Prof. Dr.-Ing. B.-R. Höhn

Emission vs. E-Mission

Ways to a Sustainable Powertrain

How can we improve efficiency of conventional and alternative propulsion systems?

Dipl.-Ing. Thomas Dräxl
Forschungsstelle für Zahnräder und Getriebebau
Gear Research Centre (FZG)
Technische Universität München
Munich, Germany

International Conference on Sustainable Automotive Technologies – ICSAT 2010
Gut Ising, February 26, 2010

Emission vs. E-Mission

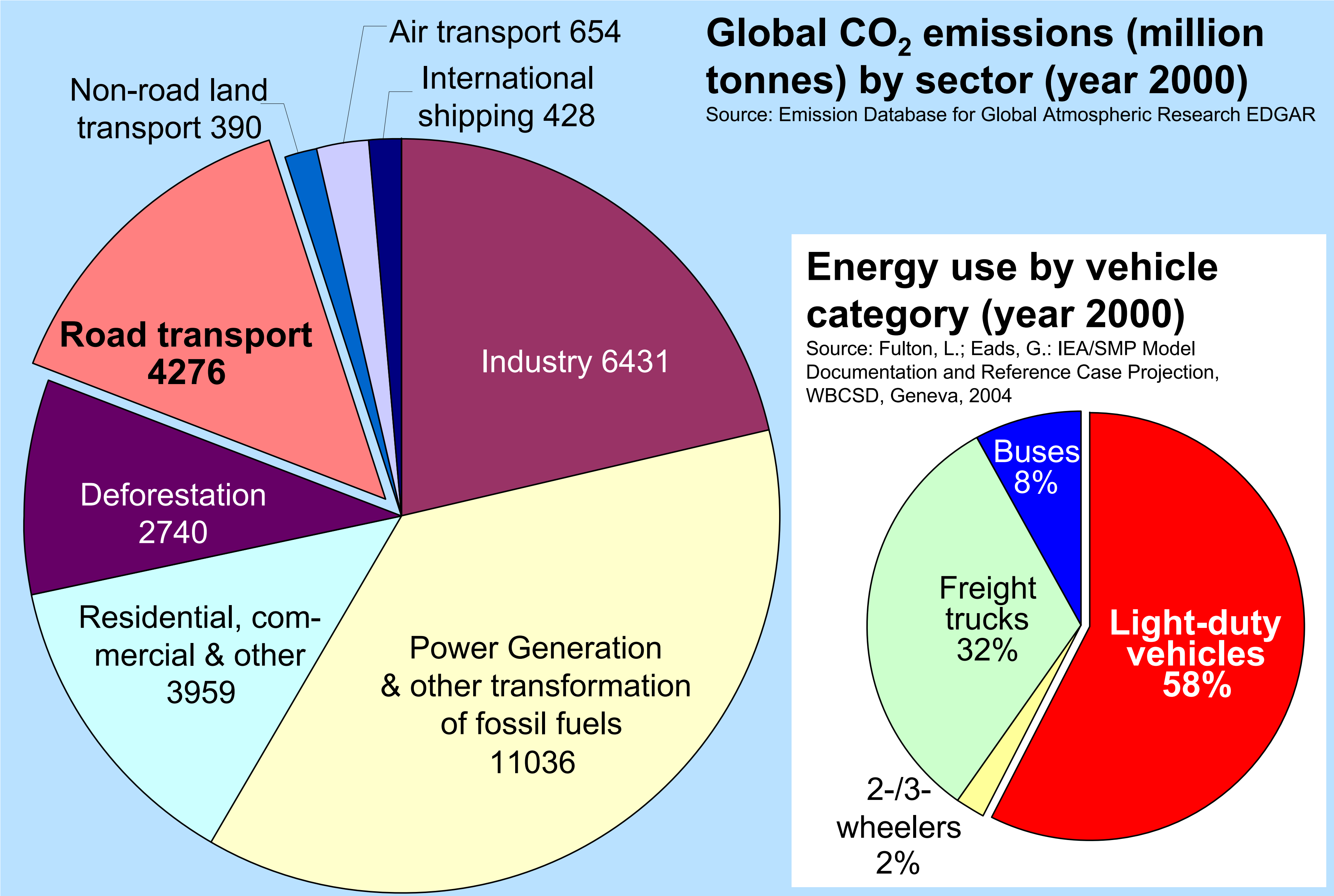
Overview

- Sustainable mobility: motivation
- Losses and emissions of road vehicles
- Electric mobility: hype or future?
- Hybrid propulsion: the best of two worlds?
- Measures to improve conventional powertrains
- Future powertrain scenarios
- Conclusions

Mobility: A cornerstone of growth and wealth

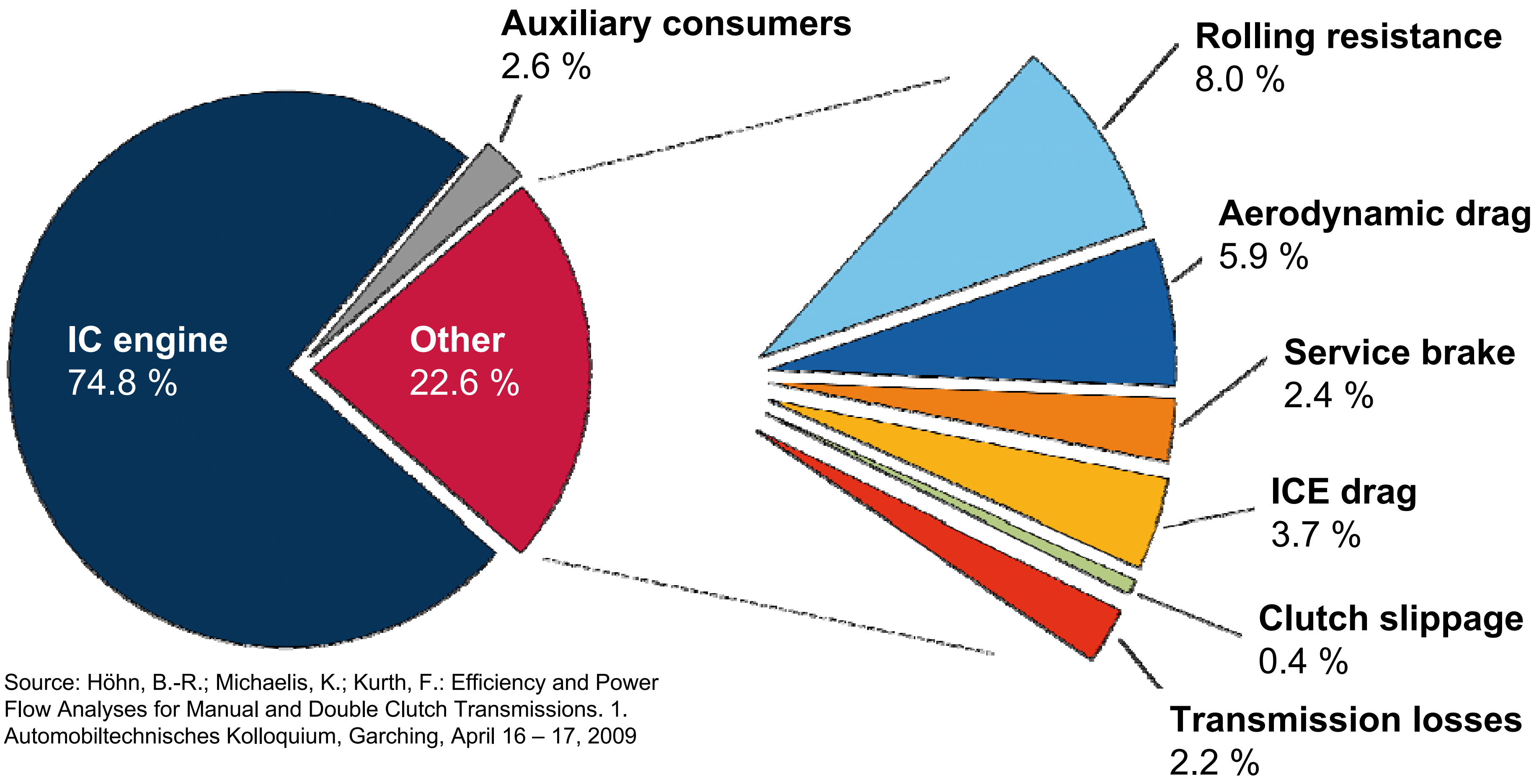
In the past – and in the future?

Road vehicles
A source of greenhouse gas emissions



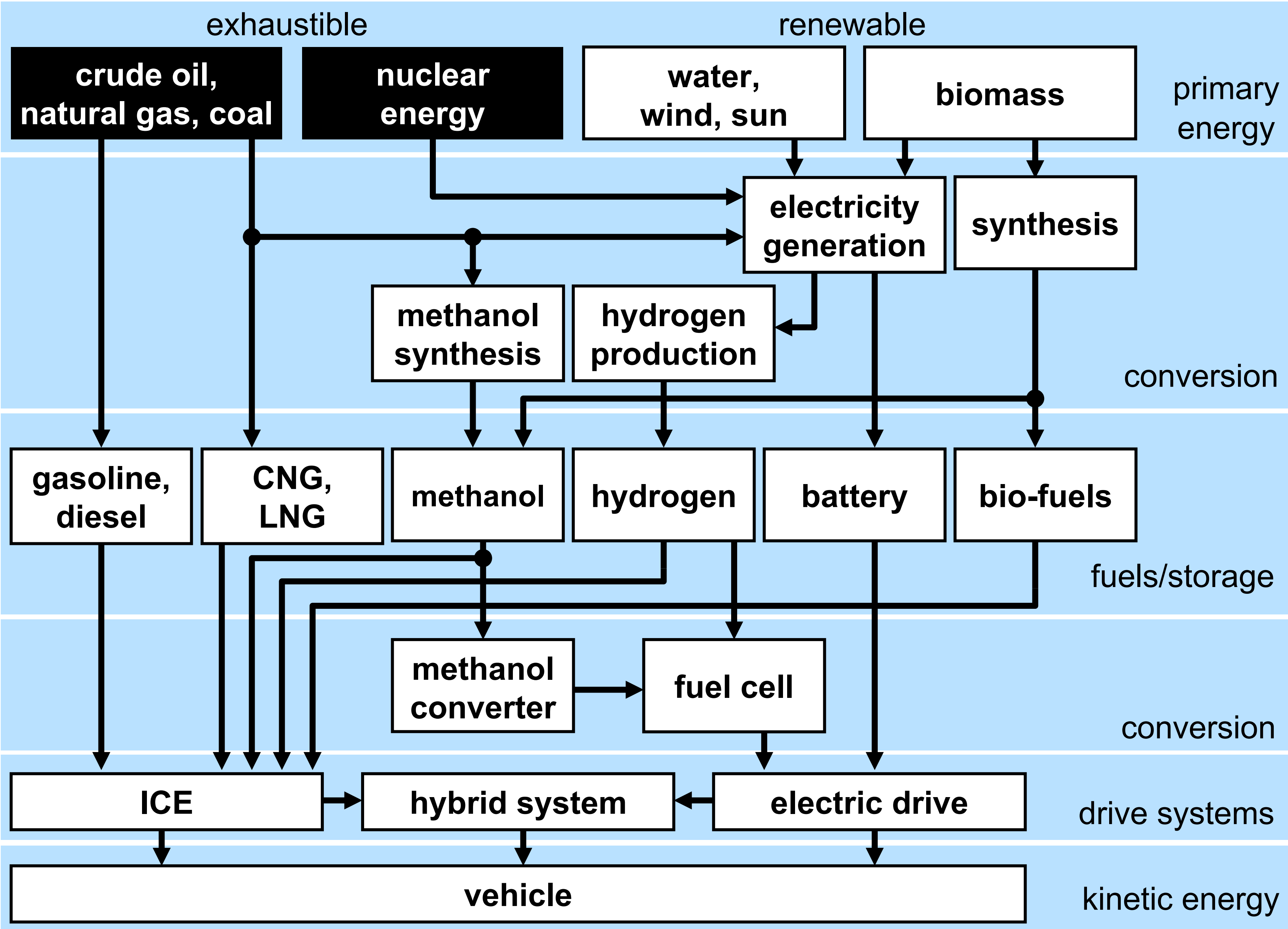
Losses in the NEDC

Simulation for a sample vehicle

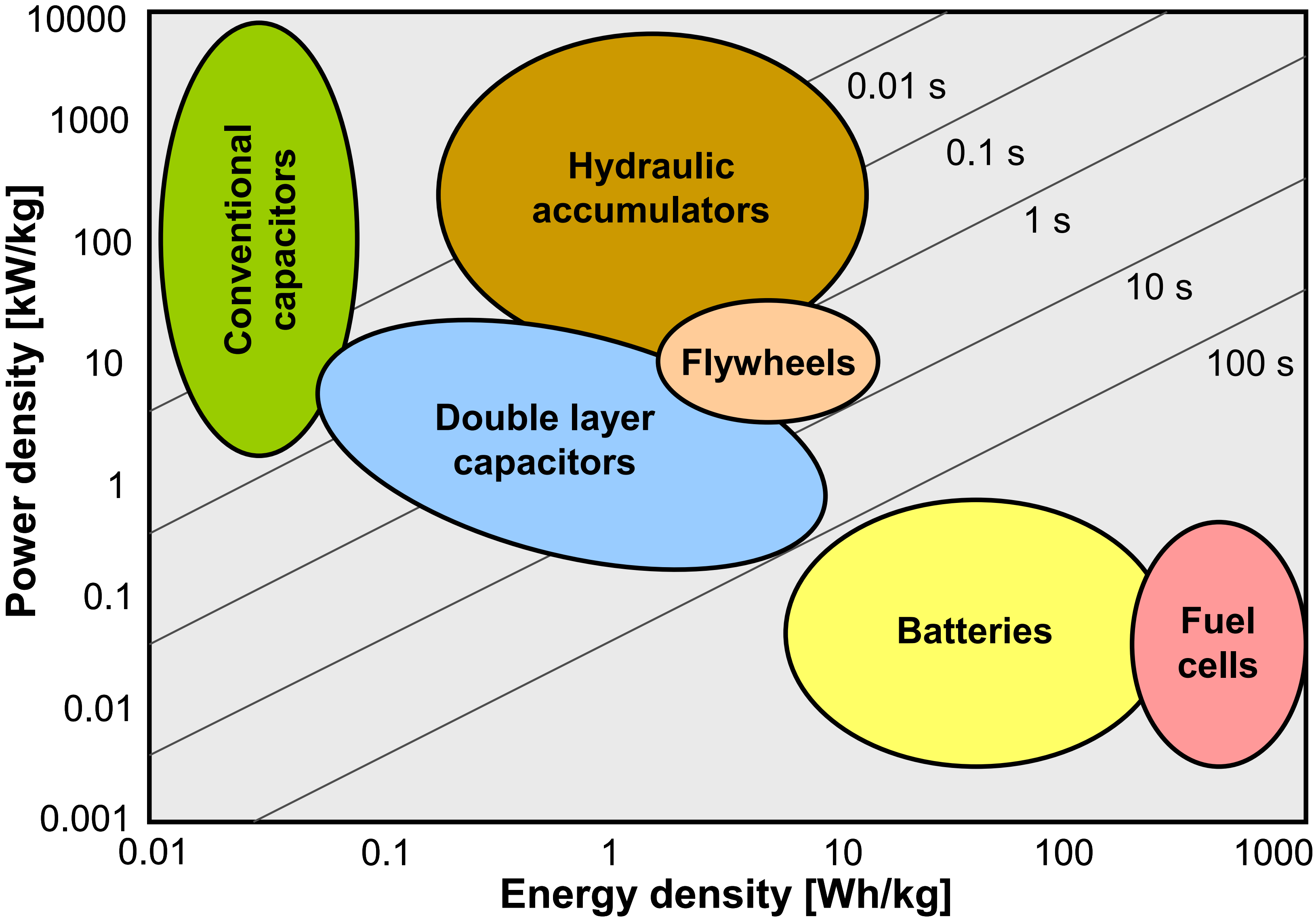


Source: Höhn, B.-R.; Michaelis, K.; Kurth, F.: Efficiency and Power Flow Analyses for Manual and Double Clutch Transmissions. 1. Automobiltechnisches Kolloquium, Garching, April 16 – 17, 2009

Energy paths for vehicle propulsion



Comparison of energy storage systems



Source: Schröder, D.; Höhn, B.-R.; Schlurmann, J.; Jörg, A.; Dräxl, T.: Der optimierte CVT-Hybrid-Antriebsstrang: Maximale Kraftstoffeinsparung bei minimalem Aufwand. EMA 2008, Aschaffenburg, October 10 – 11, 2008

Battery electric vehicles (BEVs)
Requirements in transition?

Example: Mitsubishi i-MiEV / Peugeot iOn / Citroën C-Zero

▪ **Electric motor**	Power:	47 kW
	Max. torque:	180 Nm
▪ **Battery**	Usable capacity:	16 kWh (Li-Ion)
	Voltage:	330 V
	Mass:	~200 kg → ~80 Wh/kg
	Recharging time:	~6…7 h at household outlet
▪ **Vehicle**	Max. speed:	130 km/h
	Acceleration 0…100 km/h:	13 s
	Crusing range:	160 km in 10-15-Mode cycle
	Mass:	1080 kg
	Consumption (B2W):	10 – 11 kWh/100 km
	Price in Japan:	~34.000 € (-11.000 € subsidy)

→ What would an ICE-driven vehicle look like with respect to

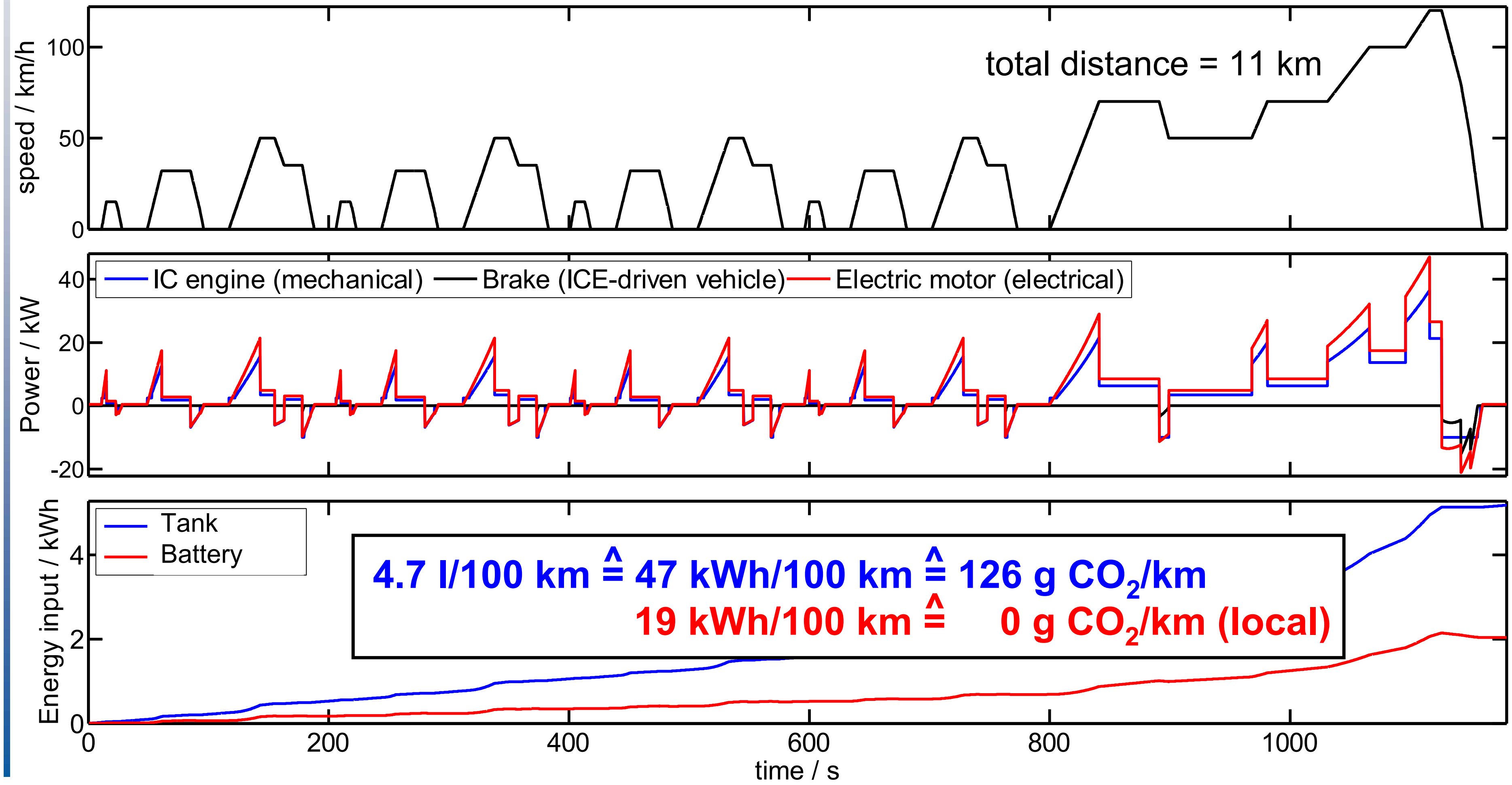
- Weight
- Fuel economy
- Cost

if it were designed for the same requirements?

Conventional vs. electric propulsion

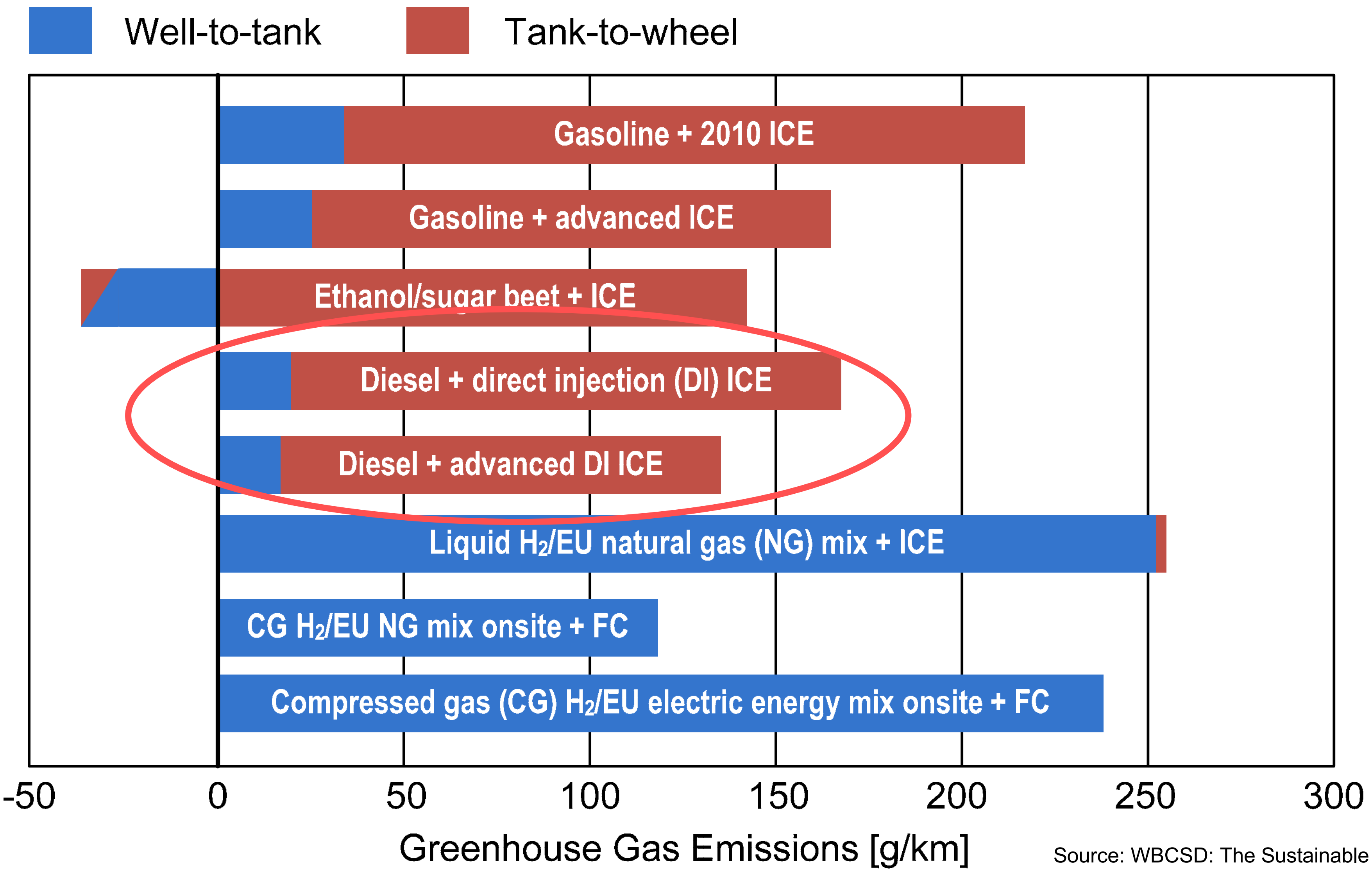
Tank/battery-to-wheel comparison

Simulation-based estimate of **fuel**/**electric energy** consumption in the NEDC for a **1400 kg conventional (diesel)** and a **1600 kg BEV**



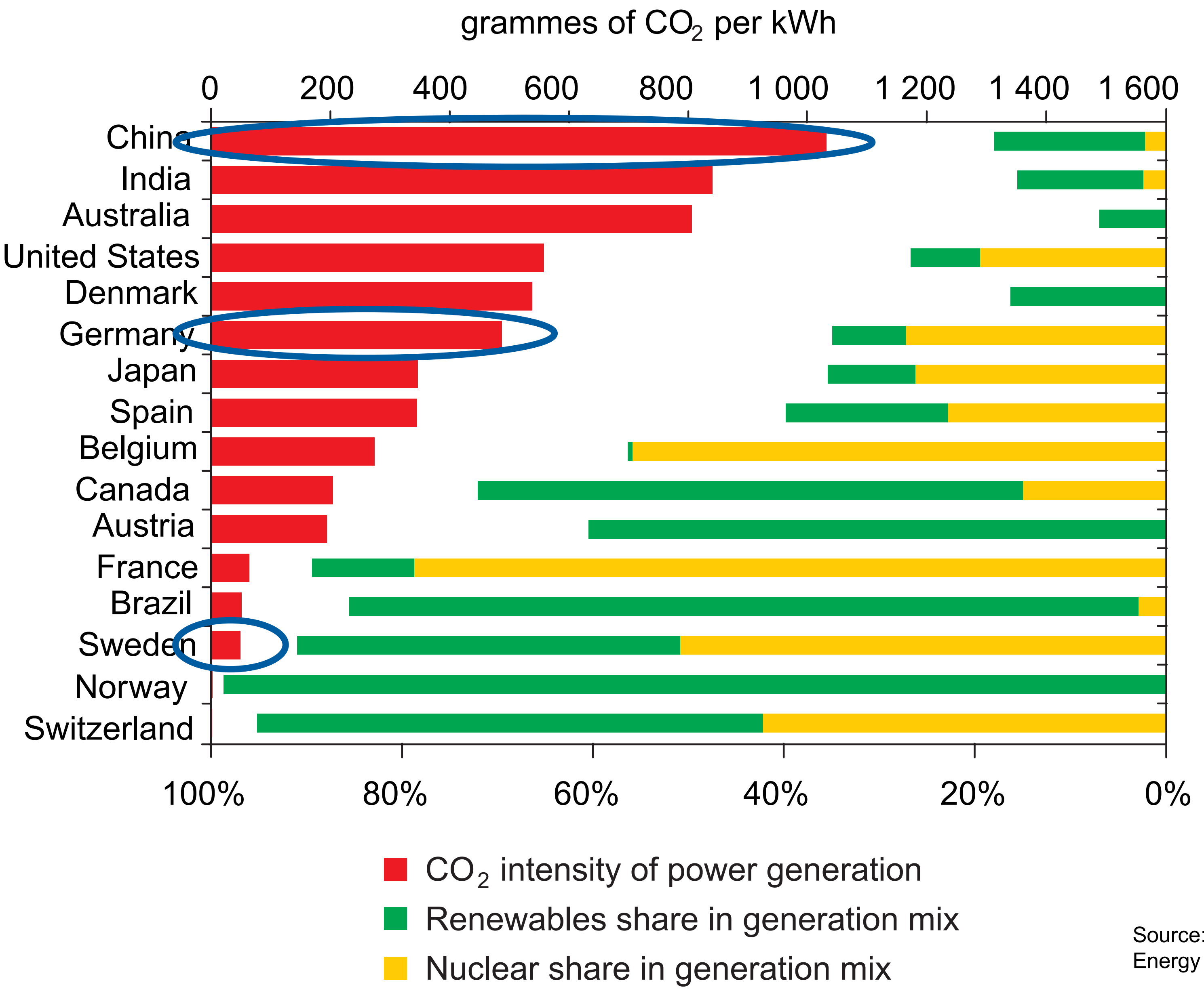
Fuels/ICEs

Well-to-wheel comparison



Source: WBCSD: The Sustainable Mobility Project, Full Report 2004

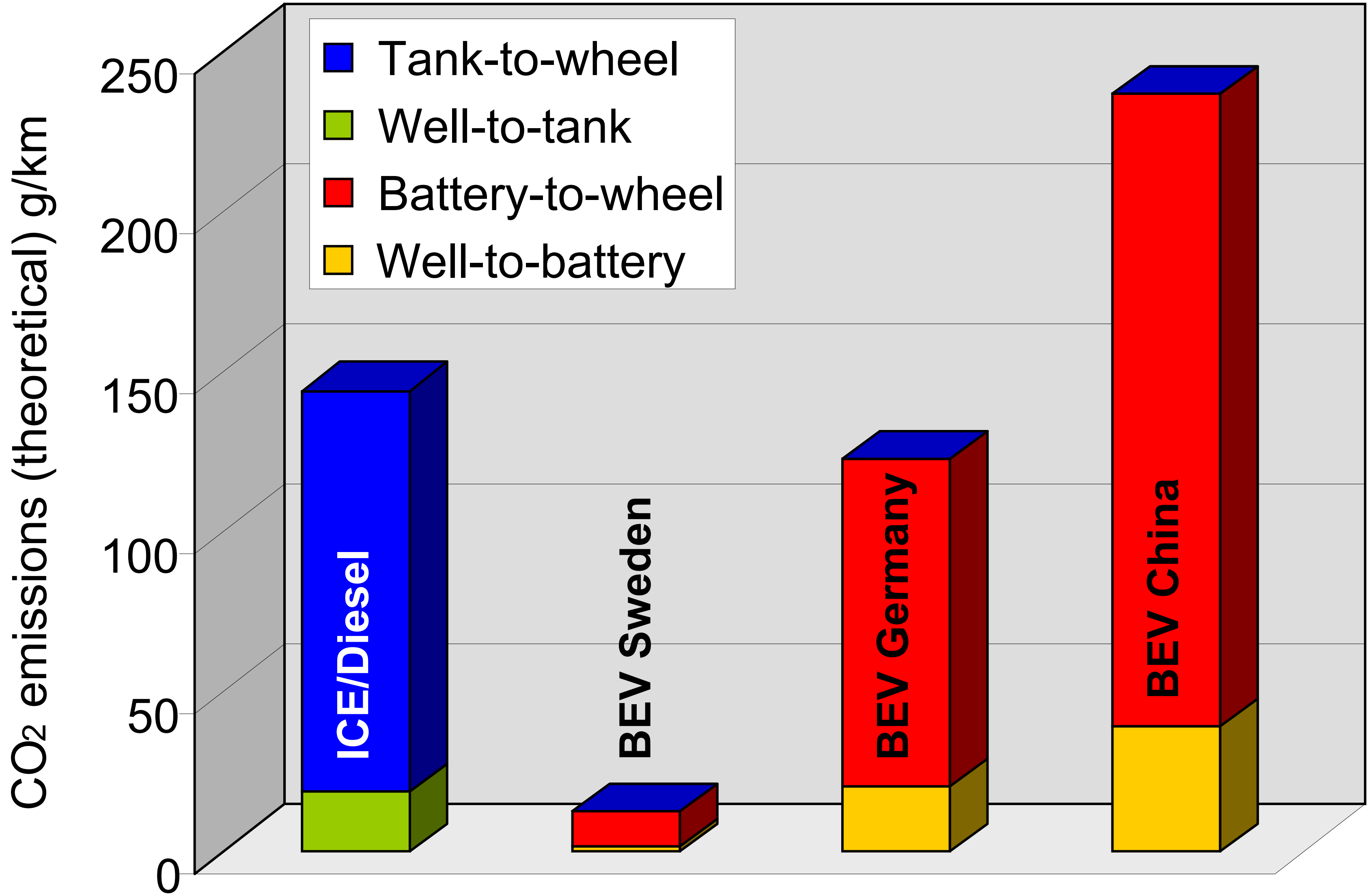
Power sector CO_2 emissions and shares of nuclear power and renewables (2004)



Source: OECD/IEA World Energy Outlook 2006

Conventional vs. Electric propulsion

Well-to-wheel comparison

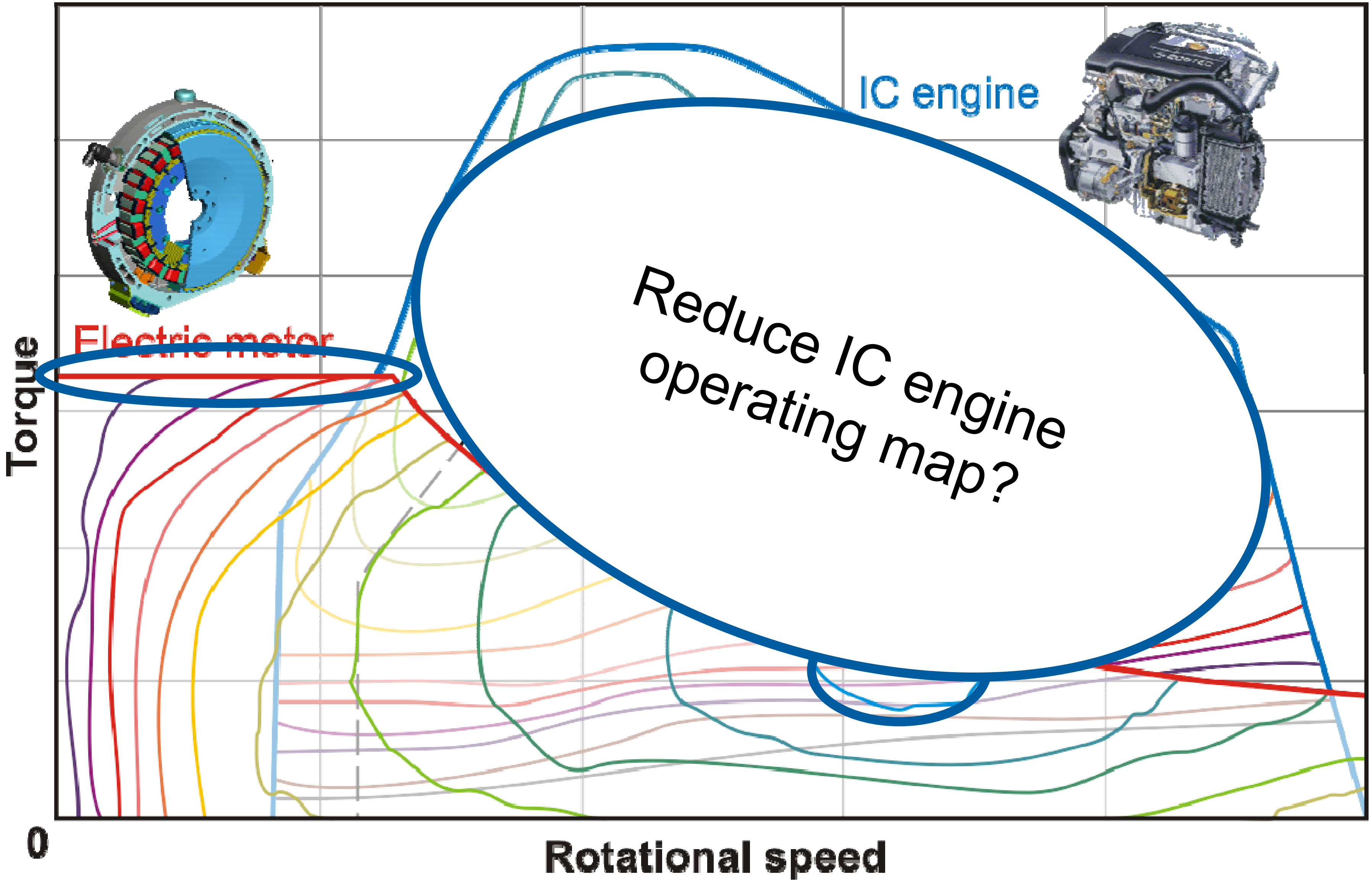


Electric mobility

Energy storage and other challenges

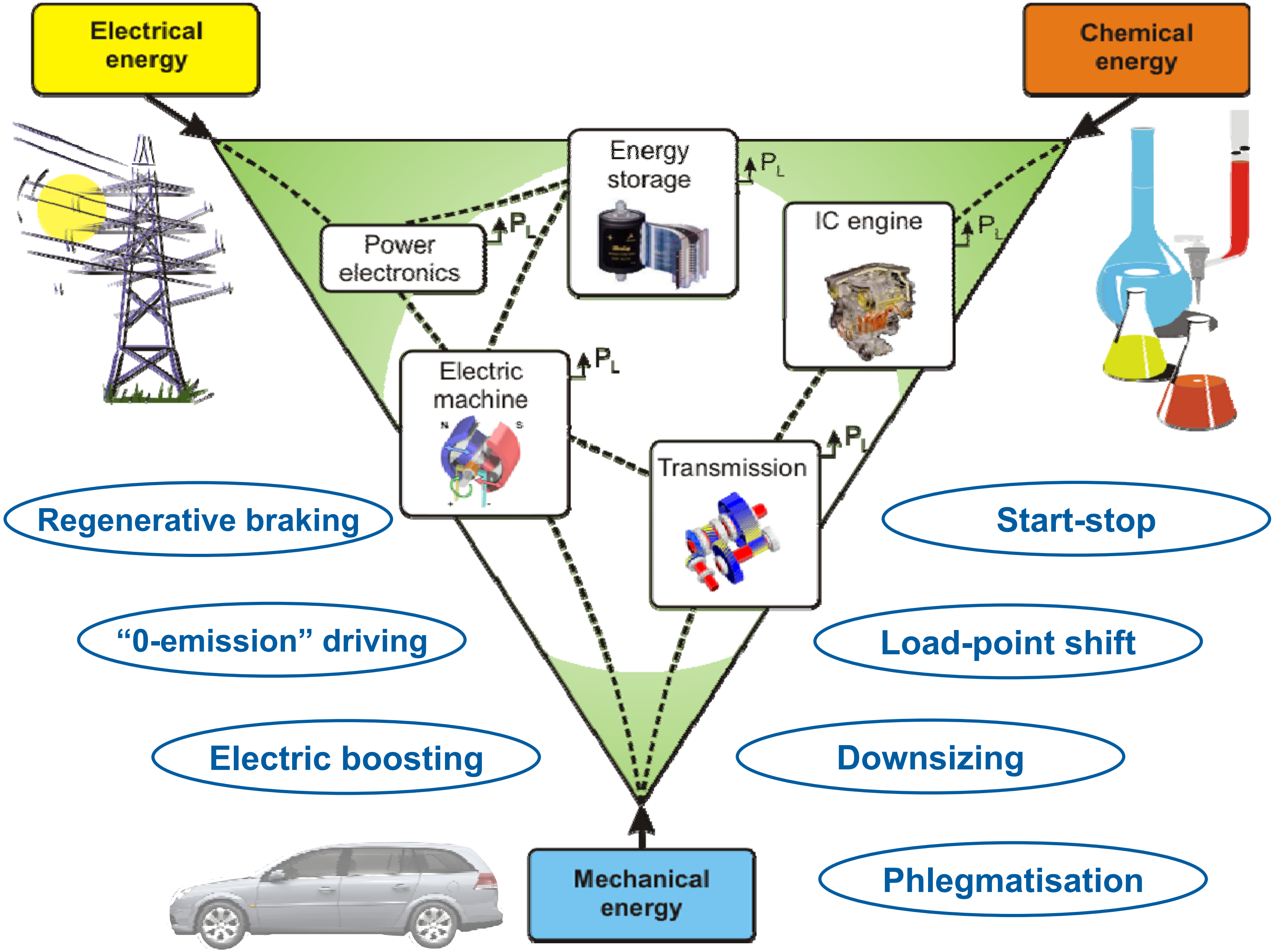
- ➔ Today's BEVs are not suitable as all-purpose vehicles due to limited range.
- ➔ Market entry barriers for new suppliers
- ➔ Mainstream technologies yet to be found:
  - Safety issues
  - Recharge and/or exchange?
  - Infrastructure, connectors
  - NVH/acoustics
  - ➔ Solvable problems
- ➔ Battery costs are still too high
  - „Green customers“ are only a boundary phenomenon
  - Tax benefits necessary
  - New business models: Buy a car, rent a battery?

Hybrids
The best of two worlds?



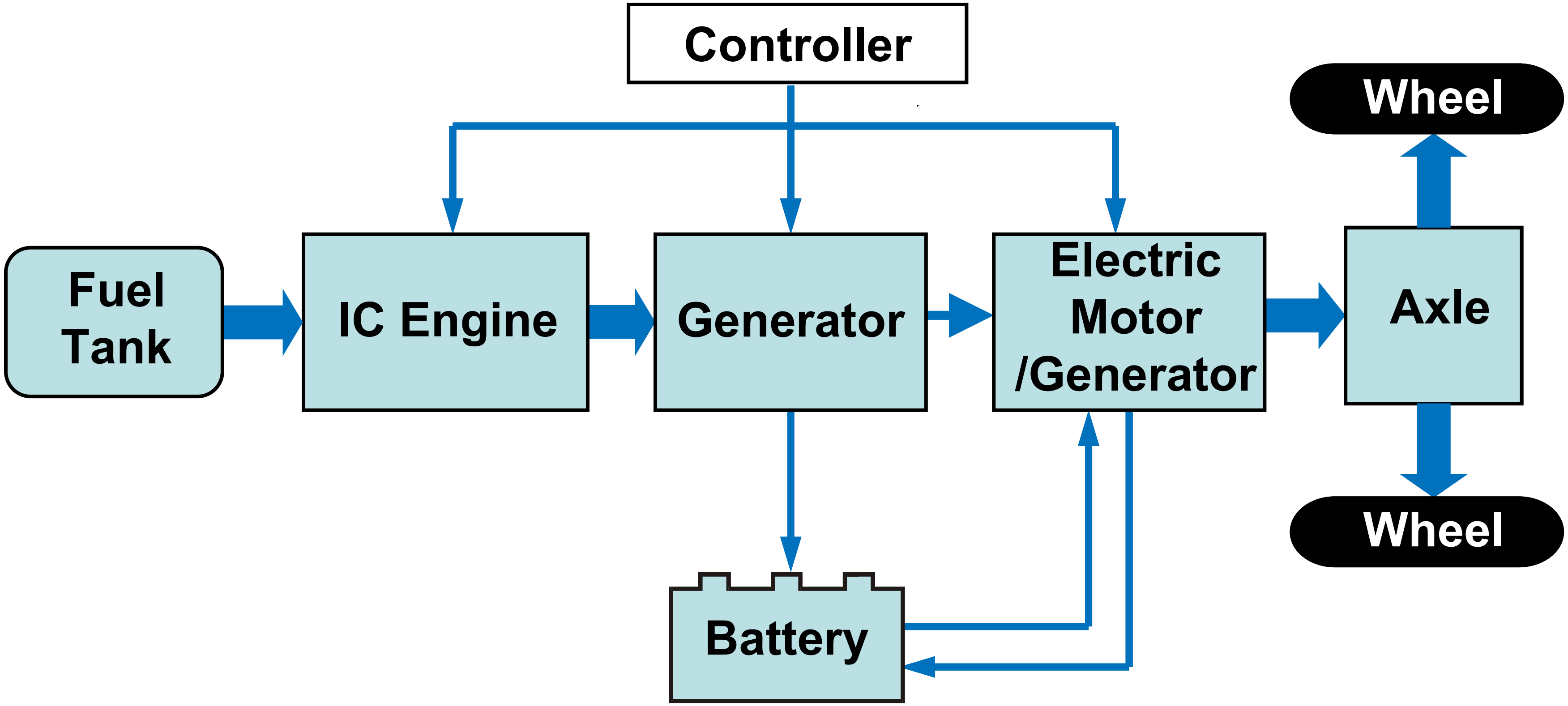
Hybrids

Power flows and measures



Hybrid driveline topologies

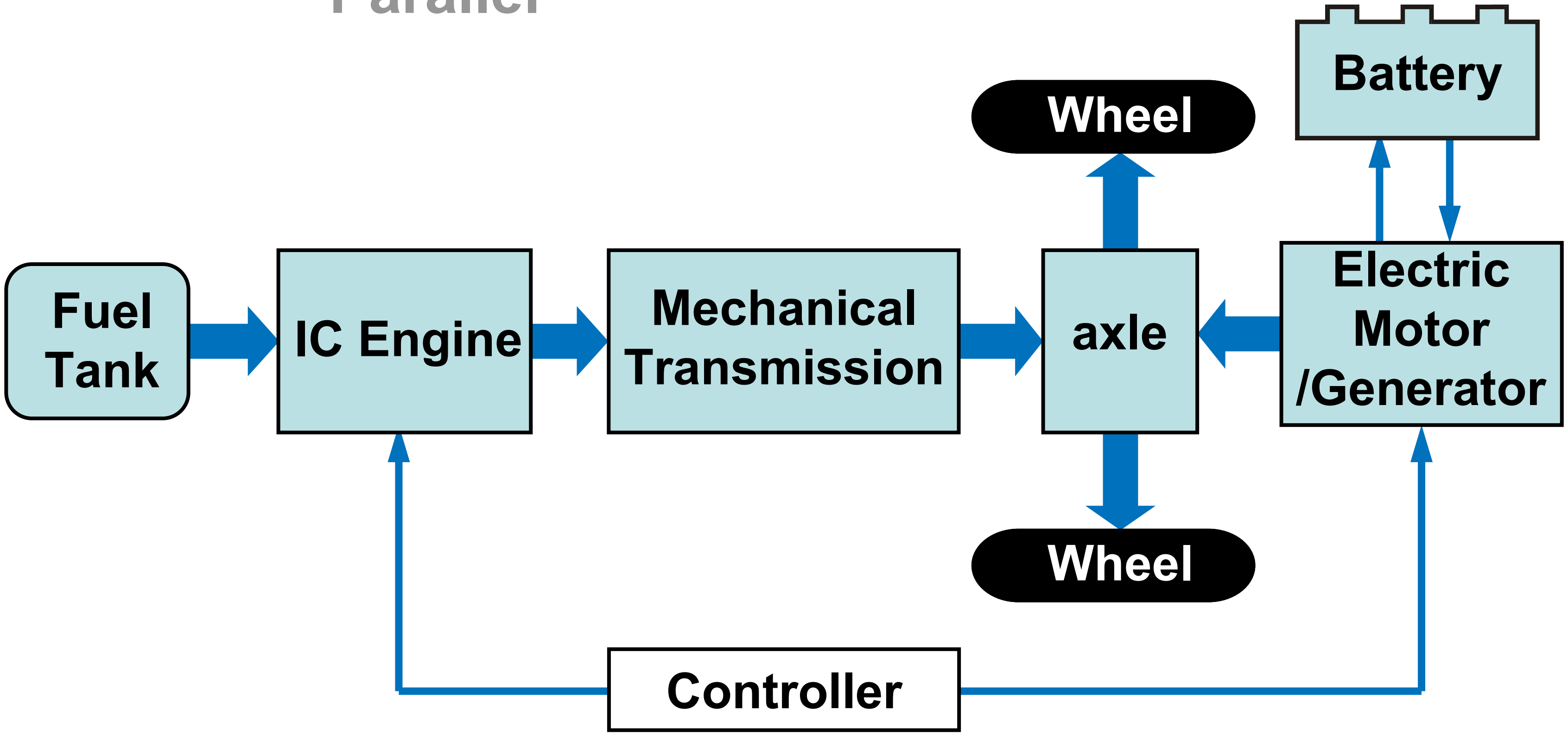
Serial



+ Free choice of IC engine operating point
+ Full power available also in electric mode

- Large/heavy electric equipment
- Increased losses due to double energy conversion

Hybrid driveline topologies
Parallel

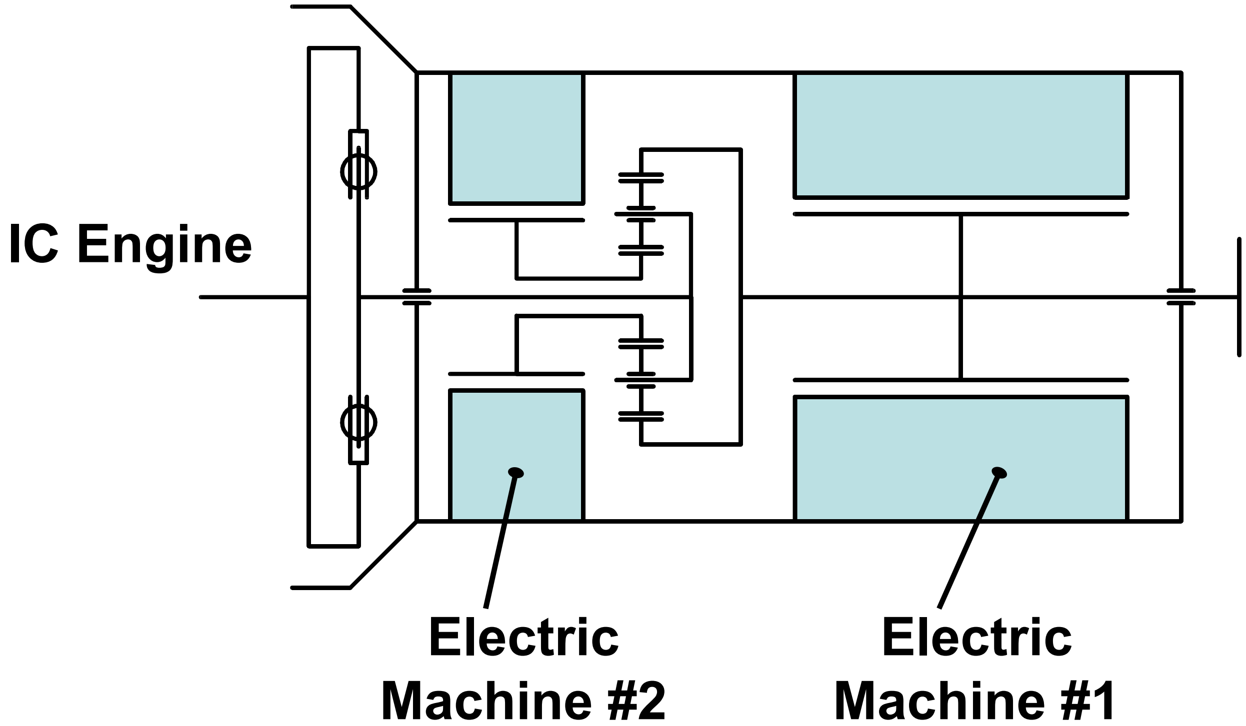


+ Low complexity, can be derived from existing driveline concepts
+ Small installed electric power can already improve fuel economy significantly

- NVH problems caused by IC engine start and shutdown
- Limited driving performance in electric mode

Hybrid driveline topologies

Input power-split

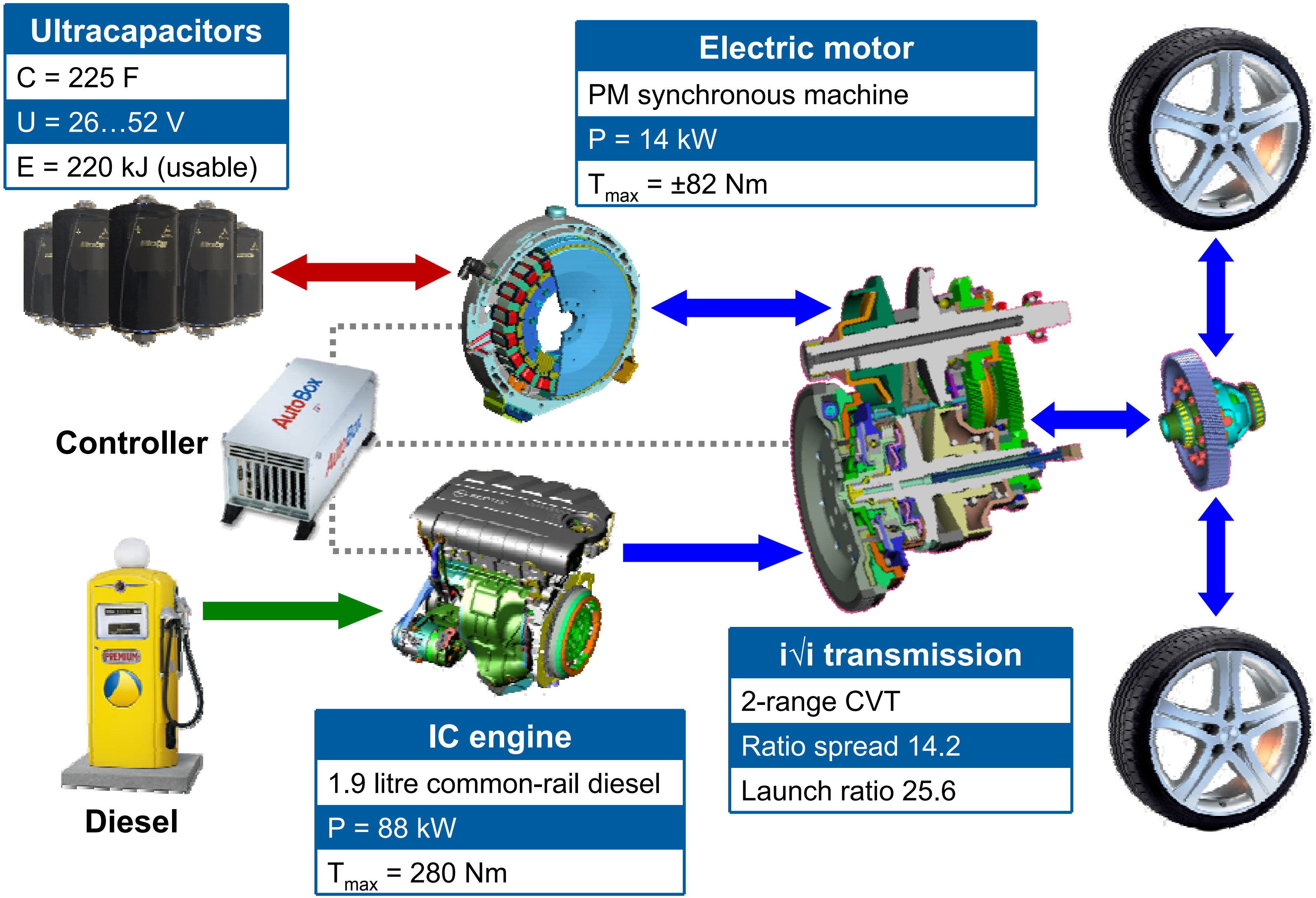


+ **Simple transmission concept**

- **Permanent electric power flow is necessary for speed superposition**

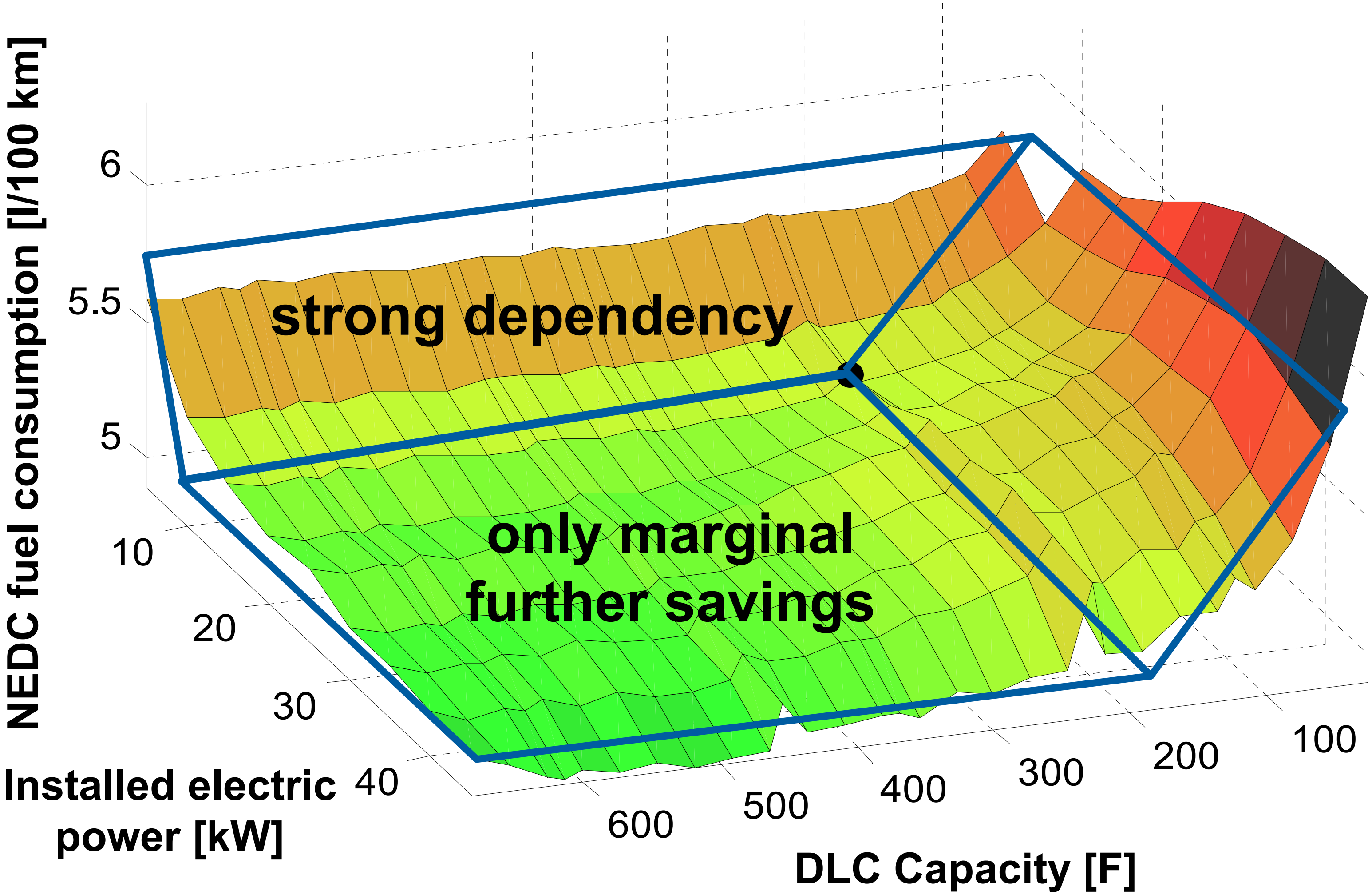
Example: FZG's Optimised CVT Hybrid

Driveline concept



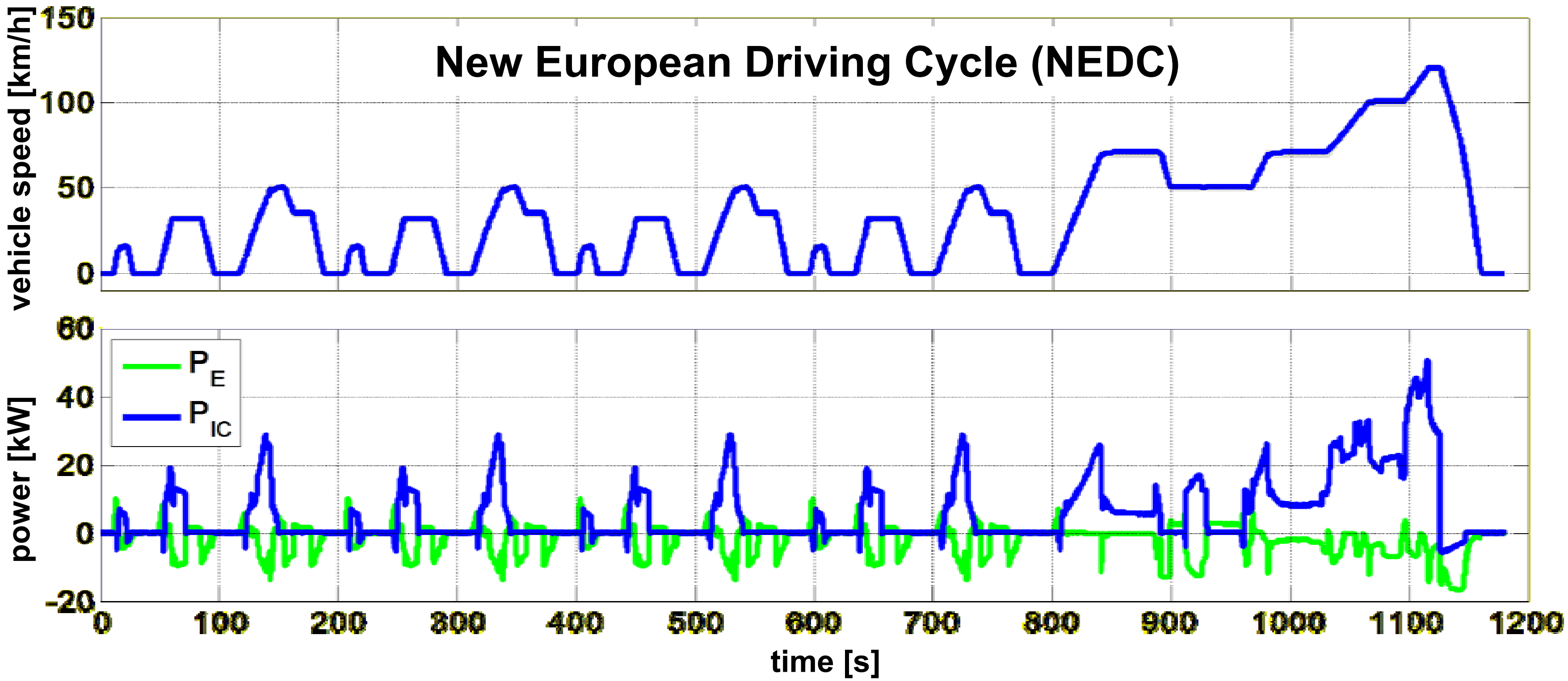
Example: FZG's Optimised CVT Hybrid

Dimensioning



Example: FZG's Optimised CVT Hybrid

Fuel economy

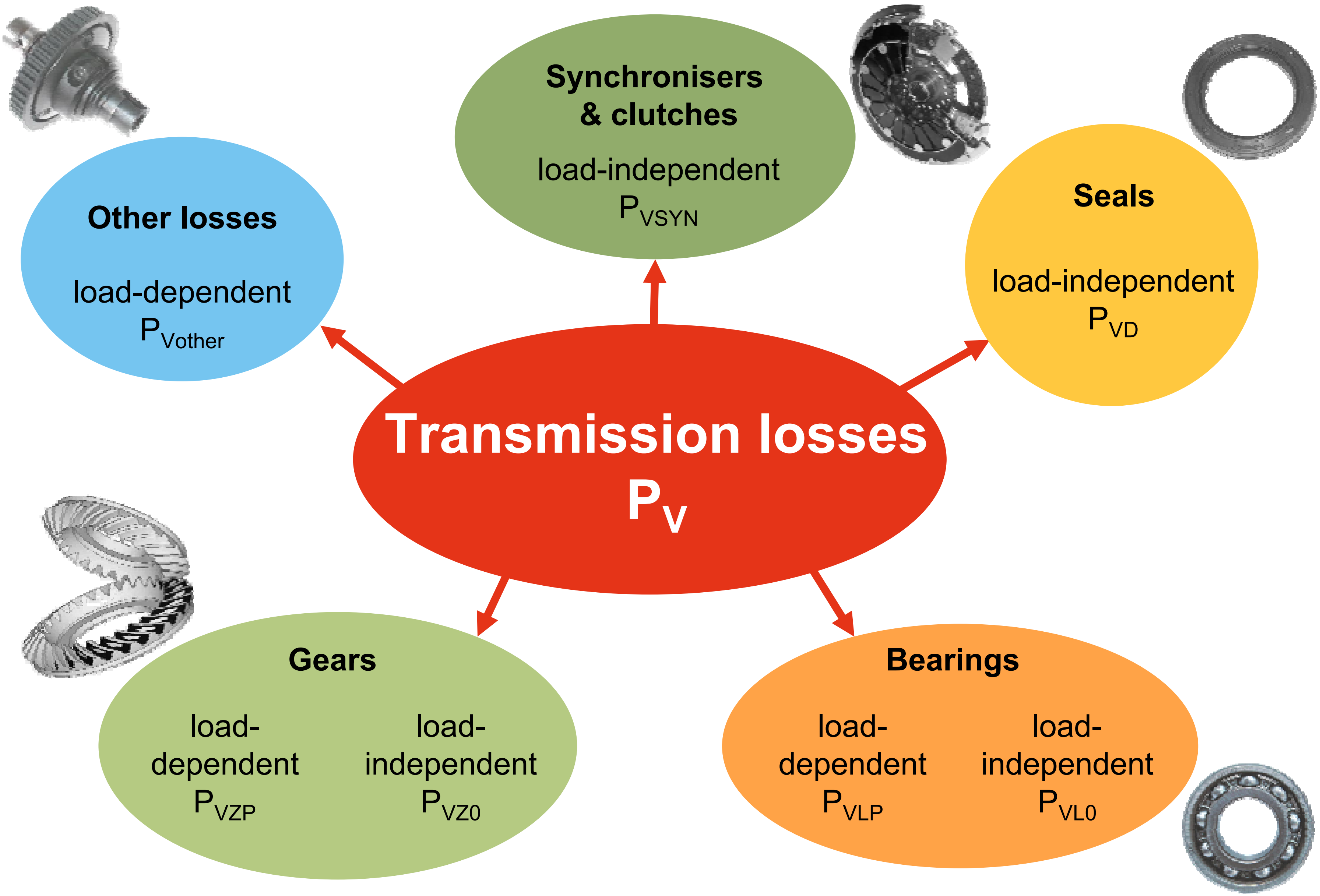


6-speed MT	Optimised CVT Hybrid	Automatic
5.9 l/100km	5.25…5.55 l/100km	7.0 l/100km

(- 11 ... - 6 %)

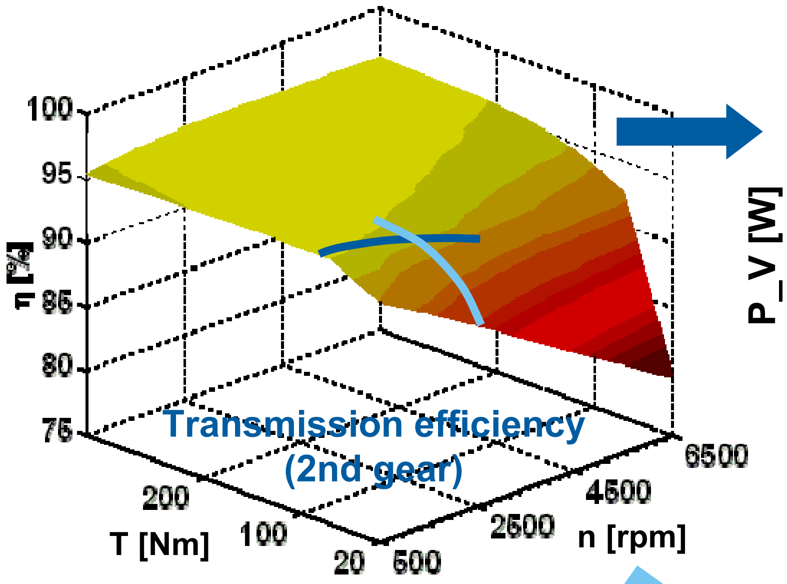
(- 26 ... - 21 %)

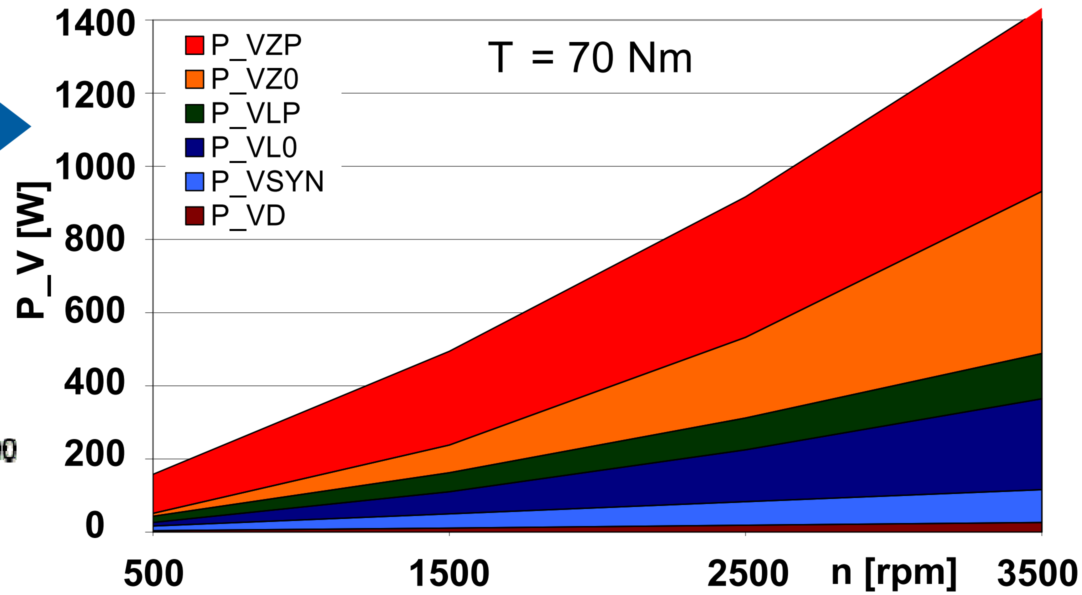
The good old gearbox
A fully developed drive component?

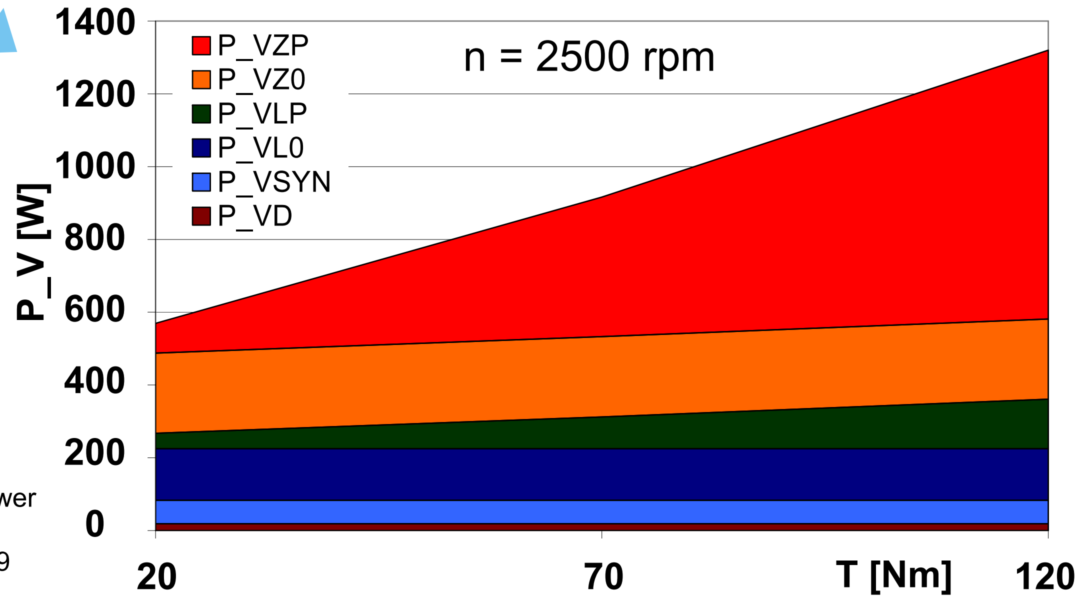


Breaking down transmission losses

WTplus calculation for a sample vehicle







Conclusion:
Load-dependent and load-independent losses should be reduced.

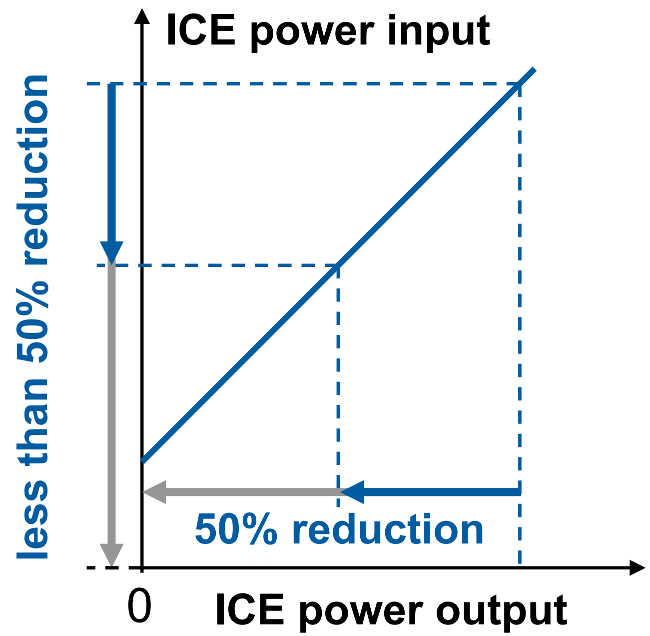
Source: Höhn, B.-R.; Michaelis, K.; Kurth, F.: Efficiency and Power Flow Analyses for Manual and Double Clutch Transmissions. 1. Automobiltechnisches Kolloquium, Garching, April 16 – 17, 2009

Transmission loss reduction measures
Overview

- LowLoss gears
- Lower oil level
- Baffle plates
- Optimised arrangement of loose wheels
- Dry instead of wet clutches
- Efficiency-optimised bearings
- Low-viscosity lubricants

But: „basic charge“ problem

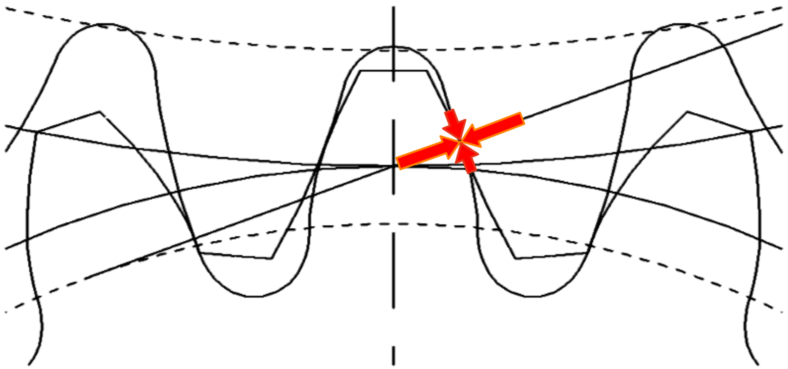
- Loss reduction after the ICE does not reduce fuel consumption by the same percentage.

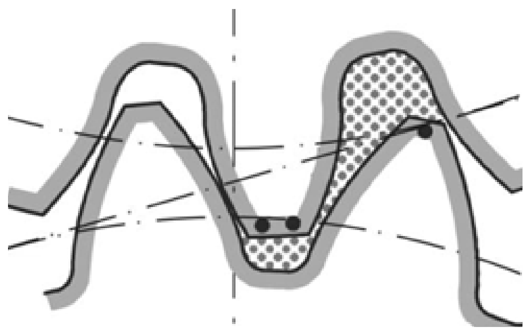


Fundamentals of gear losses

Load-dependent gear losses
↓
Friction in the tooth contact
(**tooth geometry parameters**, operating conditions, oil properties)

Load-independent gear losses
↓
Oil splashing/squeezing
(oil properties, geometry, **oil level, rotational speed**)

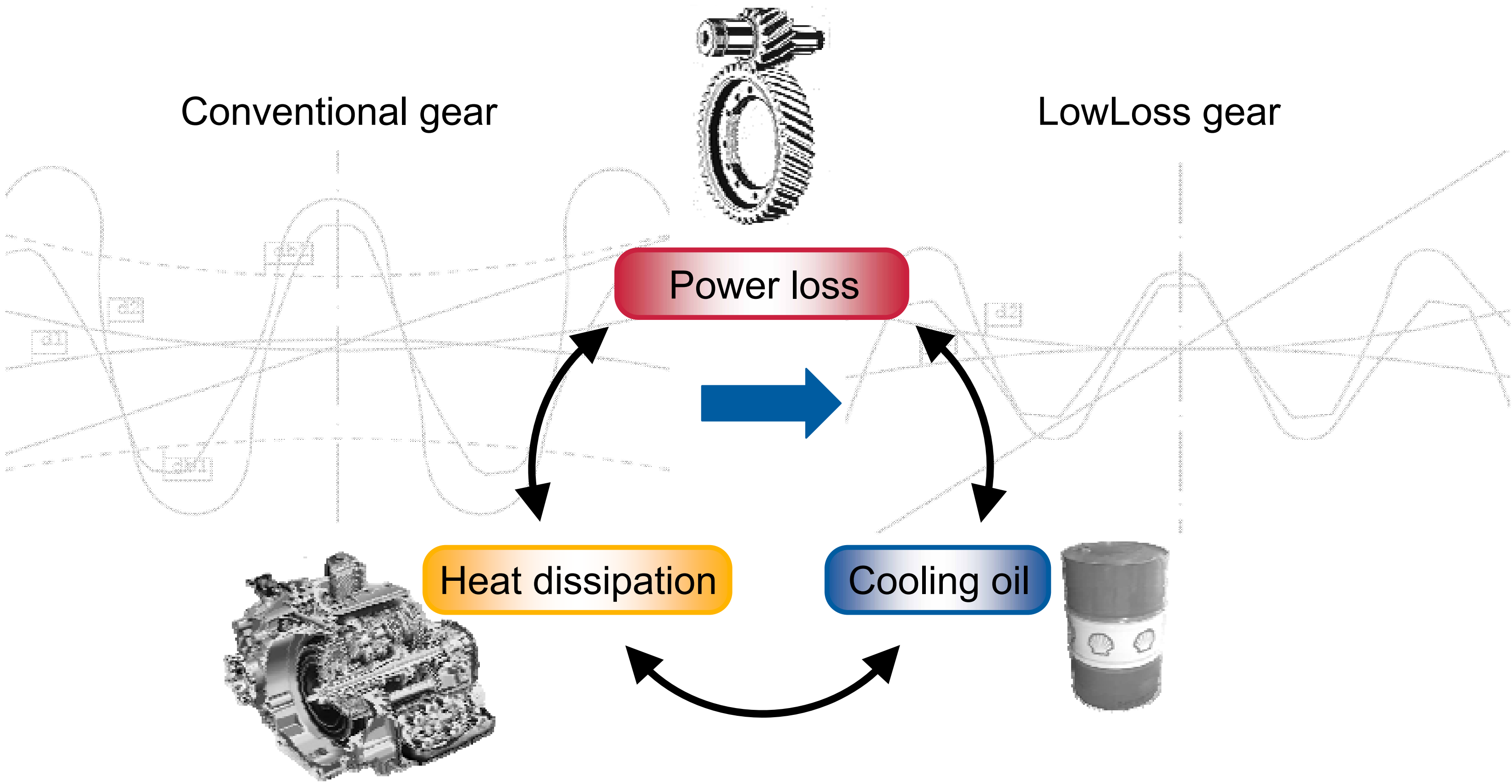




1. Loss-optimised transmission design: reduce rotational speeds by smart arrangement of loose wheels
→ Reduction of load-independent losses

2. Minimum-friction „LowLoss“ gears in conjunction with lower oil level
→ Reduction of load-dependent and load-independent losses

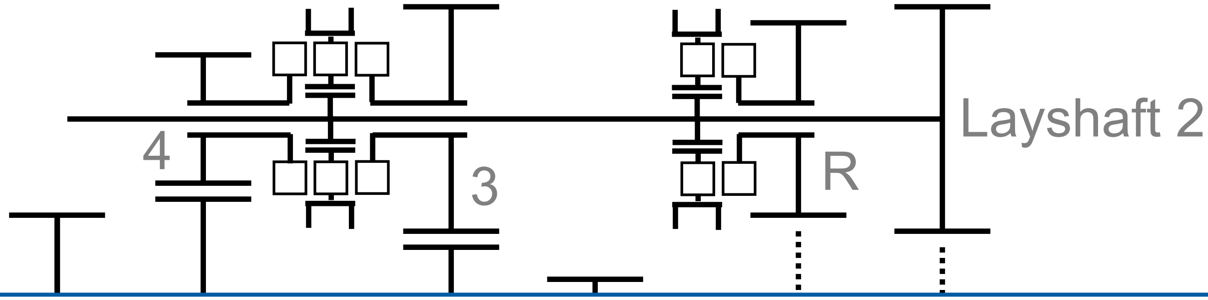
Reduction of load-dependent gear losses by LowLoss design



Up to 70% loss reduction

Optimised arrangement of loose gears

6-speed manual transmission

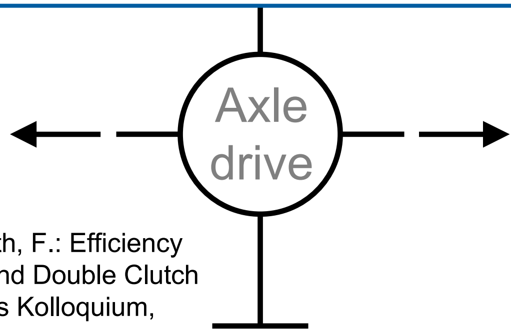


For low rotational speed of loose wheels:

➔ Loose wheels of high gears on input shaft and vice versa

For low rotational speeds of bearings:

➔ Loose wheels of gears with transmission ratios <1 on input shaft and vice versa



Source: Höhn, B.-R.; Michaelis, K.; Kurth, F.: Efficiency and Power Flow Analyses for Manual and Double Clutch Transmissions. 1. Automobiltechnisches Kolloquium, Garching, April 16 – 17, 2009

Loss reduction through lower oil level

Influence of the oil level on gear temperature

$$\vartheta_M = \vartheta_0 + 7400\left(\frac{P_{VZP}}{a\cdot b}\right)^{0.72}\cdot\frac{X_S}{1.2\,X_{Ca}}$$

Gear power loss (P_{VZP})

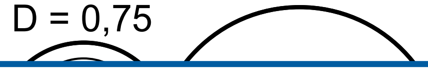
Tooth bulk temperature (ϑ_M)

Lubrication factor (X_S)

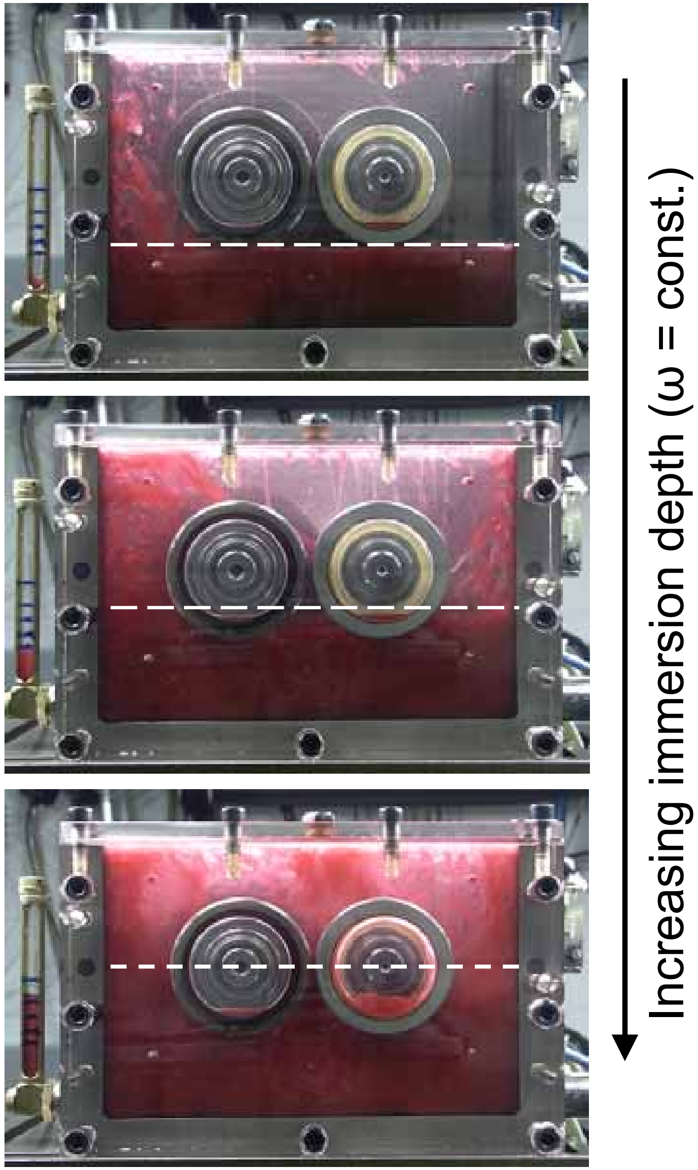
$$0.3 \le X_S = 0.35\left(\frac{e}{d_a}\right)^{-D} \le 3.7$$

Immersion depth (e)

D = 0,75

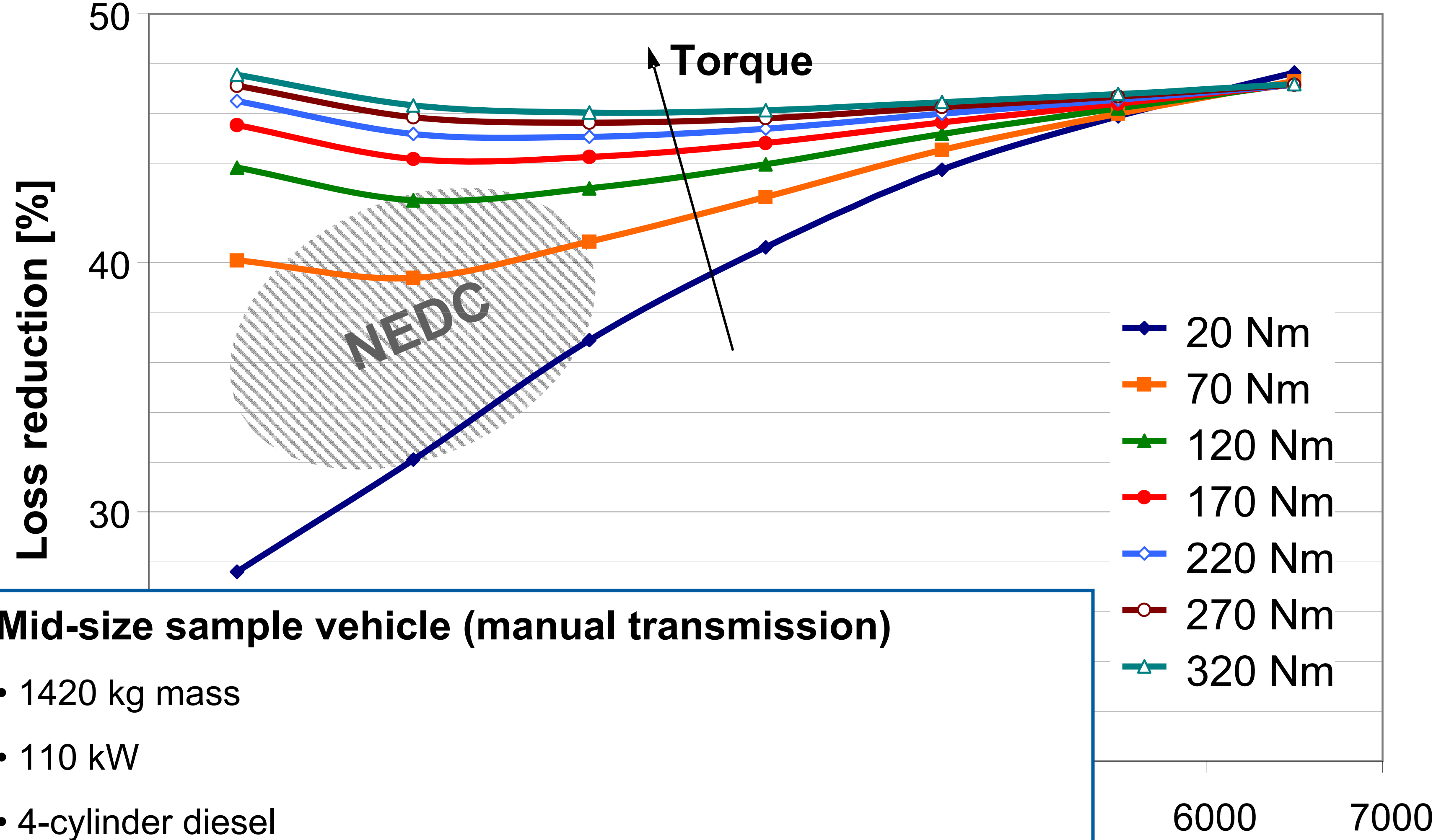


Conclusion:
Reduction of gear losses allows for lower oil level without increasing thermal stress.



Reduction of total transmission losses

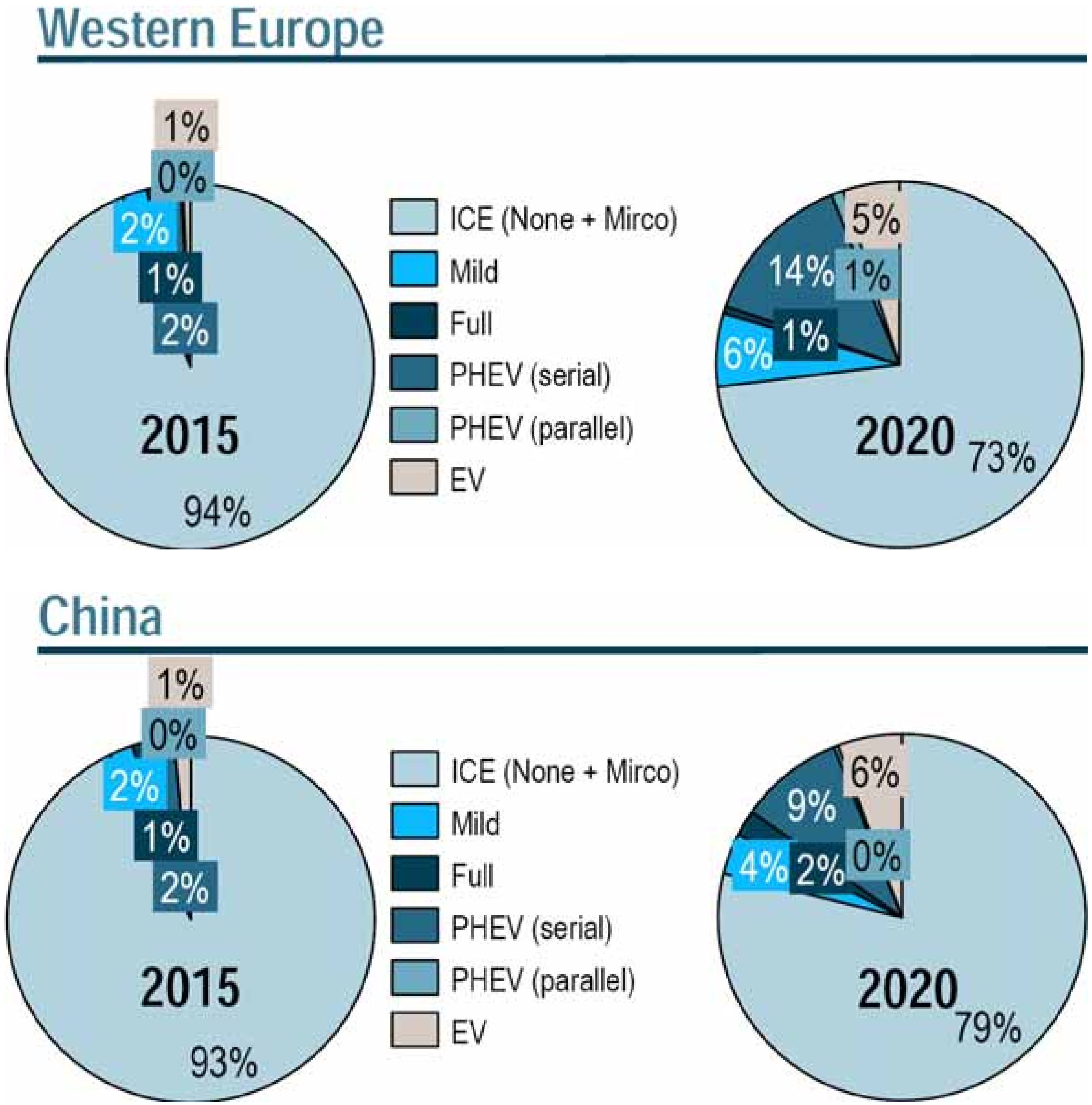
LowLoss gears and lower oil level



Mid-size sample vehicle (manual transmission)

- 1420 kg mass
- 110 kW
- 4-cylinder diesel
- **NEDC: 5.8 litres/100 km, 153 g/km CO_2, savings up to 3 g/km**
- **CADC: 6.3 litres/100 km, 168 g/km CO_2, savings up to 3.5 g/km**

Future powertrain scenarios



McKinsey&Company scenario for 2030

8% EVs
24% EVs
28% PHEVs
40% ICE/Micro hybrids

➔ -22% CO_2 compared to 2009
➔ -49% CO_2 compared to „no measures at all“
➔ Emission benefit for BEVs from 2017 on

Little agreement about the role of hydrogen in future car applications

Conclusions

- Purely Electric propulsion with present/near-future technology seems suitable only for cities.
- Hybrids might be a viable alternative for some applications and markets.
- Conventional powertrains must be further improved.
- Different solutions for different markets (customers, infrastructure, energy mix etc.) may be necessary despite increased costs.
- Engineers can shape the future, but environmental and financial policy have a strong influence.
- Sustainability does not necessarily mean renouncement, but can also mean superior, highly efficient solutions.
- Revolutions can come unexpectedly.