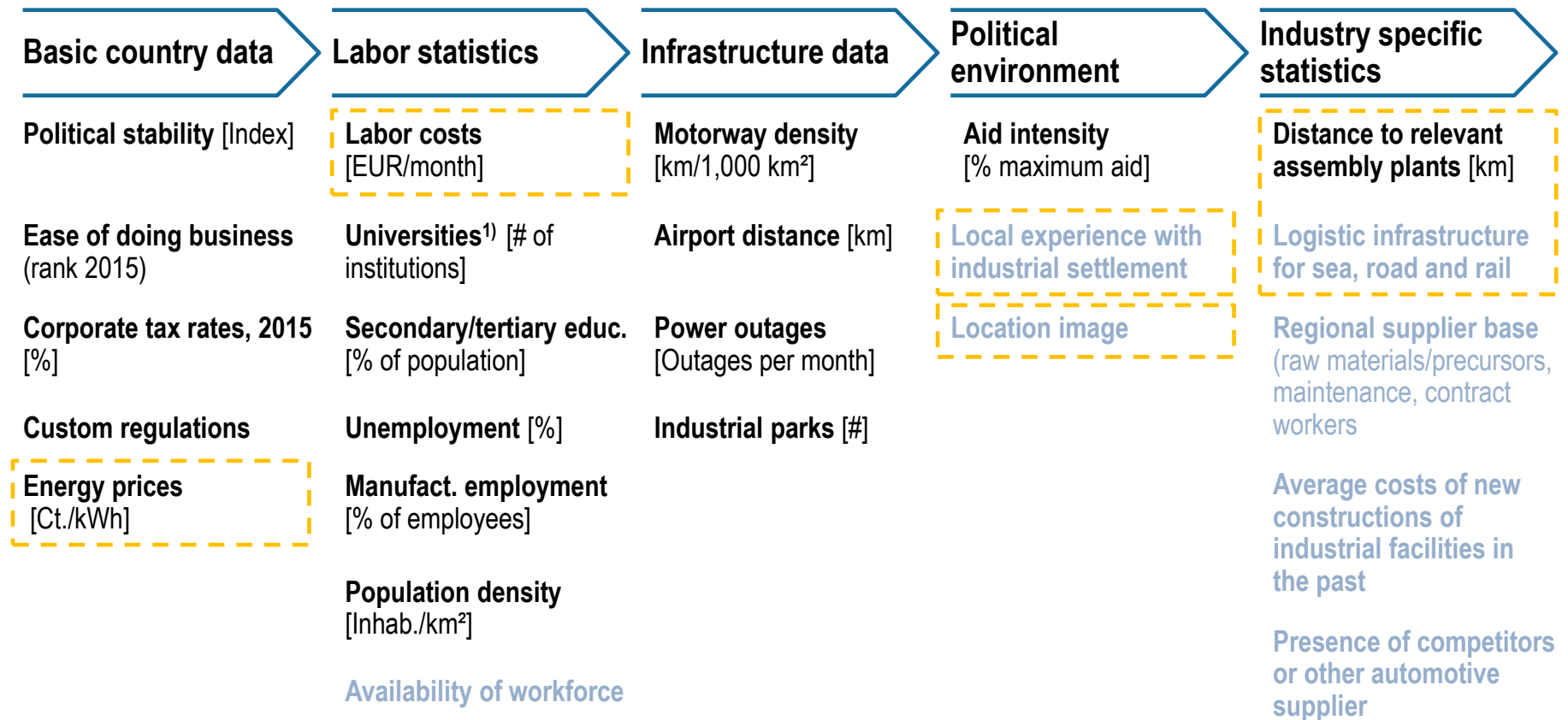
## C. Benchmarking of Emden in site analysis




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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



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

1) With technical focus

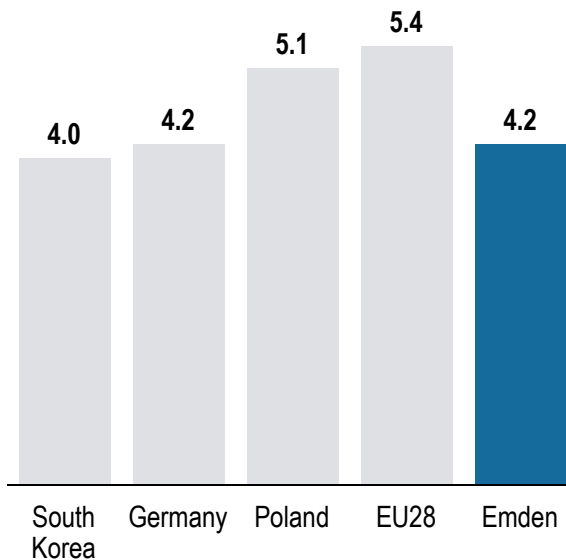
# Energy prices are on a European competitive level and average labor costs on a slightly advanced level

## Comparison on location specific energy and labor costs

Energy prices are highly volatile

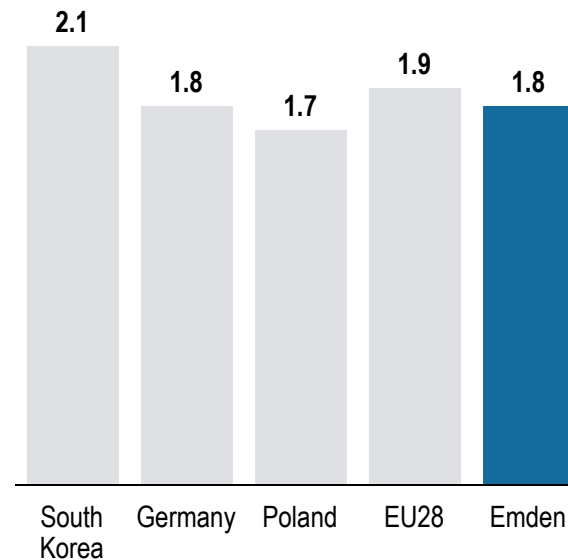
### Ø Electricity prices [EUR ct/kWh]<sup>1)</sup>

Consumer group IG: >150 GWh

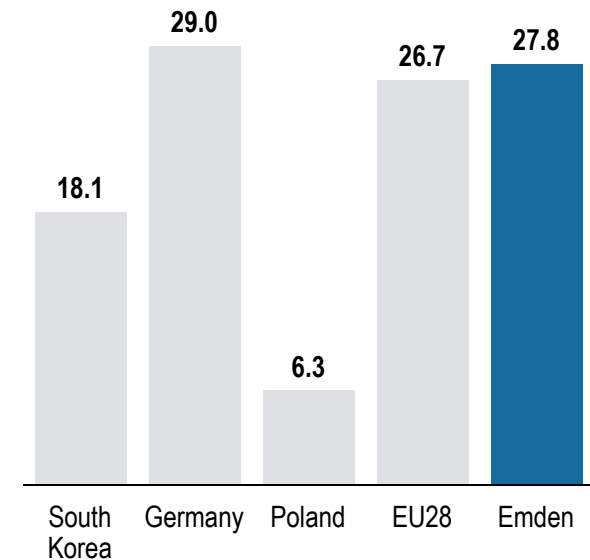


### Ø Natural gas prices [EUR ct/kWh]<sup>1)</sup>

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

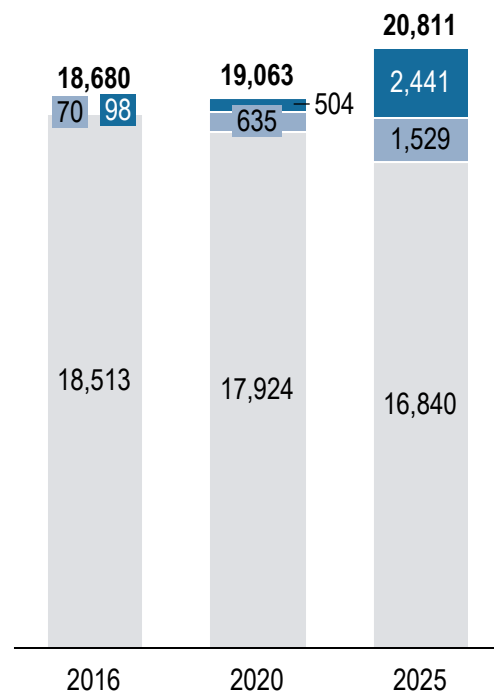
- > Average wages per hour cover all industries, as such industry specific differences might occur

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

# 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

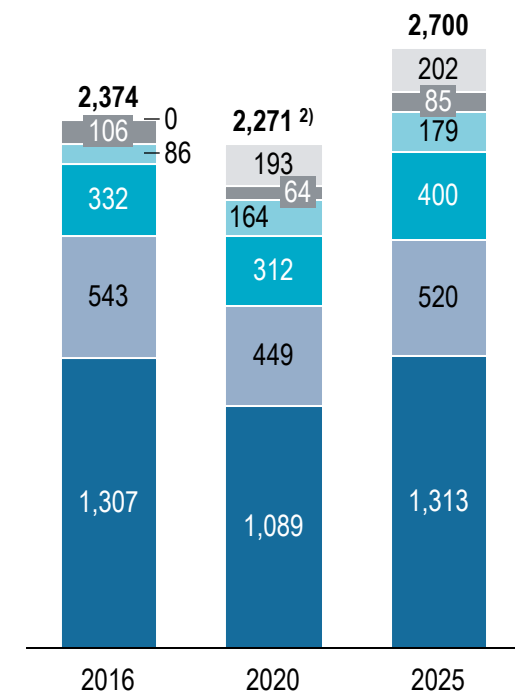


■ BEV ■ PHEV ■ ICE<sup>1)</sup>

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



## Target production from Emden



■ Volvo / Geely ■ Audi ■ Ford ■ Daimler ■ BMW ■ Volkswagen

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.

Roland  
Berger

