Automotive technologies of alternative propulsion and automated driving

Colloquium at the Department of Electrical Power Engineering
Brno University of Technology

Date:
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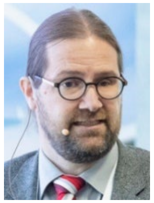
Host:
Assoc. Prof. Ing. Petr Baxant

Speaker:
Associate Prof. Dr. Mario Hirz
Institute of Automotive Engineering
Graz University of Technology

Associate Prof. Dr. Mario Hirz



Institute of Automotive Engineering

a: Inffeldgasse 11/2

p: 0316 873 35220

w: https://www.tugraz.at/institute/ftg/home/
https://online.tugraz.at/tug_online/visitenkarte.show_vcard?pPersonenGruppe=3&pPersonenId=A9333817B52C635A
https://www.researchgate.net/profile/Mario_Hirz

e: mario.hirz@tugraz.at

- PhD at the Institute of Internal Combustion Engines and Thermodynamics in 2005, habilitation at the Institute of Automotive Engineering in 2011, Associate Professor since 2016.
- Research topics include future mobility, sustainable transport, alternative powertrains & electric propulsion systems, new vehicle technologies, automotive mechatronics and virtual product development.
- Lecturer and researcher at Universities in the USA (Tampa, FL), China (Shanghai, Zhenjiang), Thailand (Bangkok), Saudi-Arabia (Riyadh), Slovenia (Maribor) and Innsbruck (Austria).
- Program Coordinator of the Double Degree Program Mechanical Engineering in co-operation with Tongji University, Shanghai, China.
- Scientific head of the university course Mechatronics Academy and the Mobility Module in the university course Leadership in Digital Transformation.

The transition in the automotive industry is driven by …

(1) Legislative boundary conditions targeting to a reduction of emissions

(2) Digitalization & automation

(3) New mobility concepts & business models

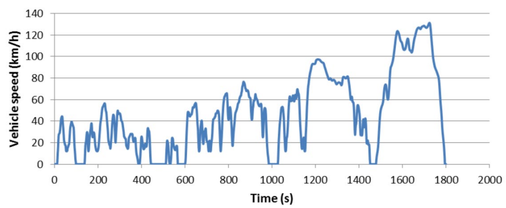
Legislative boundary conditions targeting to a reduction of emissions … and driving electrification of propulsion systems

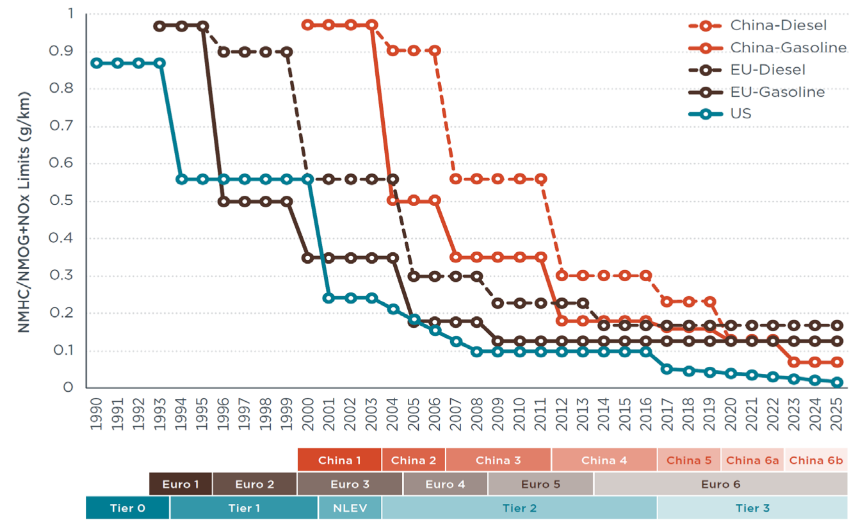
Legislative boundary conditions targeting to a reduction of exhaust emissions

Reduction of harmful exhaust emissions

- Hydro-carbons HC
- Carbon monoxide CO
- Nitro-oxygen NO_x
- Particulate emissions

WLTP & RDE





Example: Limitation of NOx-emissions in different markets

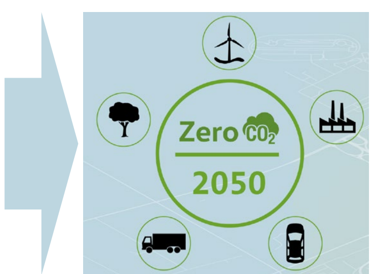
Reduction of greenhouse gases

e.g. EU "Green Deal" targets:

CO_2 reduction of

- 50% in 2030
- 100% in 2050

... in all branches.



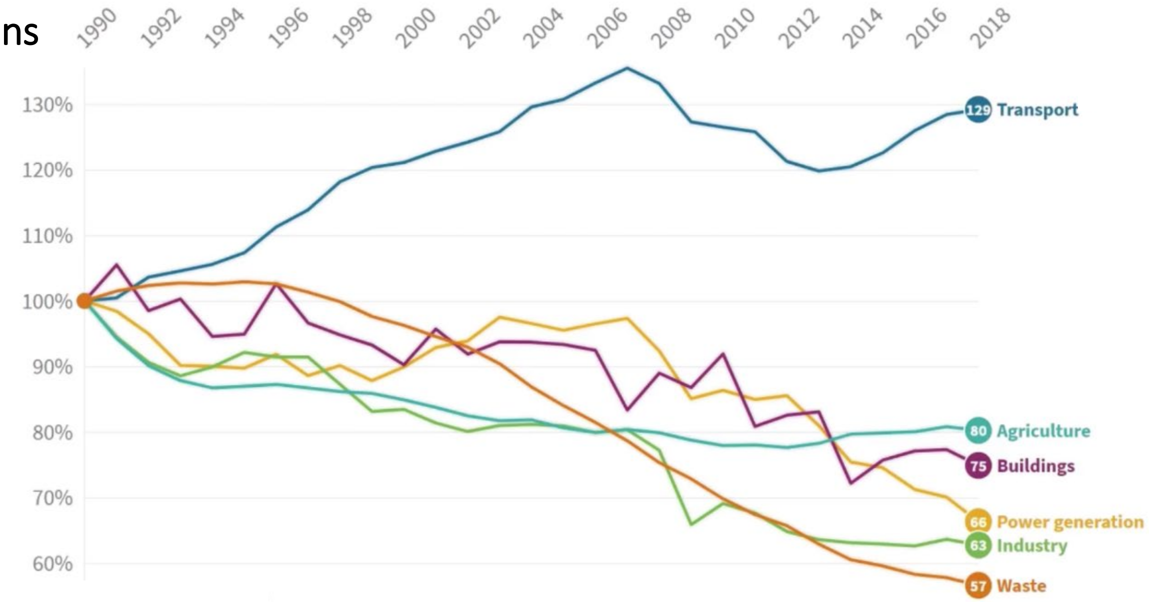
Proposed technologies:

- "Green" electricity production
- Electrification of mobility (cars, trucks)
- Hydrogen as a fuel (cars, trucks, ships)
- Synthetic fuels (trucks, ships, aviation)
- Carbon capture & storage (industry)

Transport

Legislative boundary conditions targeting to a reduction of exhaust emissions

Emitted CO_2 – emissions in the EU since 1990
(1990 = 100%)



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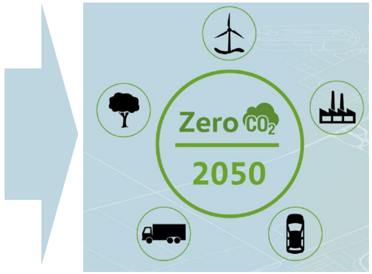

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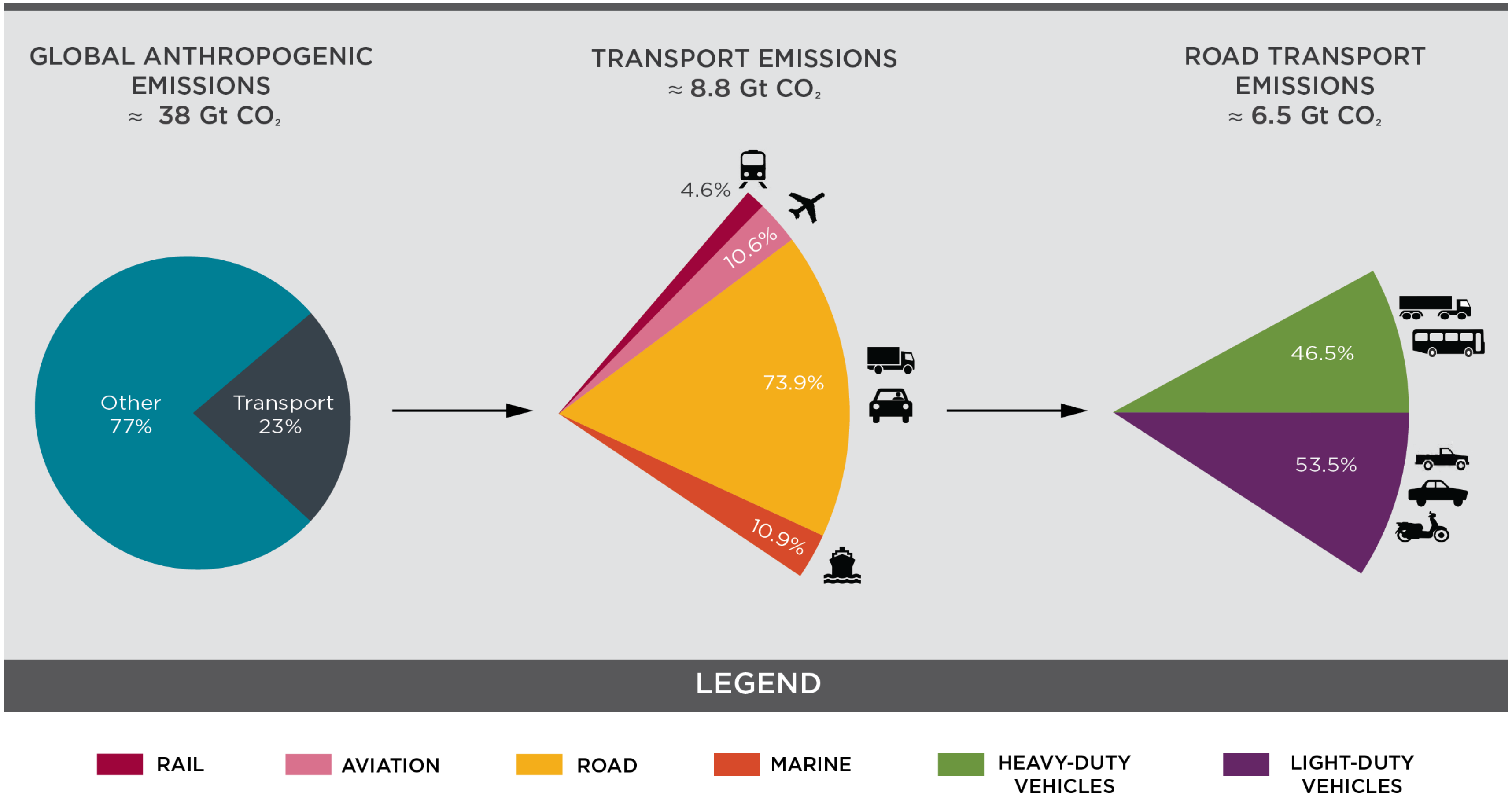
Transport

Source: EU, Transport & Environment

Worldwide CO_2-impact of the transportation sector



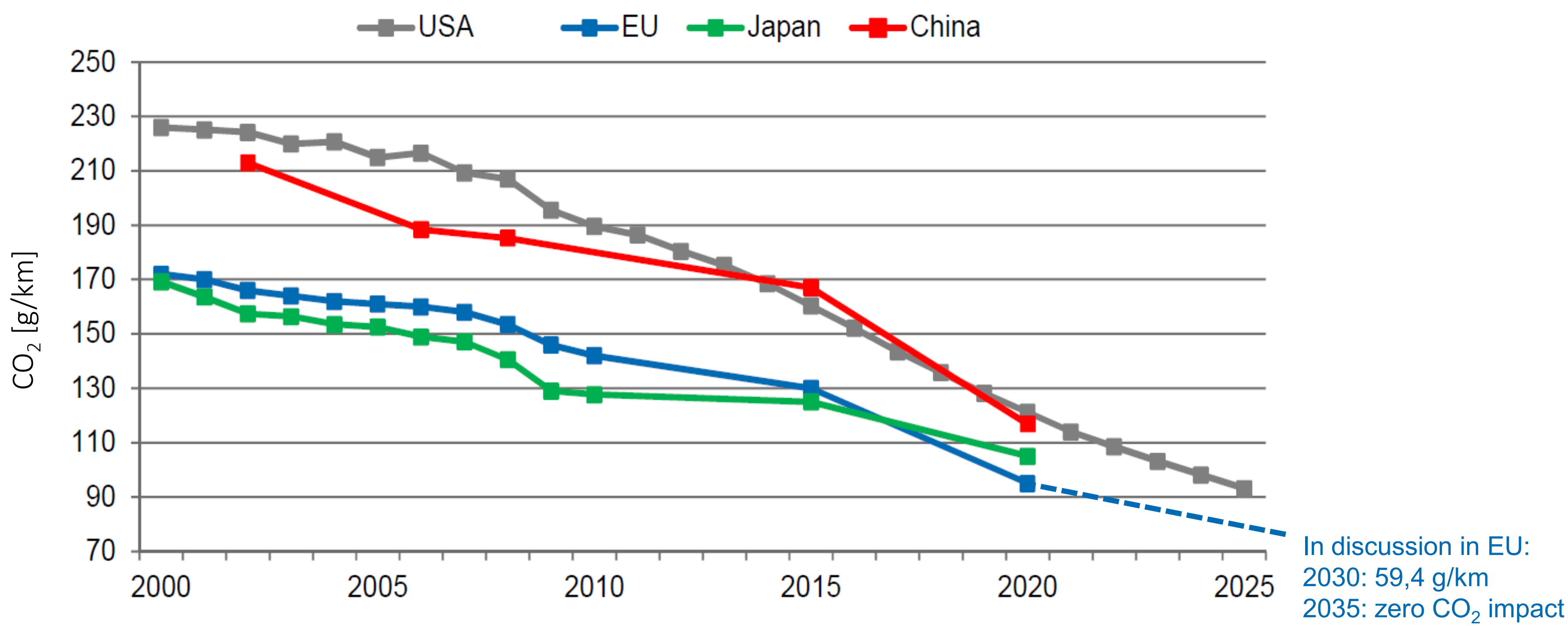
⇒ ca. 17% CO_2 from road transportation

… 8% CO_2 commercial transport

… 9% CO_2 individual mobility

Source: ICCT

Legislative boundary conditions: Trends of CO_2 fleet-emissions of personal cars



95 g/km CO_2 → 4.1 liter per 100km Gasoline
→ 3.6 liter per 100km Diesel fuel

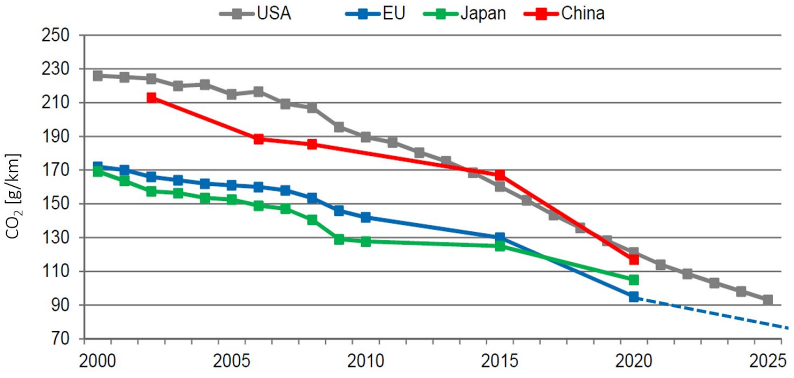
59.4 g/km CO_2 → 2.6 liter per 100km Gasoline
→ 2.3 liter per 100km Diesel fuel

Source: ICCT, EU

Penalty payments in the EU

Penalty payment for car manufacturer that do not reach the CO_2 - target:

- 95 € per Gramm CO_2 target violation per car sold and registered in the EU in a year
- Phasing-in regulations 2021 - 2023, special credits for eco-innovation
- Pooling is allowed (group-wide consideration)
- Reliefs for small manufacturers



Strategies of the automotive industry:

Short term (- 2027):

→ Optimization of combustion engines
→ "Smaller" combustion engines
→ Electrification (HEV / PHEV / BEV)

Mid- / long term (2030 +):

→ Electric cars
→ Hydrogen vehicles
→ Synthetic fuel applications

Comparison of propulsion technologies

Overview of propulsion technologies

Conventional drive systems

+ Established technologies, low costs
+ Quick fuel-filling, large driving distances
+ Potential for further improvements

- Thermodynamically bad efficiency
- Local exhaust emissions
- Direct dependency on crude oil (today)

Electric drive systems

+ Most efficient propulsion technology
+ No local emissions
+ Quiet technology, high driving comfort

- Expensive & complex battery systems
- Short driving distances, long charging times
- Environment-friendliness depends on the technology of electric power generation

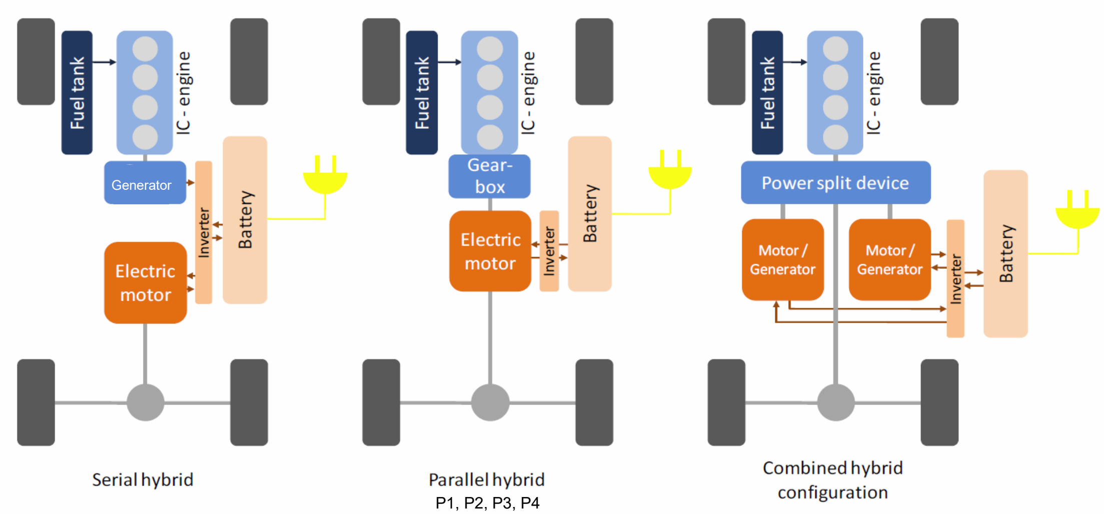
Hybrid drives

+ Combination of conventional and electric drive systems
+ Good efficiency possible
+ No driving range limitation
+ Specific test-procedures defined (for PHEV)

- Complex technology, integrating two propulsion systems
- CO_2 reduction potential is significantly influenced by user pattern / customer behavior

Architectures of hybrid- and battery-electric drive trains

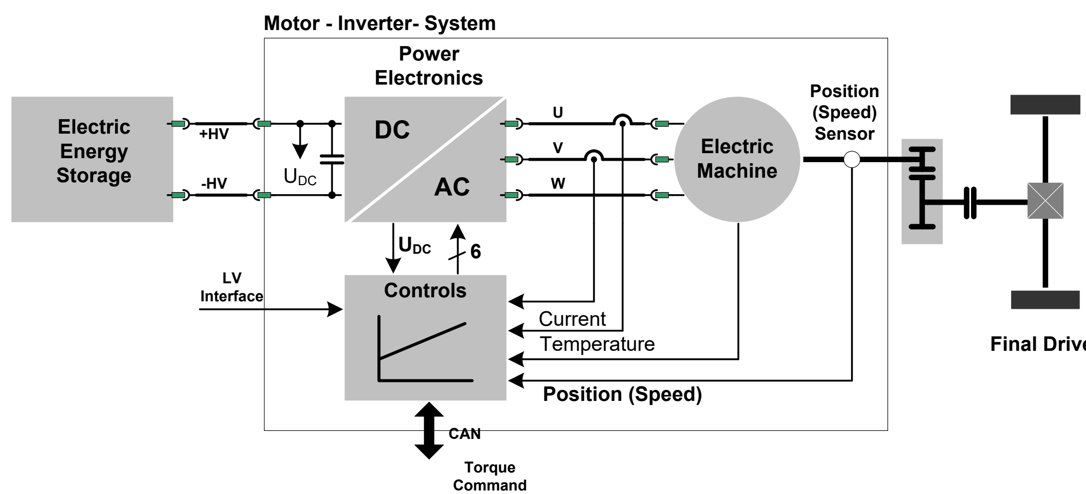
Overview of hybrid drive train configurations



- Different combinations of ICE and e-drive possible
- Different levels of hybridization (MHEV, HEV, PHEV)
- CO_2 – reduction potential between 5% and > 50%, depending on the user behavior

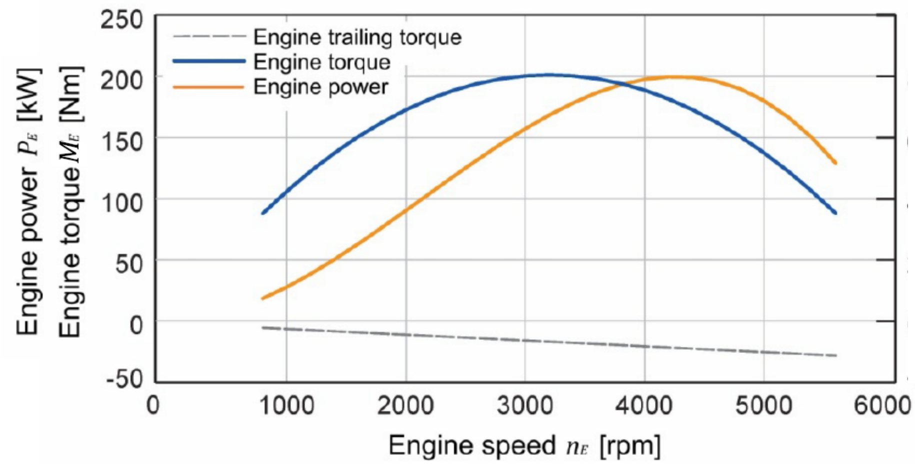
Battery-electric drive trains

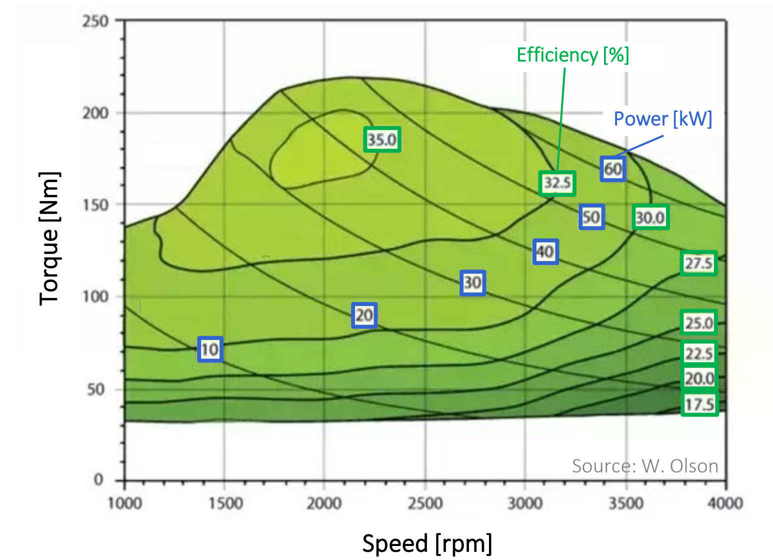
- Simple mechanical powertrain
- … but complex E/E systems
- Key components:
  - Battery
  - Inverter
  - Electric motor



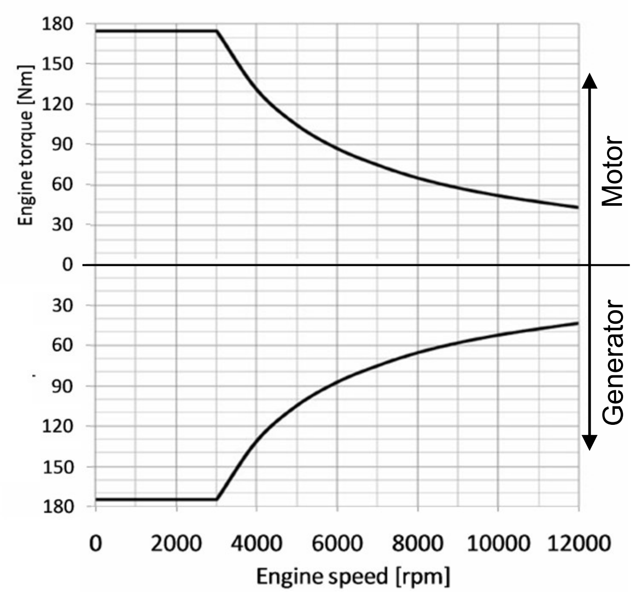
Internal combustion engine vs. electric motor

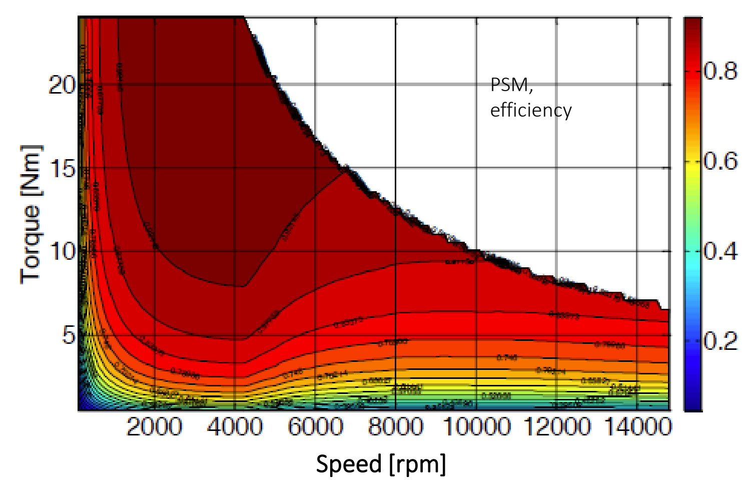
ICE



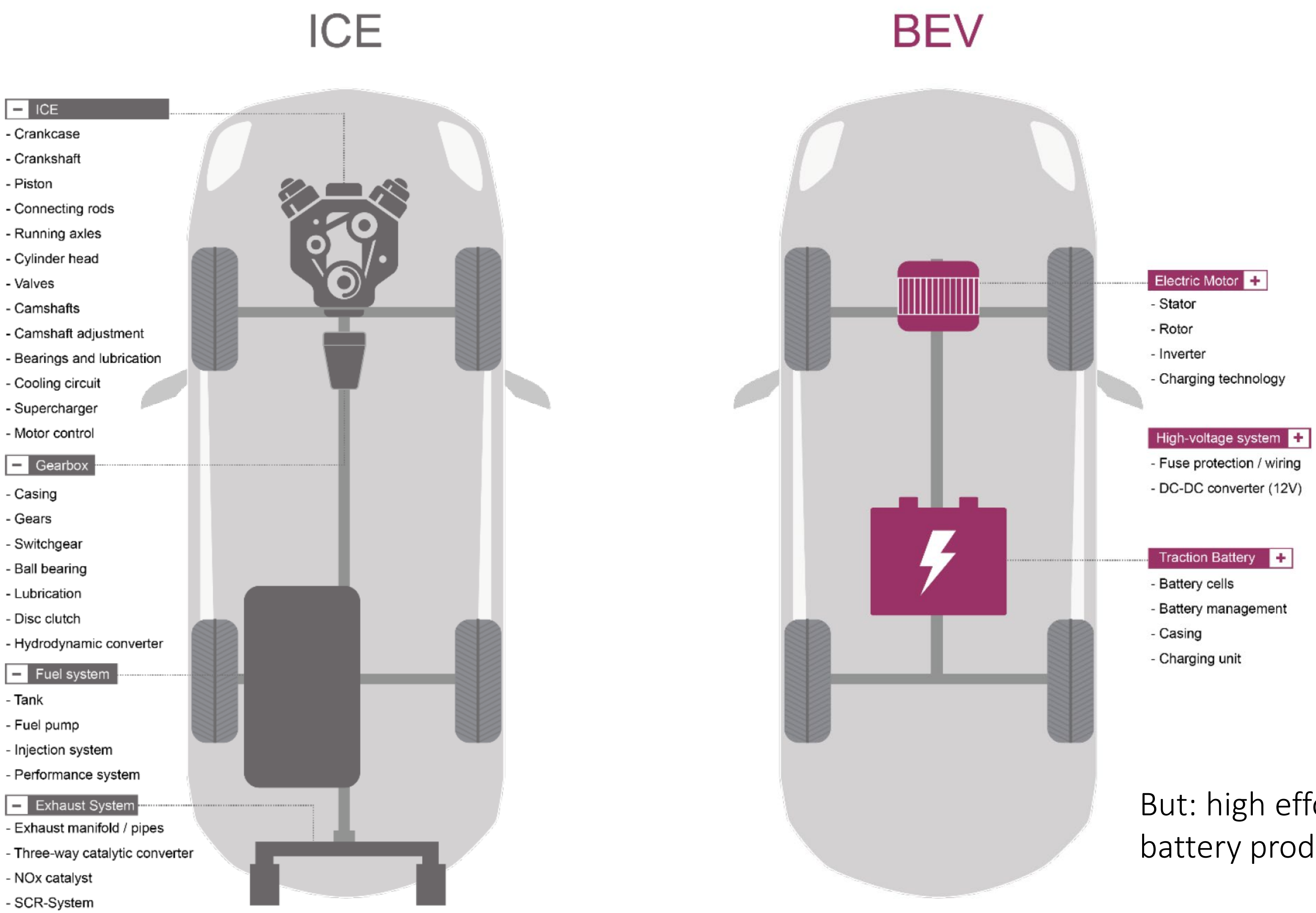


E-Motor





Electric drive trains: reduction of complexity

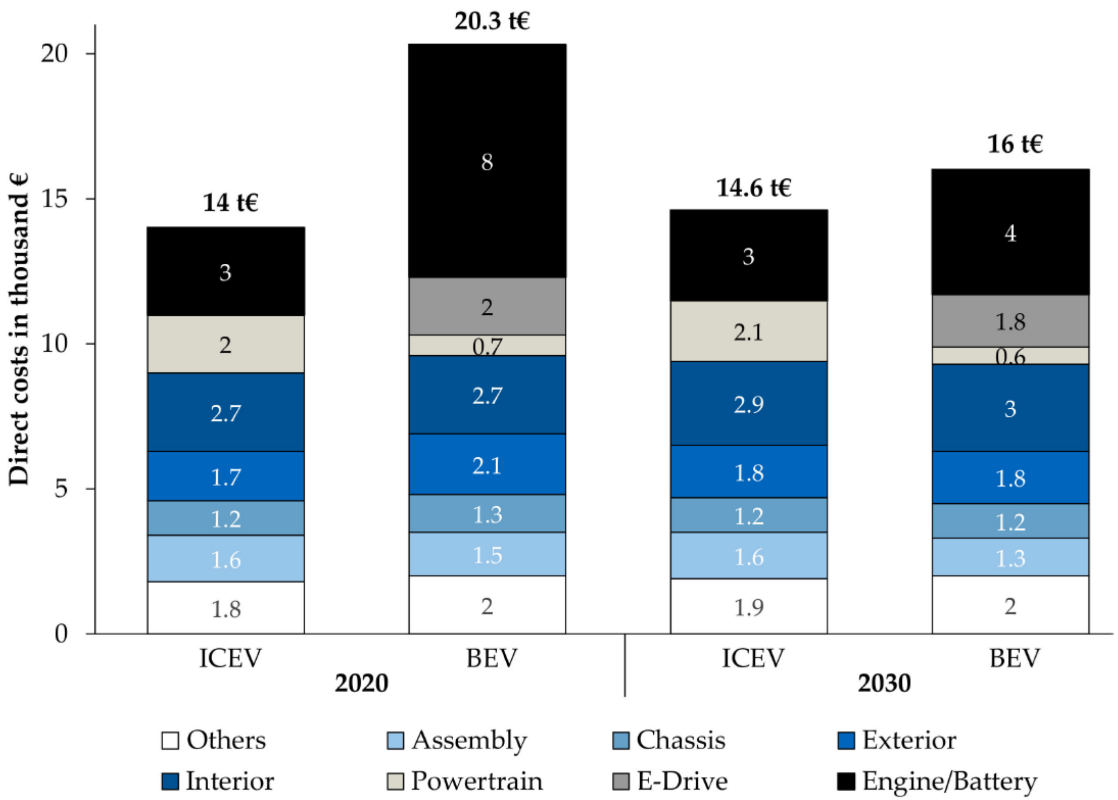


But: high effort for battery production

Source: Semmer

Cost comparison of propulsion technologies

Cost breakdown, compact SUV



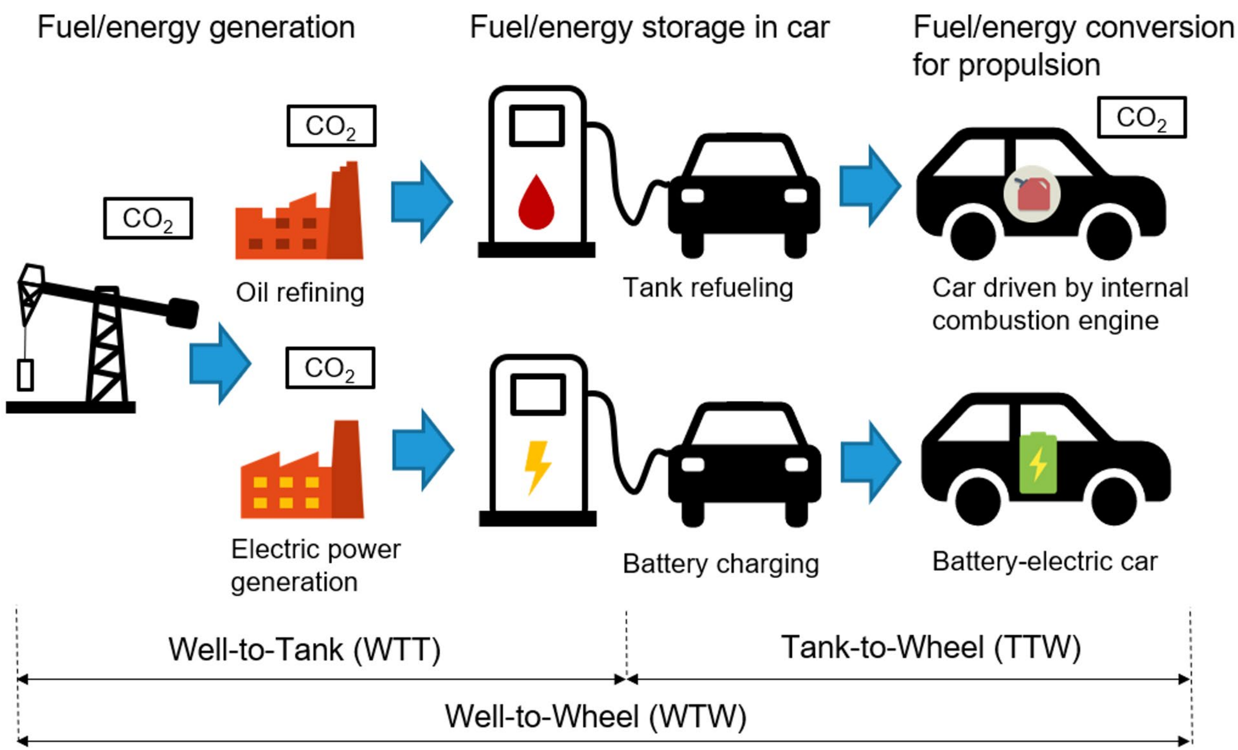
Source: König et.al, TU-Munich

CO_2 – impact of propulsion technologies

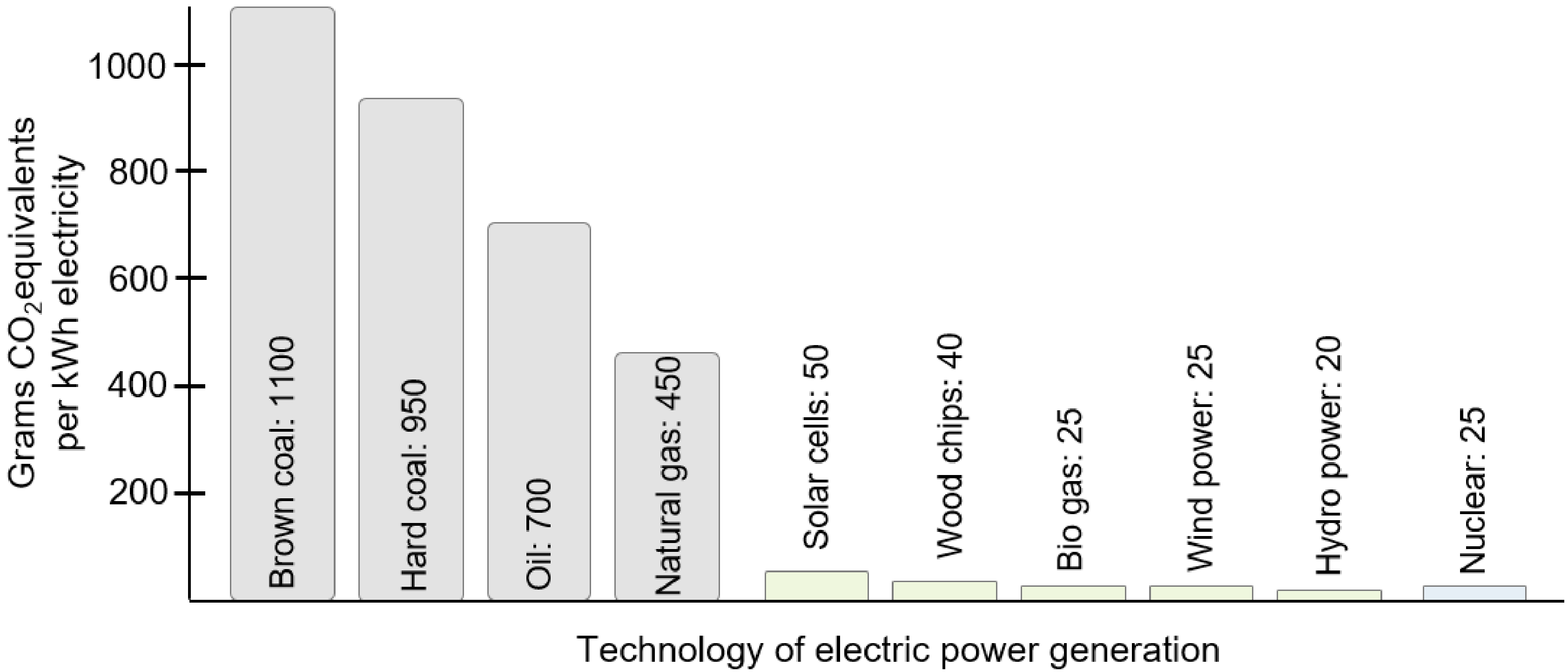
Well-to-tank & tank-to-wheel emissions

CO_2 equivalent emissions include:

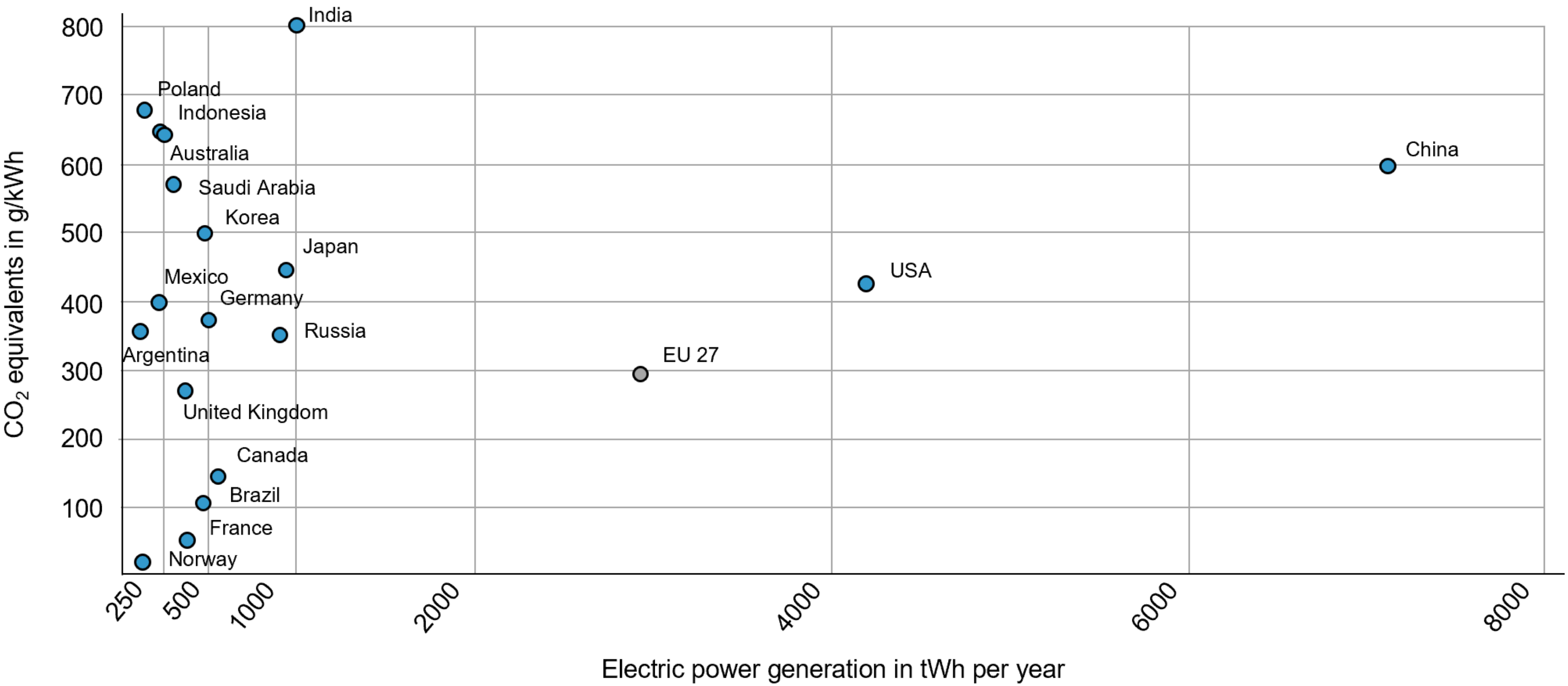
- Production of fuel (electric energy): WTT (well-to-tank emissions) ... not considered in fleet-related CO_2-legislation
- Conversion of energy in the car: TTW (tank-to-wheel emissions) ... => fleet emission targets
- Sum of WTT & TTW: WTW (well-to-wheel emissions)



Key role: electric energy production
Different technologies have different CO_2-impact



Key role: electric energy production
Electricity mix in selected countries / regions



… a link to real-time data: https://www.electricitymap.org/map

Example:

Comparison of different propulsion technologies, WTT and TTW: Electric car vs. Gasoline / Diesel car

Remark: Calculation of CO_2 emissions out of fuel consumption by use of factor 26.2 for Diesel and factor 23.2 for Gasoline fuel: *liter/100km * factor =* CO_2 *[g/km]*

Life-cycle - related consideration of technologies

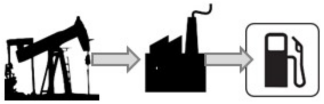
Life-Cycle Assessment (LCA): Evaluation of technologies and products under consideration of the entire life-cycle (production, use-phase, end-of-life-phase). Standardized procedure, e.g. according to ISO 14040, ISO 14044.

Technical specifications

- Vehicle type, size, weight…
- Propulsion technology
- Vehicle technology
- Materials

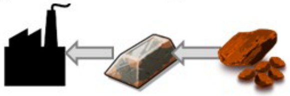
Supply of resources and energy

- Type and amount of energy for production and use
- High-/low impact materials
- Raw-materials



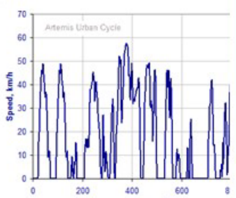
Production and recycling technology

- Efficient production, supplier & logistics processes
- Design for recycling
- Recycling technologies

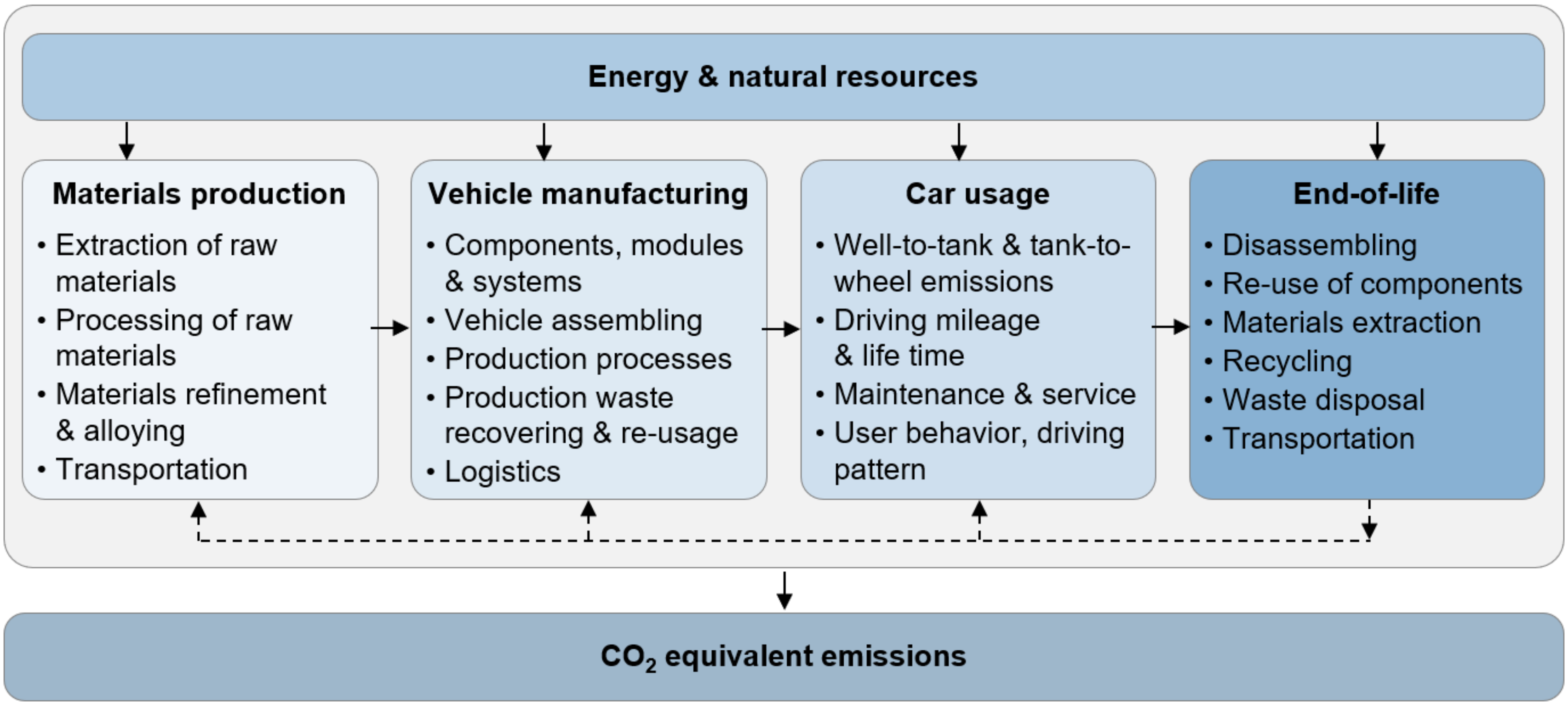


In-use phase

- Transportation demands
- User profiles, driving behavior
- Fuel- & energy consumption
- Maintenance & service effort

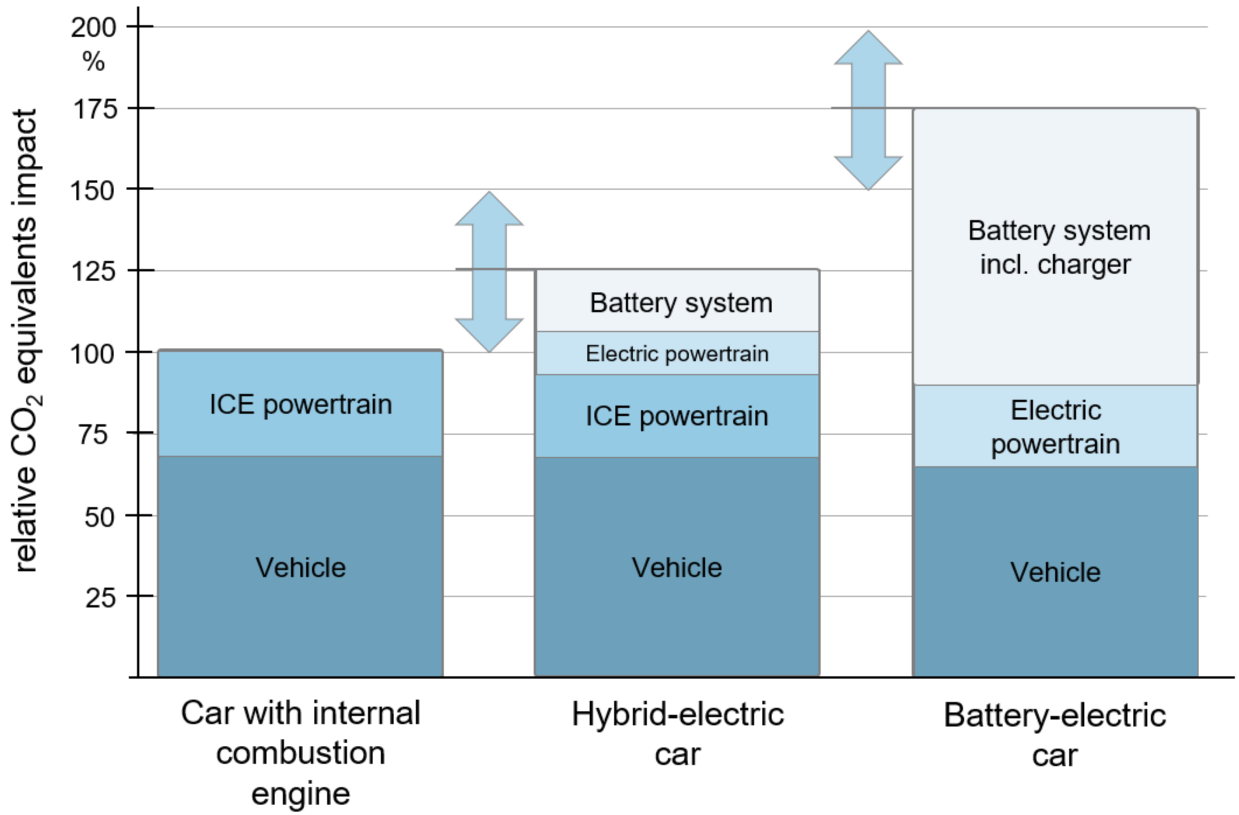


Life-cycle assessment – a tool for objective technology evaluation



Life-cycle - related consideration of technologies

CO_2 - impact of vehicle production in comparison



Influence of vehicle production

Comparison of mass-production compact cars with different propulsion technologies.

ICEV: Internal combustion engine vehicle
HEV: Full-hybrid vehicle
BEV: Battery-electric vehicle

	ICEV	HEV	BEV
Car type:	Compact car (C-class)	Compact car (C-class)	Compact car (C-class)
Vehicle mass:	1400 kg	1450 kg	1800 kg
Propulsion:	Gasoline engine	Comb. full hybrid, gasoline engine	Permanent magnets synchr. motor
Max. power:	90 kW	90 kW	110 kW
Fuel / energy consumption:	6 liter / 100 km	4.5 liter / 100 km	20 kWh / 100 km incl. charging losses
Battery capacity:	-	1.3 kWh	60 kWh
Country of battery cell production:	-	China	China
Country of vehicle manufacturing:	Germany	Japan	Germany
Car body main material:	Steel	Steel	Steel
Vehicle comfort equipment level:	Standard	Standard	Standard
Total carbon footprint of production:	7.5 tonnes CO_2 equivalents	9.0 tonnes CO_2 equivalents	14.0 tonnes CO_2 equivalents

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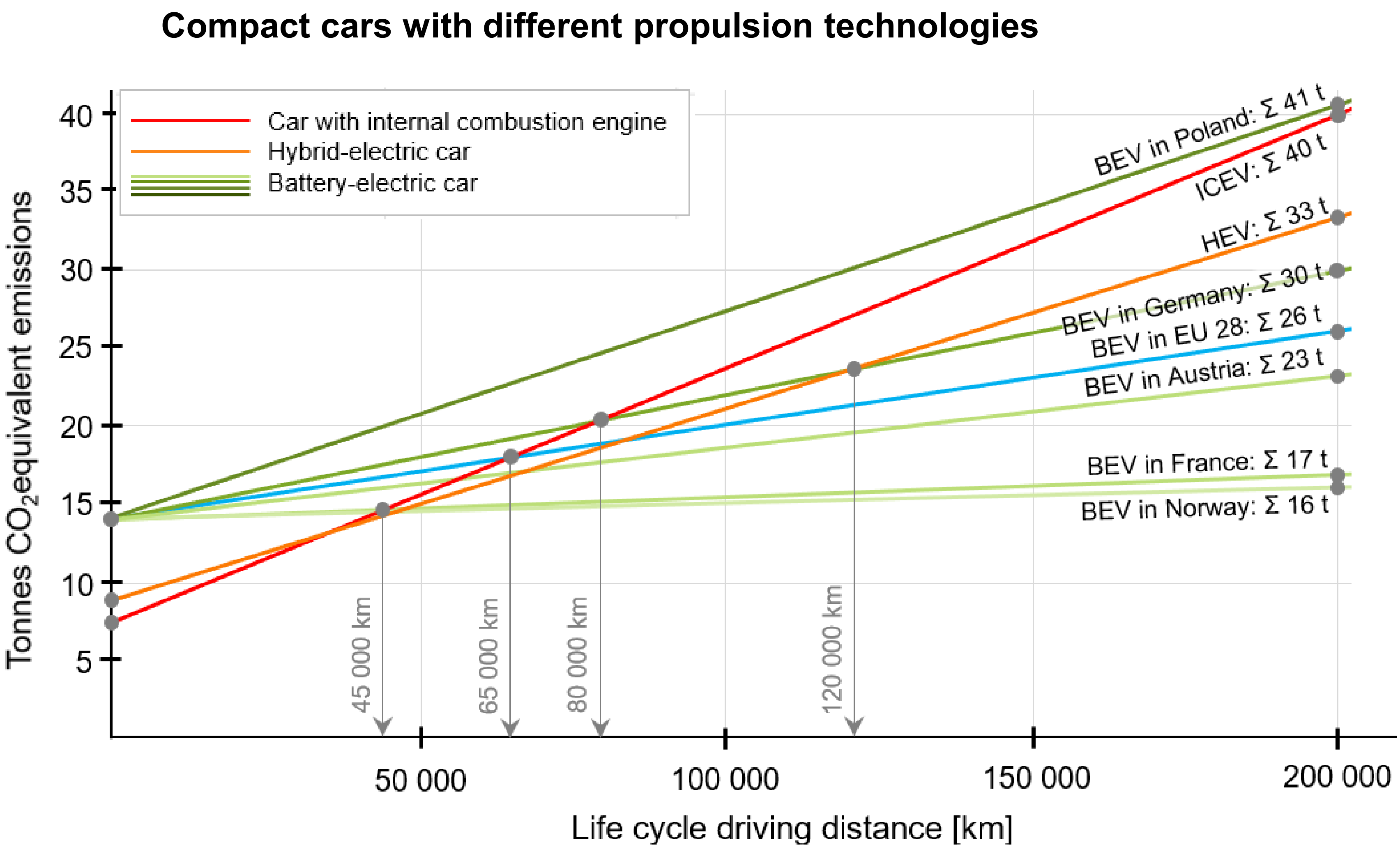
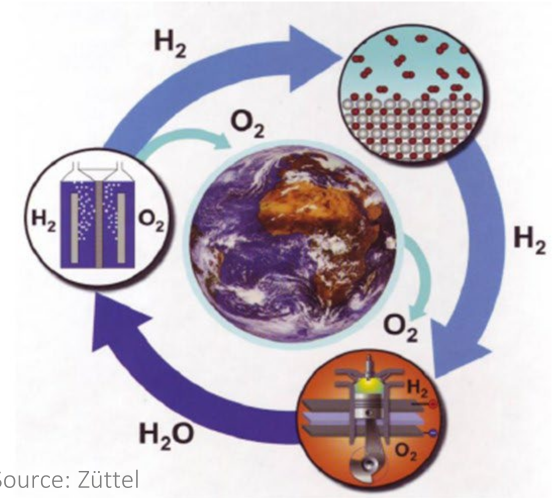
Total life cycle carbon footprint in comparison



Alternative fuels: a possible solution?

Hydrogen: Fuel for a closed energy circle

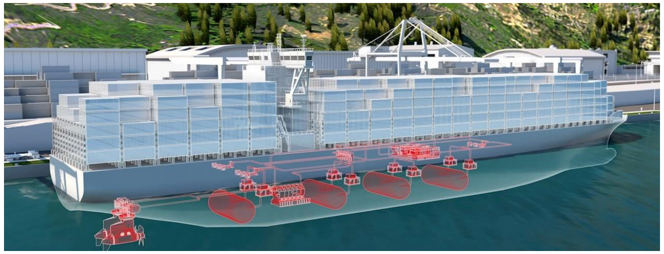
Electric Energy



Source: Züttel

Electric / mechanical output

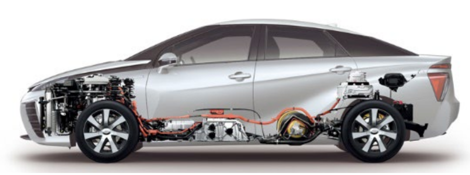
ships, (airplanes) … research



Sources: ABB, NASA

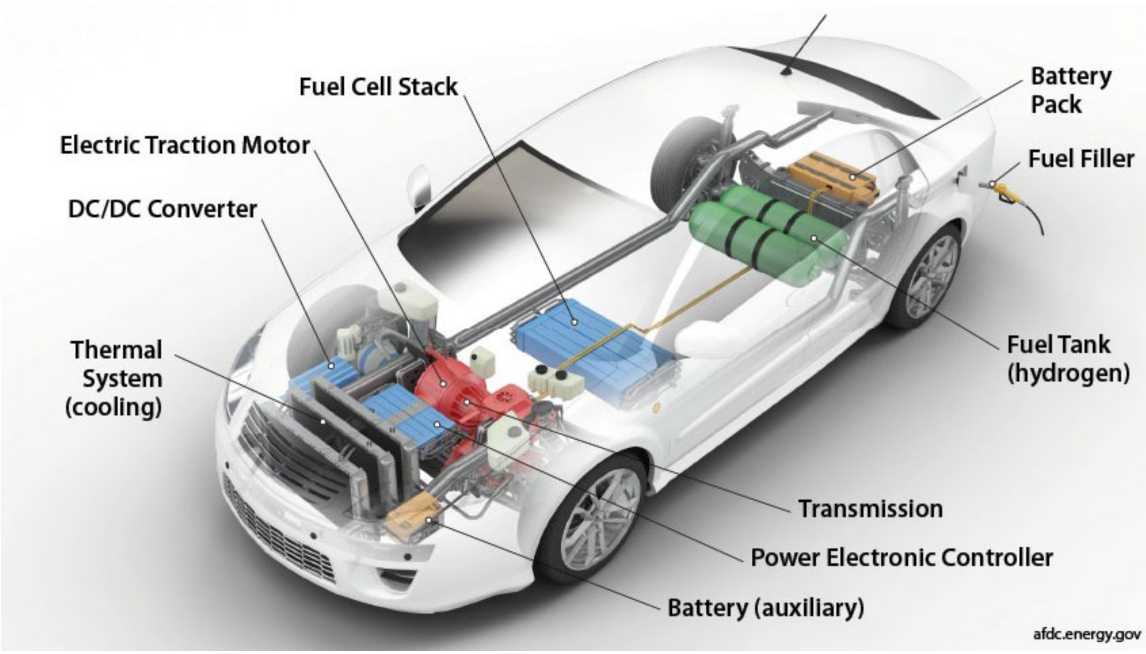
in use today: commercial vehicles, trains, (cars)

Source: Hyundai



Source: Toyota

Fuel-cell vehicles



Hydrogen is seen as the fuel for future mobility. Advantage is the potential for CO_2 emission free operation.

Fuel cell systems provide good efficiency behavior in comparison with internal combustion engines.

Main challenges for a broad application of hydrogen as fuel are hydrogen generation and storage.

Some numbers:

Hydrogen fuel consumption of a typical personal car: 0.7 – 1.6 kg/100km

Energy content of hydrogen:120 MJ/kg = 33,3 kWh/kg

Hydrogen costs: 6 – 10 € per kg

CO_2 footprint of hydrogen production from natural gas: 8.5 – 11 kg CO_2 per kg H_2

CO_2 footprint of hydrogen production from wind / solar energy: potentially near zero.

Alternative fuels: a possible solution?

Synthetic fuels

State-of-the-art:

- GTL – gas to liquid: made of natural gas (methane, CH_4)
- CTL – coal to liquid: made of coal (historical)
- BTL – biomass to liquid: made of different bio-sources, e.g., ethanol, bio-diesel

In development with future potentials:

- PTL – power to liquid: fuel (hydrocarbons) made of H_2, CO_2 & CO by electrolytic conversion of water (production of H_2) and synthesis of CO_2 & CO.

  \+ result is synthetic fuel that can have similar characteristics as gasoline or diesel.
  \+ use of existing tank systems and infrastructure possible
  \+ different application possible, e.g. cars, trucks, ships, airplanes, construction machines
  \+ electric energy is needed (a lot); use of green electric energy results in sustainable fuel
  \+ => CO_2 reduction out of the atmosphere … theoretically CO_2 neutral fuel possible.

  \- Worse production efficiency, high electric energy consumption
  \- market-relevant volumes after 2030 expected (@ Shell)

Alternative fuels: a possible solution?

Prototype e-fuel production facility in Chile (Punta Arenas)
Partners: Siemens, Porsche, Gasco, Enap, Enel, ExxonMobil
Planned are 130.000 liter e-fuels per year

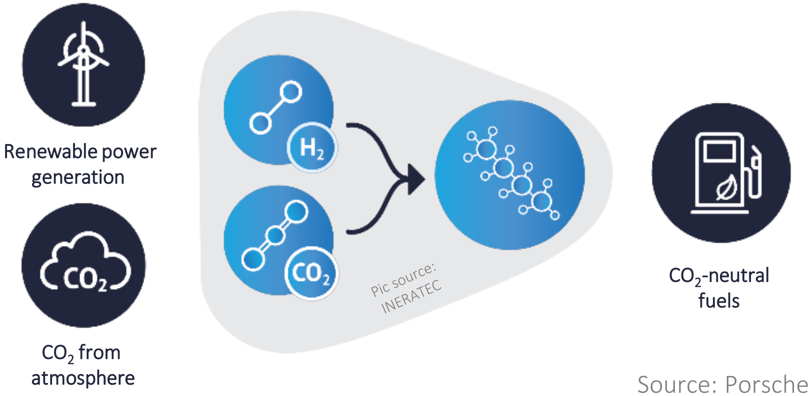
PTL – “e-fuels”

Process:

(1) CO_2- neutral production of hydrogen, e.g. by electrolytic conversion of H_2O by use of wind- or water power
(2) Extraction of CO_2 from processes of out of the atmosphere (direct air capture). Use of Ceramic filters, which bind CO_2, and subsequently performed periodic purging of the filters under heat.
(3) Synthetic process for production of methanol (CH_3OH, respectively CH_4O).
(4) Final synthetic processes methanol to gasoline => formation of the actual fuel.

Production of 1 liter e-fuel requires:

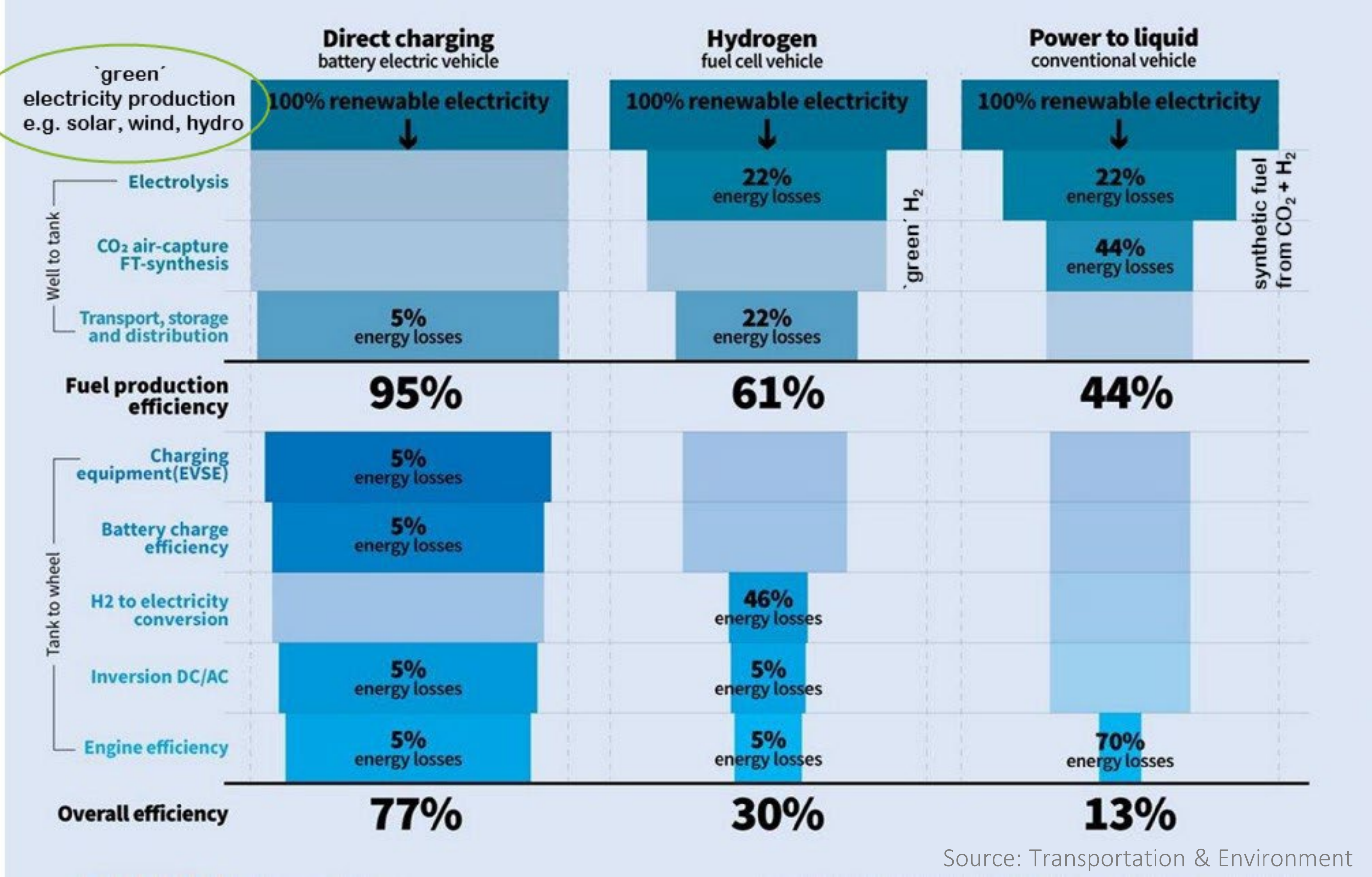
3 liter water
+ ca. 6000 m^3 air for CO_2- extraction
+ ca. 16 $kWh^{(+)}$ electric energy
… resulting in 8.5 kWh energy content per liter
(e-fuel as gasoline replacement)



Source: Porsche

Under "Green Deal" aspects: WTW-efficiency of different propulsion technologies

Assumption: renewable initial energy – the "green" way

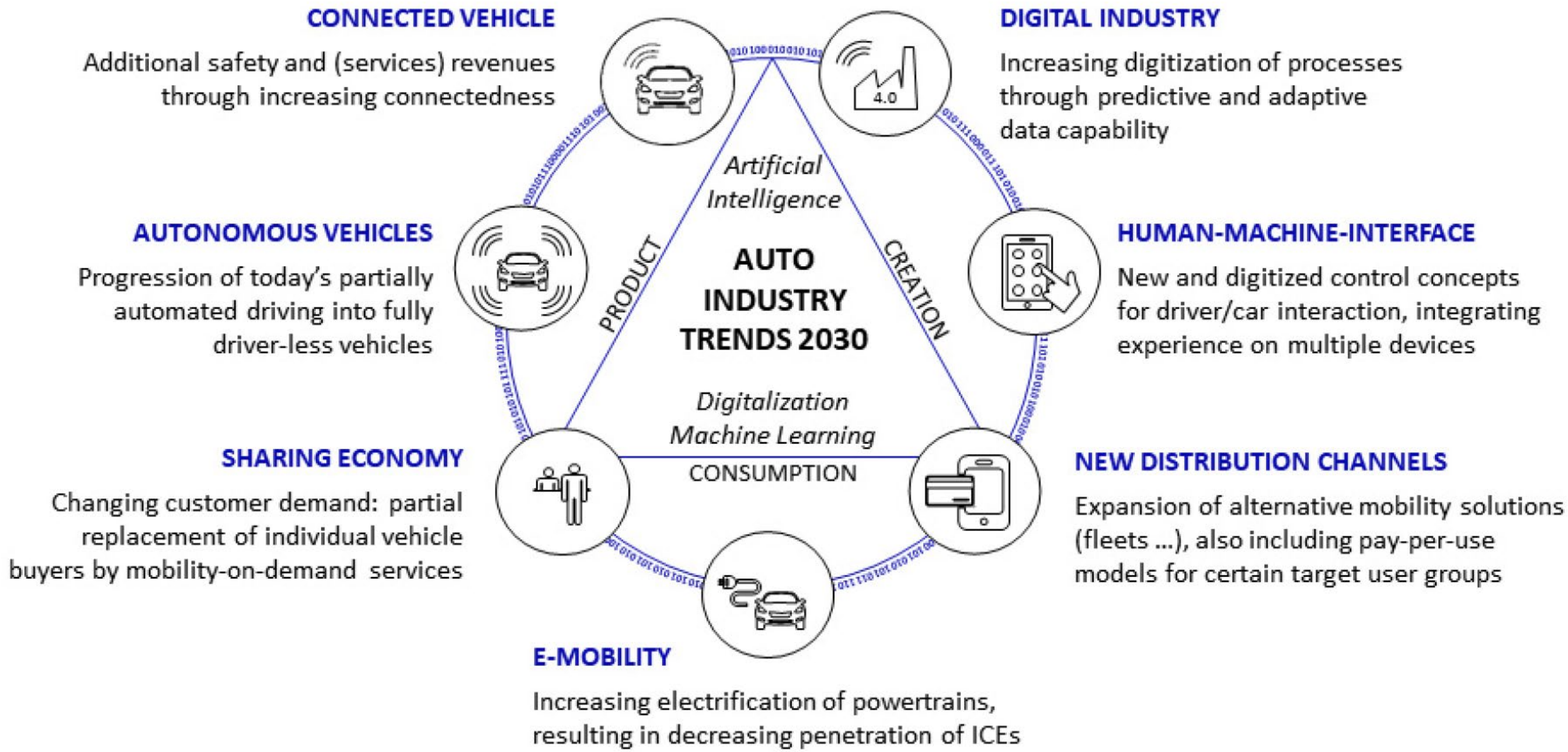


Discussion:

- Total efficiency
- Storage of (renewable) electric energy
- Transportation of energy
- Availability
- Effects on costs for
  energy / fuels
  vehicle technology
  infrastructure

Digitalization & automation
… enabling new mobility concepts & business models

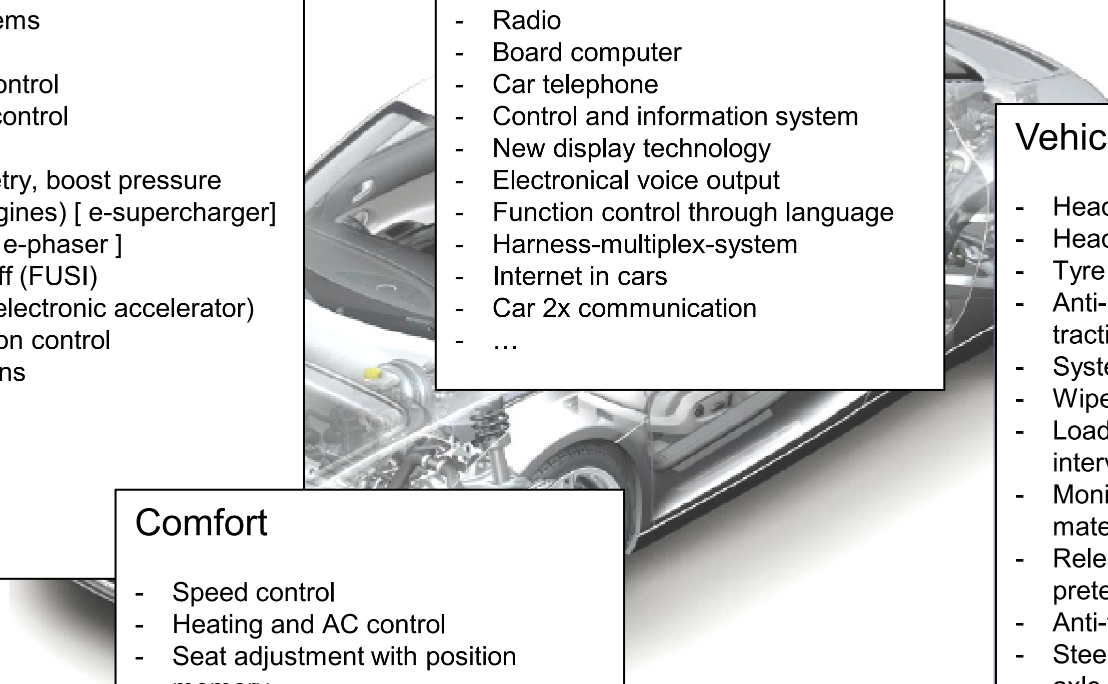
Transition of the automotive industry is significantly influenced by digitalization



Source: Oliver Wyman FAST 2030 Study

The car as a digital / mechatronics system

The most popular mechatronics system is the car. It consists of a multitude of mechatronics subsystems for engine & drive train management, communication, safety and comfort.



Engine / propulsion systems

- Electronic ignition systems
- Fuel injection systems
- Electronic idle speed control
- Air/fuel ratio (lambda) control
- Start / stop automatism
- Variable turbine geometry, boost pressure control (for charged engines) [e-supercharger]
- Variable valve control [e-phaser]
- Electronic engine cut-off (FUSI)
- Engine power control (electronic accelerator)
- Exhaust gas recirculation control
- Automated transmissions
- All-wheel drive
- Electric drive systems
- Hybrid drive systems
- Battery systems
- …

Communication

- Radio
- Board computer
- Car telephone
- Control and information system
- New display technology
- Electronical voice output
- Function control through language
- Harness-multiplex-system
- Internet in cars
- Car 2x communication
- …

Comfort

- Speed control
- Heating and AC control
- Seat adjustment with position memory
- Central lock
- Chassis control
- Automated driving functions
- …

Vehicle safety

- Headlamps adjustment and cleaning
- Headlamps with gas discharge lamp
- Tyre pressure monitoring
- Anti- lock braking system (ABS), traction- control- system (ASR)
- System diagnosis
- Wipe-wash-control
- Load-dependent maintenance interval report
- Monitoring system for operating material and wear parts
- Release system for airbag, belt pretensioner, roll bar
- Anti-theft system
- Steering system for front and rear axle
- Adaptive cruise control (ACC)
- Lane assist
- Brake assist
- Automated driving functions
- …

Focus: Automated / autonomous driving

Automated driving:

- **Traffic safety**
- **Comfort**
- **Ecological motivations**
- **Mobility for all**
- **Economical motivations**

Source: Eichberger, Bosch

Automated driving

Development is driven by tech-companies and some car manufacturers

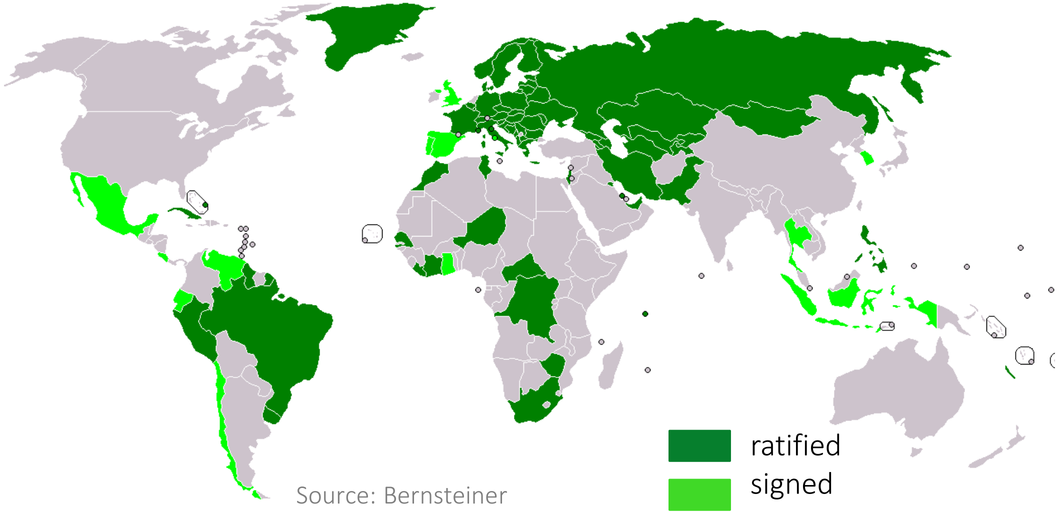
Expectations:

- Big business by increasing comfort, offering new services and having access to customer data
- Increase of safety (very likely) and reduction of traffic (to be discussed)

Challenges:

- Complex task, high technological effort
- Unclear legislative boundary conditions
- Issues in terms of responsibility and ethics questions

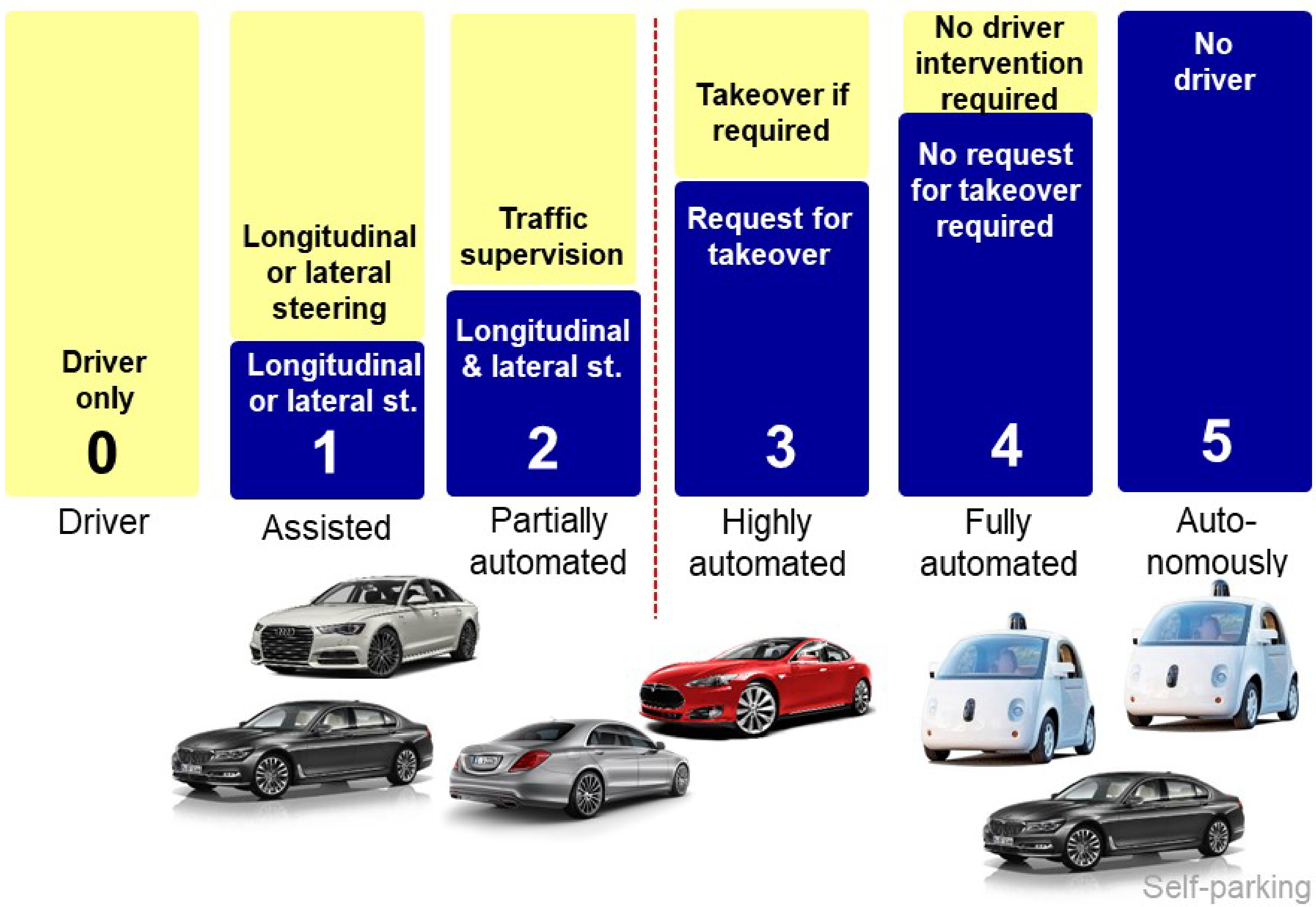
Vienna Convention: Driver's responsibility



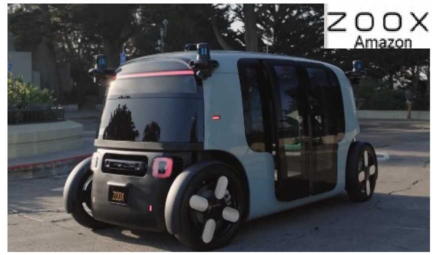
Source: Bernsteiner

Advanced Driver Assistance Systems (ADAS)

SAE / VDA – levels of automated driving

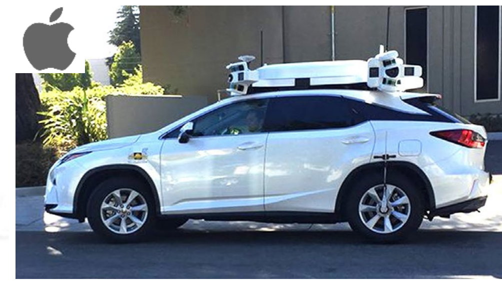


Tech-companies that invest in autonomous driving, e.g.:



Pony.AI

Apollo



… and of course car manufacturers, e.g.:

Tesla: "Autopilot"
in Series => ca. Level 2.5

Mercedes Benz: Level 3 in mass production cars since 2022

VW Moia: Autonomous people mover fleet planned in Hamburg

…

New vehicle concepts

Example: Zoox

Source: Zoox

… and some Youtube-links:

https://youtu.be/ksyiIqf3HMU
https://youtu.be/B8R148hFxPw
https://youtu.be/g5SeVxYAZzk
https://youtu.be/3r7PEl0tMSk

Autonomous delivery & logistics - new services

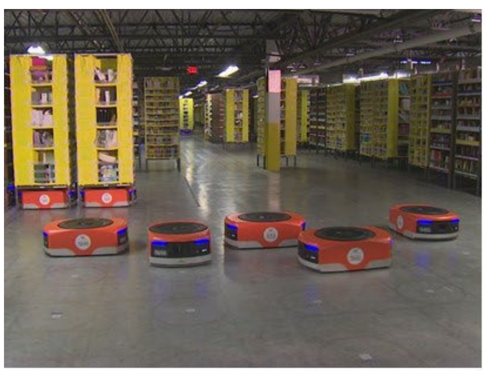
Starship Tech

Nuro

Amazon delivery

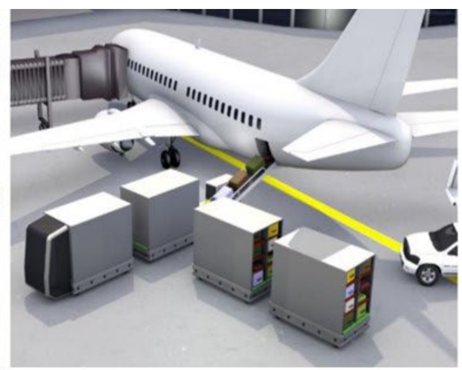
PostBot

Drones



Amazon warehouse logistics robots

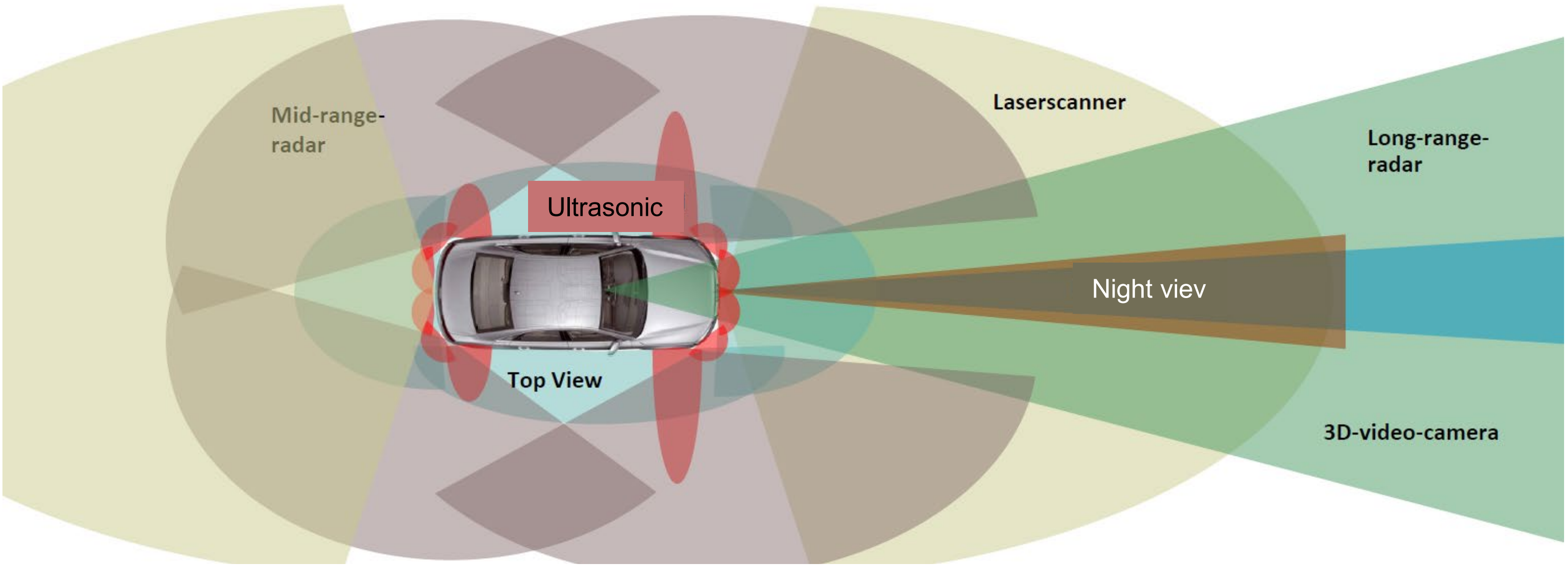
Production logistics robots



Autonomous airport cargo concept

Sources: amazon, KUKA, HET engineering, starship, forbes, wired, theverge, spiegel, dpdhl, amazon, diepresse, engadget, nuro

Sensors for ADAS



Source: VW, T. Form

- Vision systems
  - *Long range- & midrange-radar, laser scanner, 3D videocamera, topview-cameras, ultrasonic sensors, infrared (night view) ...*
- On-board sensors
  - *e.g. ESP: Lateral acceleration sensors, wheel speed, yaw rate, steering angle, brake system pressure sensor; ... , ambient temperature, air pressure, rain sensor ...*
- Further sensors / information sources
  - *Digital maps & GPS, Car2Car, Car2Infrastructure, Car2Home, ...*

Example: Waymo Driver Technology

Base vehicle | Ready for the Waymo Driver | Custom-built HW and compute | Waymo Driver application

Base vehicle

I-PACE (Model Year 2021) Manufactured and sold by Jaguar Land Rover (JLR)

Waymo Driver-ready vehicle

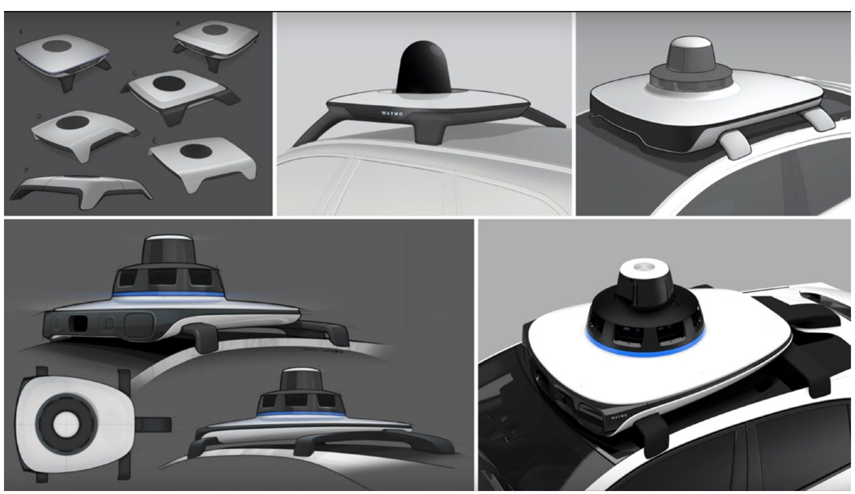
Waymo custom I-PACE configuration built and delivered by JLR

The Waymo Driver

Collections of custom modules that collectively make up the Waymo Driver

Final vehicle with the Waymo Driver

Final configuration of the custom vehicle with the Waymo Driver

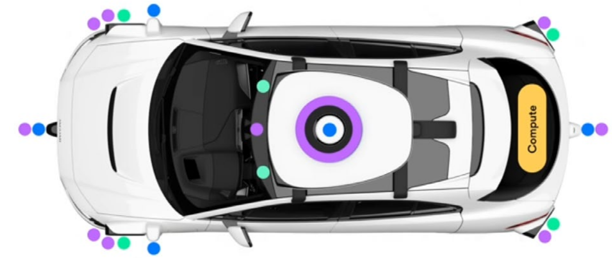


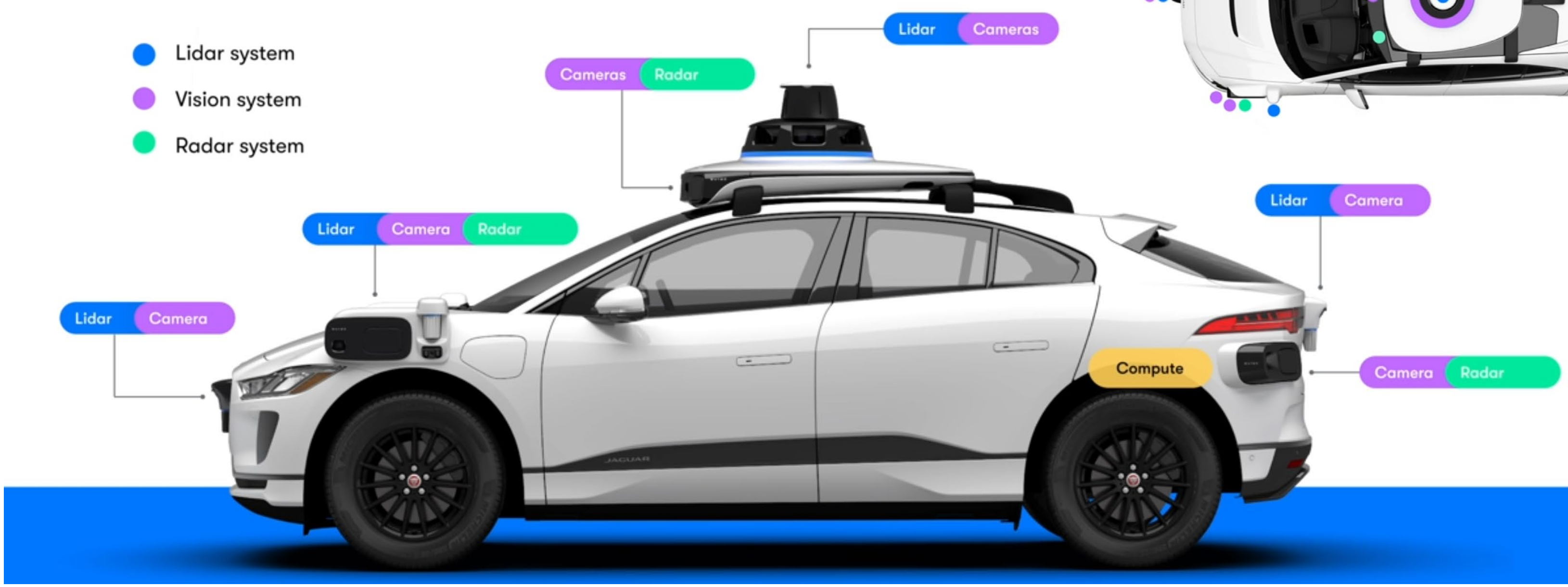
Waymo Driver components

The Waymo Driver

Source: Waymo

Example: Waymo Driver Technology





- 360° Lidar: max. 300m range, day & night applicability
- Perimeter Lidar: objects close to the vehicle
- 29 cameras: high resolution images, overlapping fields, equipped with cleaning systems and heaters
- 360° long range cameras > 500m range
- Perimeter cameras ... near field
- Radar: high resolution radars at 6 spots around the car. Complements the cameras and Lidars in bad weather conditions

Source: Waymo

Example: Waymo Driver Technology

Some detail views on the components

Roof unit:
360° Lidar
360° cameras
Long range cameras
2 Radars

Both side units:
Radar, perimeter Lidar, cameras

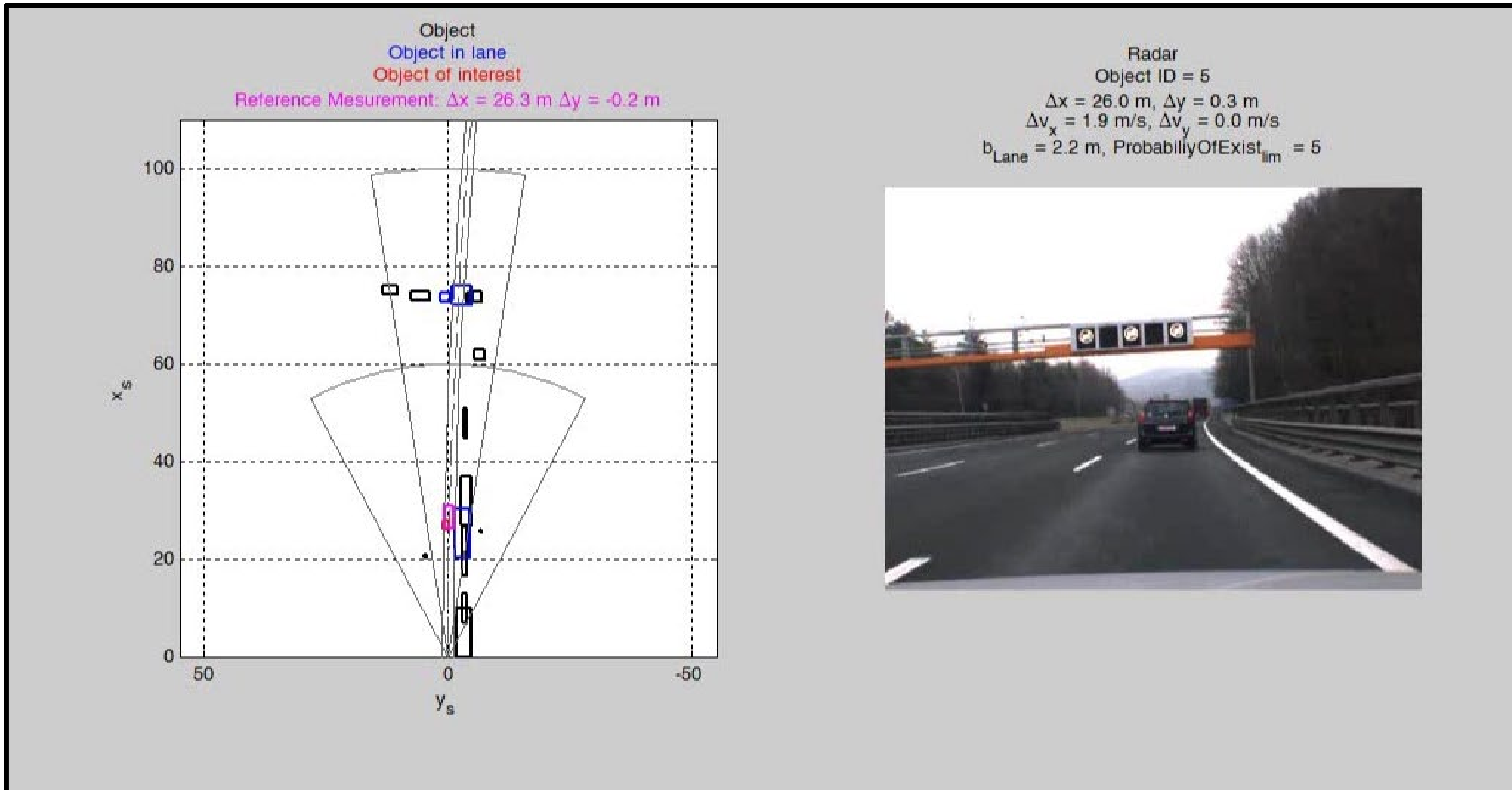
Front unit: Perimeter Lidar, cameras

Rear side units:
Radar, perimeter Lidar, cameras

Source: Waymo

Sensors for ADAS

What does a RADAR sensor see?



Source: Bernsteiner

Sensors for ADAS

Published by Tesla
...unclear boundary conditions...

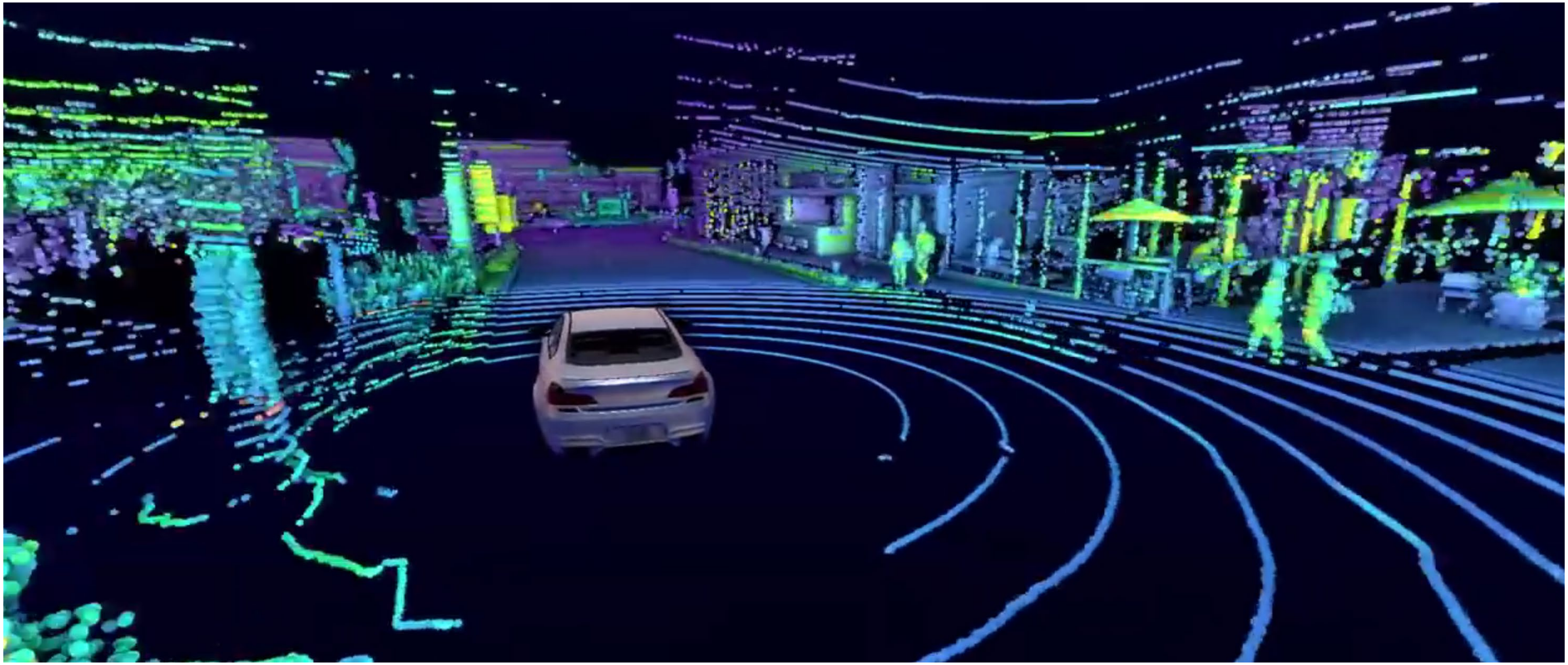
What does a camera – based sensor system see?

... here is another video (Tesla FSD Beta 10.4, status 11-2021): https://www.youtube.com/watch?v=65gvtEQqTCw

Source: Tesla

Sensors for ADAS

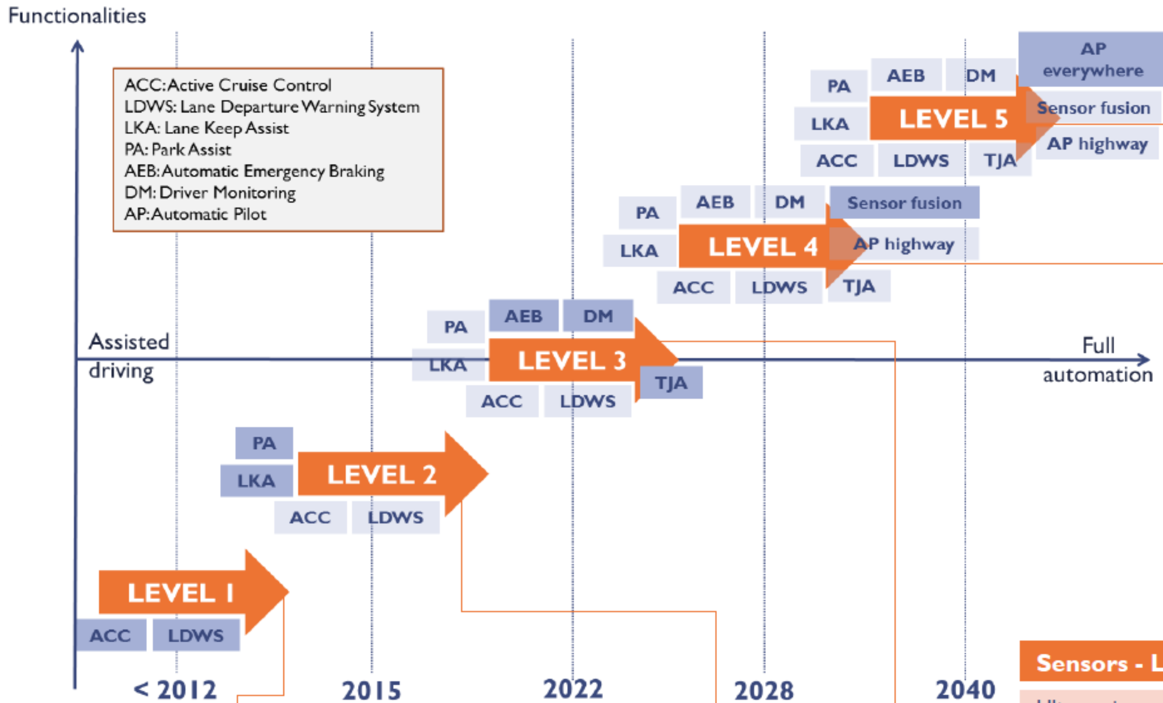
What does a LIDAR*) sensor see?



*) Light Detection and Ranging (Laser – Sensor)

Source: Velodyne

Exemplary road map for different SAE-levels



Sensors – Lvl 5	#	Cost
Ultrasonic	10	
Radar LRR	2	
Radar SRR	6	
Long distance cam	4	
Camera surround	5	
Stereo camera	2	
µbolo	1	
LIDAR	1	
Dead reckoning	1	
TOTAL	32	

Sensors – Lvl 4	#	Cost
Ultrasonic	10	
Radar LRR	2	
Radar SRR	6	
Long distance cam	2	
Camera surround	5	
Stereo camera	1	
µbolo	1	
LIDAR	1	
Dead reckoning	1	
TOTAL	29	

Sensors - Lvl 3	#	Cost
Ultrasonic	10	
Radar LRR	2	
Radar SRR	6	
Long distance cam	2	
Camera surround	5	
Stereo camera	1	
µbolo	1	
LIDAR	1	
Dead reckoning	1	
TOTAL	29	

Sensors - Lvl 2	#	Cost
Ultrasonic	8	
Radar LRR	1	
Radar SRR	4	
Camera for surround	4	
TOTAL	17	

Sensors - Lvl 1	#	Cost
Ultrasonic	4	
Radar LRR	1	
Camera for surround	1	
TOTAL	6	

Source: MAGNA, Yole Développement, 2017

Thx for your attention!

Contact:

Associate Prof. Dr. DI. Mario Hirz

Institute of Automotive Engineering
Graz University of Technology

Inffeldgasse 11/2, 8010 Graz

E-Mail: mario.hirz@tugraz.at
Web: http://www.ftg.tugraz.at