VOLKSWAGEN

AKTIENGESELLSCHAFT

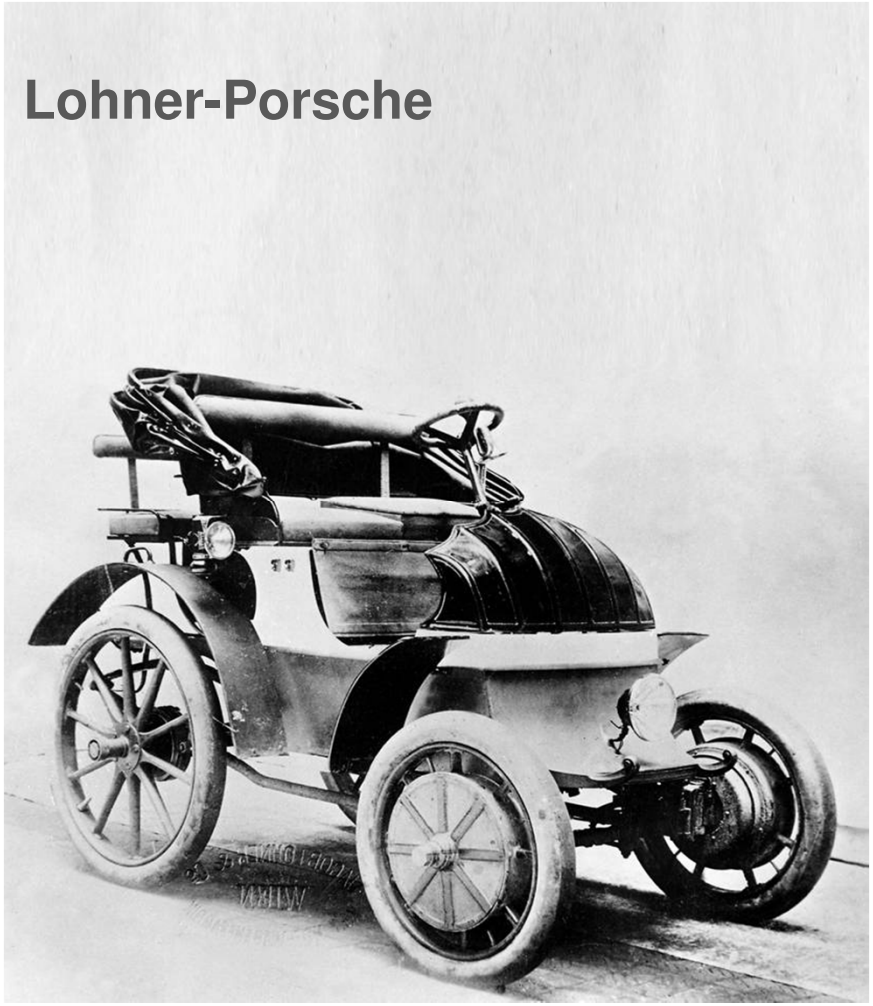
Electric Vehicles: Opportunities vs. Challenges

Prof. Dr. Jürgen Leohold, Group Research Volkswagen AG

Outline

- Driving factors for electromobility
- Competing drivetrain technologies
- Energy pathways
- Challenges and requirements for electric cars
- New business models and interaction with the power grid
- Design considerations for electric cars

First Electric Car by Ferdinand Porsche presented April 14th 1900 at the World Exhibition in Paris



2 wheel-hub electric motors

P_{max} = 2 x 7 PS

P_{rated} = 2 x 2.5 PS (at 120 rpm)

44 cells for a 300 Ah battery with 80 V

v_{max}= 50 km/h

Range 50 km

Electric brake in the front,
mechanical band brake in the rear

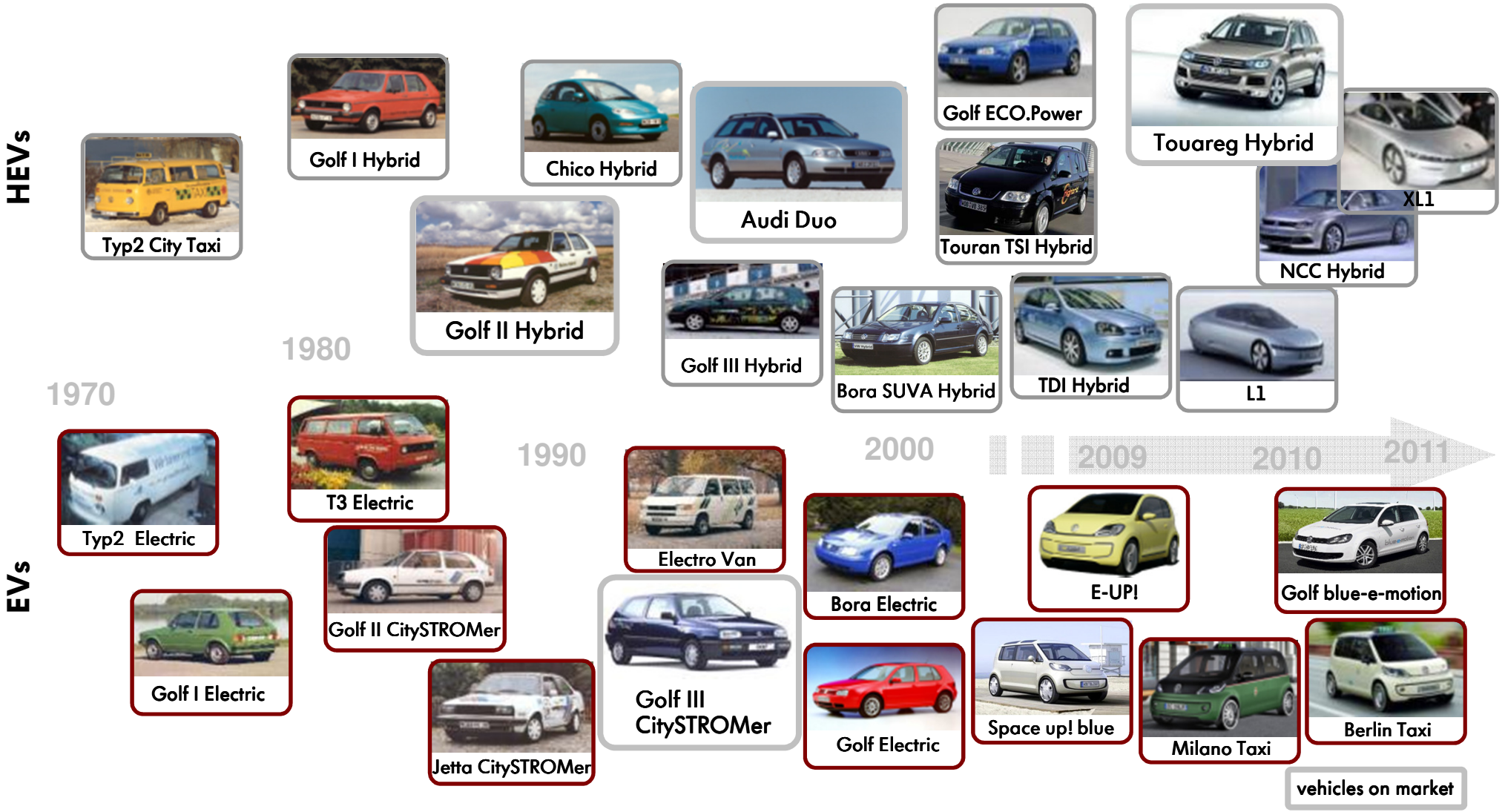
Total weight 980 kg

Battery weight 410 kg

1 front wheel 115 kg

Approx. 300 vehicles sold

Volkswagen History in Hybrid and Electric Vehicle Development



It´s Time for Electrification….

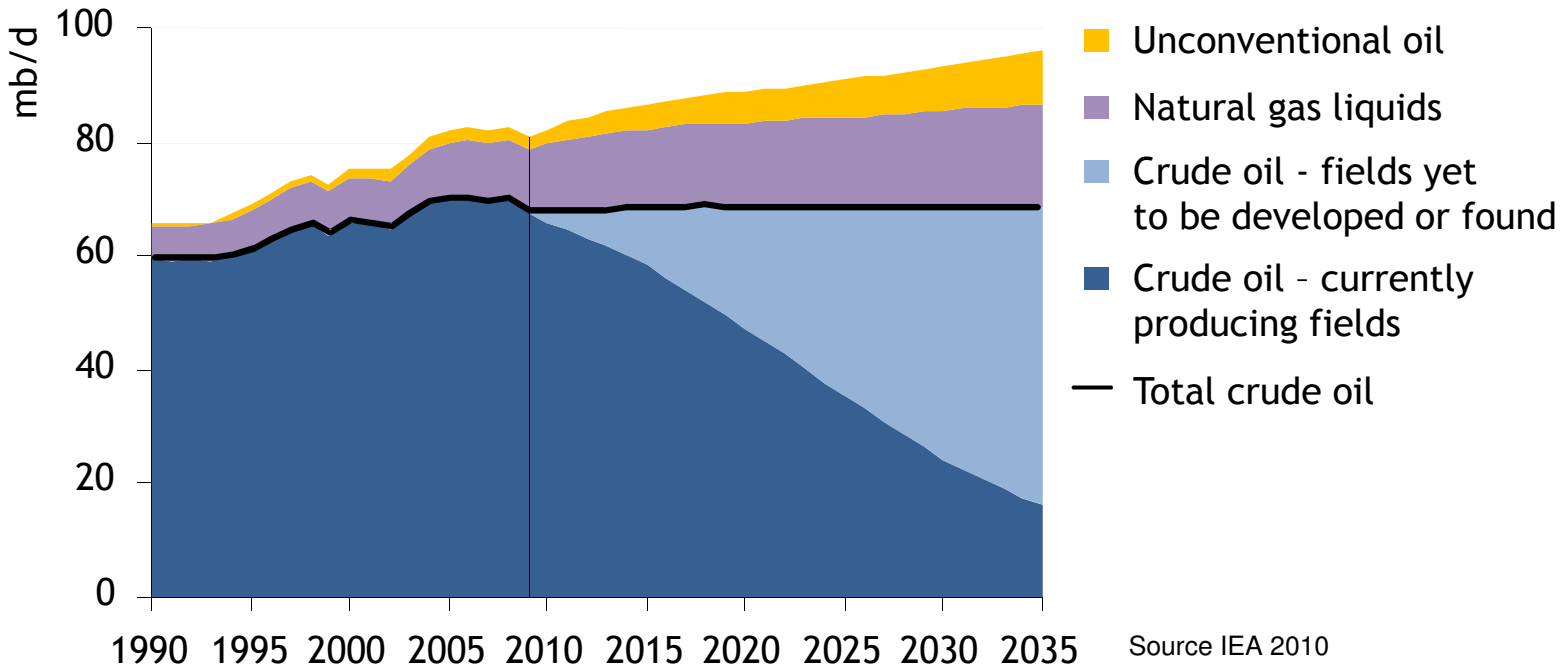
Climate Change – Emissions

Urbanization and Megacities

Shortage of Fossil Fuels

Global Oil Production - Forecast

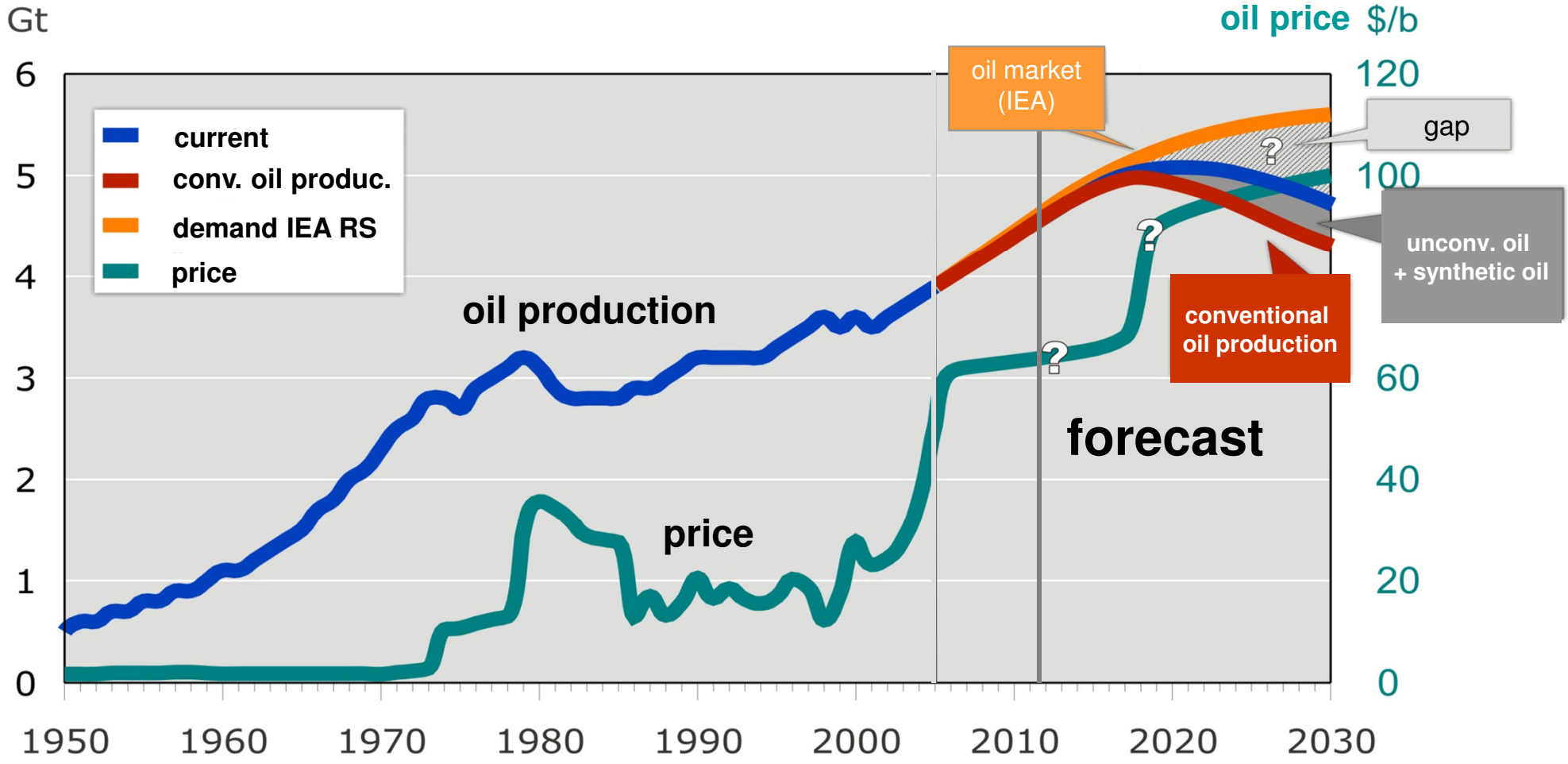
World oil production by type in the New Policies Scenario



Source IEA 2010

Global oil production reaches 96 mb/d in 2035 (including natural gas liquids & unconventional oil)

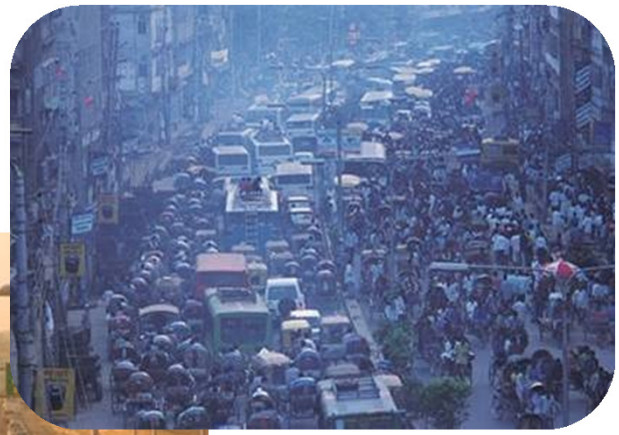
Impact of Availability on Price



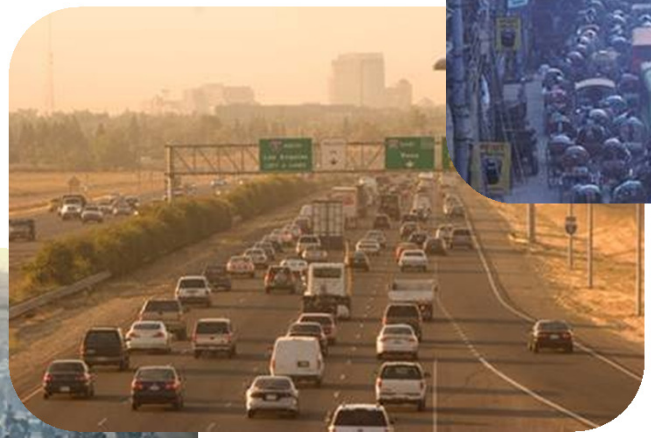
Source: BGR Bundesanstalt für Geowissenschaften und Rohstoffe
GEOZENTRUM HANNOVER

Environmental Impact

Air pollution & noise
have an impact on everyone …



Dhaka



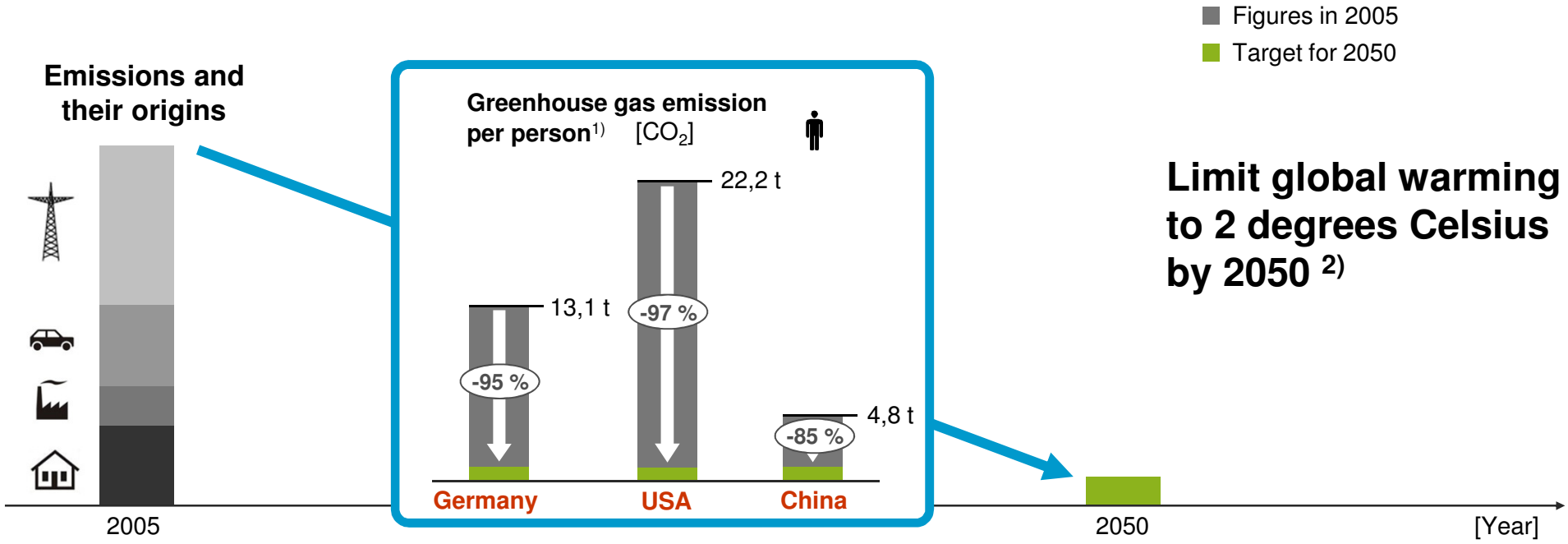
Sacramento

Bangkok

Los Angeles

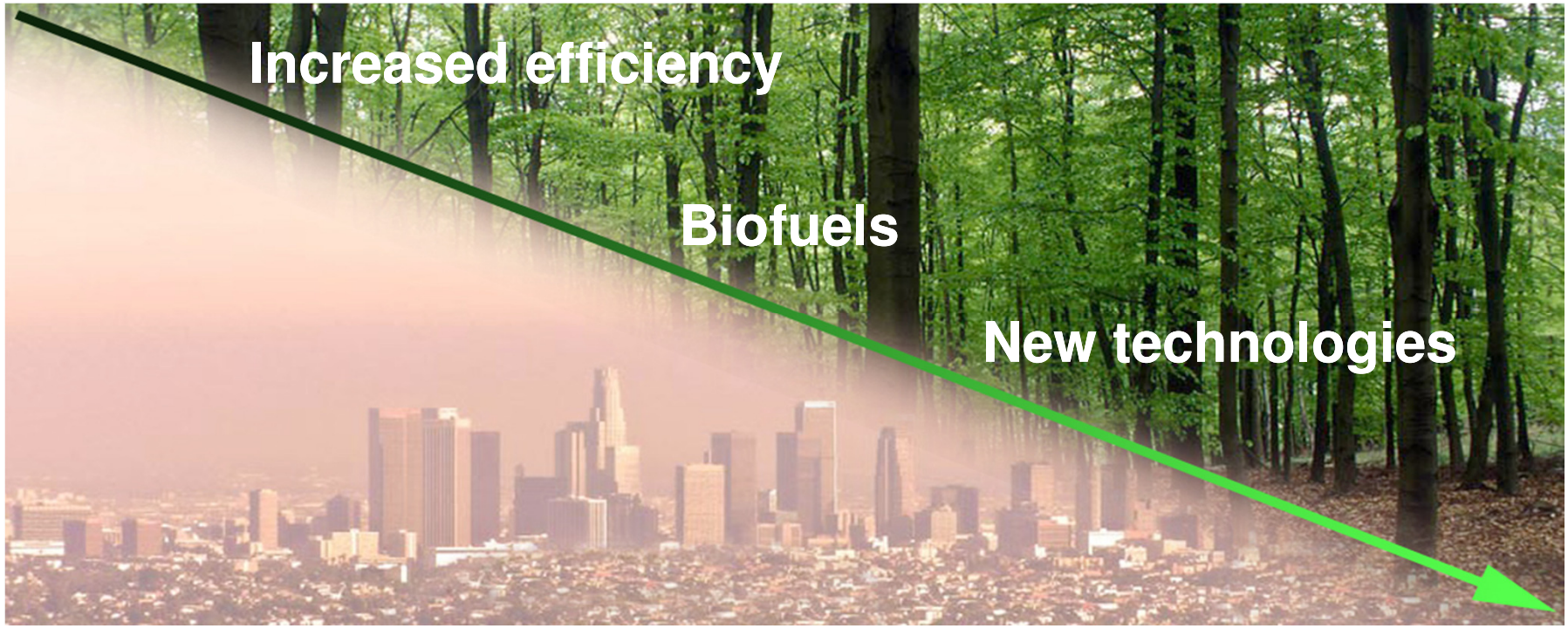
… everywhere !!!

Drastic steps are required to limit global warming…



1) Source: IPCC Fourth Assessment Report: Climate Change 2007, provided in part by McKinsey & Company
2) Political declaration of intent, e.g. by the EU and the G8+5 countries, part of the Copenhagen Accord 2009

The CO_2 Emission Challenge



TDI®,TSI® / TFSI® and DSG®:

basic building blocks of Volkswagen´s drivetrain strategy

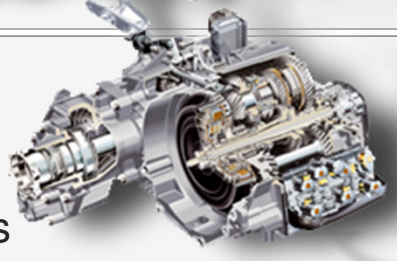
A modular vehicle architecture supports a variety of today's and future drivetrains

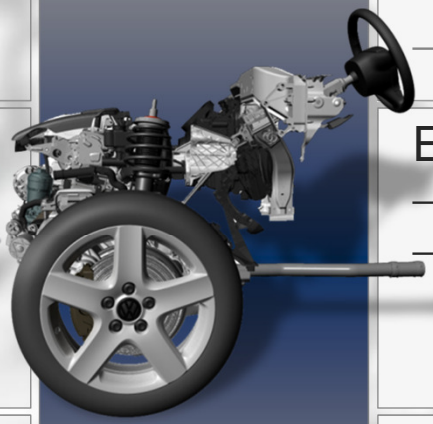
Conventional drivetrains

Gasoline engines
- TSI
- CNG
- LPG
- E85

Diesel engines
- TDI
- CleanDiesel
- Bi-TDI

Transmission
- DSG
- manual gearbox
- emerging Markets

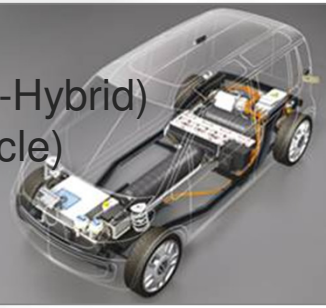




Alternative drivetrains

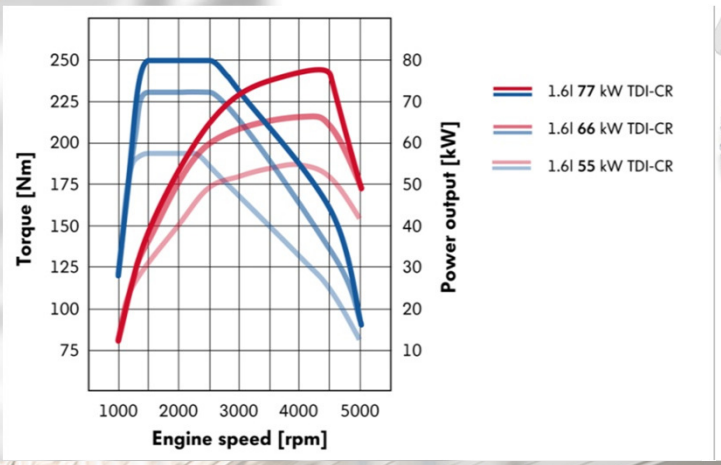
Hybrid
- µ-Hybrid
- Mild-Hybrid
- Full-Hybrid
- Plug In-Hybrid

Electricity
- TwinDrive (Plug In-Hybrid)
- BEV (Battery Vehicle)



Fuel Cell
- LT-PEM

The new 1.6l TDI engine from Volkswagen



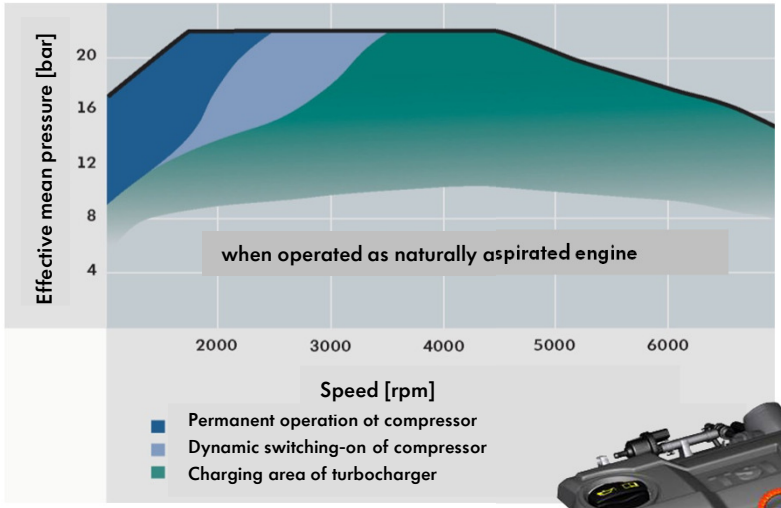
Vehicle results

Power output [kW] at [1/min]	55 * 4000	66 ** 4200	77 ** 4400
Torque [Nm] at [1/min]	195 1500 to 2000	230 1500 to 2500	250 1500 to 2500
Top speed [km/h]	170	178	189
Acceleration 0 - 100 km/h [sec]	14.0	12.9	11.3
Elasticity 80 - 120 km/h (4.G) [sec]	14.0	12.5	11.0
MVEG consumption [l/100 km]	4.2	4.5	4.5
CO_2 emissions [g/km]	109	118	119
Emissions standard [-]	EU5	EU5	EU5

* Polo ** Golf

New generation of fuel efficient engines: the 1.4l TSI engine

Monoturbo 90 kW
Twincharger 103 / 110 / 118 / 125 kW



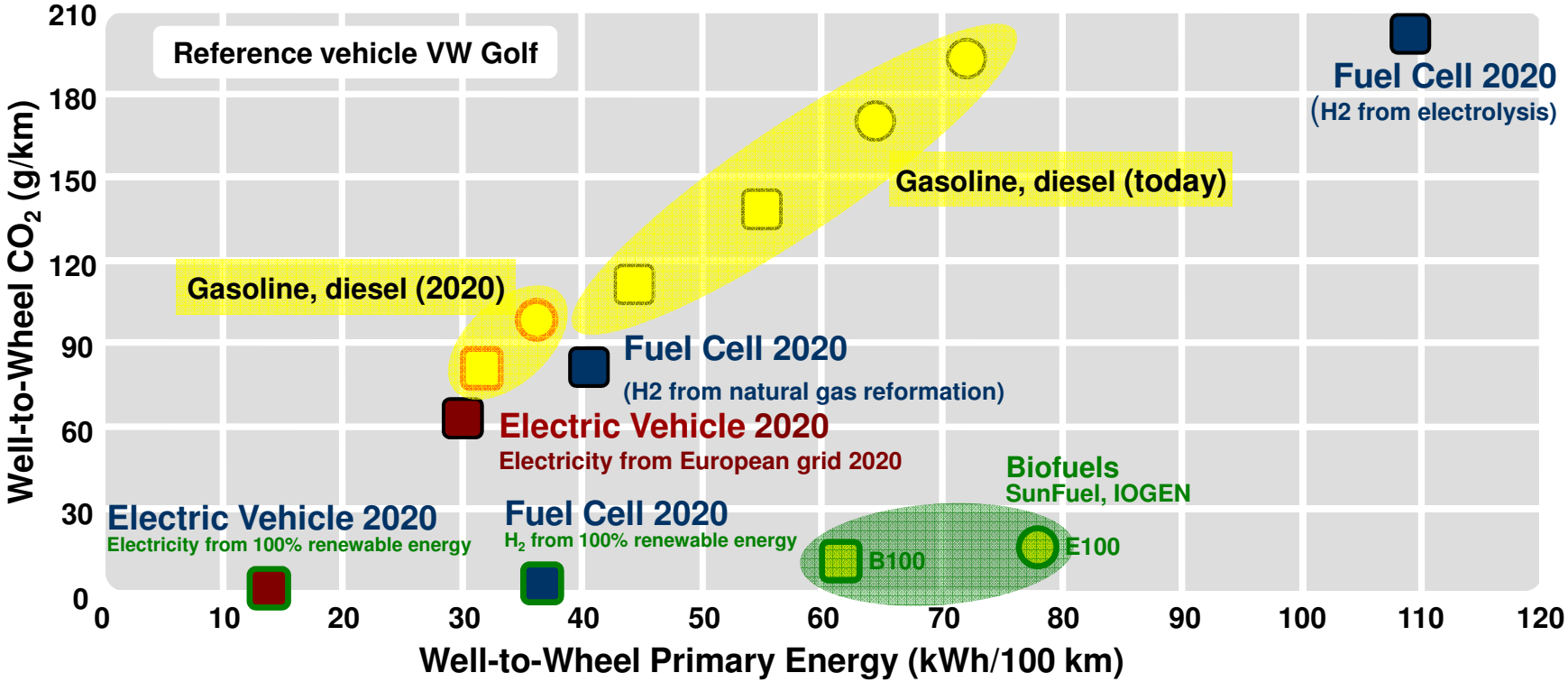
Germany

Paul-Pietsch-Preis für TSI-Entwicklung für Dr. Rudolf Krebs von Volkswagen	Feb. 2006 Stuttgart
"Auto-Umwelt-Zertifikat" für Golf 1,4 TSI	April 2007 Wuppertal
"Gelber Engel 2008" für die Technologie Kombination TSI-Motor und 7-Gang DSG	Jan. 2008 München

International

Best of What's new Award	Nov. 2005 New York
"Best New Engine of 2006" für das	
"International Engine of the Year Awards 2007"	Mai 2007 Stuttgart
Barcelona International Motor Show Awards 2007	Juni 2007 Barcelona
Technology of the Year 2008	Dez. 2007 Japan
Japan Car Of The Year Most Advanced Technology Award 2008	Dez. 2007 Japan
Sportauto 2007: TSI-Technologie im Golf GT	Jan. 2008 Moskau
What Car? Award 2008 - Best Small Family Car	Jan. 2008 London
"International Engine of the Year Awards 2008"	Mai 2008 Stuttgart
Energie- und Umweltpreis "Goldener Öltropfen"	Mai 2008 München
5 Sterne im ADAC Ecotest	April 2009 München
„International Engine of the Year Awards 2009"	Juni 2009 Stuttgart

Energy efficiency of different drivetrain/fuel combinations (until 2020)

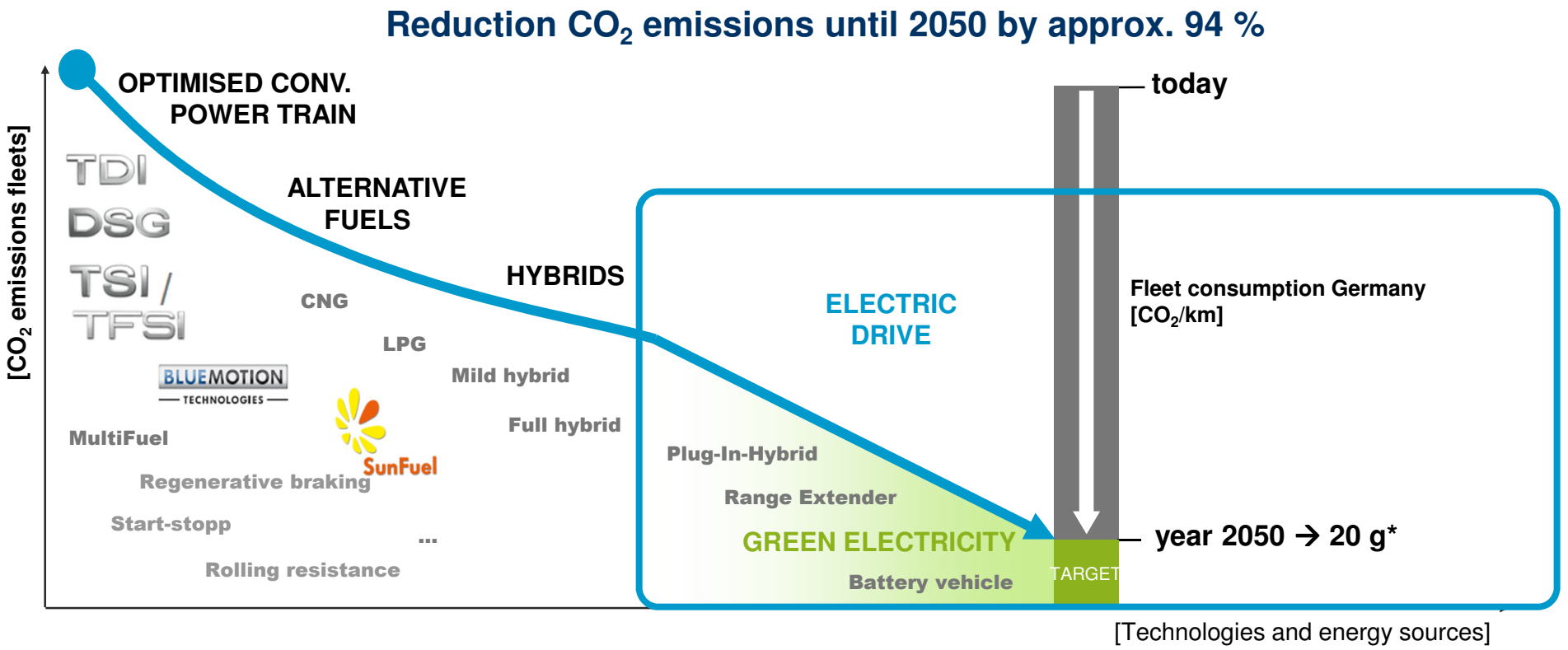


Consumption-optimized models in the Volkswagen Group

5 models	60 models	176 models
≤ 100 g CO_2/km	≤ 120 g CO_2/km	≤ 140 g CO_2/km

176 models ≤ 140 g CO_2/km

Conventional power train technologies do not suffice for the radical target „Limitation of a global warming to 2 °C until year 2050“



*Derived from the political target (Europe, G8 states) not to exceed global warming by more than 2 °C until the year 2050!

Source: EL

20 g CO_2 / km: it can be done!

XL1 PHEV:

- **0.9 l / 100 km**
- **Engine:**

  - 800 ccm TDI
  - 35 kW
  - 120 Nm
- **Electric motor:**

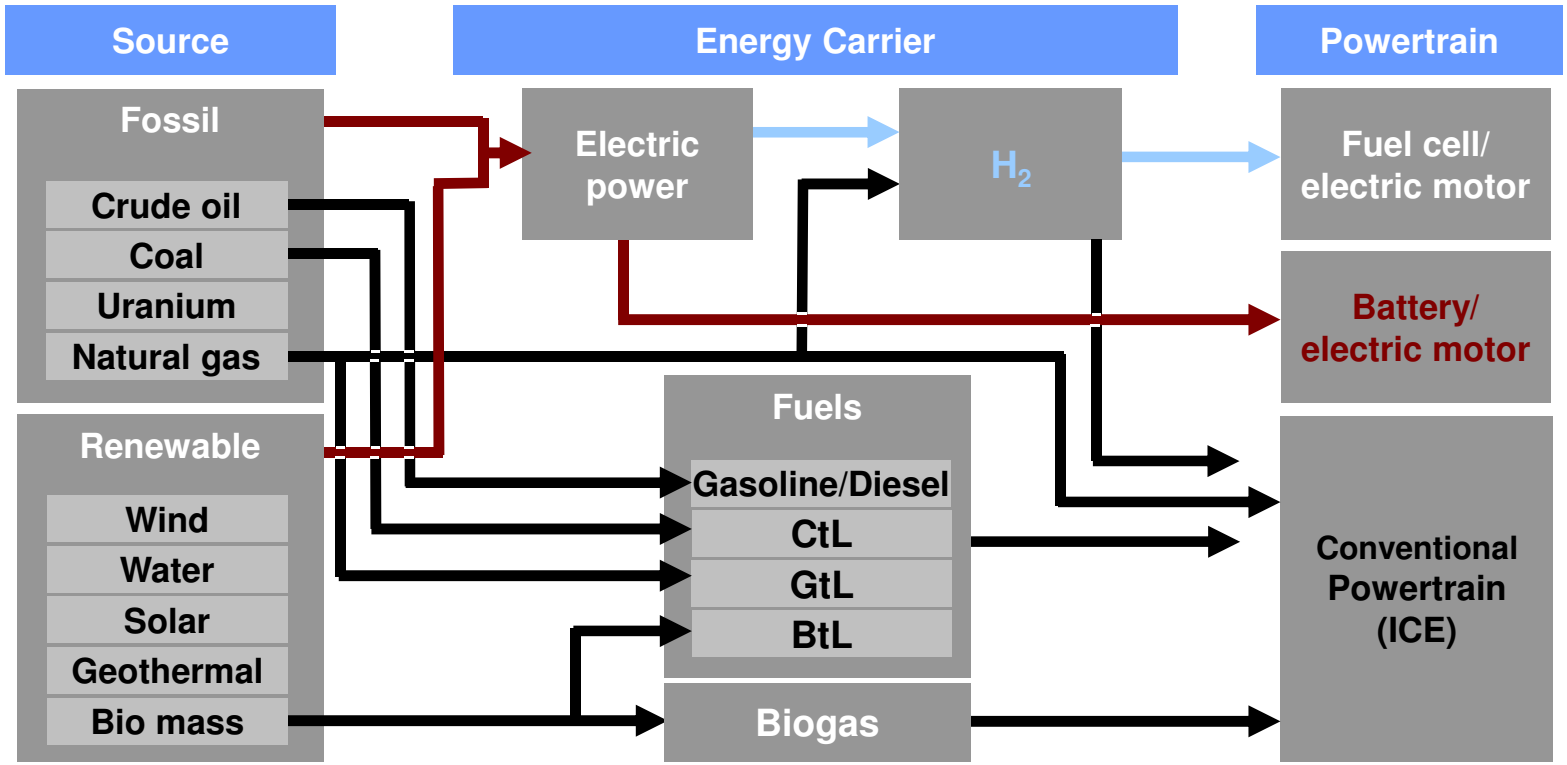
  - 20 kW
  - 100 Nm
- **Transmission:**

  - 7-gear-DSG

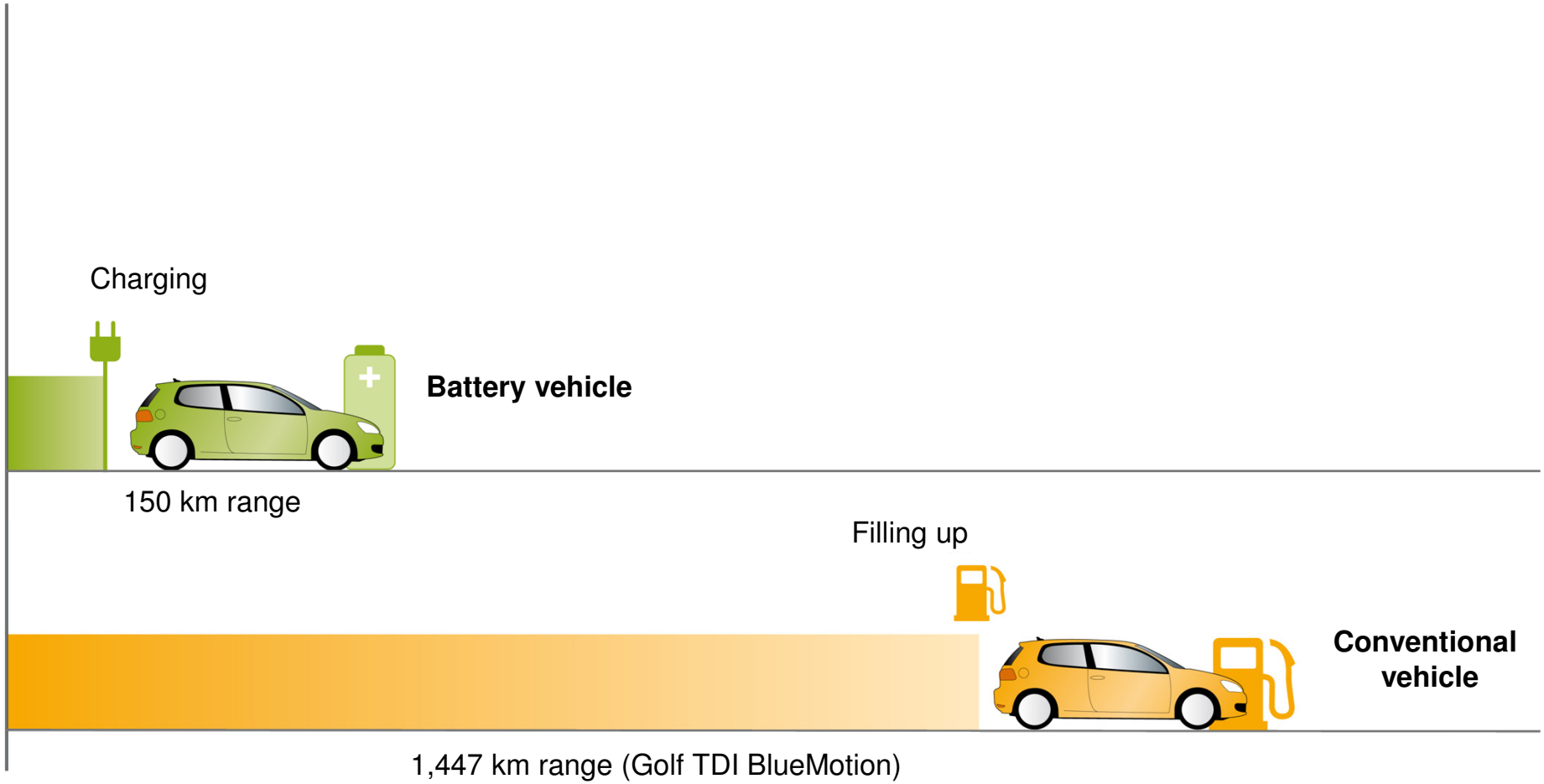
Shaping the future of automotive drivetrains…

- Increasing efficiency of powertrain, vehicle and energy supply chain
- Alternative/renewable sources for fuel and energy production
- Pathways to CO_2 neutral driving

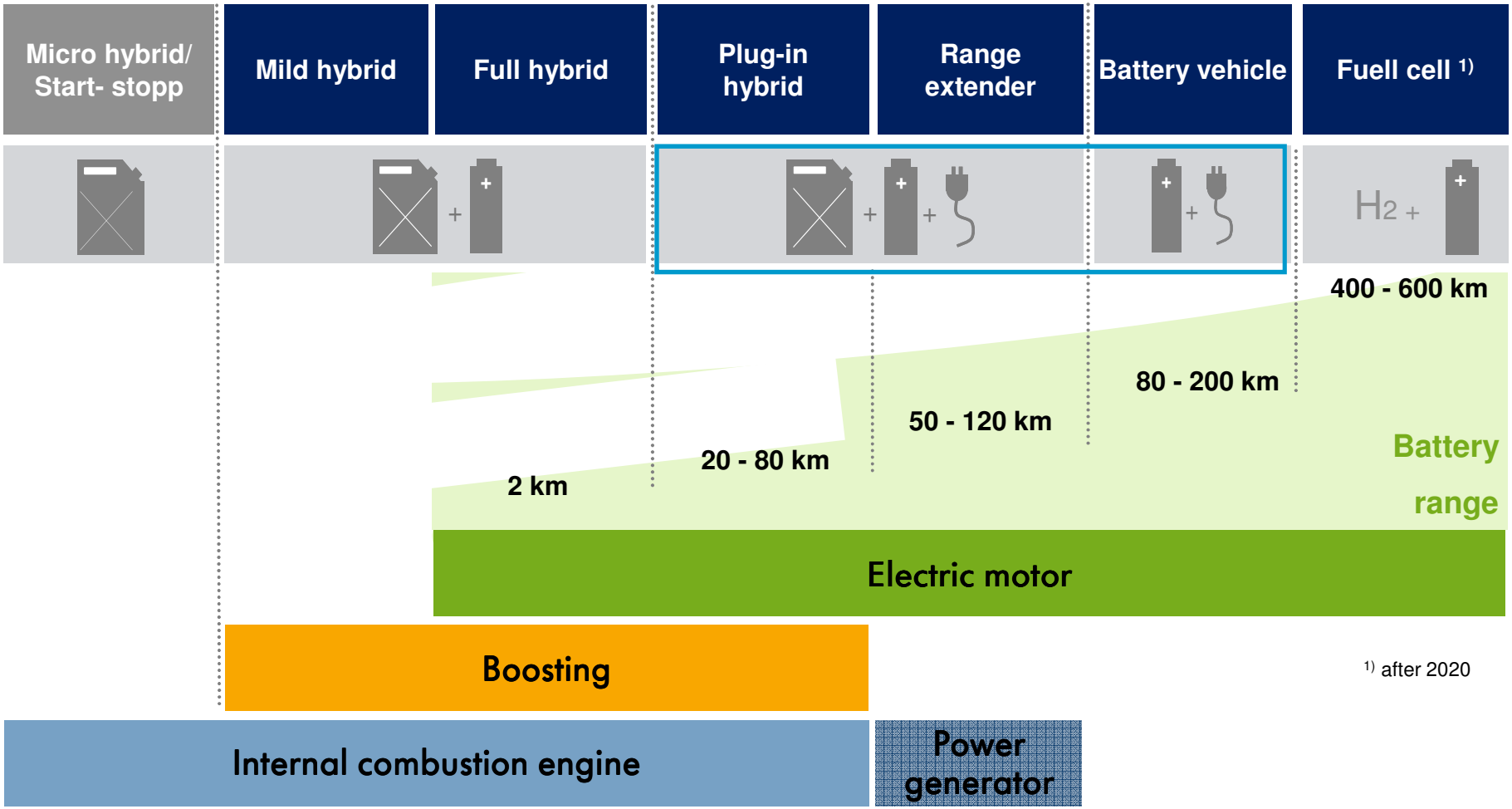
Energy Pathways - Overview



The challenge of limited range…

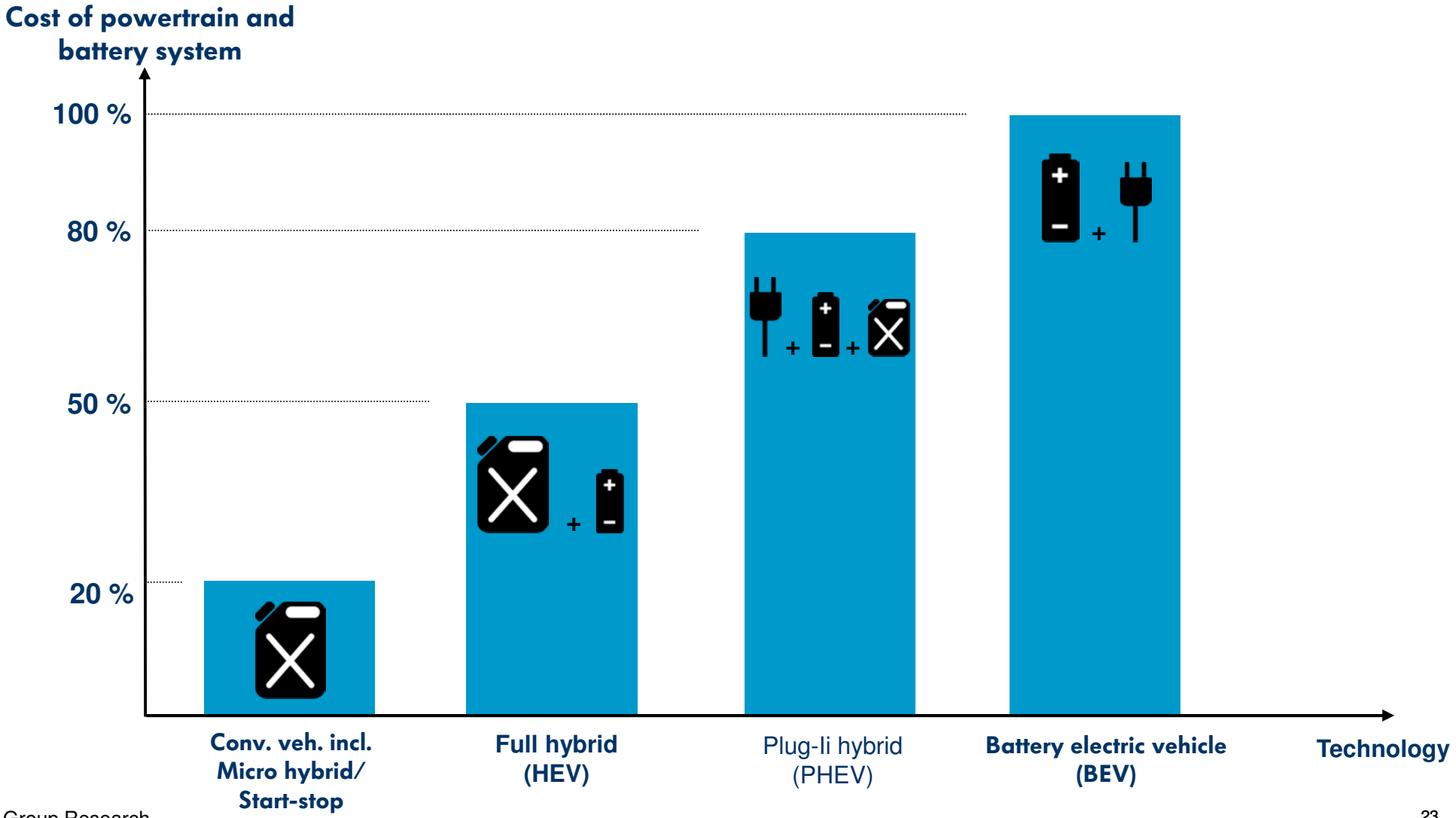


Different levels of electrification



1) after 2020

Cost comparison between different technologies



Vehicle parameters on fuel consumption

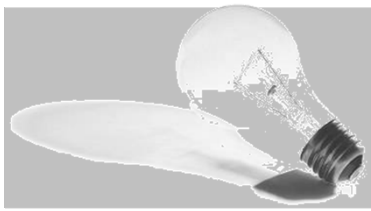
Conventional power train

Mechanical power demand
1 kW ~ 16 g CO_2/km

Weight
100 kg ~ 8.4 g CO_2/km

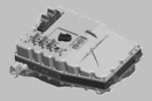
Air resistance
(~ $c_w \cdot A$)
0.1 m² ~ 3.4 g CO_2/km

Rolling resistance
1 ‰ ~ 1.9 g CO_2/km



Electric consumer
1 A ~ 0.34 g CO_2/km

Battery electric power train *

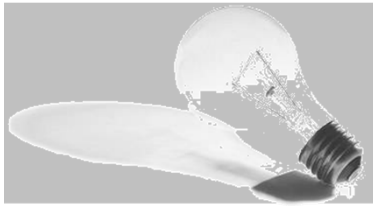


Electric power demand (HV) ↑

Weight ↗

Air resistance →

Rolling resistance ↑



Electric consumer ↗

* Relative impact compared to conventional power train

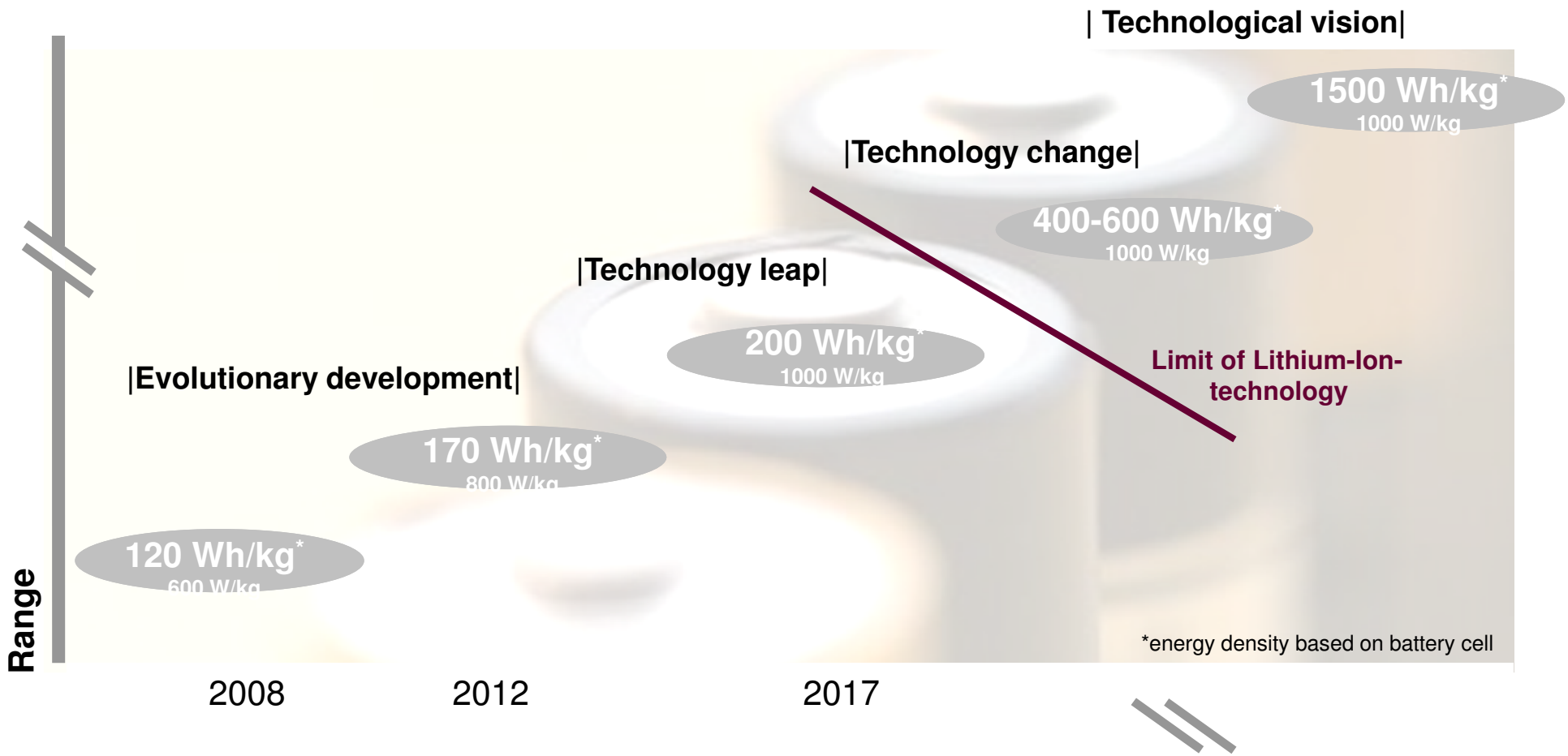
Impact of lightweight design on range (Δm = -100kg)

Conventional Otto (Golf VI 1.4 TSI)		Electric vehicle (VW360e)*
500 kWh (= 55l fuel tank)	**Primary energy**	**21 kWh** (useable)
~ 870 km	**Range in the NEDC**	**~ 150 km**
~ 575 Wh/km	**Specific consumption (NEDC)**	**~ 140 Wh/km**
	Reduced power demand for Δm_{Fzg} = - 100 kg	
+ 2.4 %	**Relative increase of range**	**+ 3.6 %**

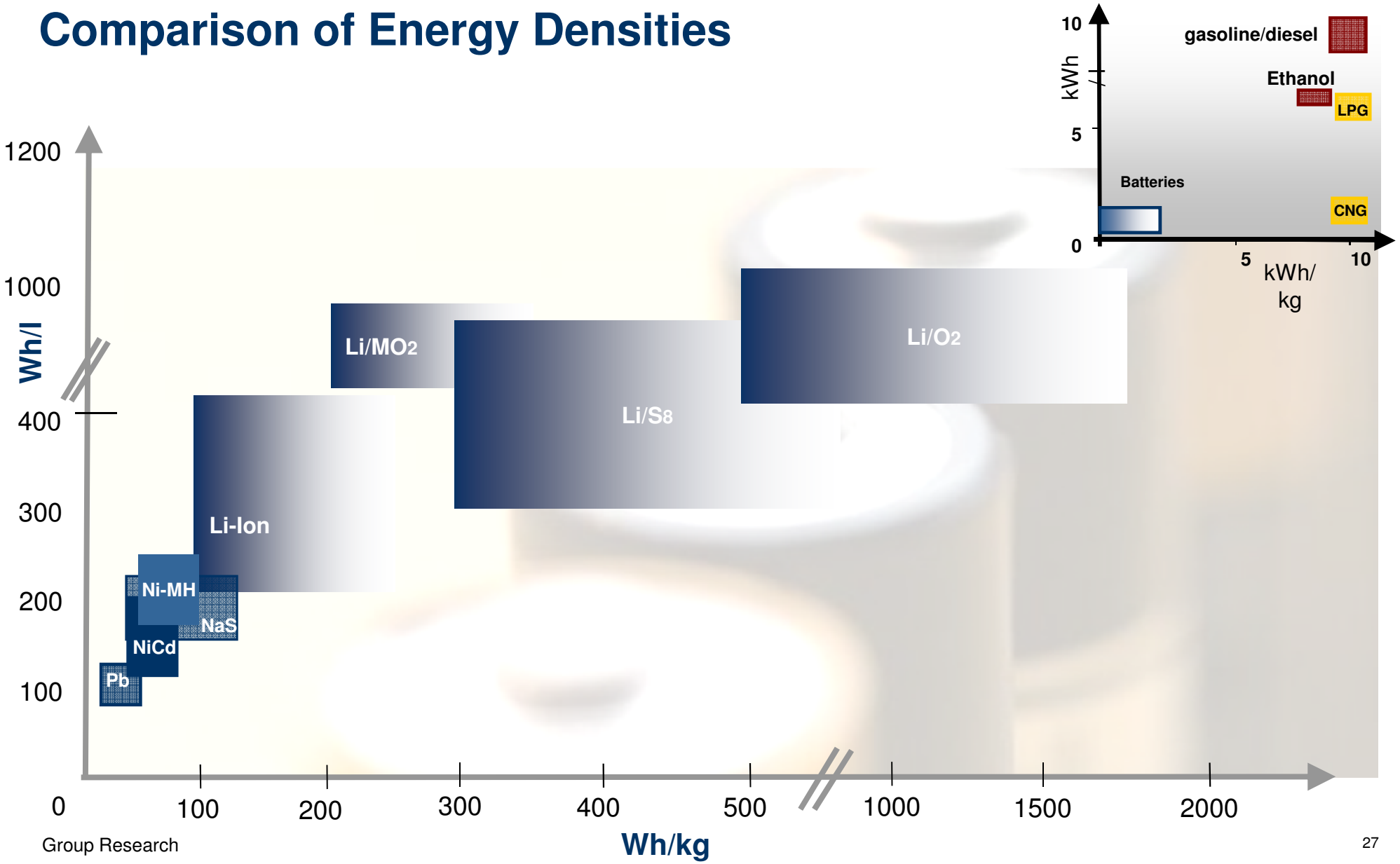
*Assuming 85% regenerative braking

Source: K-EF

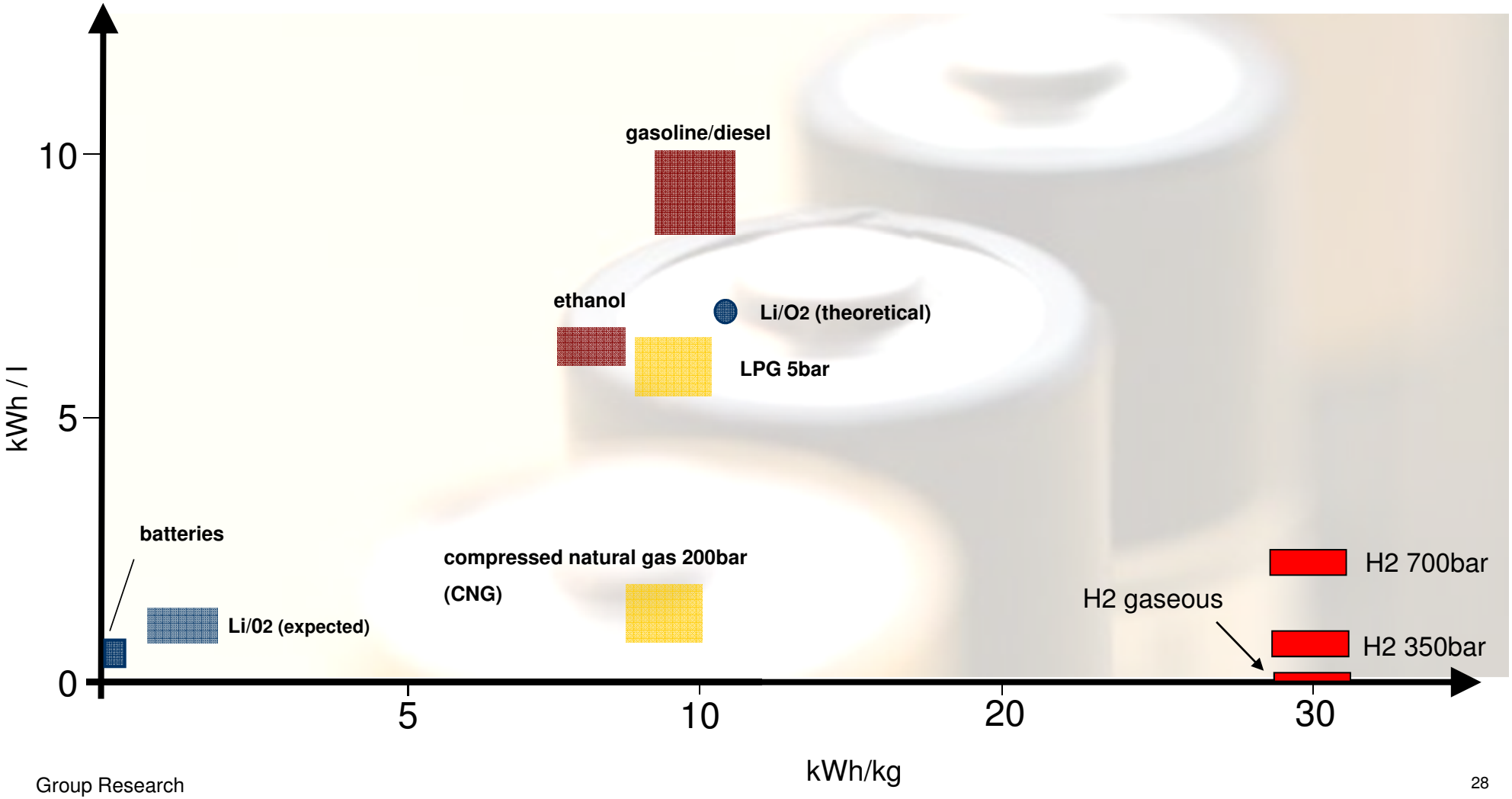
Requirements on Future Electrical Energy Storage



Comparison of Energy Densities



Comparison of Energy Densities

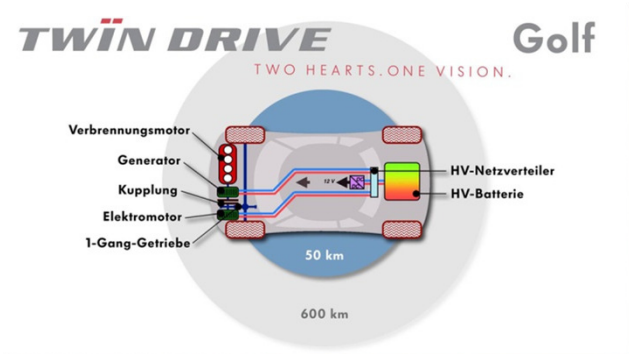


Today Electromobility …

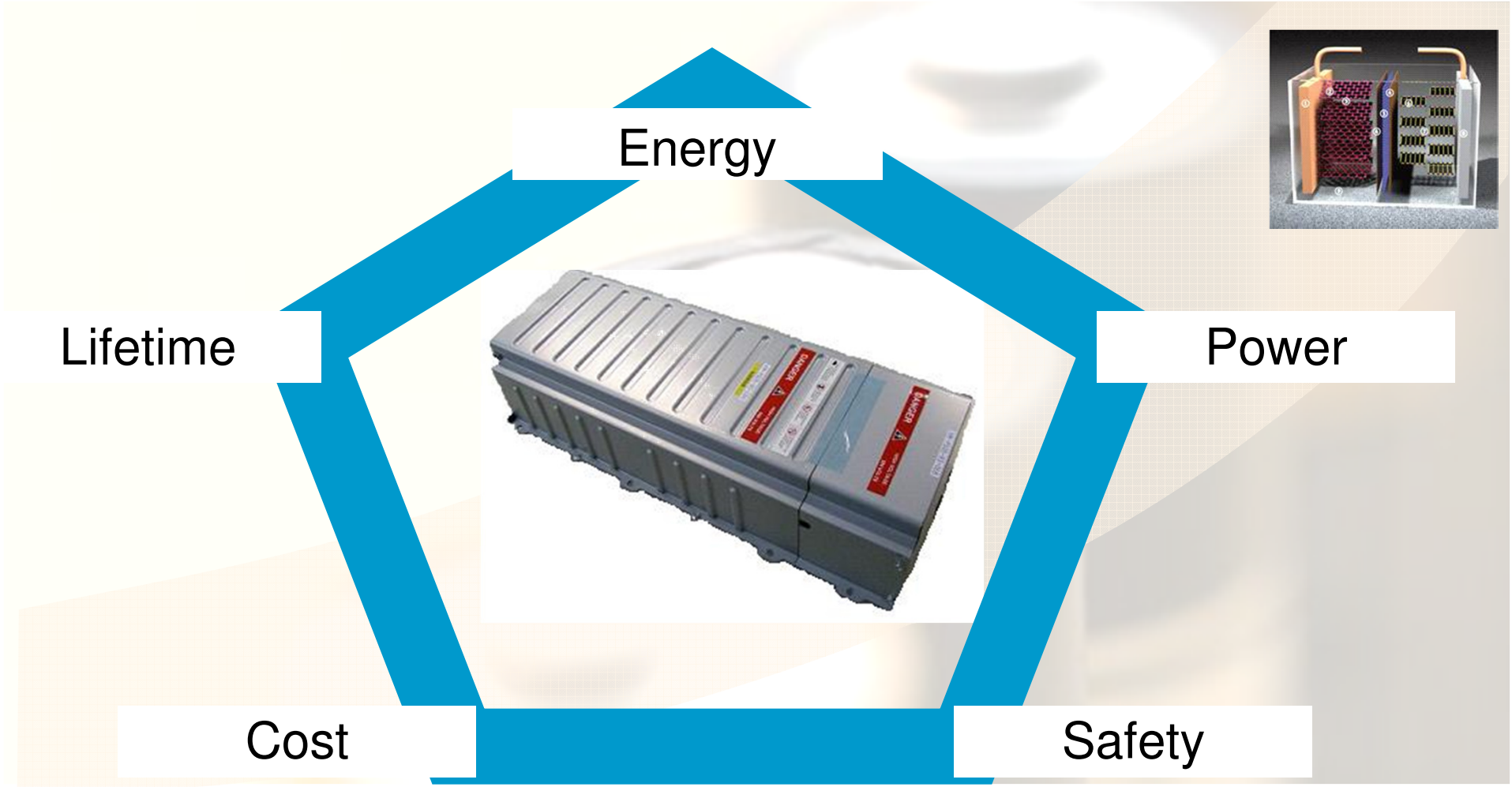
Important for urban agglomerations…

… and ideal for commuters

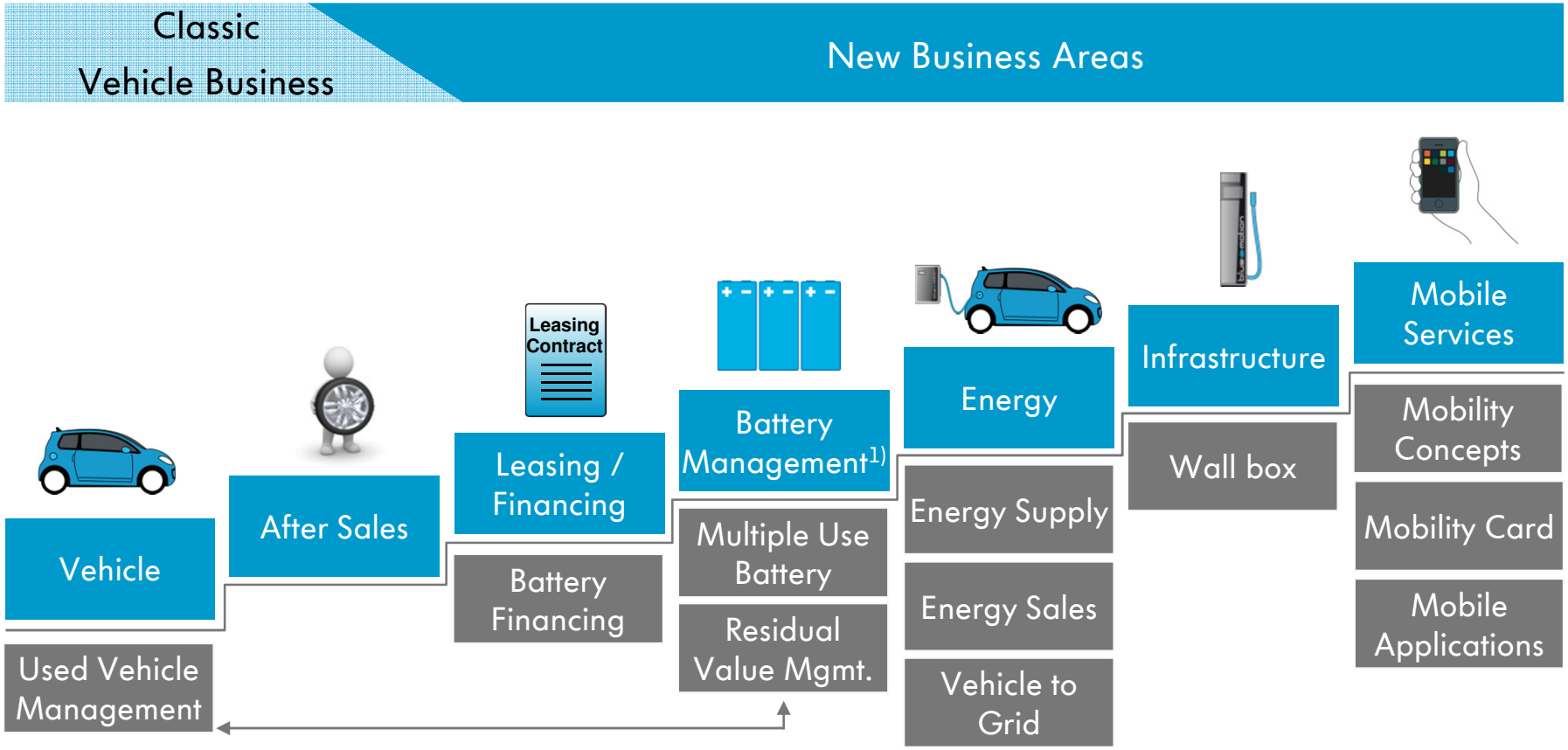
twinDRIVE: Plug-in hybrid concept



Requirements on Electrical Energy Storage Devices



Various new fields of business for E-Mobility



1) Economic implementation of battery management in current technical concept of E-Golf and e-Up! tbd.

The Battery Electric Vehicle in the networked world

Mobile Services for BEV Drivers

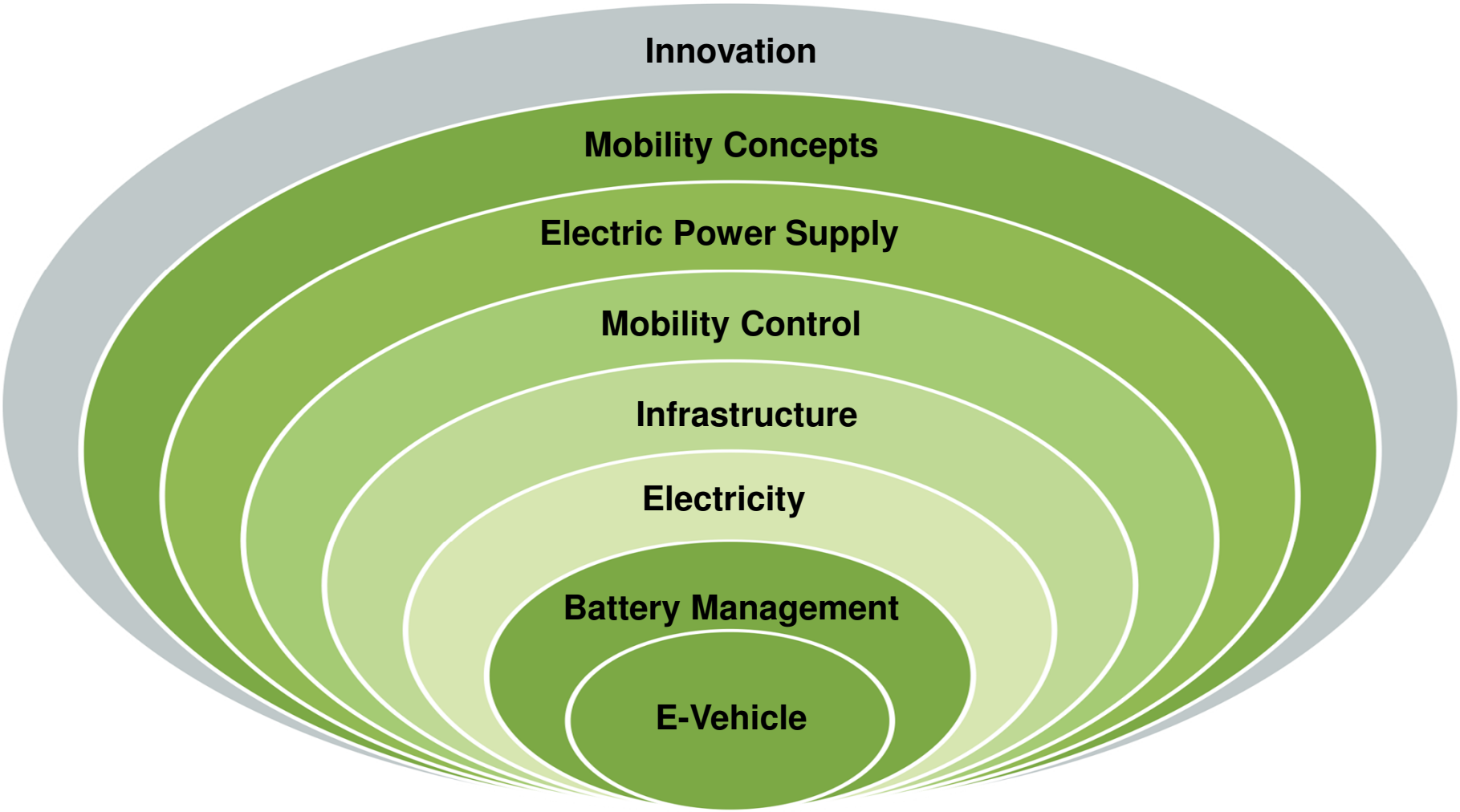
Energy management
- Range indicator and charge level display
- Air-con. from the socket before starting a trip

Navigational services
- Display of vacant recharging bays

Location surveillance
- For car-sharing applications

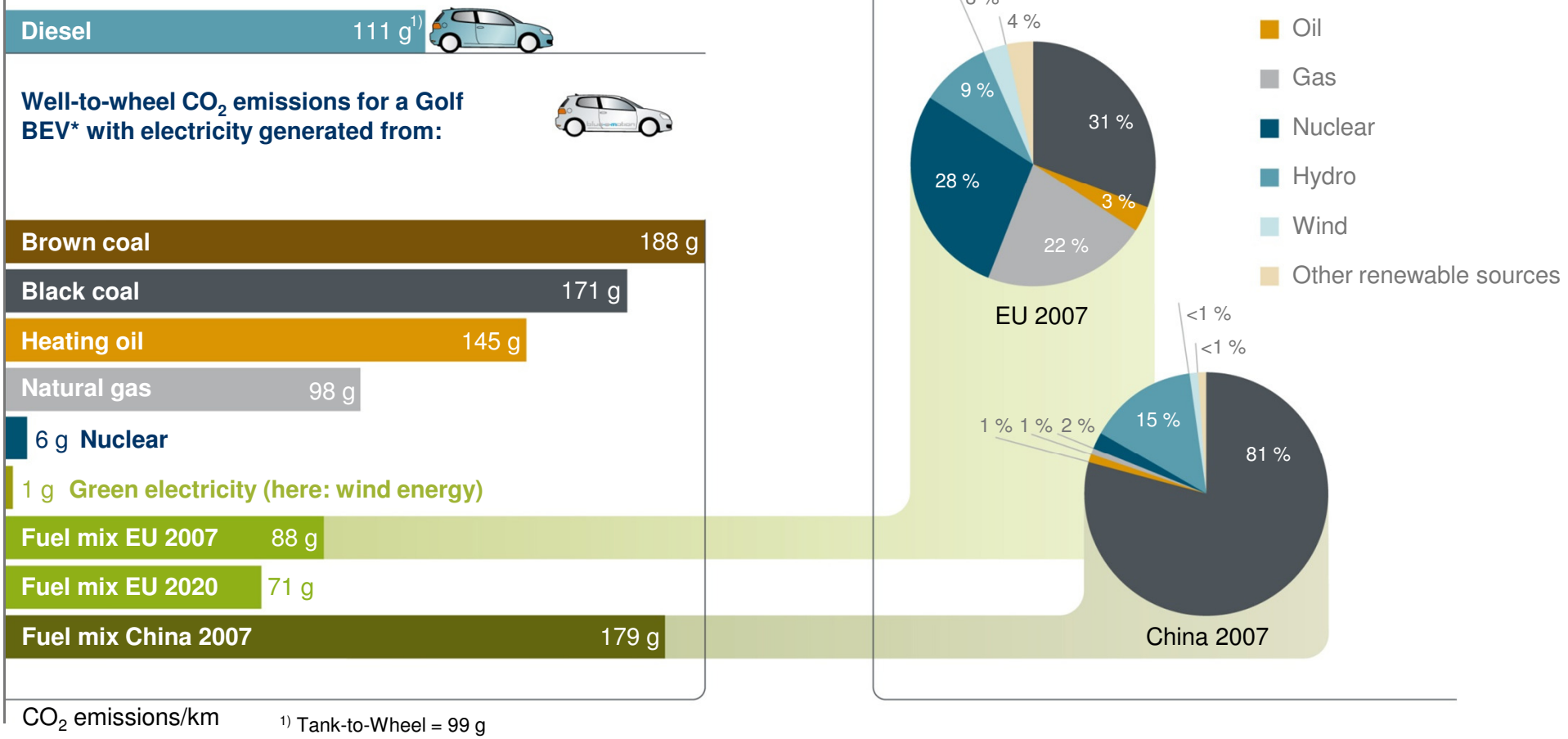
Battery Electric Vehicle **Service provider**

The many elements of electromobility



The well-to-wheel comparison

Well-to-wheel CO_2 emissions Golf TDI BlueMotion



Fuel mix

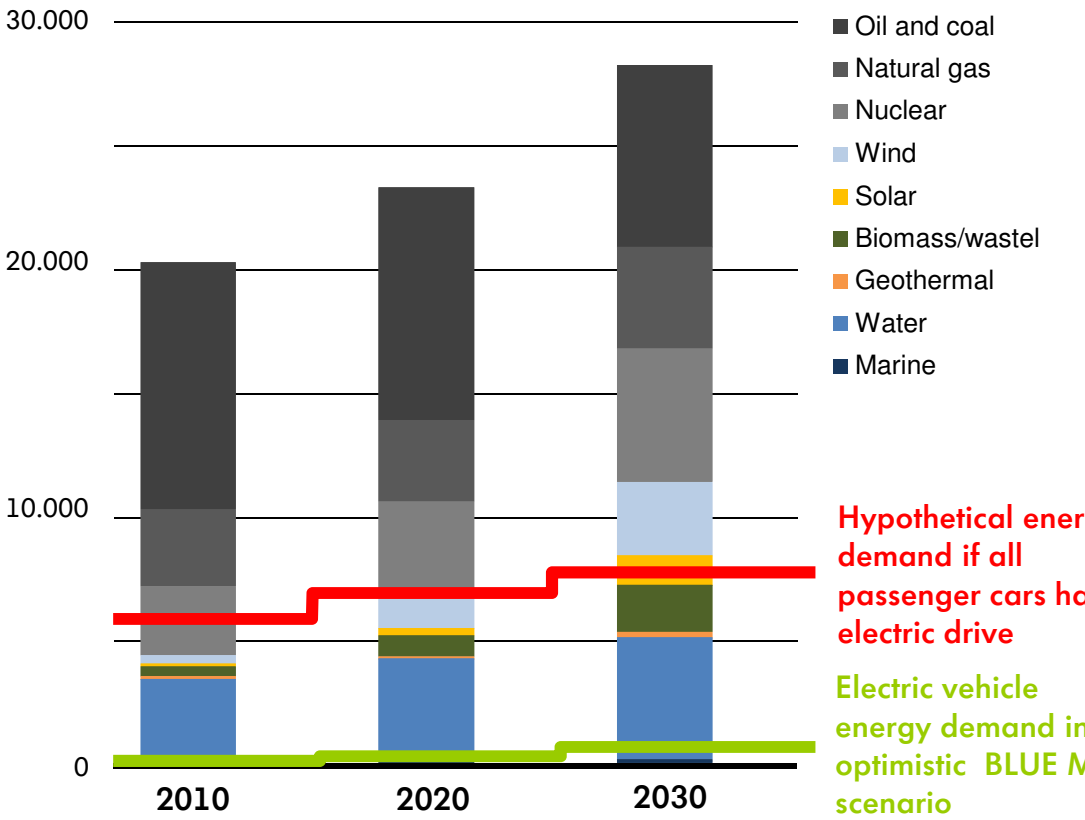
1) Tank-to-Wheel = 99 g

* Fuel consumption: 15,7 kWh/100 km (NEFZ)

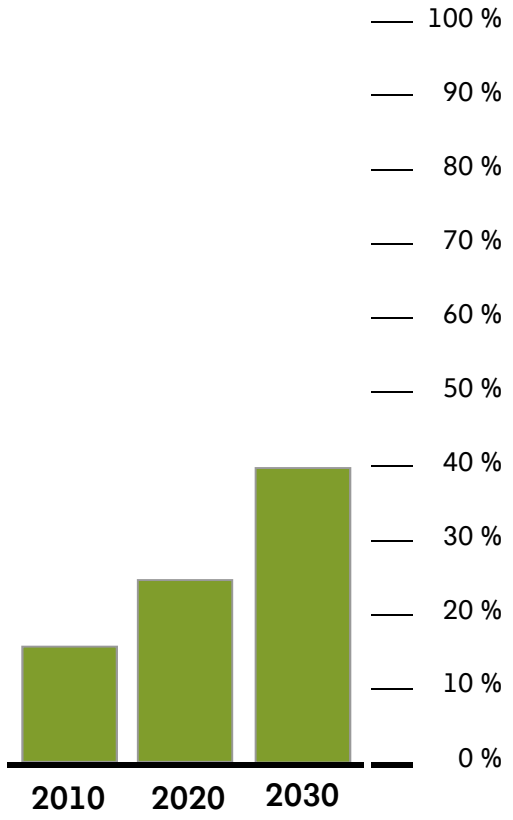
Potential of green electricity

Gross power generation

(BLUE Map scenario) TWh/a

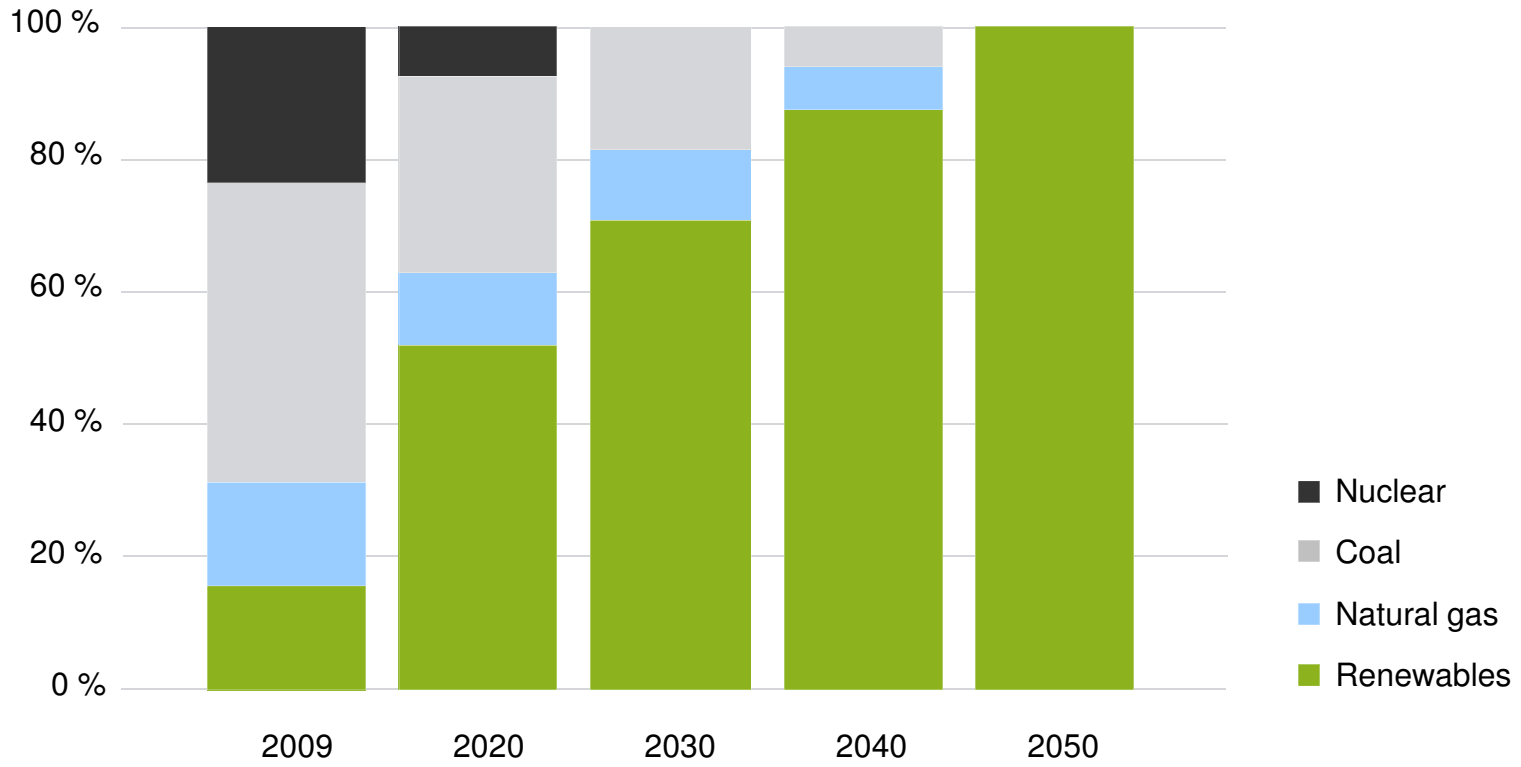


Share of regenerative power



Source: „Energy Technology Perspectives“ IEA 2010

Forecast on the use of renewable energy sources used for generating electricity



➡ **There is a clear tendency towards renewable energy sources**

Source: Lichtblick AG

Electricity Demand for EVs (electric vehicles)

Germany

2008
Electricity demand: **615 TWh**
Met by wind energy: **40 TWh**

2020
Electricity demand: **615 TWh**
Estimated energy: **150 TWh**

Electricity demand for EVs:
1 Mio EV** **2 TWh**
= **0,3 %** (from total demand)
= **1,3 %** (from total wind energy)

* Source: Bundesverband Windenergie, Bundesministerium für Umwelt, Deutsche Energie Agentur
** Bundesregierung, 10,000 km, 20kWh/100 km

EU 27

2008
Electricity demand: **3.381 TWh**
Met by wind energy: **142 TWh**

2020
Electricity demand: **3.587 TWh**
Estimated energy: **477TWh**

electricity demand for EVs:
2,7 Mio EV** **5,4 TWh**
= **0,15 %** (from total demand)
= **1,1** % (from total wind energy)

* Source: European Eind Energy Association, International Energy Agency
** EUCAR, 10,000 km, 20kWh/100 km

World

2008
Electricity demand: **19.800 TWh**
Met by wind energy: **260 TWh**

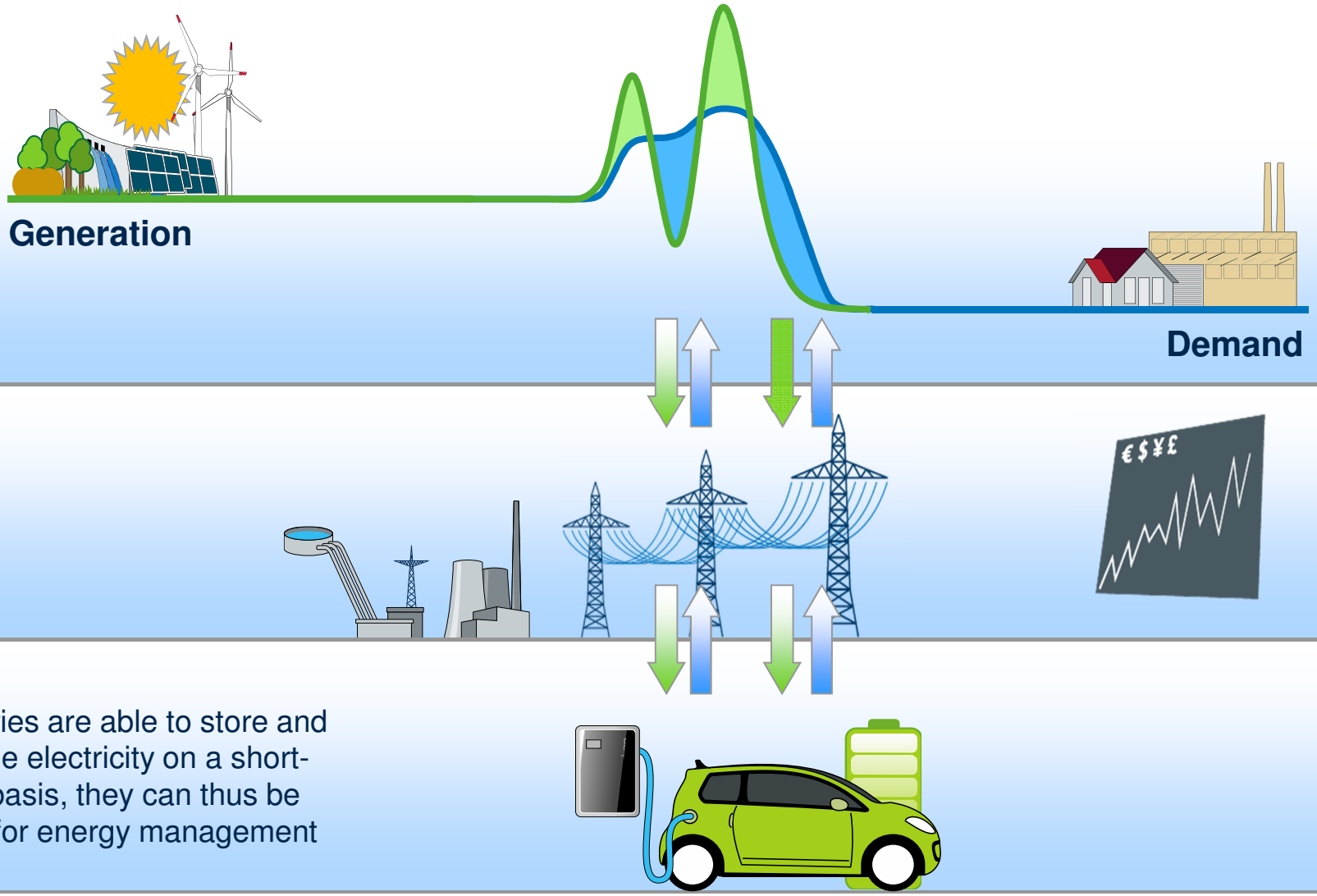
2020
Electricity demand: **27.200 TWh**
estimated wind energy: **1.640TWh**

electricity demand for EVs:
7 Mio EV** **14 TWh**
= **0,05%** (from total demand)
= **1,4 %** (from total wind energy)

* Source: World Wind Energy Association , International Energy Agency
** IEA, 10,000 km, 20kWh/100 km

- Disproportionate increase of renewable energy (wind energy) in Germany
- Energy demand can be easily met by wind energy without impact on other consumers
- Lower availability of renewable energy demands facilities with increased power or grid stabilizing technology (pumped-storage hydroelectricity, load management)

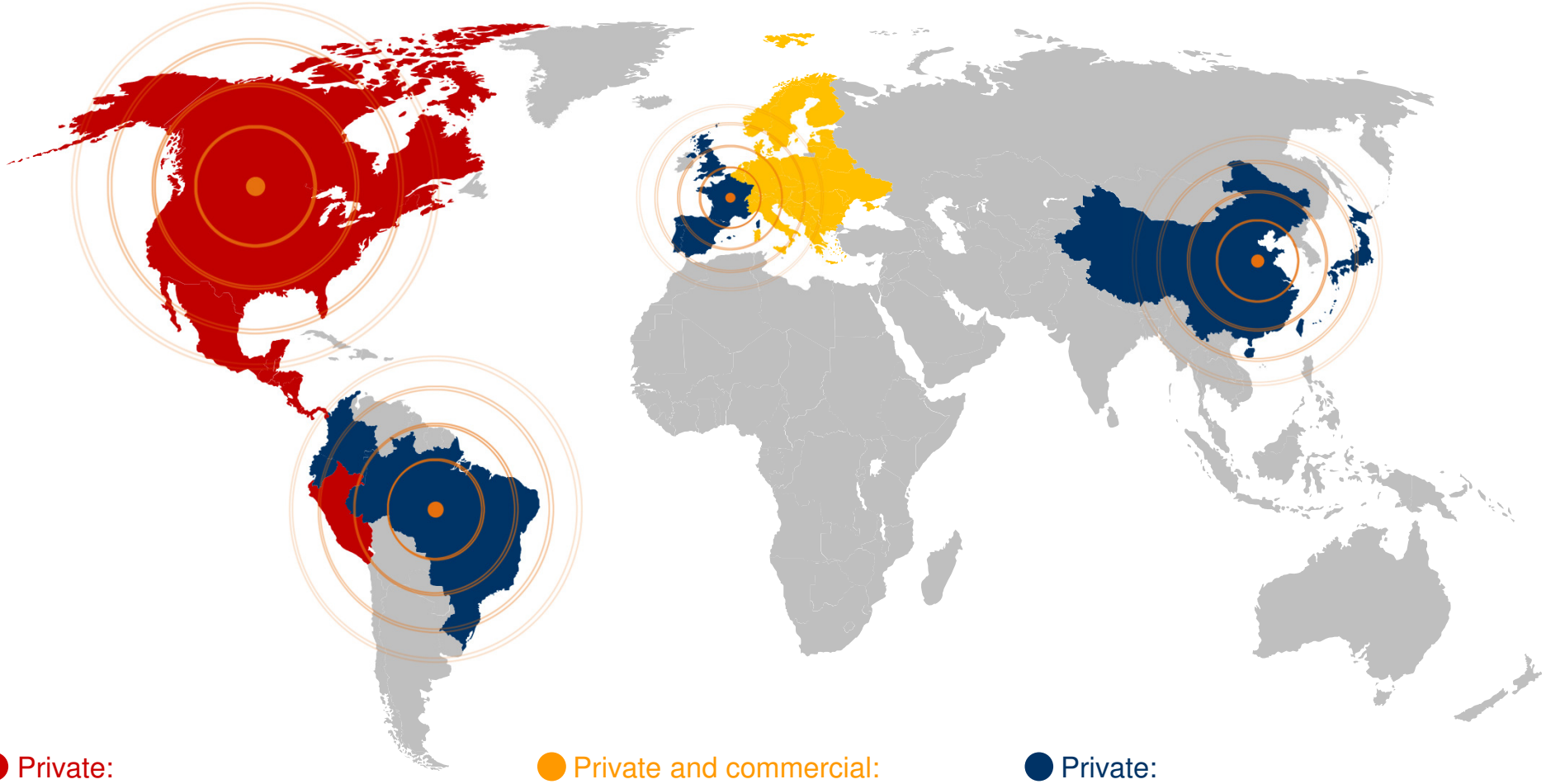
The electric vehicle as part of the electricity market



Batteries are able to store and provide electricity on a short-term basis, they can thus be used for energy management

Challenges on infrastructure

Insufficient power grid infrastructure



- Private:
  1-phase power grid (~110 V)
  Commercial:
  3-phase power grid (~480 V)
- Private and commercial:
  3-phase power grid
  (~400 V)
- Private:
  3-phase power grid (~400 V), not available everywhere (particularly in southern Europe and Latin America)

Major drivers for governments to promote electromobility

Climate and environmental targets

Safeguarding jobs and competitiveness

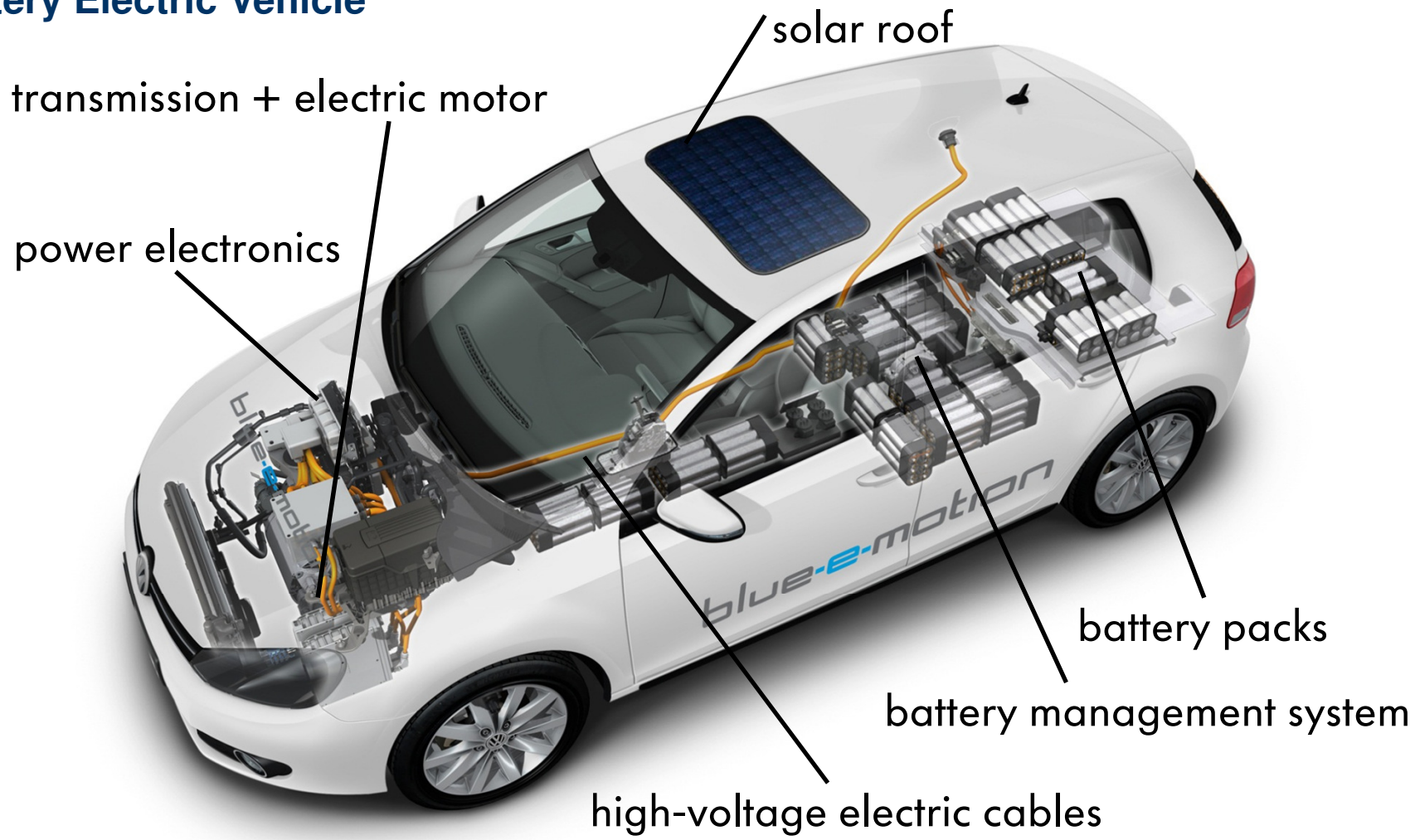
Setting up competitive automotive industry focusing on alternative drive technology

National industrial policy

National OEMs aiming to increase leading edge in technology

Volkswagen Golf blue-e-motion

Battery Electric Vehicle



Volkswagen Golf blue-e-motion

Battery

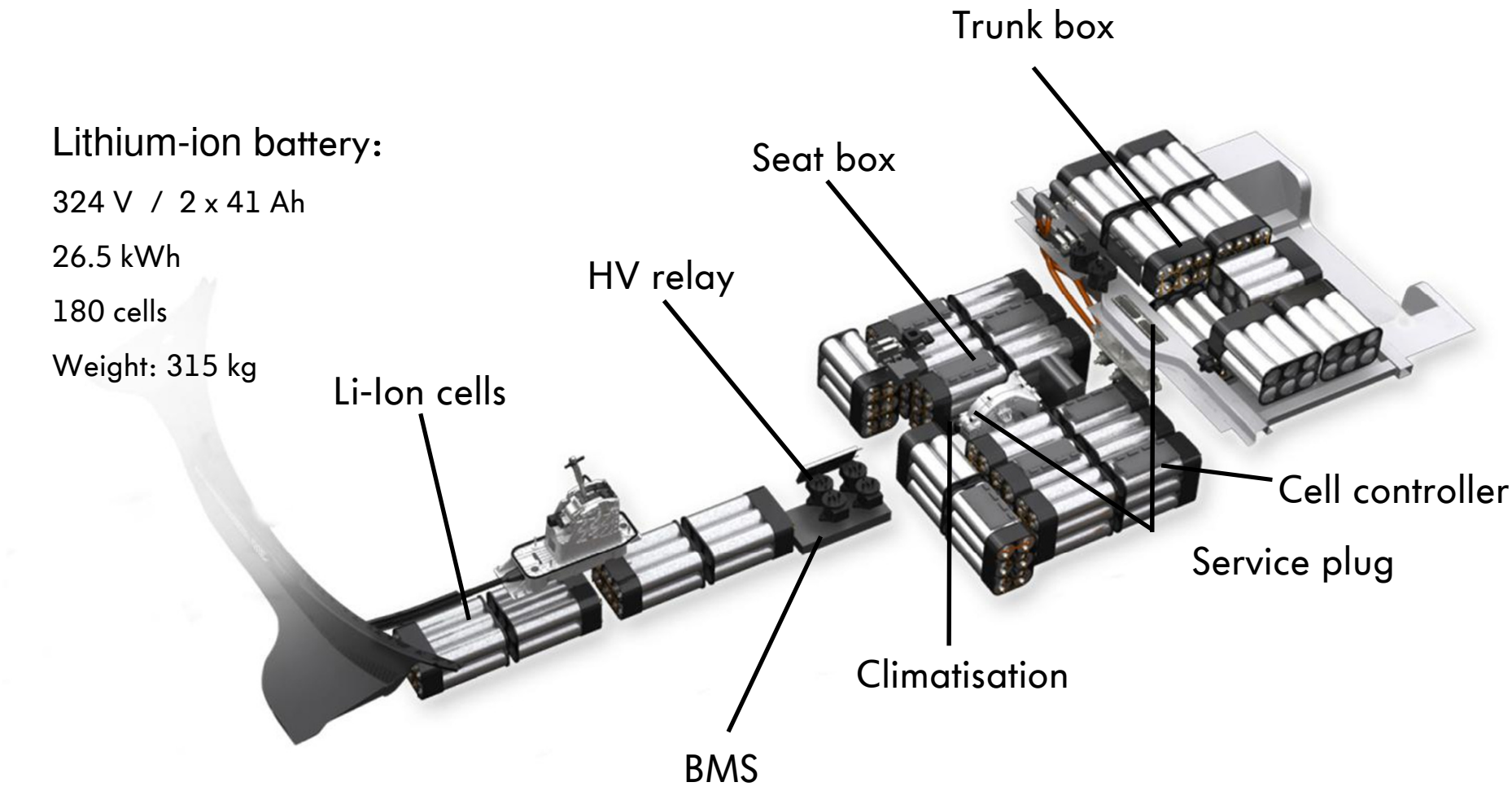
Lithium-ion battery:

324 V / 2 x 41 Ah

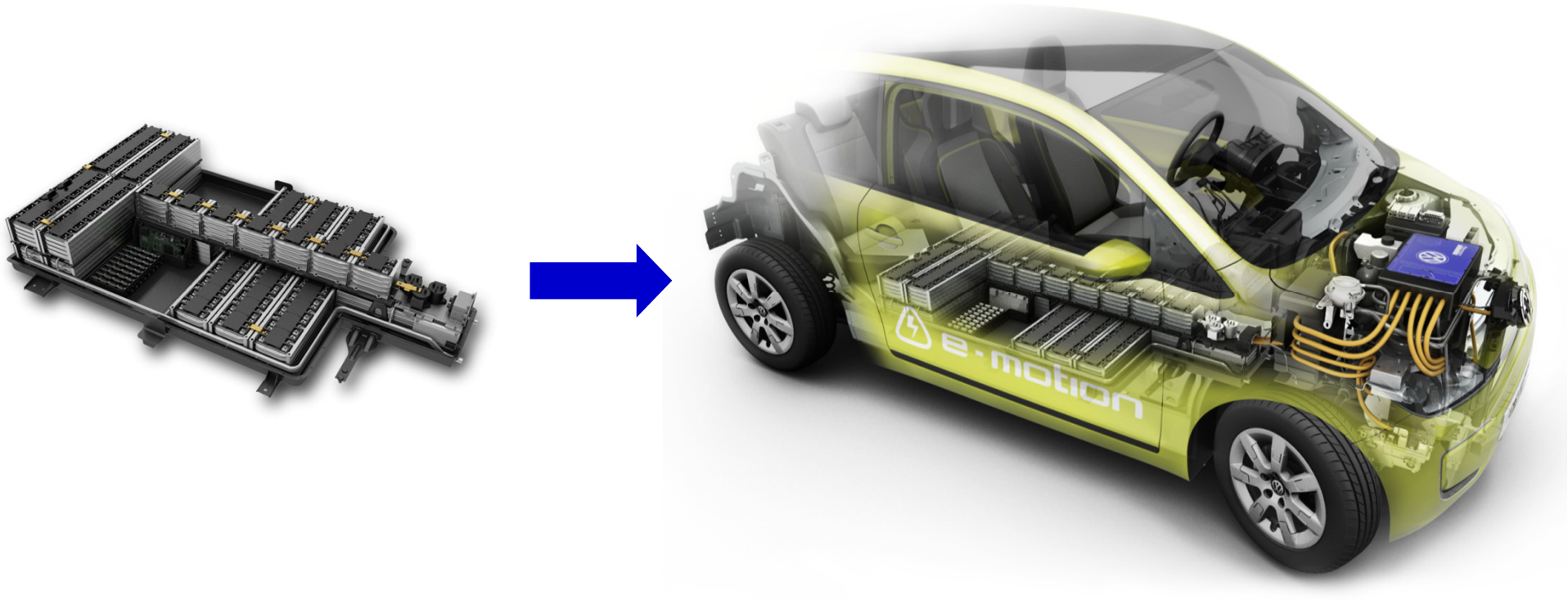
26.5 kWh

180 cells

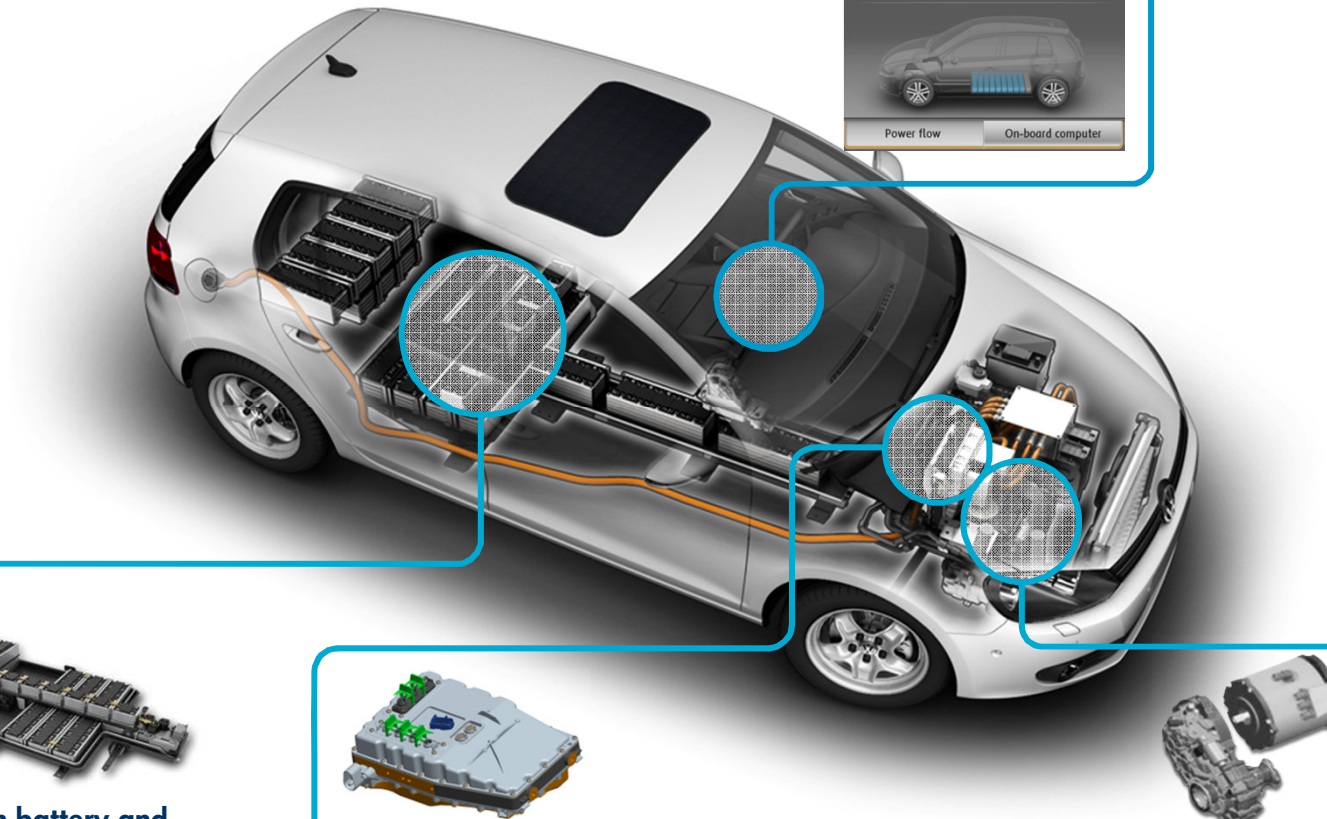
Weight: 315 kg



Integrating the battery into the vehicle

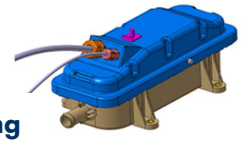


There is more to an electric vehicle than just a battery and an electric motor

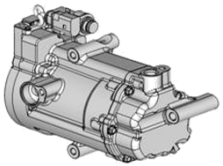


Infotainment

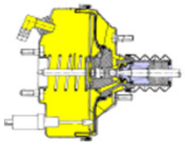
Remote-control / mobile services



Heating



Air conditioning system



Electric brake booster

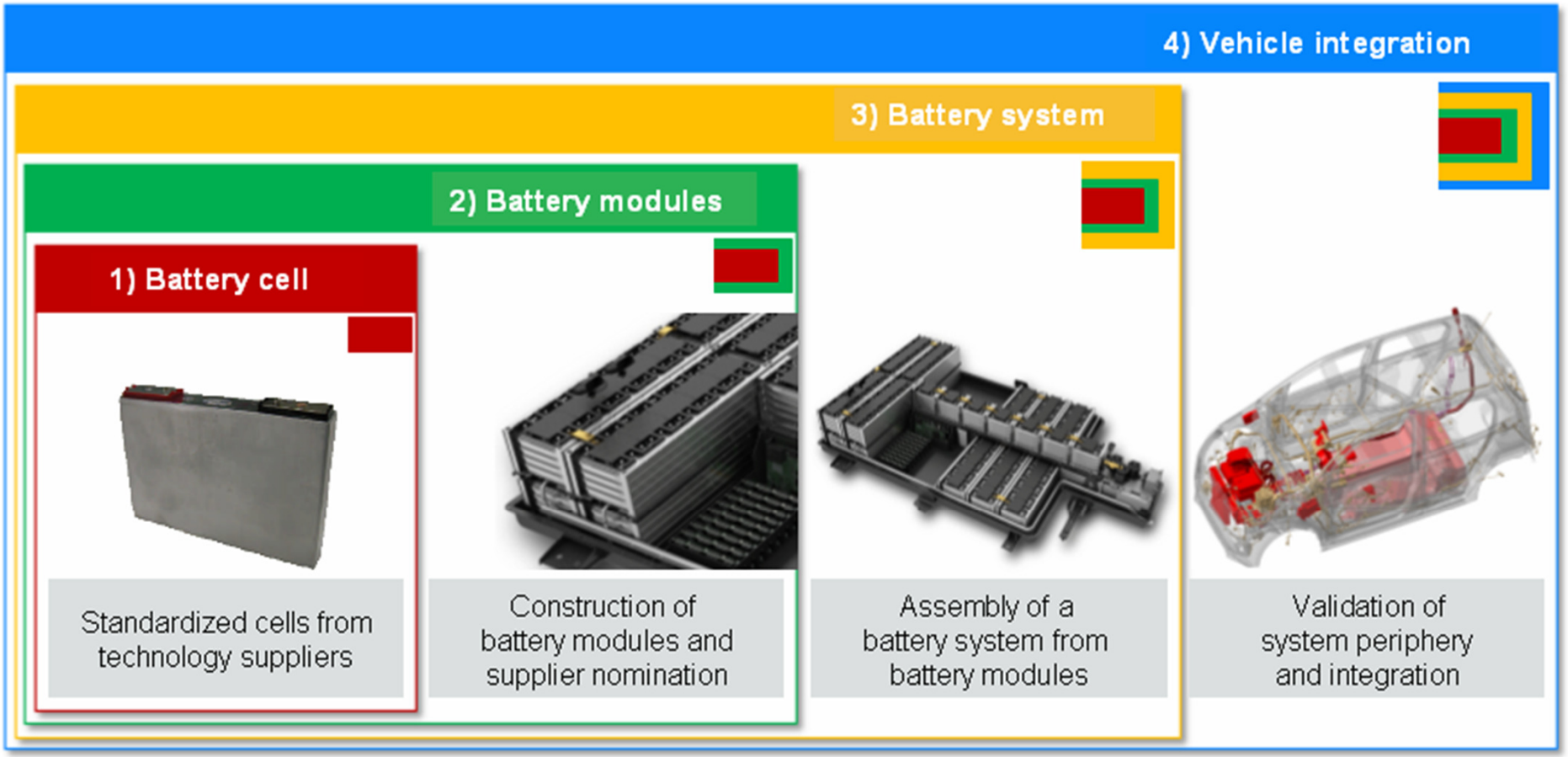
High-voltage lines

Traction battery and battery management

Power electronics

Electric motor and transmission

A modular approach to battery system design…



Market integration phases of electromobility

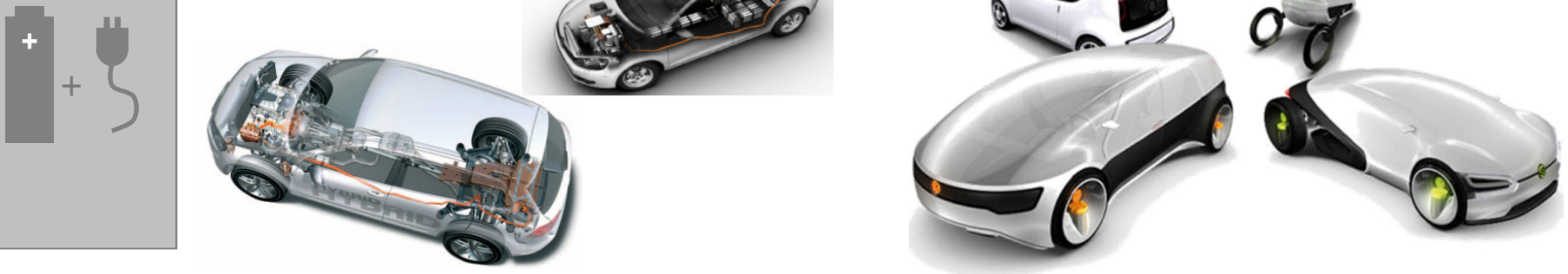
I Demonstration

II Series entry

III Mass market

Phases e-mobility

today 2013 2018 20xx

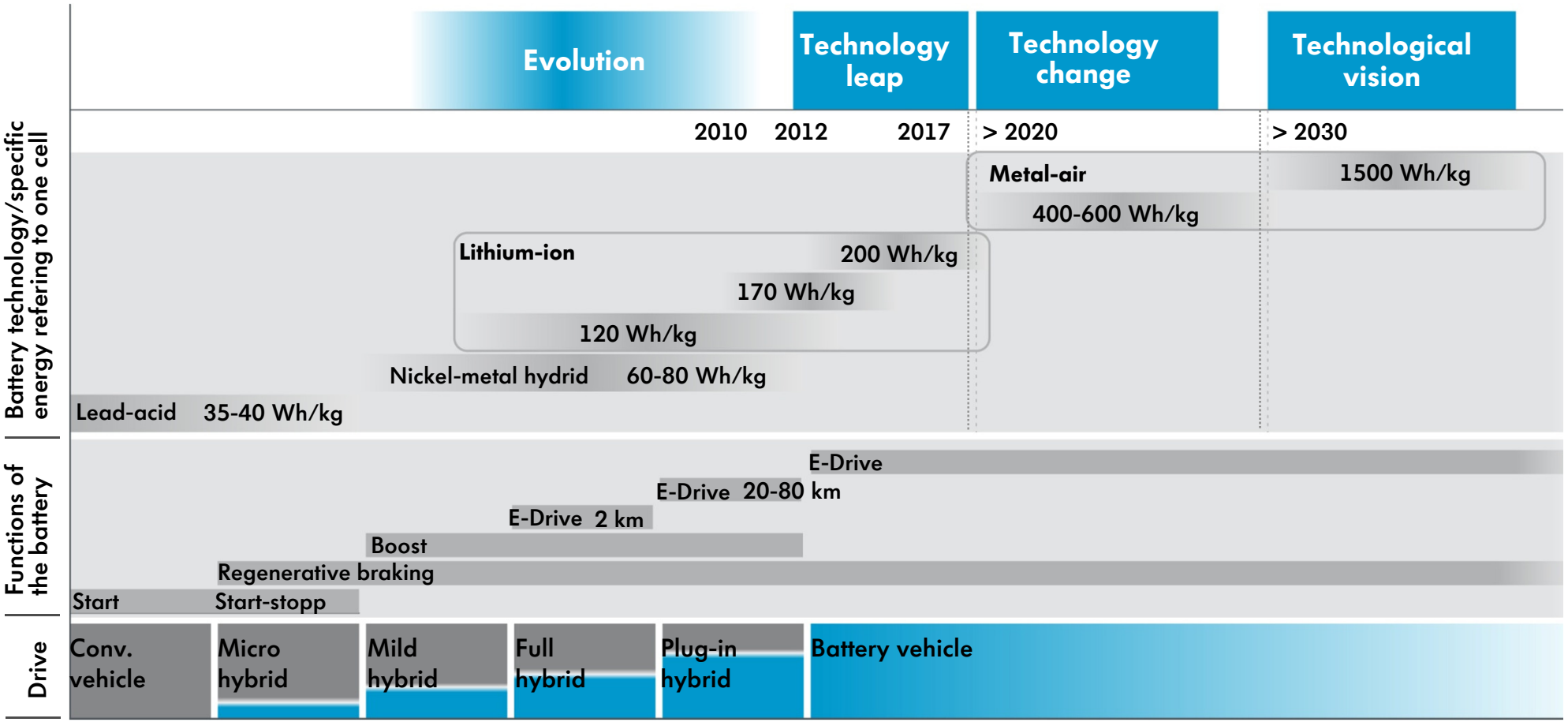


Conversion design (combustion derivate)

Purpose design (new concept)

Source: PMS-E

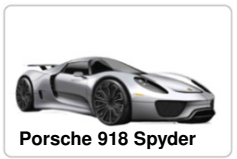
Battery technology development



Source: EL

Volkswagen‘s roadmap of electric and hybrid vehicles

Hybrids



Battery vehicles

Other brands

Some of the images show predecessor models or conventional vehicles.

Thank you for your attention…