Life-cycle assessment of electric vehicles

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2050:

- **5 billion cars**
- **50 trillion km / year**
- **2.5 trillion l fuel / year (ca. 18% of global oil demand 2009)**
- **6 billion t CO_2/year (ca. 20% of global GHG emissions 2010)**

Electric vehicles as a solution?

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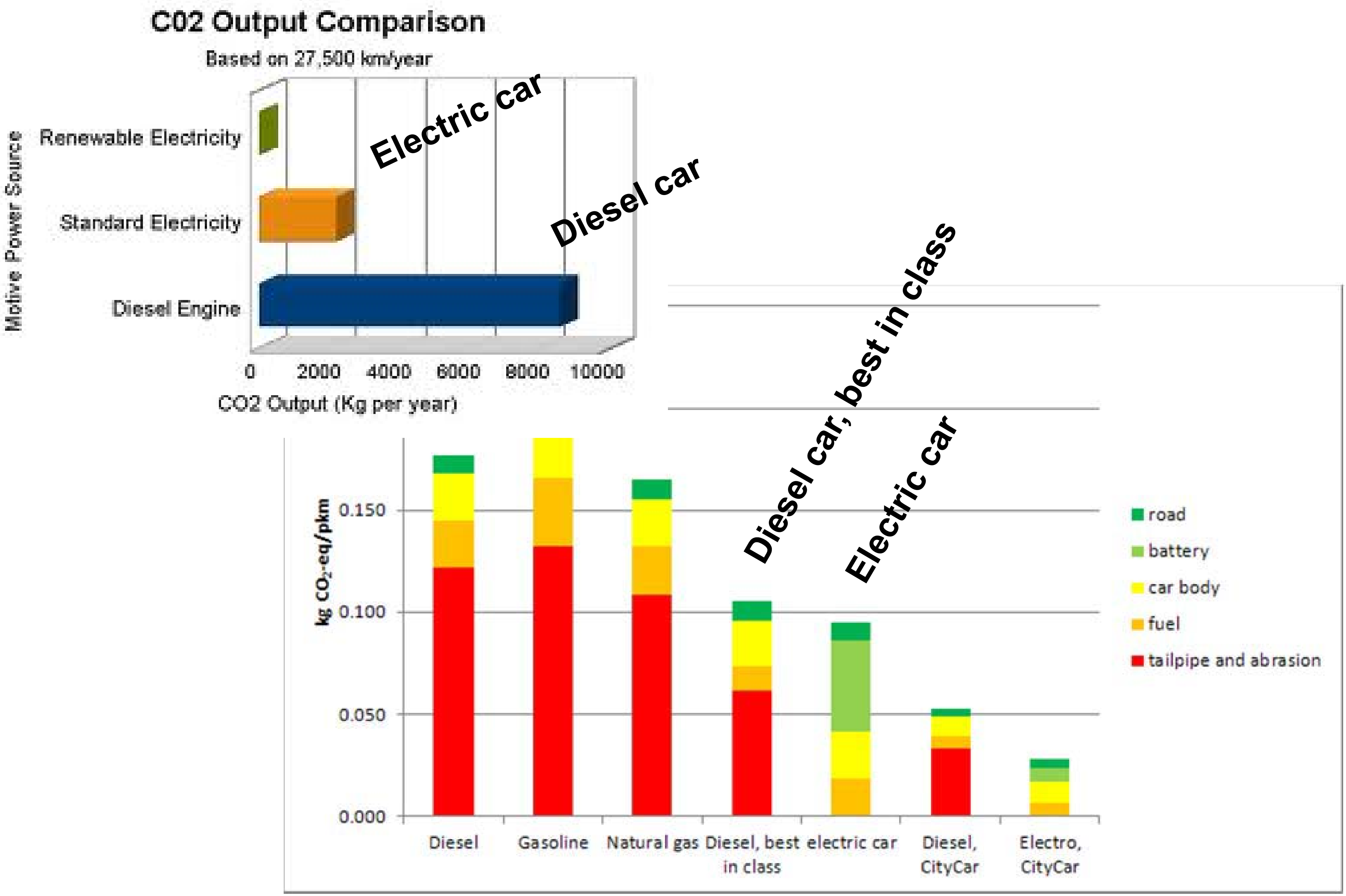
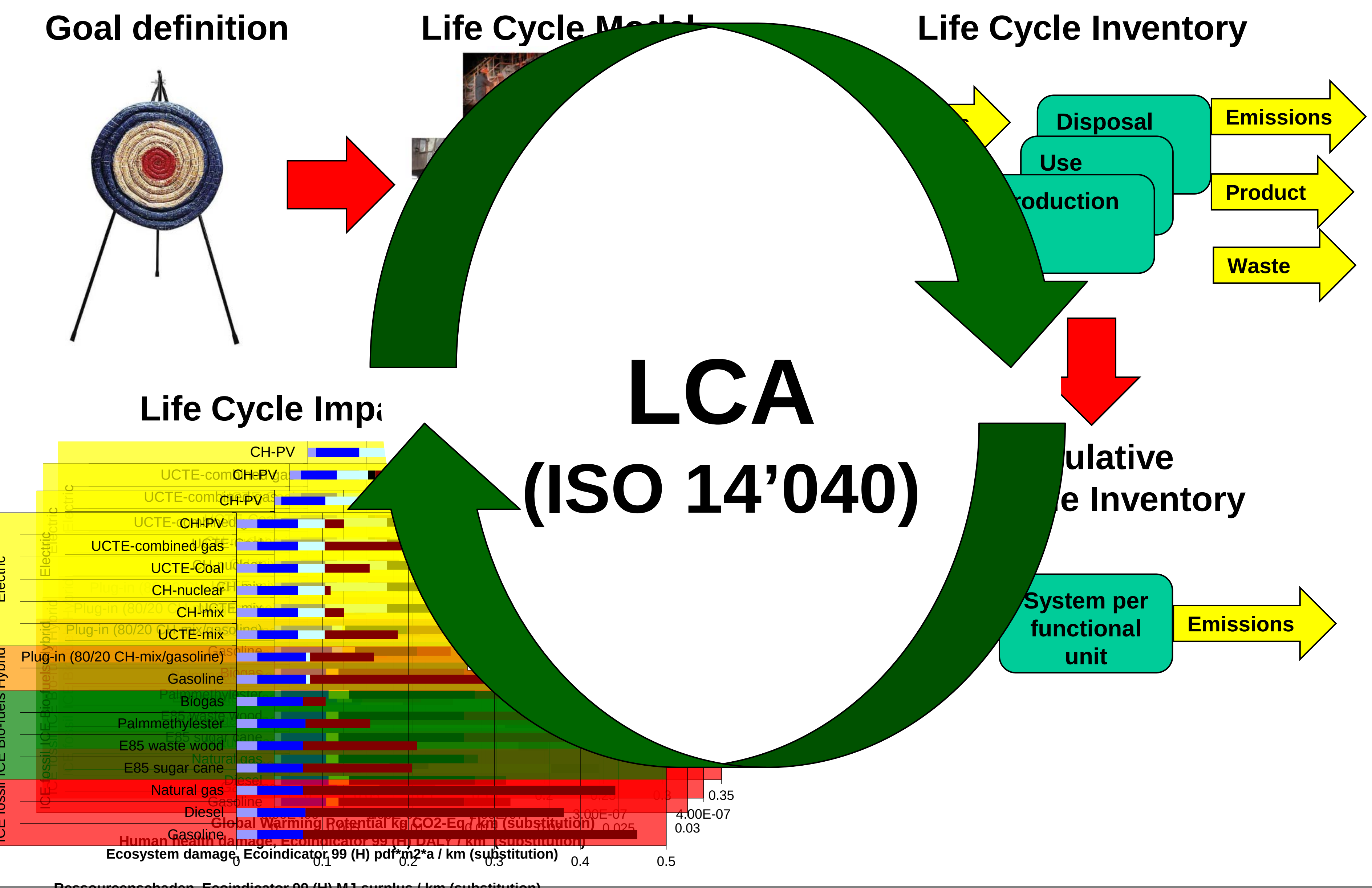


Outline

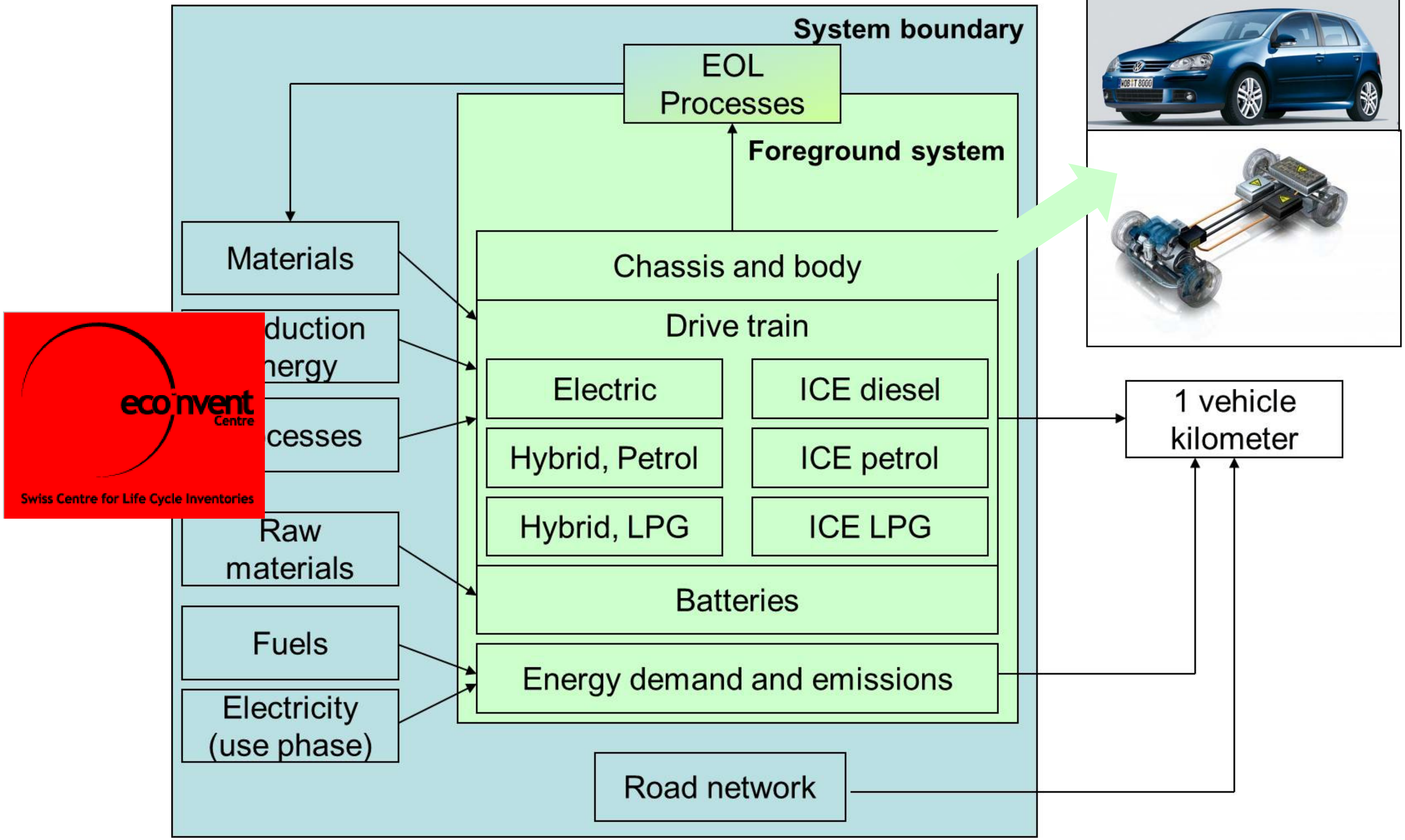
- How are (indirect) CO_2-emissions (and other environmental indicators) assessed?
- How do we model «mobility»?
  - Functional units and system boundaries
  - Data
- Results: Global Warming Potential (GWP)
- Is GWP a suitable environmental indicator for (electric) mobility?
- How variable are the results?
  - What are the reasons for variability?
  - What are the ranges?
- Conclusions

How are environmental burdens assessed: LCA procedure



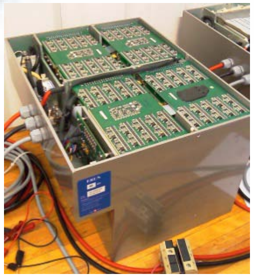
System boundaries

- Functional unit: 1 vehicle kilometer (vkm) per year 2015



How is mobility modelled: Vehicle

- Golf-Class vehicles with different (hypothetical) drive-trains



Conventional car

Body & glider

Axles, breaks, wheels, suspension, Cockpit, A/C-system, seats, doors, lights, entertainment, …

Drive train

Engine, gearbox, cooling system, fuel system, starter, exhaust, lubrication, …

Electric car

Body & glider

Axles, breaks, wheels, suspension, Cockpit, A/C-system, seats, doors, lights, entertainment, …

Drive train

Electric motor, gearbox, controller, charger, cables, cooling system, …

Battery

400 kg Li-ion-battery (45 kWh)

How is mobility modelled: Energy consumption

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- Golf-Class vehicles with different (hypothetical) drive-trains
  - Life mileage: 150‘000 km
  - Energy demand calculated: NEDC + real world addition
  - Break wear reduced for electric & hybrid cars
  - Maintenance: spare & wear parts. Batteries are replaced in every second electric vehicle
  - Use on Swiss road network

Golf BlueMotion → best in class!

Energy carier / Drive train	Electricity[1]	Diesel	Gasoline	Natural gas	Palmmethyl-ester PME (Maleysia)	E85 from sugar cane[2] (Brazil)	Biogas (Swiss Kompogas)
Electric	20 kWh/100km 0.72 MJ/km	-	-	-	-	-	-
Plug-In hybrid	Mix CH (80%) 16 kWh/100km 0.58 MJ/km	-	Hybrid (20%) 0.98 l/100km 0.31 MJ/km	-	-	-	-
Hybrid	-	-	Euro 5 4.9 l/100km 1.56 MJ/km	-	-	-	-
ICE	-	Euro 5 4.9 l/100km 1.76 MJ/km	Euro 5 6.8 l/100km 2.17 MJ/km	Euro 5 6.3 m3/100km 2.17 MJ/km	Euro 5 5.44 l/100km 1.76 MJ/km	Euro 5 8.07 l/100km 2.17 MJ/km	Euro 5 6.3 m3/100km 2.17 MJ/km

[1]: 6 generation scenarios (mix CH, mix UCTE, nuclear power CH, combined gas power UCTE, coal UCTE, PV CH)
[2]: Scenario with E85 from European waste wood

Results: Global Warming Potential (GWP)

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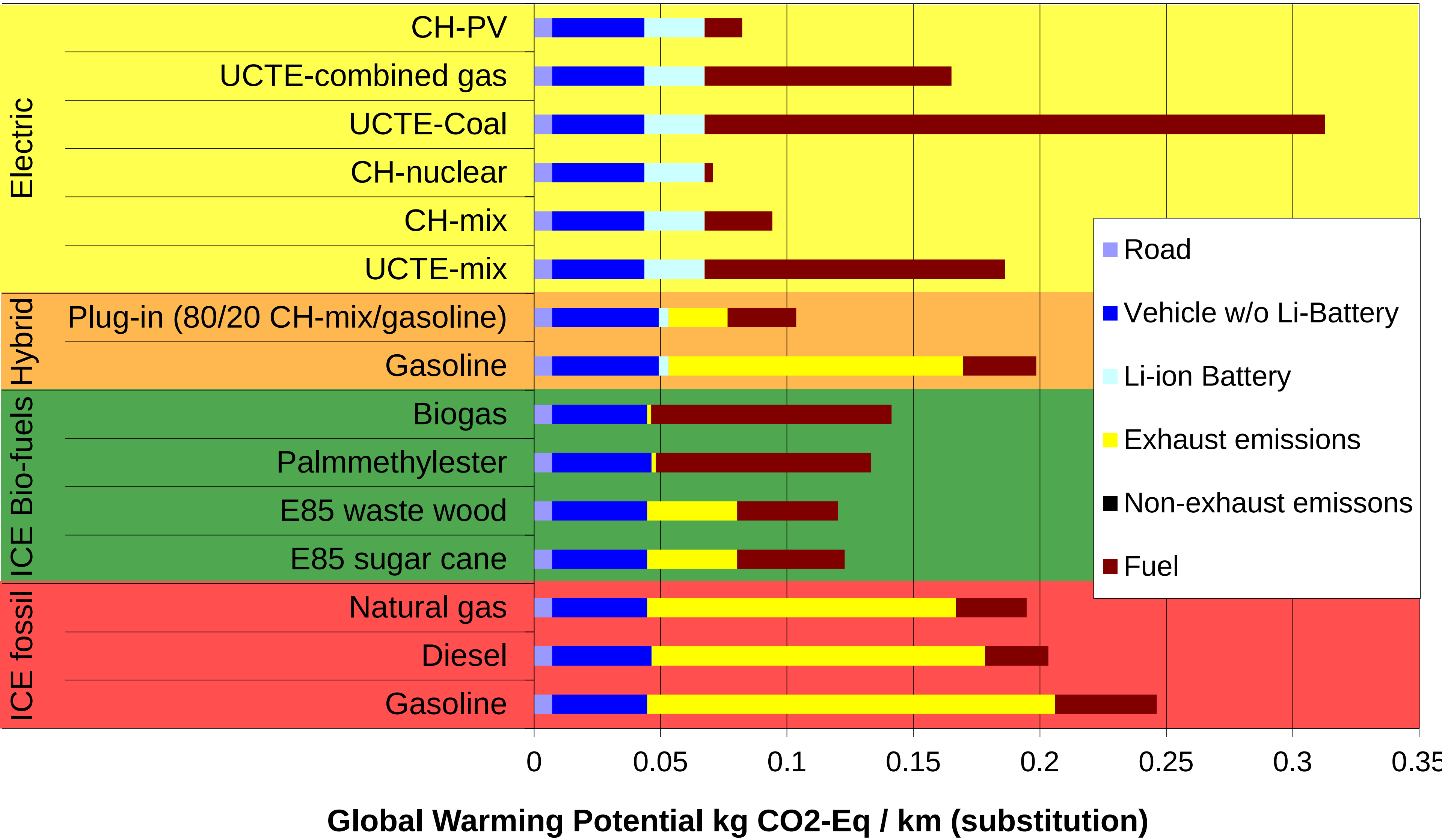
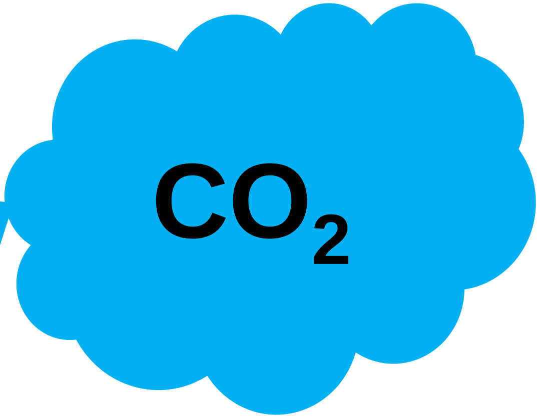


Is GWP suited to measure «environmental impacts»?

What are relevant environmental aspects for E-mobility?

- Human health damage
  - Climate change
  - Toxic emissions
  - Smog formation
- Damage to ecosystem
  - Climate change
  - Land use / land use changes
  - Eutrophication
- Damage to resources
  - Non renewable energy demand (fossil, nuclear)
  - Resource depletion (non energetic)
- Others
  - Radioactive waste



Is GWP a suitable environmental indicator?

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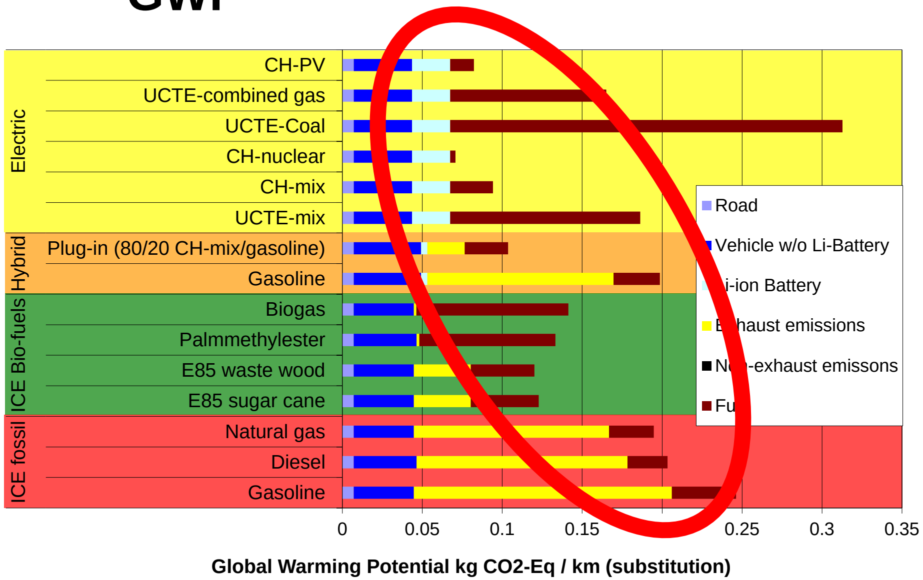
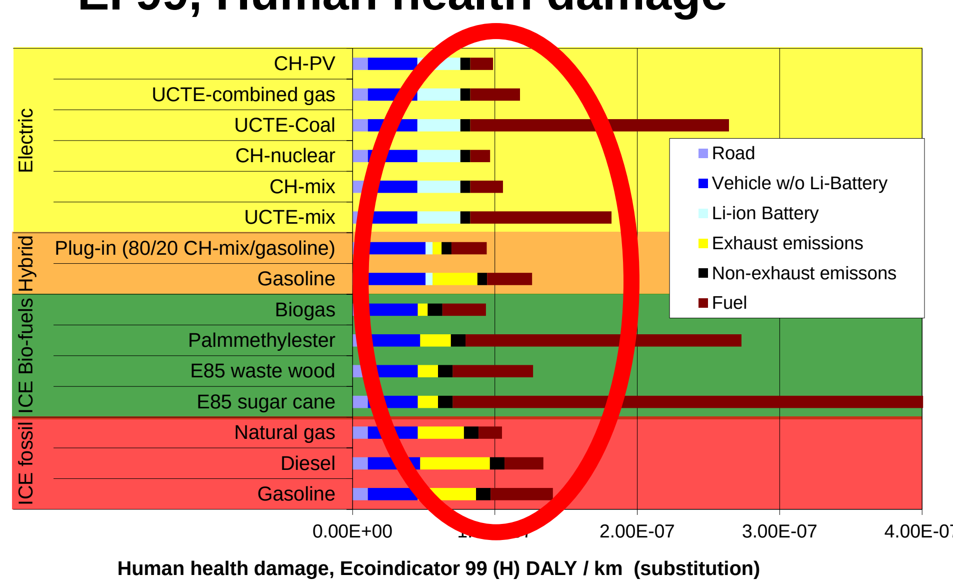
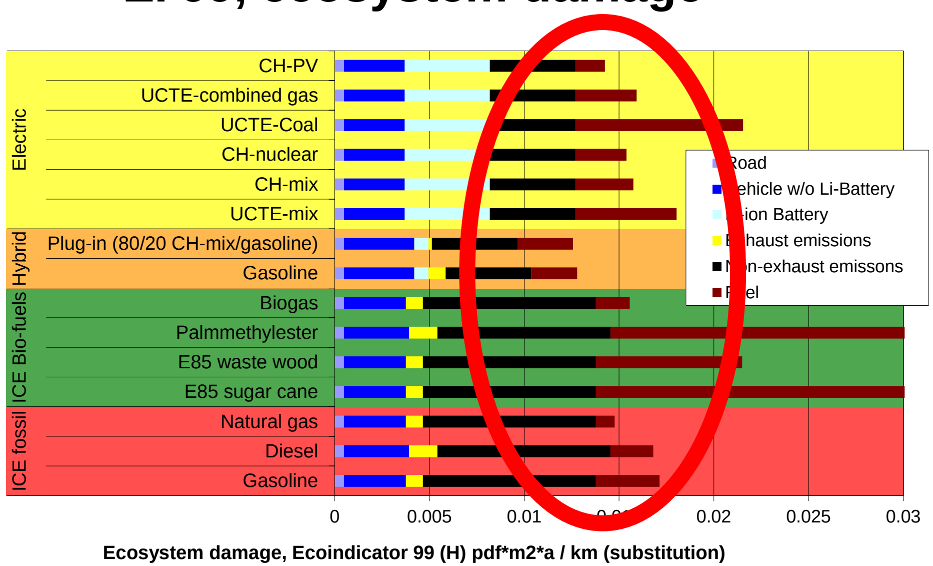
GWP



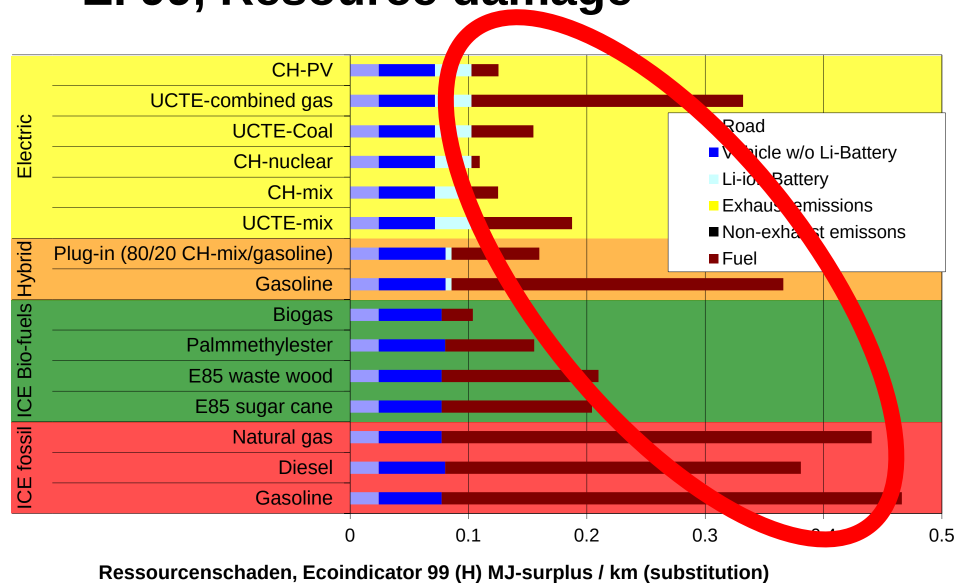
EI 99, Human health damage



EI 99, ecosystem damage

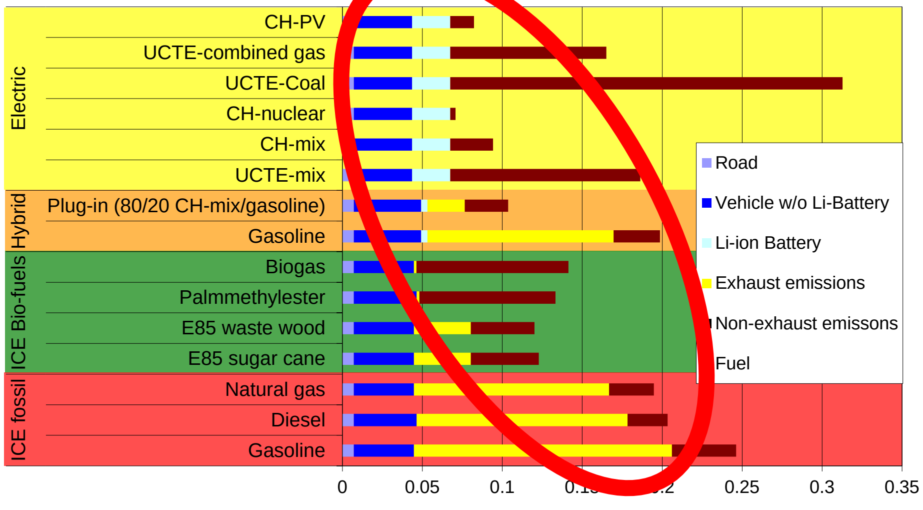


EI 99, Resource damage

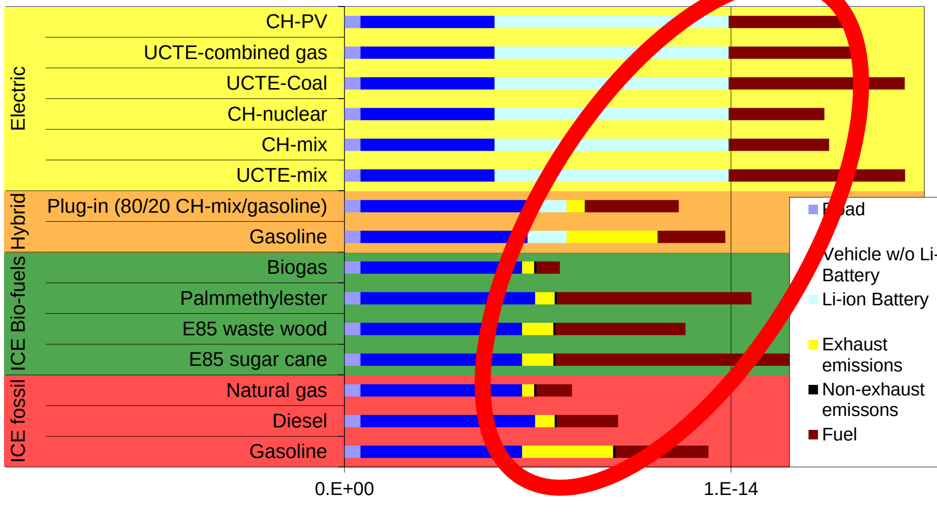


Is GWP a suitable environmental indicator?

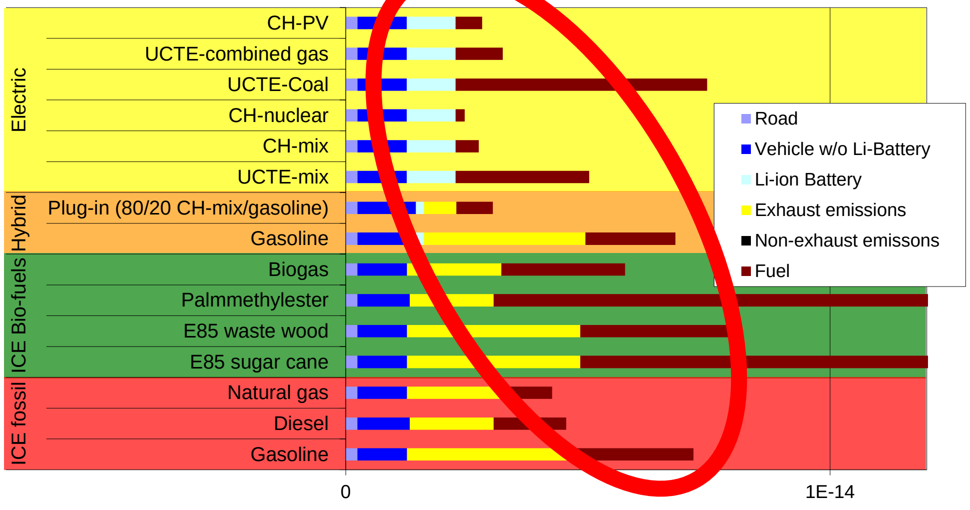
GWP



CML 01, Human toxicity potential

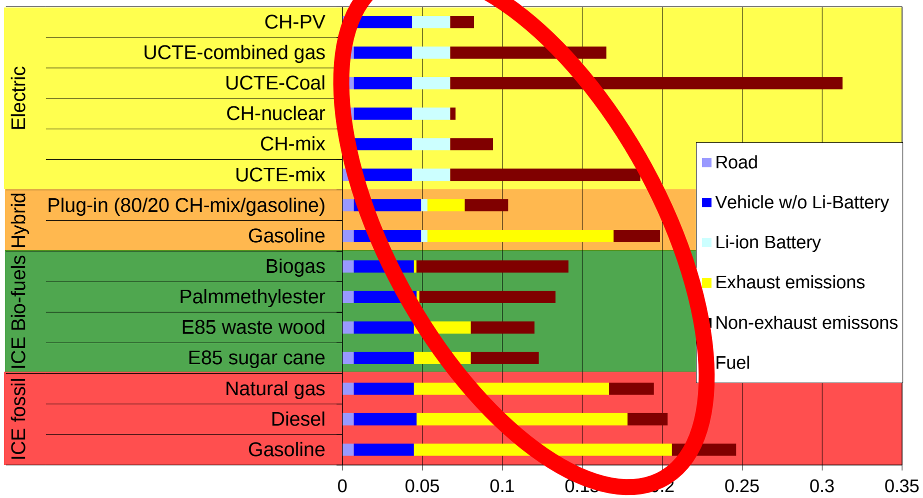


CML 01, photochemical oxidation potential

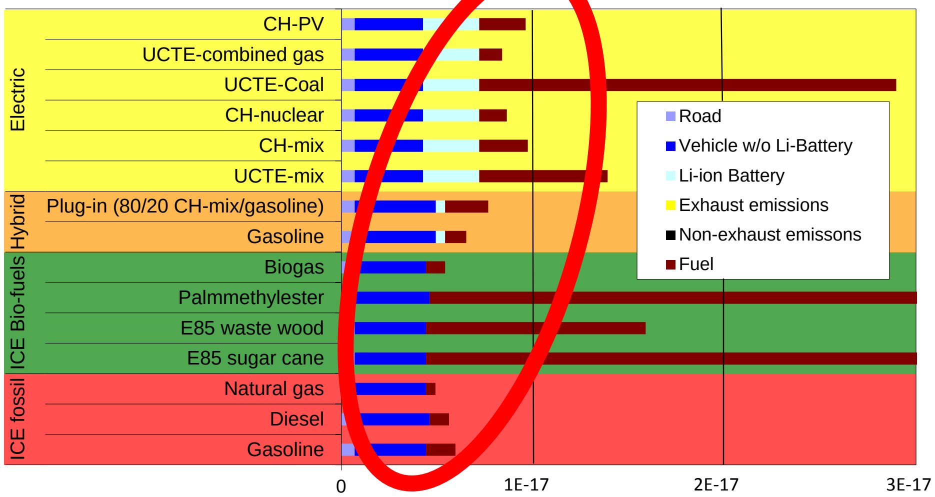


Is GWP a suitable environmental indicator?

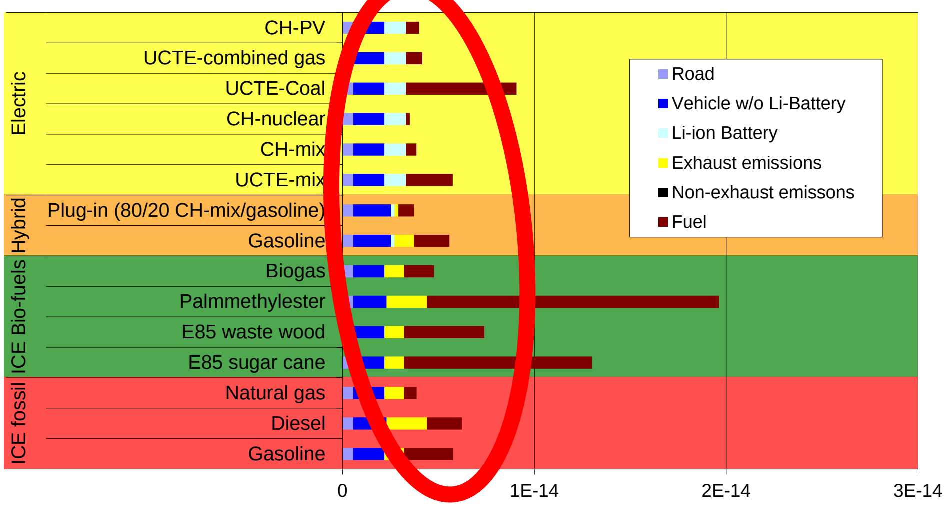
GWP



CML 01, Land use



CML 01, eutrophication potential



Is GWP a suitable environmental indicator?

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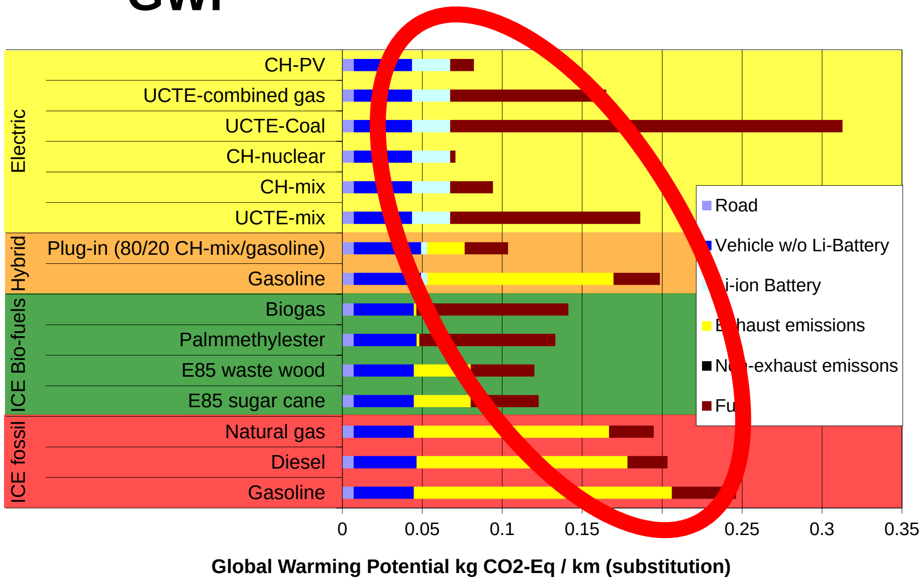
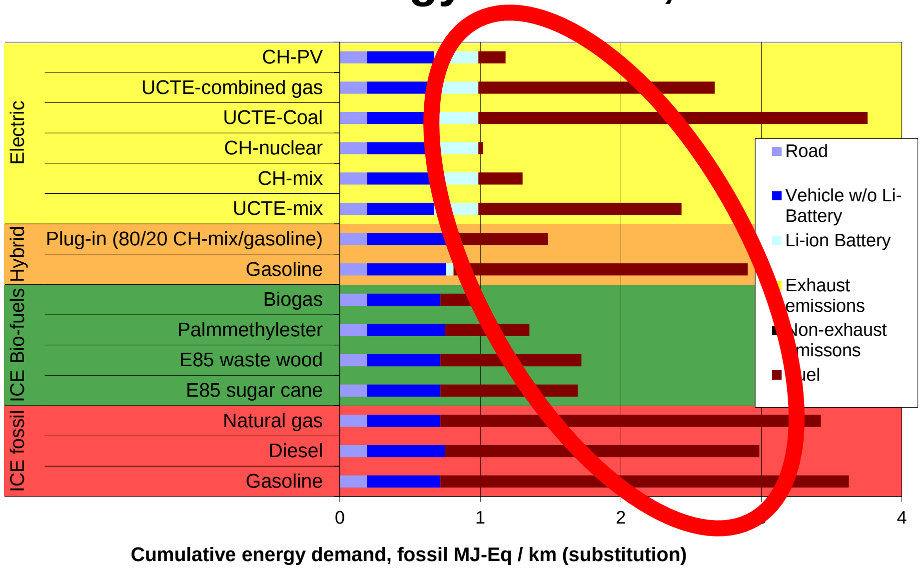
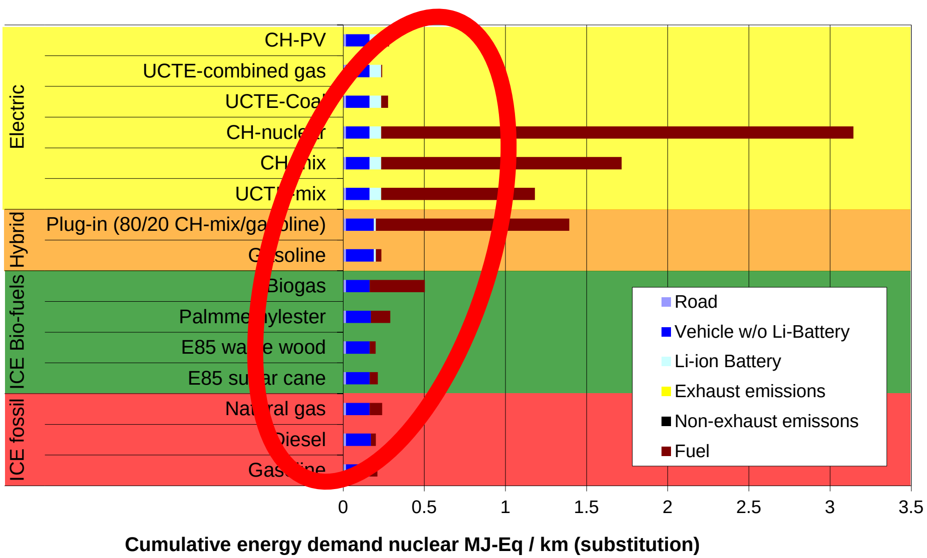
GWP



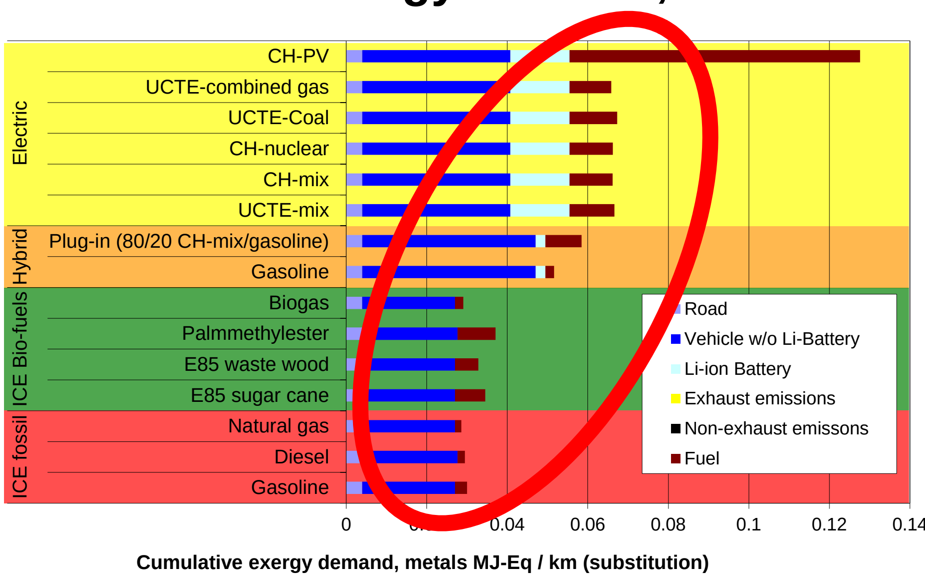
Cumulative energy demand, fossil



Cumulative energy demand, nuclear



Cumulative exergy demand, metals



Uncertainties of LCA results

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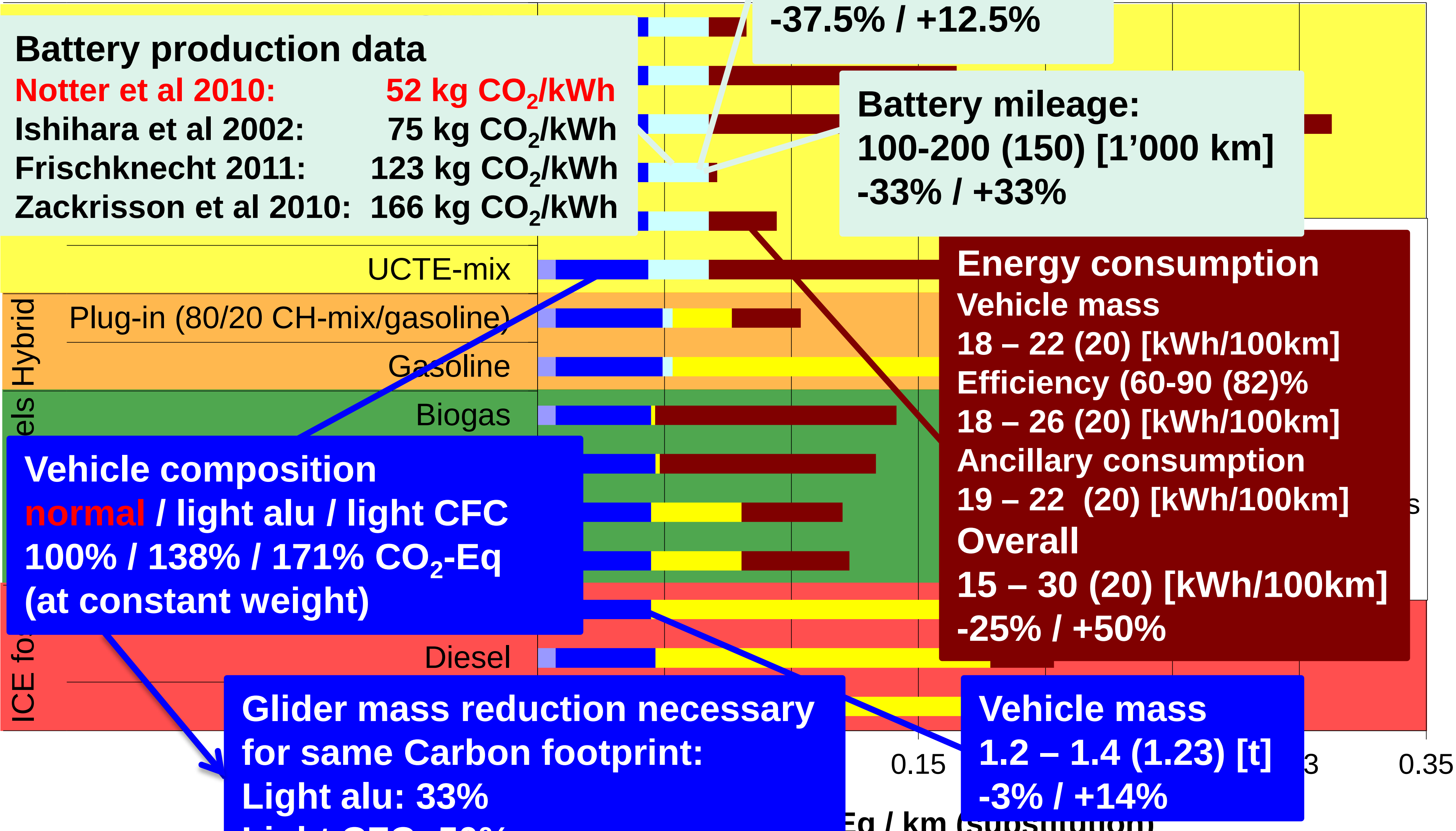
Variability of Global Warming Potential (GWP)

- Variability within Golf-Class



Battery production data
Notter et al 2010: 52 kg CO_2/kWh
Ishihara et al 2002: 75 kg CO_2/kWh
Frischknecht 2011: 123 kg CO_2/kWh
Zackrisson et al 2010: 166 kg CO_2/kWh

Battery mass
250 –450 (400) [kg]
-37.5% / +12.5%

Battery mileage:
100-200 (150) [1'000 km]
-33% / +33%

Energy consumption
Vehicle mass
18 – 22 (20) [kWh/100km]
Efficiency (60-90 (82)%
18 – 26 (20) [kWh/100km]
Ancillary consumption
19 – 22 (20) [kWh/100km]
Overall
15 – 30 (20) [kWh/100km]
-25% / +50%

Vehicle composition
normal / light alu / light CFC
100% / 138% / 171% CO_2-Eq
(at constant weight)

Glider mass reduction necessary for same Carbon footprint:
Light alu: 33%
Light CFC: 50%

Vehicle mass
1.2 – 1.4 (1.23) [t]
-3% / +14%

Variability of GWP caused by variability of energy consumption

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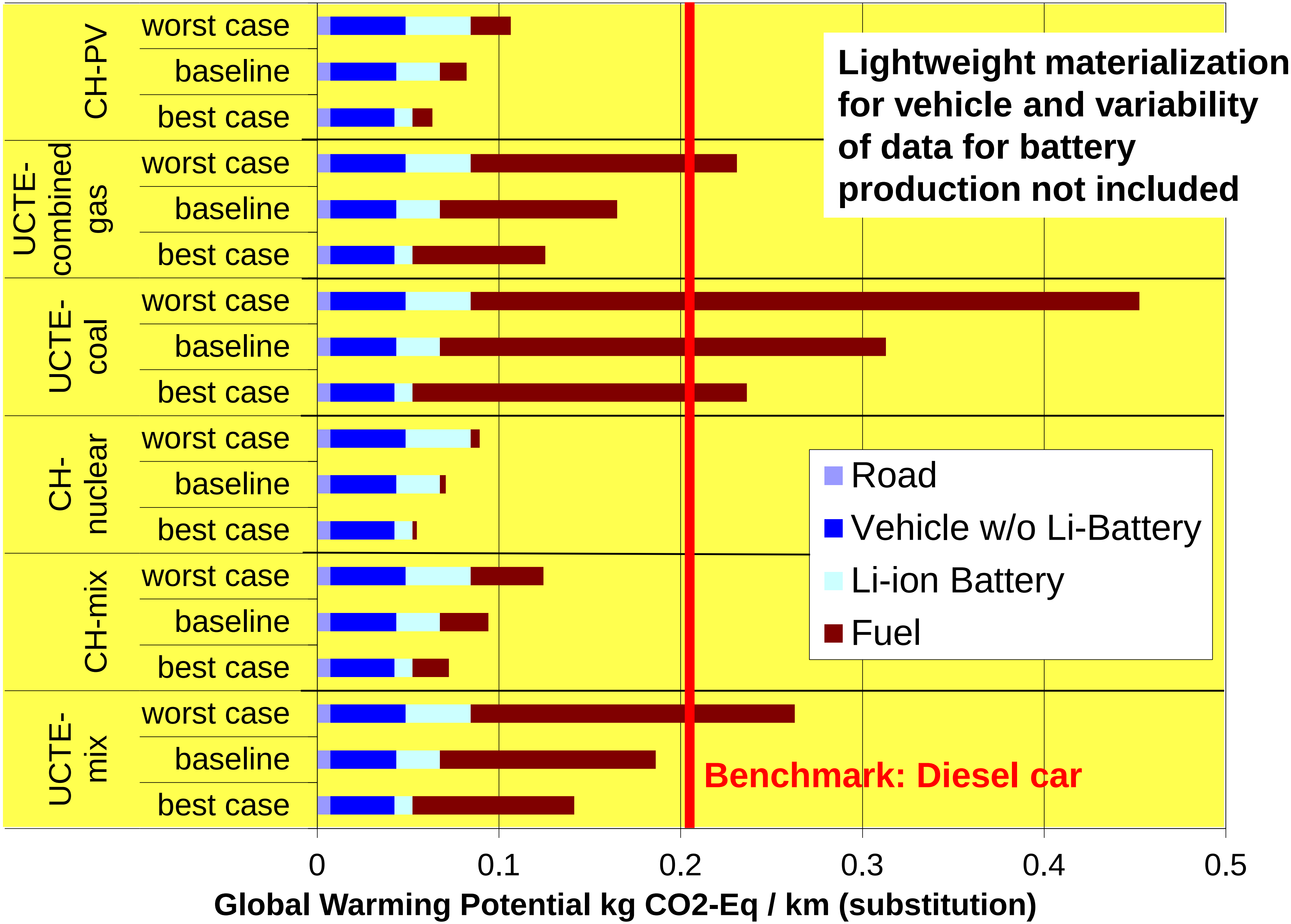
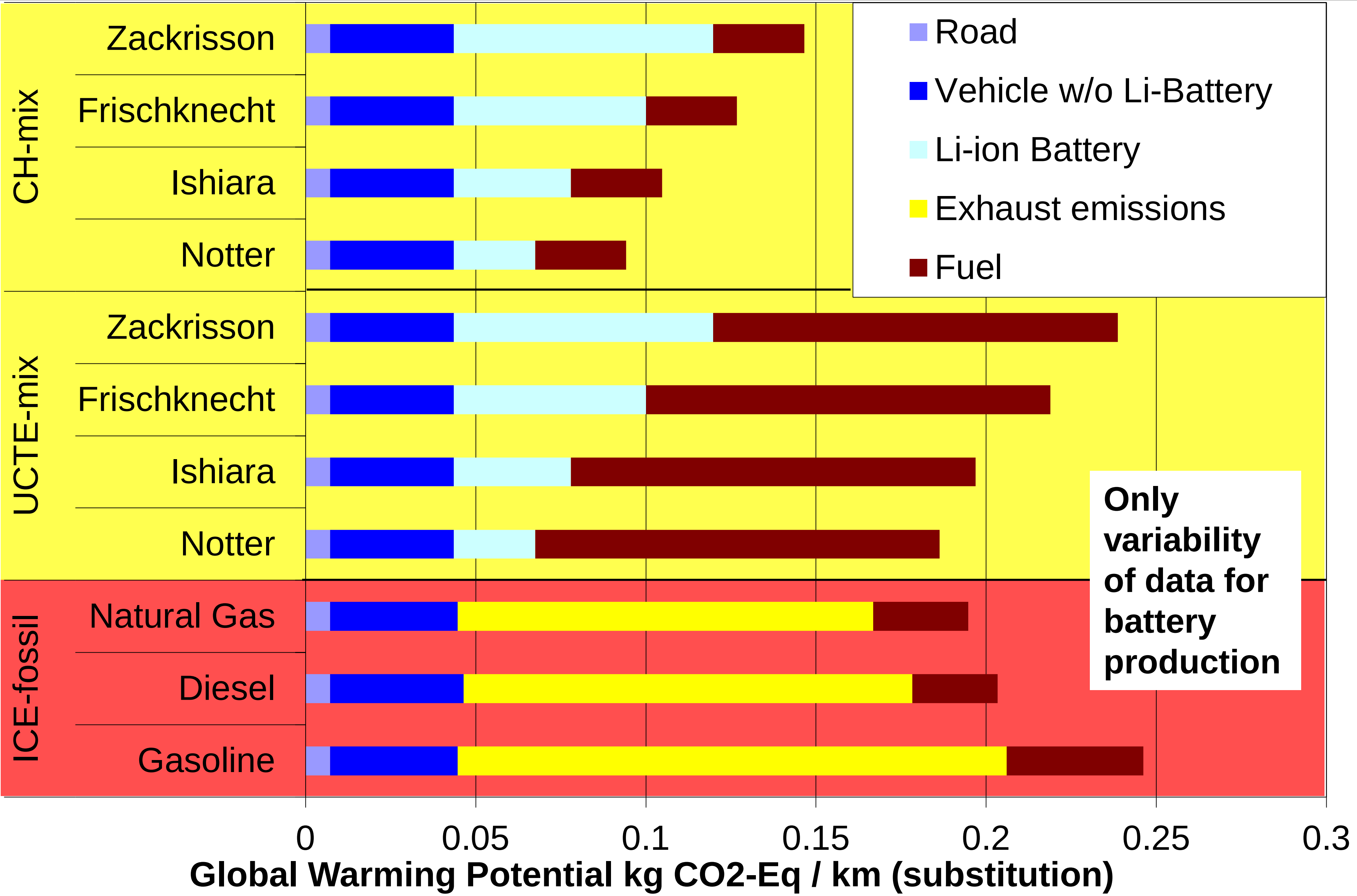


Variability of GWP with different battery data



Variability Battery data: main differences

Energy consumption in cell / battery production

- Notter et al / Ishihara et al: bottom up modelling of processes
- Energy demand calculated from measured or theoretical demand for e.g. heating.
- No allocation necessary

- Zackrisson et al / Frischknecht: top down from producers
- Total energy demand from “sustainability report” of producer
- Allocation between various products of this producer by turnover and battery price

Main uncertainty with method

- Energy efficiency of processes
- Some processes might be lacking (eg. energy demand for lighting)

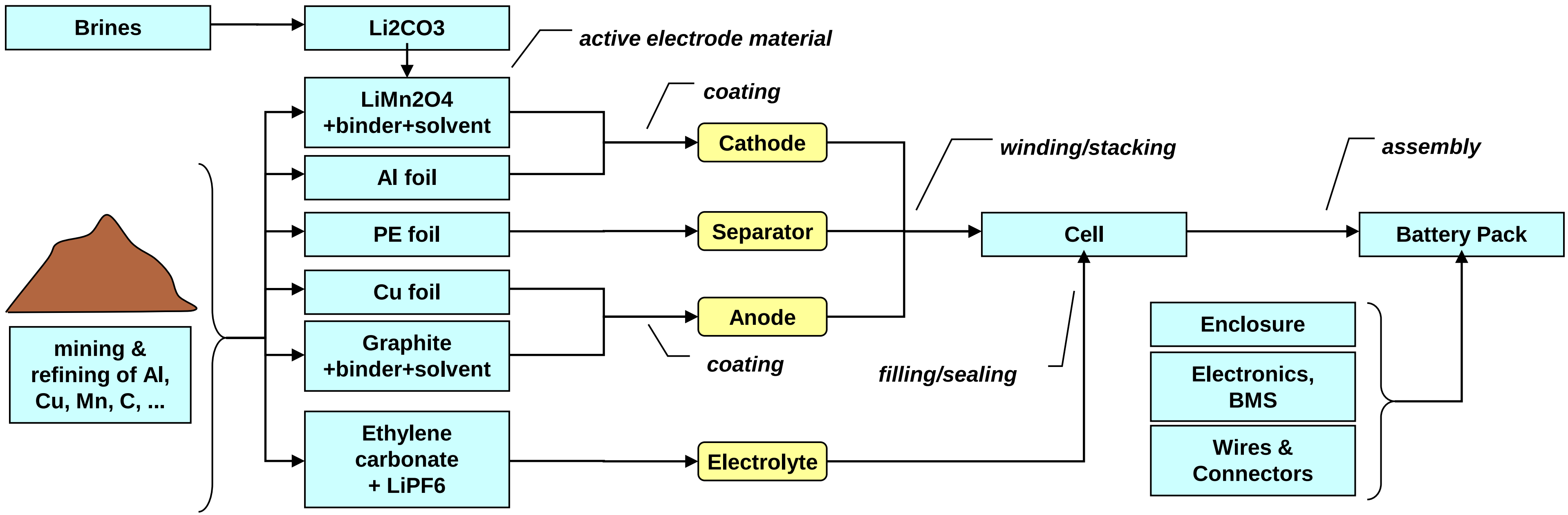
- Product prices might not correspond to energy consumption, especially if labour, amortisation of development and infrastructure cost is important

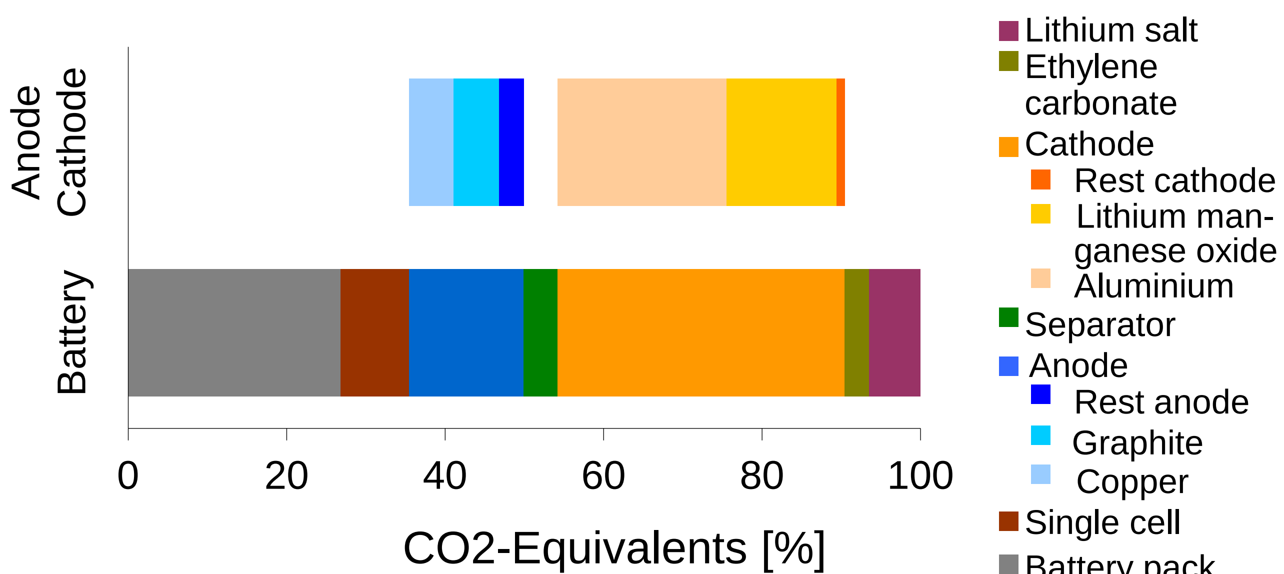
Cradle to gate electricity demand

- Notter et a.: 54 kWh/kWh
- Ishihara et al: n.A.

- Frischknecht: 153 kWh/kWh
- Zackrisson et al: n.A.

Production of a Li-Ion battery: Bottom-up





graphics: Empa

Source: Notter et al 2010

Production of a Li-Ion battery: Top-down

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Products:

Photographic paper
Disks
Videotapes
Alcaline batteries
Hard disks
Silver oxide batteries
DVD-R / Blue-ray discs
Shavers
CR batteries
Li-Cl batteries
Computer tapes
Lens units
Li-ion batteries for cell-phones
Head phones
Air-Zn-Batteries
Automatic urine sample systems
Batteries for Endoscopes
Tapes for wire connections
CR-batteries for sensors
Lenses for safety assurance

Energy demand / Sales

150 GWh electricity / 2.3 Ml oil
1 billion Euro

150 Wh/€ el.
2.3 ml/€ oil

Makes sense if share of energy cost on product price is similar for all products

Price:
1000 €/kWh

150 kWh/kWh el.
2.3 l/kWh oil
per kWh battery

Price:

Raw material cost
Energy cost
Capital cost
Marketing cost
Benefit

Source: Env. Report Maxwell (rounded) / Assumptions

Conclusions

- Carbon footprint can be dominated by infrastructure or by operation depending on electricity source
- Different data sources for carbon footprint of batteries lead to different interpretations of carbon footprint of electric mobility
- Variability of carbon footprint within the “Golf-class” is rather high (ca. 75% - 150% of baseline)

➔ Specific vehicles demand for specific assessments!

➔ Always check data sources before interpreting any results

➔ Never trust results from intransparent data

- The ranking of vehicles with different drivetrains according to carbon footprint is completely different from the ranking according to other environmental impact indicators

➔ Carbon footprint is not sufficient as environmental performance indicator!

Main sources for this presentation:

Be prepared for the non-fossil future

Mobilität:

Bio- und fossilen

roup,

An

Post for financial support.

And: