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KONZERNFORSCHUNG

RELEVANT PARAMETERS FOR THE TRANSITION OF MOBILITY TO A „DECARBONIZED WORLD“

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GLOBAL TRENDS INFLUENCING MOBILITY IN THE 21ST CENTURY

Digitalisation

Hydrogen

Downsizing

Plug-In-Hybrid

CO_2 Emissions

Climate change

Urbanisation

Peak Oil

Shared Mobility

Urban Low Emission Zones

sustainability

Electromobility

Connected Car

Battery technology

Automated Driving

Lithium-Ion

Car-Sharing

Megacities

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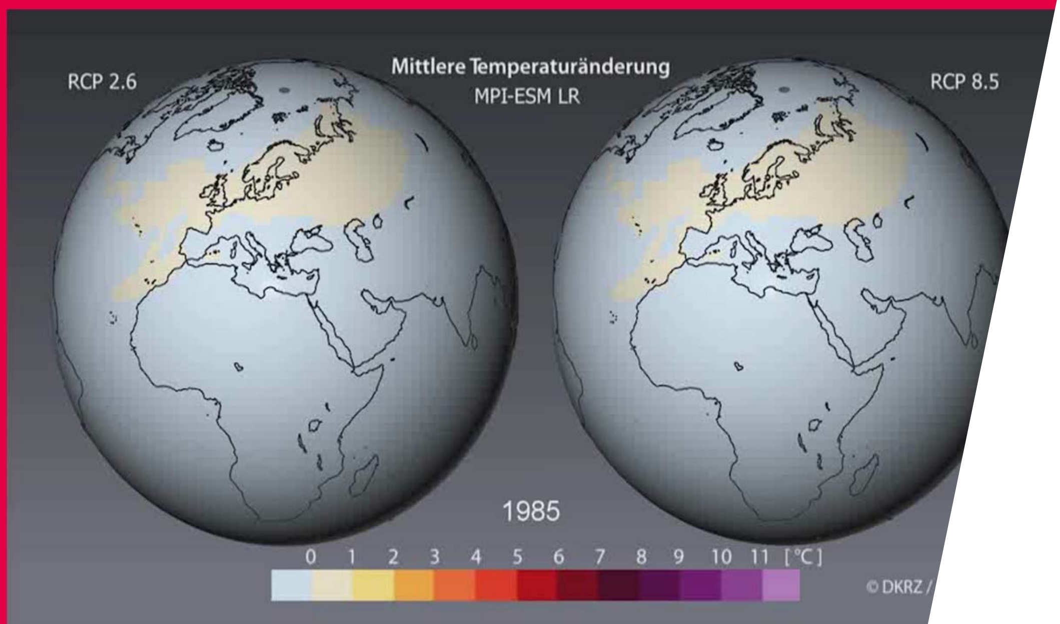
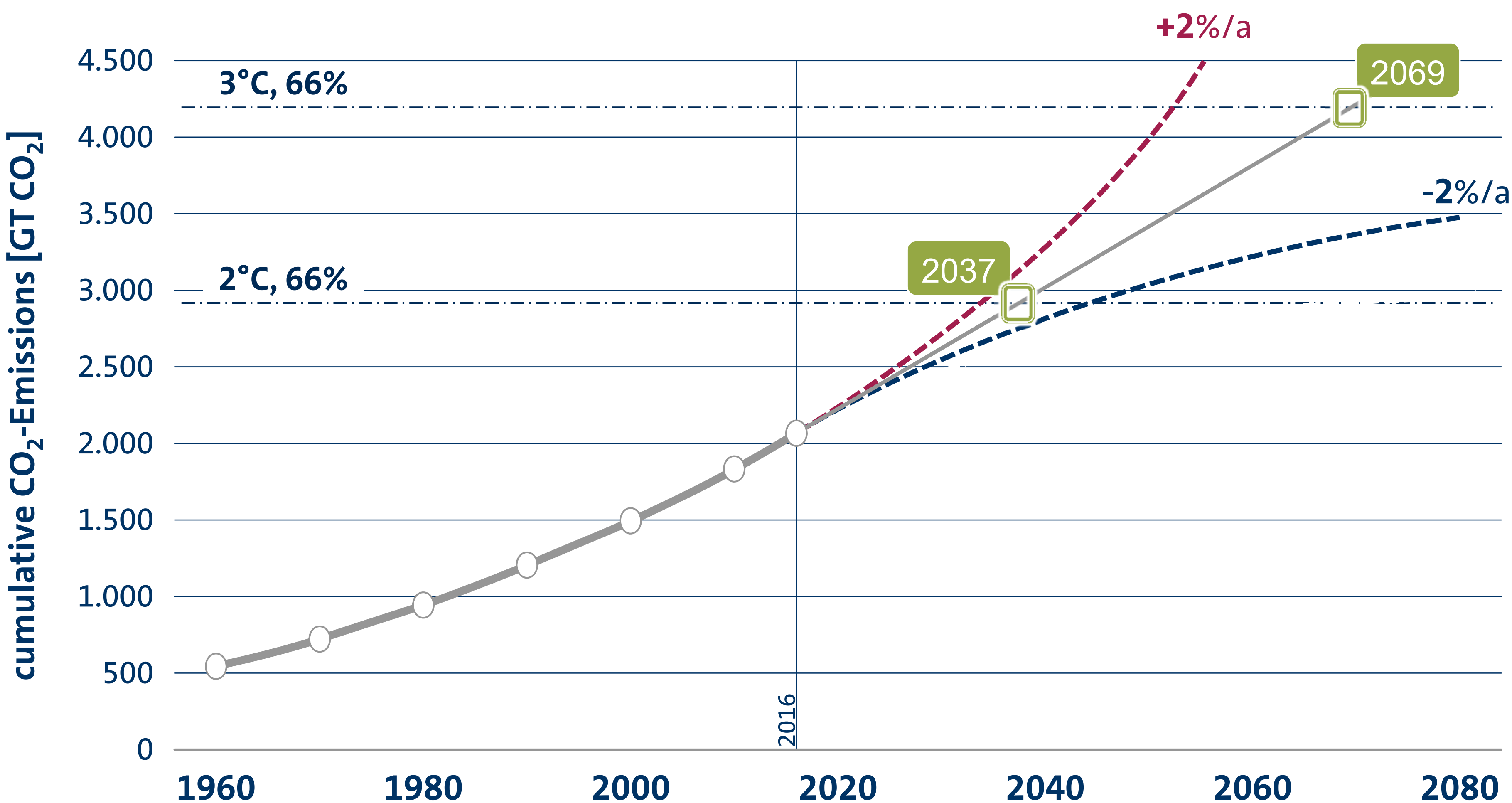
TIPPING POINTS IN THE GLOBAL CLIMATE SYSTEM



DKRZ: Deutsches Klimarechenzentrum

- Increase in extreme, unexpected environmental disasters and weatherevents
- climate- and environmental objectives remain most relevant driver for technical development
- High strain on reduction of emissions as well as fuel consumption / increase in efficiency
- Volatility in energy sources due to the energy transition

ENVIRONMENTAL- AND CLIMATE PROTECTION



Source: Jackson et al 2015b; Global Carbon Budget 2016
Data: CDIAC/GCP (Carbon Dioxide Information Analysis Center / Global Carbon Project)

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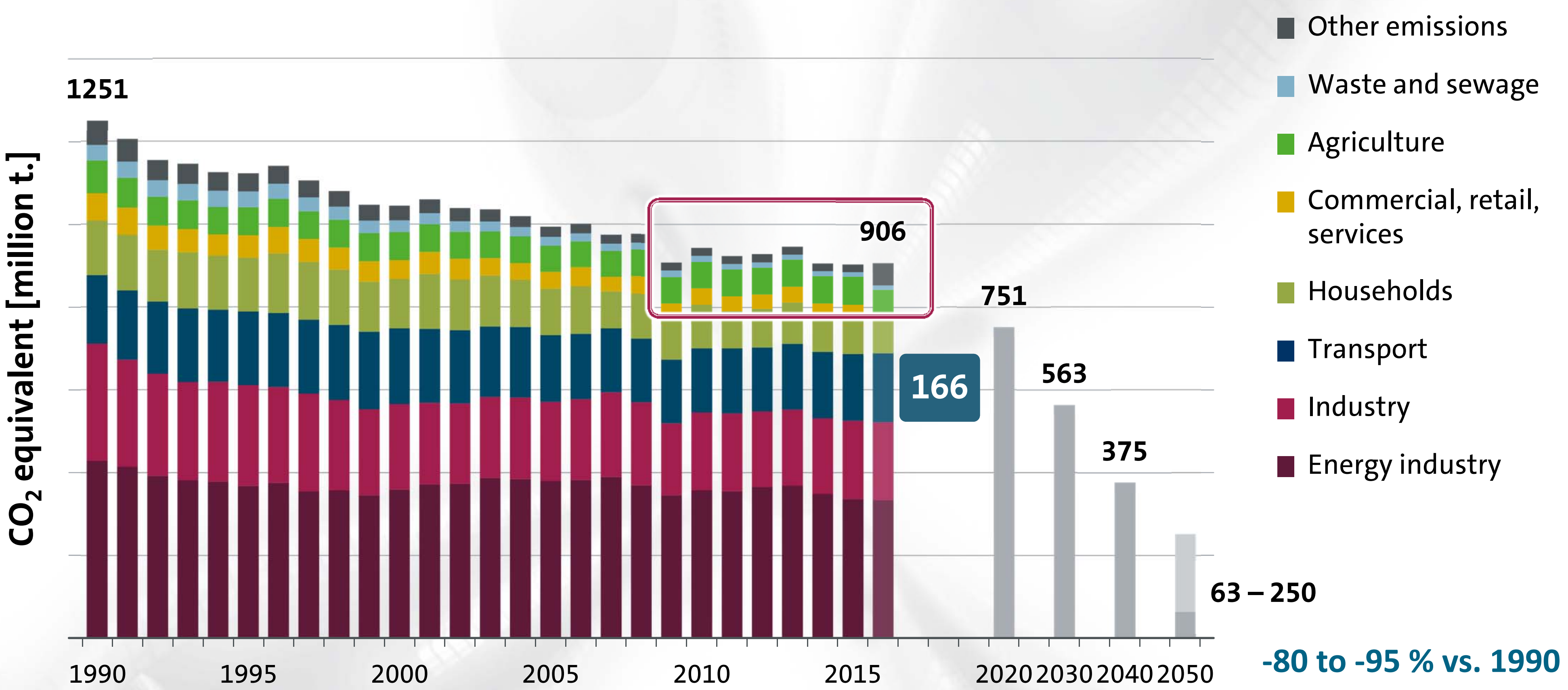
GERMANY: CLIMATE ACTION PLAN 2050

Area of activity	1990	2014	2030	2030
		Figures in million t. CO_2 equivalent		*Reduction vs. 1990*
Energy industry	466	358	175 – 183	62 – 61%
Buildings	209	119	70 – 72	67 – 66%
Transport	**163**	**160**	**95 – 89**	**42 – 40%**
Industry	283	181	140 – 143	51 – 49%
Agriculture	88	72	58 – 61	34 – 31%
Subtotal	1,209	890	538 – 557	56 – 54%
Other	39	12	5	87%
Total	**1,248**	**902**	**543 – 562**	**56 – 55%**

Source: Climate Action Plan 2050, p 26 f.

IS GERMANY REALLY A PIONEER IN CLIMATE PROTECTION?

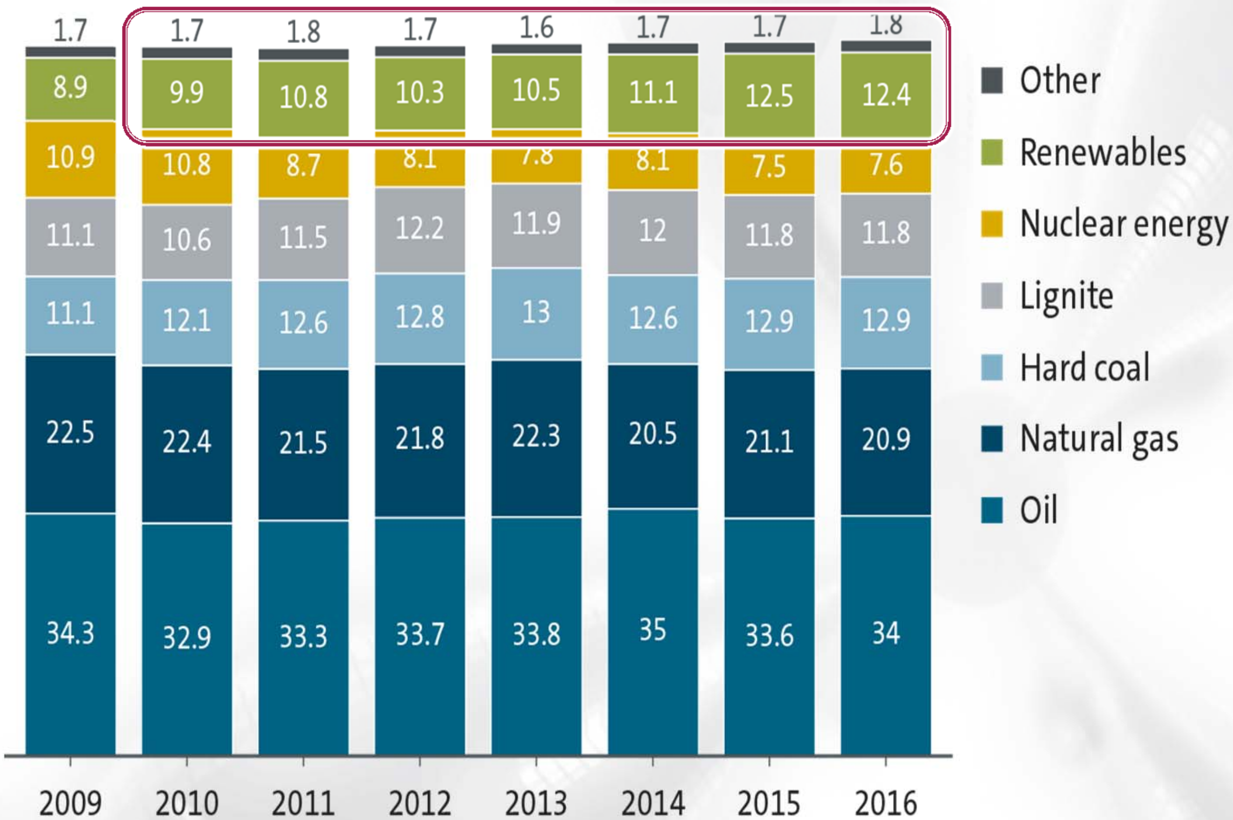
Greenhouse gas emissions
in Germany from 1990 until 2016



Source: German Federal Environmental Agency, National Greenhouse Gas Inventories 1990 to 2015 (status 02/2017) and estimate for 2016 (status 03/2017)

ENVIRONMENTAL AND CLIMATE PROTECTION IN THE TRANSPORTATION SECTOR

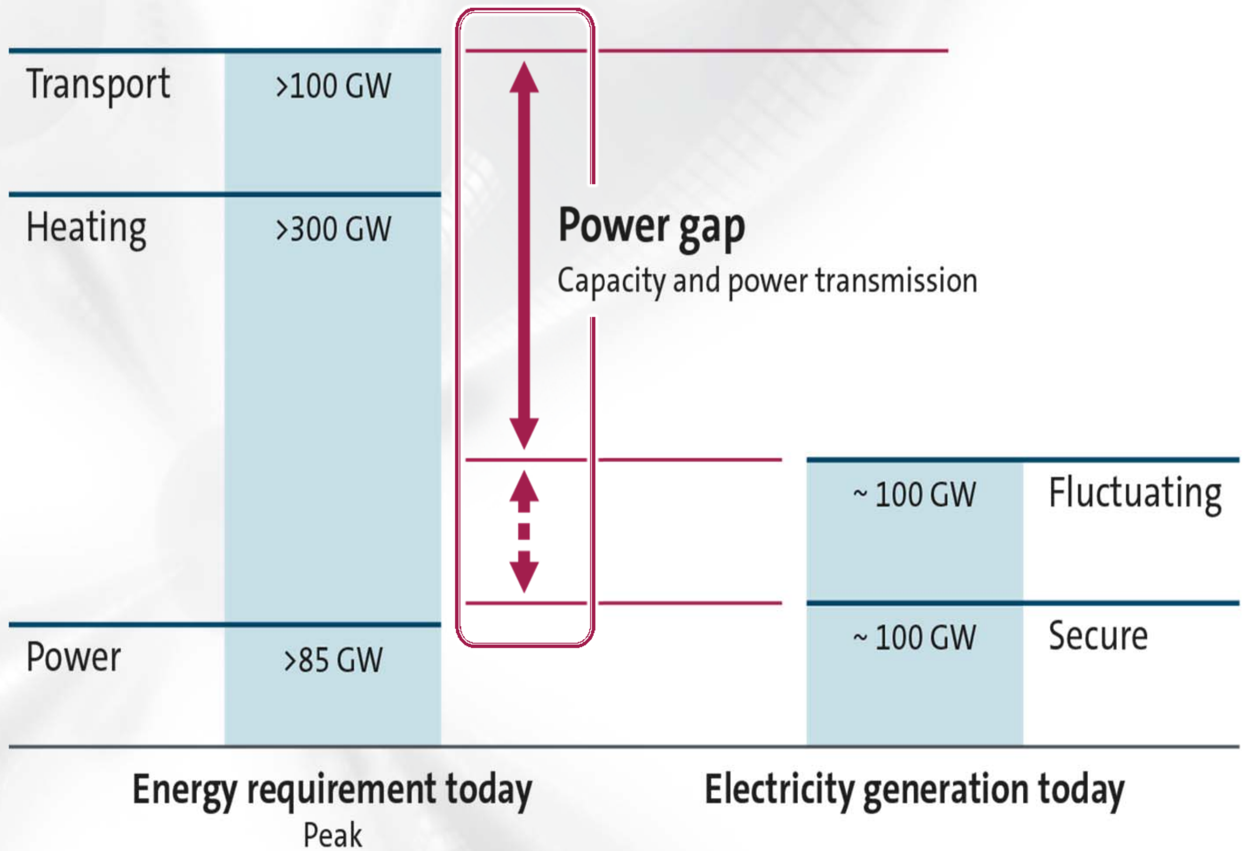
Share of primary energy source [%]
in Germany since 2009



Source: AGEB 03/2017

Source: Zukunft Erdgas e.V. (own work 2016)

ENVIRONMENTAL AND CLIMATE PROTECTION IN THE TRANSPORTATION SECTOR



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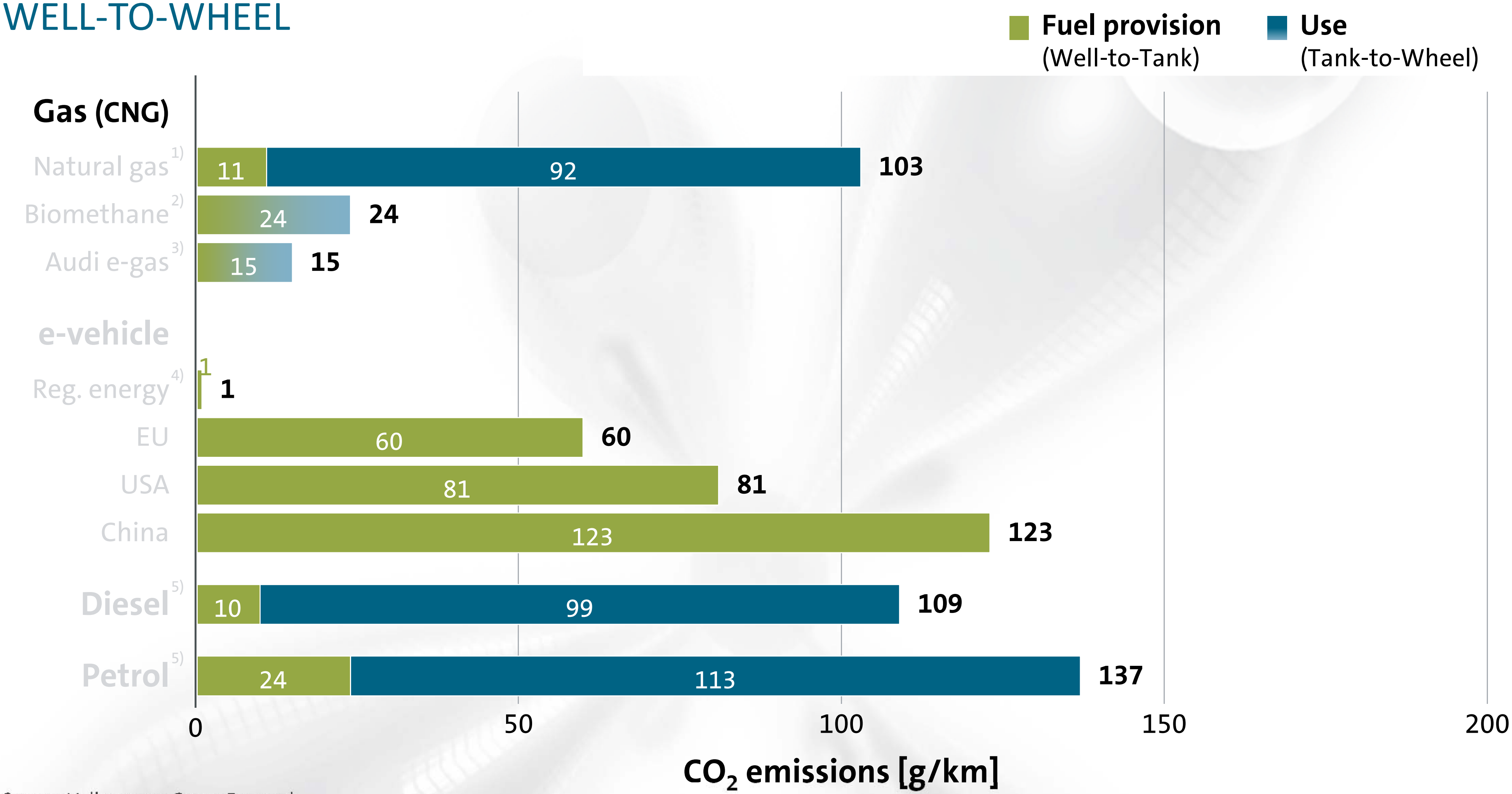
Source: Zukunft Erdgas e.V. (own work 2016)

CO2 EMISSIONS

WELL-TO-WHEEL

Comparison vehicle Volkswagen Golf (200,000 km lifetime)

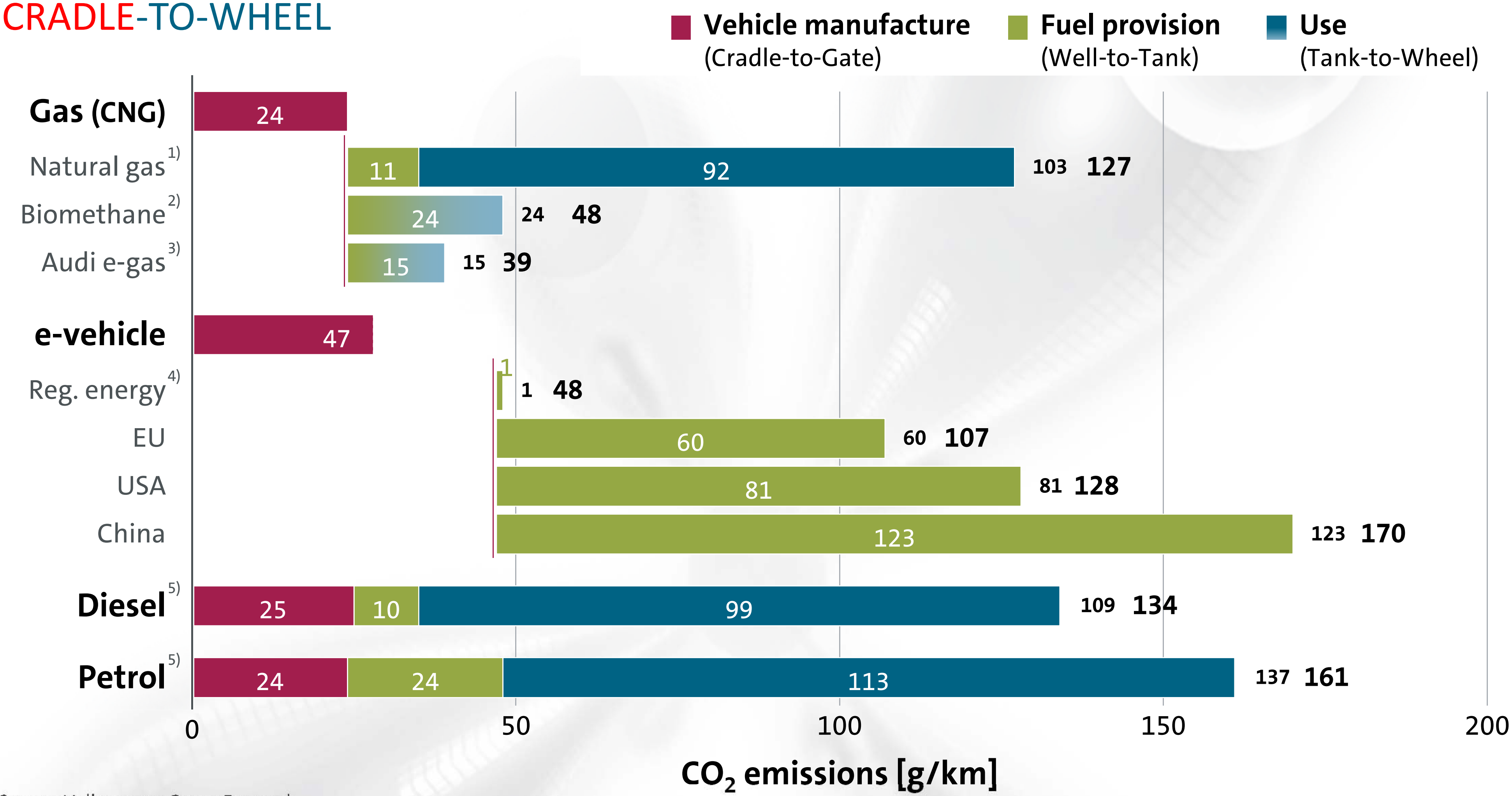


Source: Volkswagen Group Research

1) Assumption BAT: Natural gas from Norway with zero biogas content 2) Renewable Energy Directive (EU) 3) Methane from wind energy as per Audi e-gas facility in Werlte
4) Calculated with wind energy 5) WtW fig with 7% biodiesel or 5% bioethanol in acc. with EN 590 and EN 228, spec. CO_2 reduction of biofuels is 35% in acc. with EU directive 2009/28/EC

CO2 EMISSIONS
CRADLE-TO-WHEEL

Comparison vehicle Volkswagen Golf (200,000 km lifetime)



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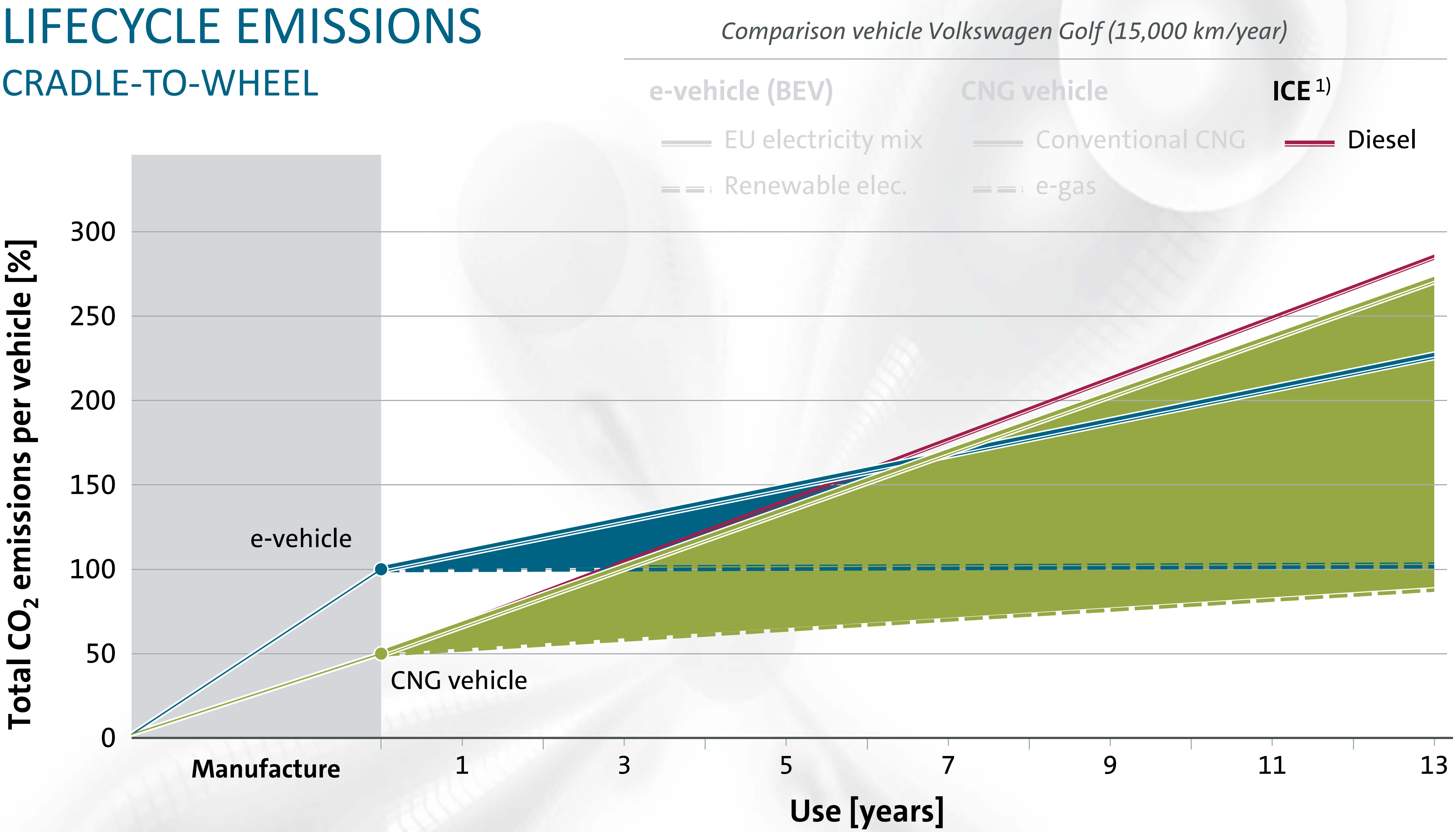
LIFECYCLE EMISSIONS

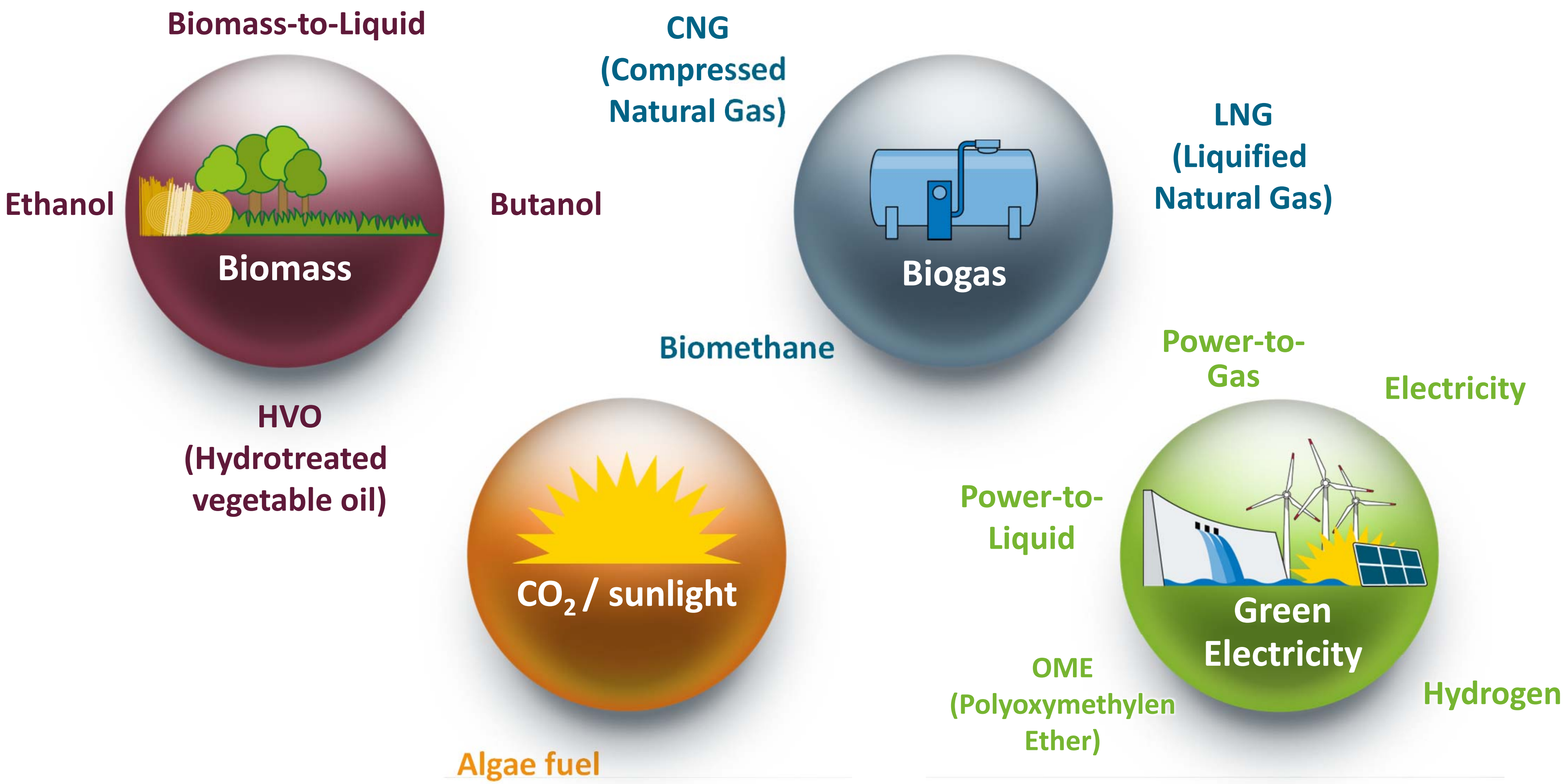
CRADLE-TO-WHEEL



Source: Volkswagen Group Research

1) ICE = Internal Combustion Engine

POSSIBLE CO_2-REDUCED FUELS FOR THE MOBILITY SECTOR



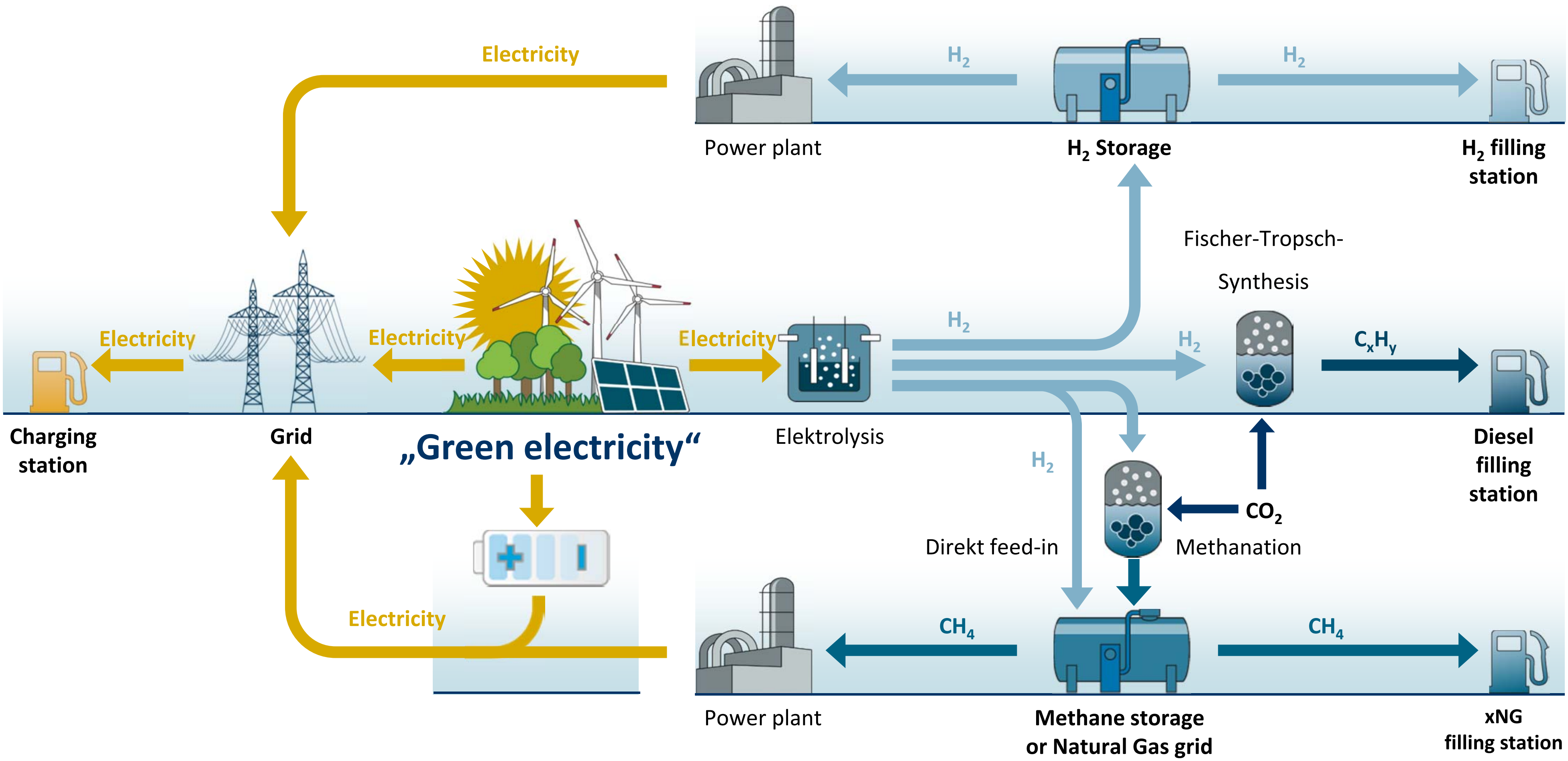
CLASSIFICATION OF BIOFUELS BASED ON COMPETITION OF SOURCES

Pathway of evolution for biofuels

Type	Examples	Not in competition with		
		Food	Agric. area	Biomass
• Conversion/use of sugar, starch and oil	• Ethanol from sugar beet • Ethanol from corn/crop • HVO*	✗	✗	✗
• Conversion of cellulose	• Biomethane from grass silage • Diesel from wood	✓	✗	✗
• Conversion of cellulose based on waste material by algae/bakteriea/yeast	• Ethanol from straw • Biomethane from straw • Diesel from wood waste	✓	✓	✗
• „Green Electricity“ as basis • Hydrocarbons from modified photosynthesis	• Power-to-Gas • Power-to-Liquid • Ethanol	✓	✓	✓

* HVO Hydrotreated Vegetable Oil

OPTIONS FOR STORAGE AND USE OF „GREEN ELECTRICITY“



CUSTOMER VALUE >TIME FOR REFUELING/RELOADING<

Gasoline/Diesel

Pump:

27.000 kW

(ca. 50 dm³/min)

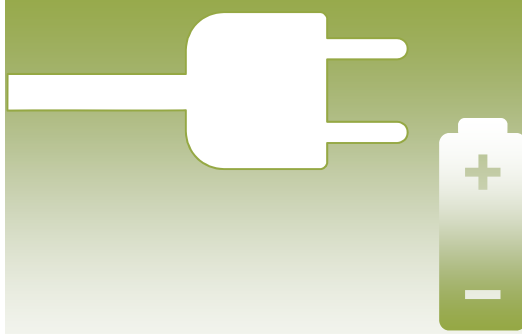
1.000 km/min

Electricity

Charging station:

3,3 - 200 kW

(Three-phase 400V)



0,3 - 20 km/min

Hydrogen

Filling station:

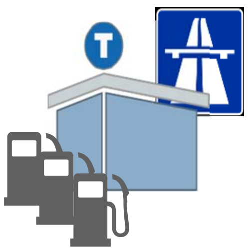
2.000 kW

(ca. 1 kg/min)

100 km/min

INFRASTRUCTURAL REQUIREMENTS ON GERMAN „AUTOBAHN“

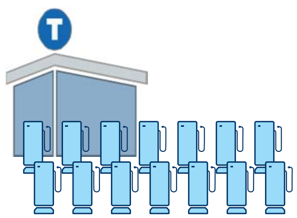
Service Area



Pumps
Gasoline/Diesel

BEV

**5 %
resp.
30 %**



Parking lots with
Fast-Charge supply
(200 kW)

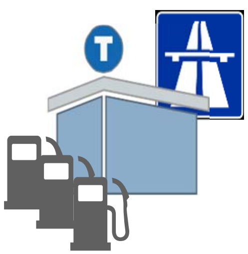
FCEV

**5 %
resp.
30 %**

H_2-refuelling station
HRS

INFRASTRUCTURAL REQUIREMENTS ON GERMAN „AUTOBAHN“

Service Area



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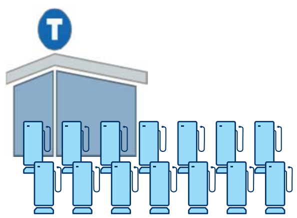

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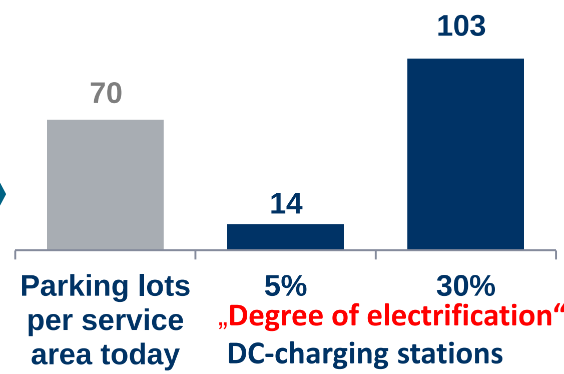

FCEV

**5 %
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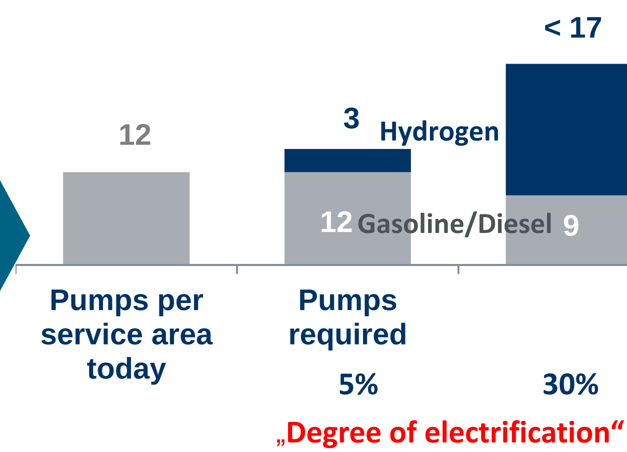
H_2-refuelling station
HRS



Pro´s & Con´s

DC-charging stations

- \+ demand-based delivery
- – Time to recharge: ~15 Min. until 80% SOC
- – Stress for the battery (fast charging)
- – Power rating for the service area > 2,5 MW resp. 20 MW

Onsite-Elektrolysis

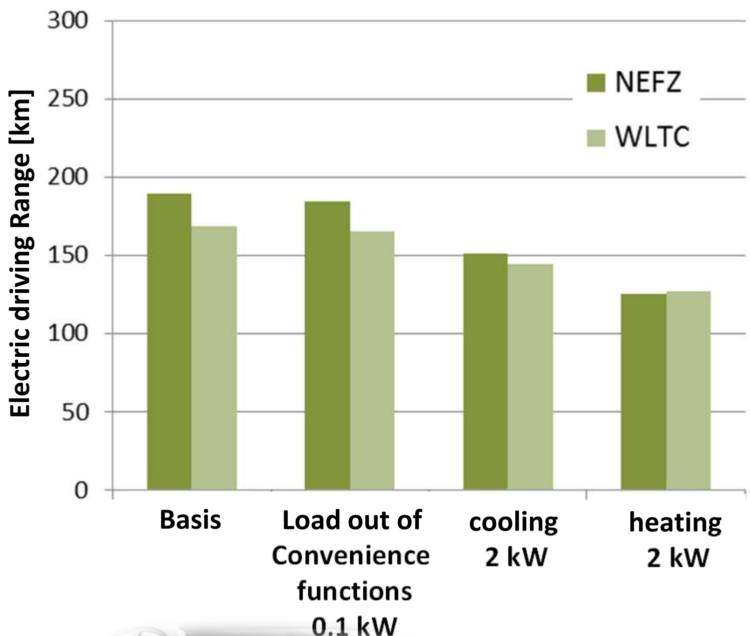
- \+ Time to recharge: 6 Min.
- – Power rating for the service area > 3 MW resp. 18 MW

Offsite-Elektrolysis

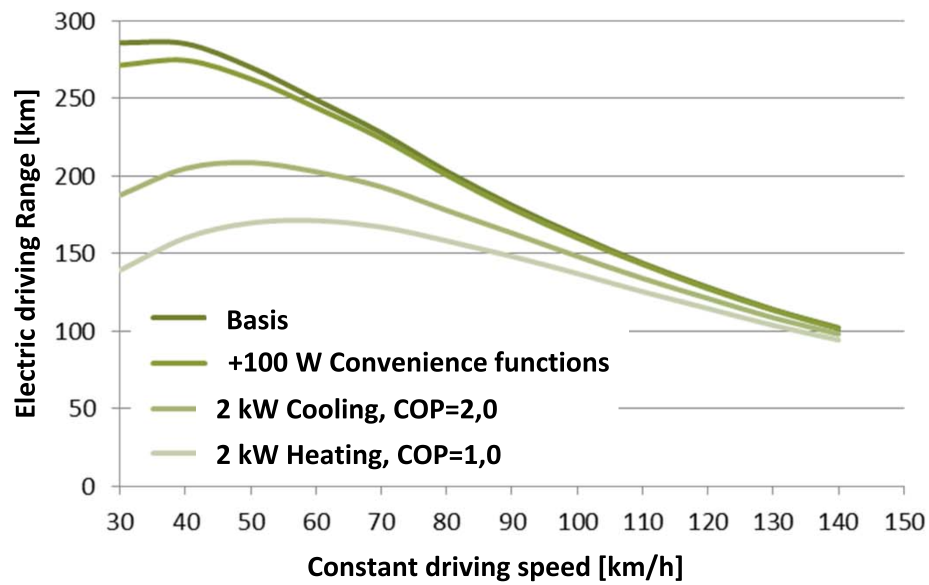
- \+ Time to recharge: 6 Min.
- \+ Power rating for the service area like today

INFLUENCE OF SYSTEM LOAD ON THE DRIVING RANGE OF A BEV

Drive cycles



Constant driving speed



Reference Vehicle (A-Segment) *1)

Golf VII (2015), 1510 kg

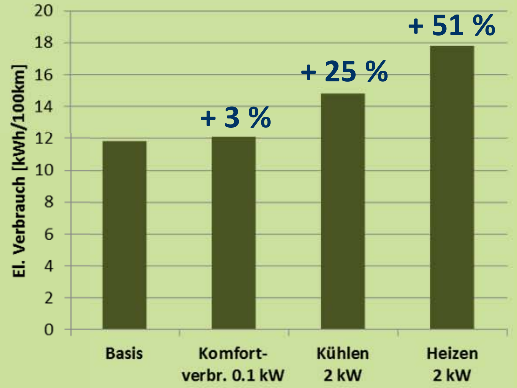
electric Motor	85 kW, 270 Nm, 12000 min^{-1}
Gearbox	1-Gear, koaxial
Battery	24,22 kWh

*1) Vehicle and component parameters referring to the E-Golf

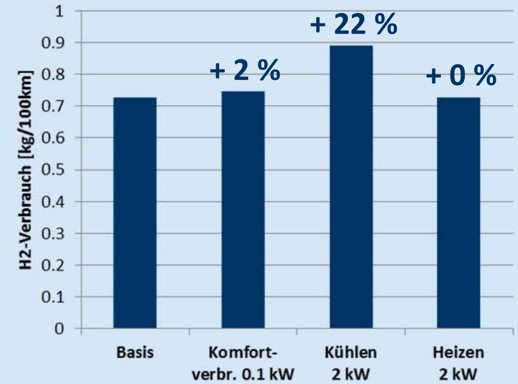
SPECIFIC INFLUENCE OF SYSTEM LOAD ON CONSUMPTION (NEDC)

VW Golf VII BMT

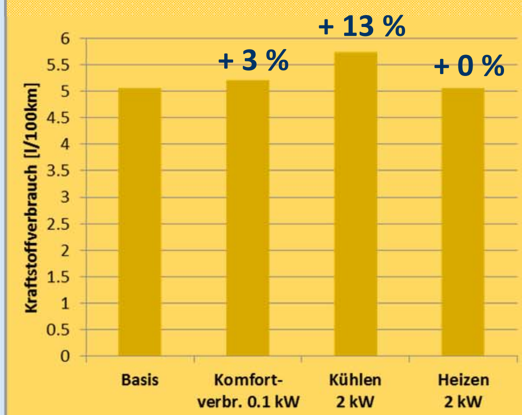
Battery Electric Drivetrain *1) (BEV)



FuelCell electric Drivetrain*1) (FCEV)



Conventional Gasoline Drivetrain *1) (ICE)

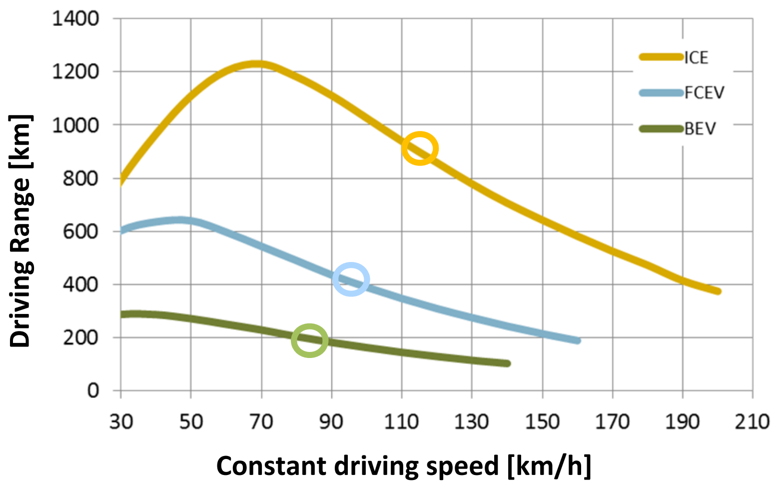


	Battery Electric Drivetrain *1) (BEV)	FuelCell electric Drivetrain*1) (FCEV)	Conventional Gasoline Drivetrain *1) (ICE)
Powertrain	85 kW el. Motor, 1-gear 24 kWh Battery	85 kW el. Motor, 1-gear 90 kW FuelCell	90 kW SI-ICE, DSG
12V-supply	12V DC/DC-converter	12V DC/DC-converter	12V Generator
Air conditioning system	Electrical refrigerant compressor (COP=2,0) *2)	Electrical refrigerant compressor (COP=2,0) *2)	Mechanical refrigerant compressor (COP=2,0) *2)
Heating system	Electrical PTC-Heater (COP=1,0)	Waste heat	Waste heat

*1) No in-production powertrains, qualitative comparison based on Golf VII BMT

*2) Coefficient of Performance, estimated for AC-system

SPEED-DEPENDANT DRIVING RANGE IN REAL-WORLD-DRIVING



If constant driving speed > O then higher consumption as in NEDC

VW Golf VII BMT

	Battery Electric Drivetrain *1) (BEV)	FuelCell electric Drivetrain*1) (FCEV)	Conventional Gasoline Drivetrain *1) (ICE)
Powertrain	85 kW el. Motor, 1-gear 24 kWh Battery	85 kW el. Motor, 1-gear 90 kW FuelCell	90 kW SI-ICE, DSG
Tank volume	22 kWh achievable	3 kg Hydrogen	45 l Gasoline (ROZ98)
NEDC Range	186 km	412 km	890 km
Max. speed	140 km/h*2)	160 km/h*2)	205 km/h*3)

*1) No in-production powertrains, qualitative comparison based on Golf VII BMT

*2) Maximum speed determined by max. speed of chosen electric engine

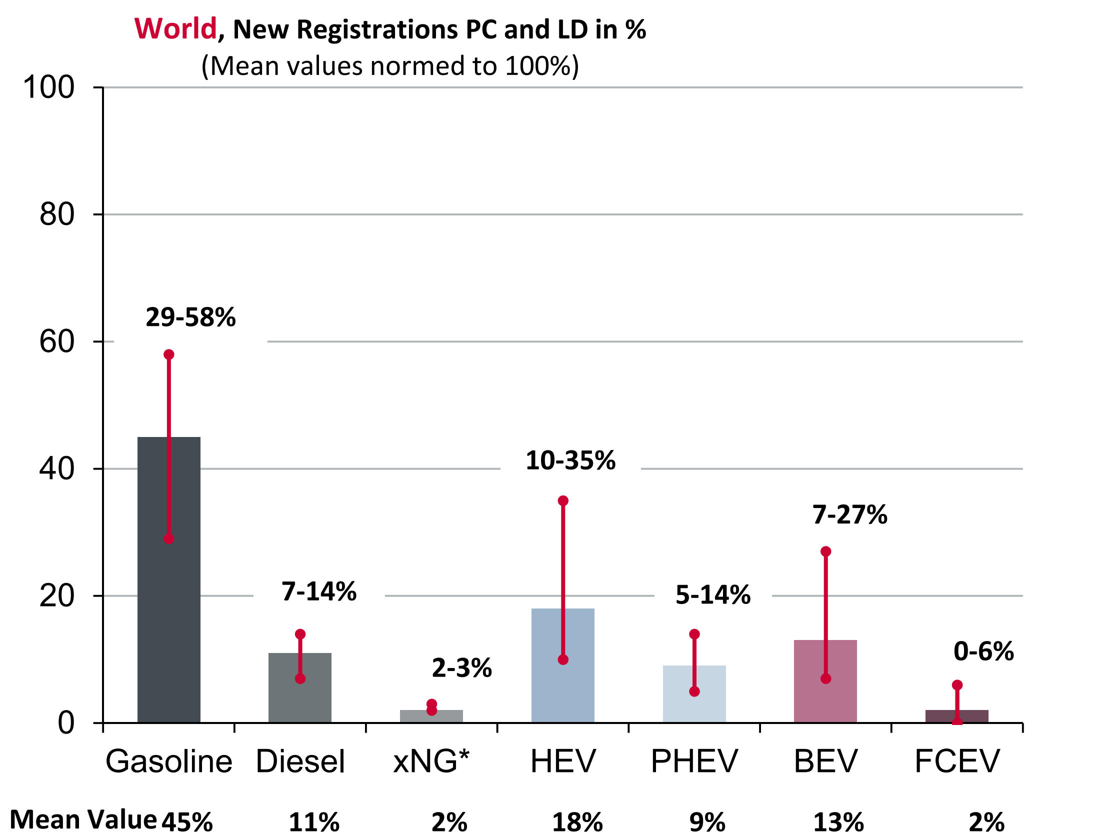
*3) Maximum speed determined by ICE rated power

WHAT WILL BE THE APPROPRIATE PORTFOLIO FOR A GLOBAL CAR MANUFACTURER BEYOND 2030?

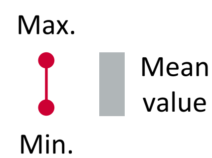
Concerning:

- **CO2-footprint**
  - **alligned with local and global options/restrictions out of the future energy supply portfolio**
- **Emission behaviour**
  - **„local“ RDE instead of cycle-based; lowest (technically) possible emissions as a „must“**
- **Various customer demands**
  - **Prolonged SUV-Trend; market-specific customs and practices; infrastructure in filling/charging stations**
- **Costs**
  - **Product related as well as R&D and capital expenditures (capex)**
- **…**

POWERTRAIN DISTRIBUTION 2030 WORLDWIDE



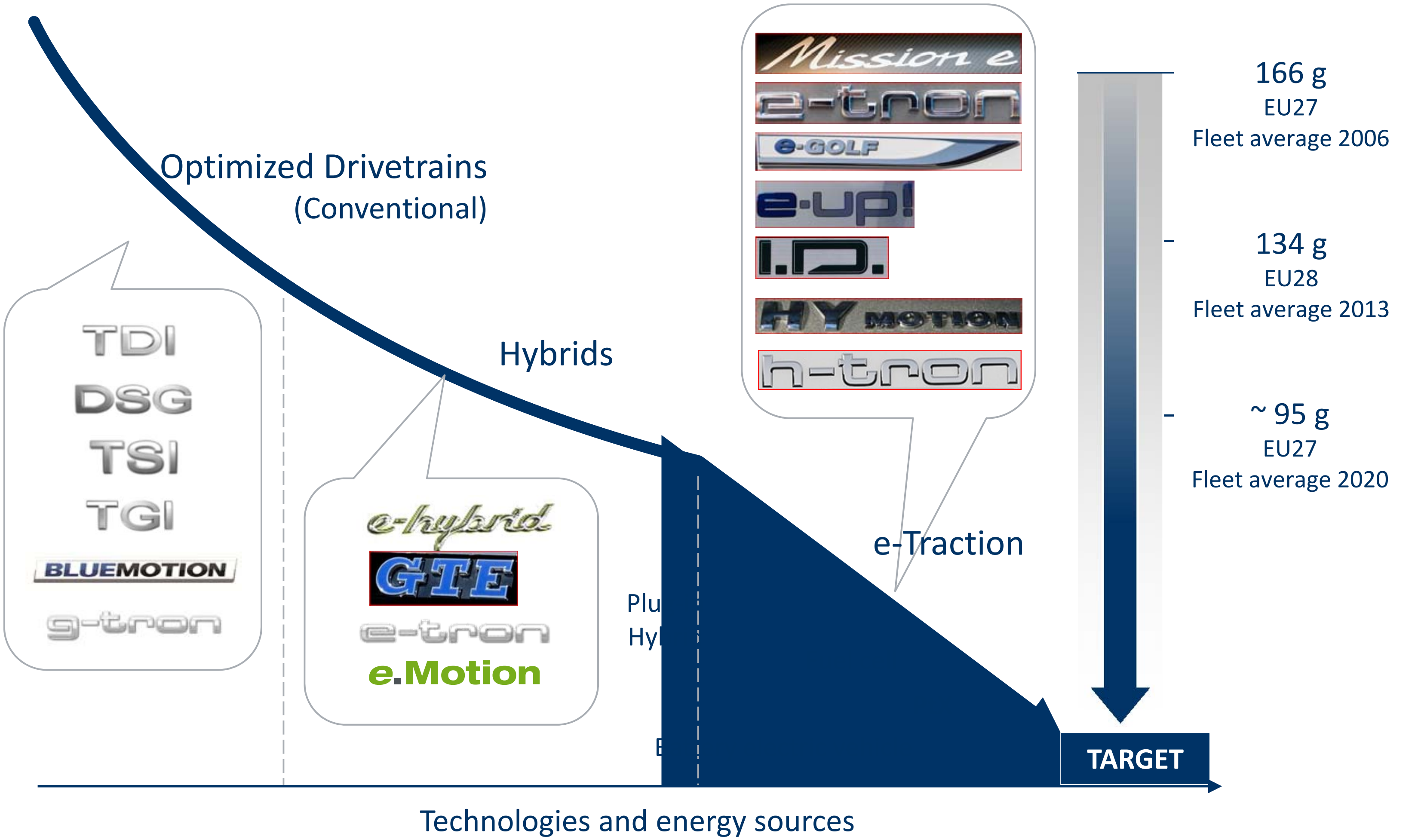
- **Coexistence of all types of Powertrains** still remains in 2030
- **Gasoline Engines** especially in connection with Hybrid Systems **remain dominant on the global market**
- In average of the results of the different studies **BEV overtake Diesel**
- Estimations concerning **market penetration by BEV** shows a **relevant dispersal (7%-27%)**
- Some studies forecast **FCEV to reach first relevant market shares in 2030**



Sources: 20 global studies by Ricardo, McKinsey, BCG, Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag, Center for International Automobile Management RWTH Aachen, Bosch, IHS Global, Navigant Research, etc.
Comment: not all years in all studies available, population of every single year different; mean values normed to 100%;
*small sampe, only 3 of 20 studies relate on xNG

VOLKSWAGENS PATHWAY TO A SUSTAINABLE MOBILITY

CO2 ROADMAP AND BROAD TECHNOLOGY PORTFOLIO



THANK YOU FOR YOUR ATTENTION!