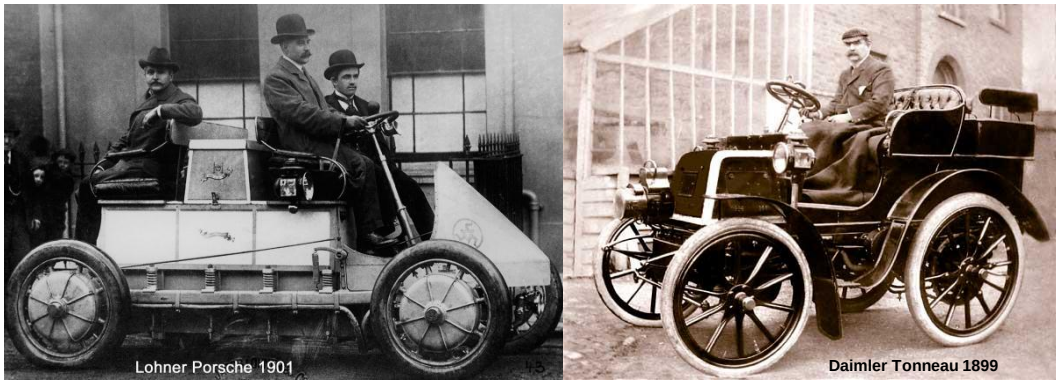
43rd LCA Discussion Forum, April 6, 2011, ETH Zurich

Life Cycle Assessment of Electromobility – Answers and Challenges

Comparative assertion of battery electric cars with various alternatives



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Empa

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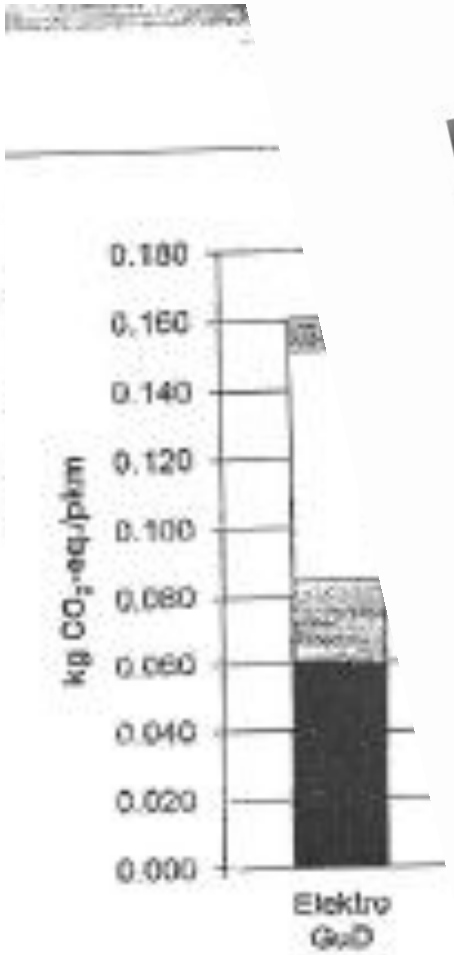
www.empa.ch/mobility

Motivation



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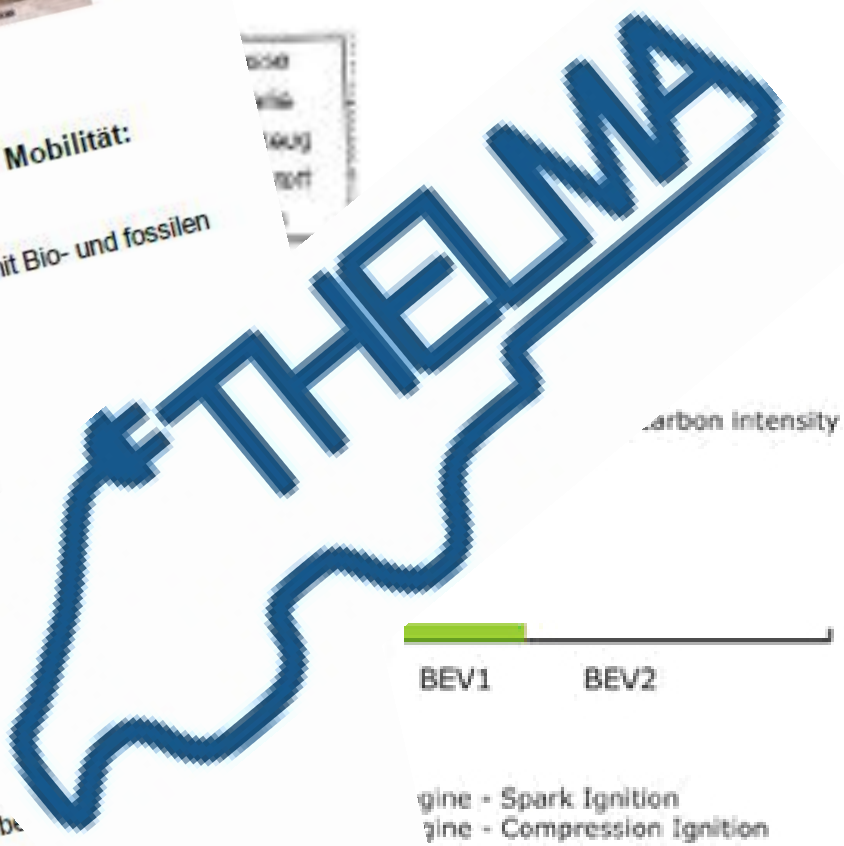
Vergleichende Ökobilanz individueller Mobilität:

Elektromobilität versus konventionelle Mobilität mit Bio- und fossilen Treibstoffen

Hans-Jörg Althaus
Marcel Gauch

Life Cycle Assessn
Technologie
En

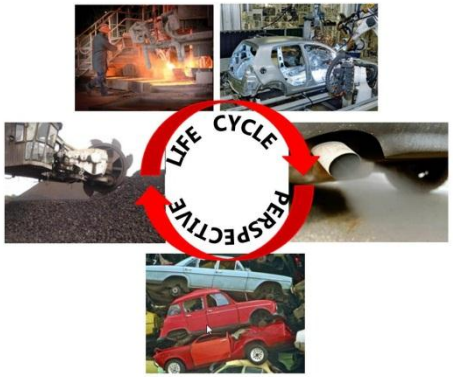
Dübendorf, Oktob



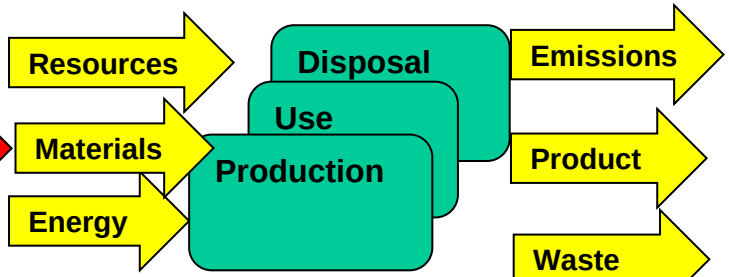
Outline of the presentation

Goal definition

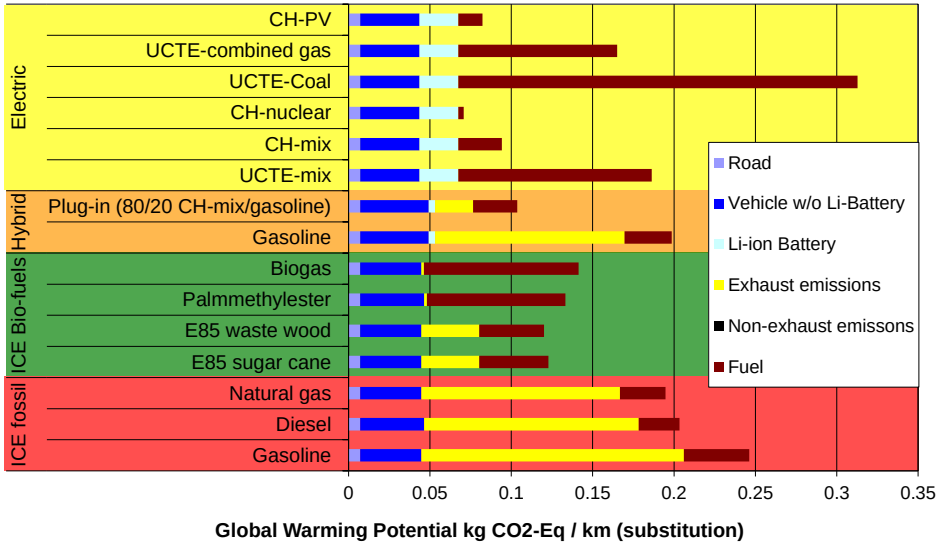
Life Cycle Model



Life Cycle Inventory



Life Cycle Impact Assessment



Goal & scope

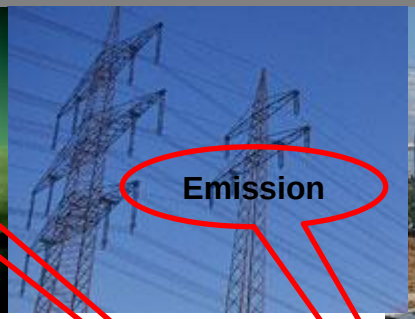
Goal definition

- Compare driving in hypothetical near future battery electric cars with driving in modern (or near future) fossil or biofuel fuelled cars
- Cars representative for Golf class
- Provide background information to discuss the potential of electric mobility to improve environmental aspects of mobility
- Comparative LCA to be presented in public
  → critical review compulsory

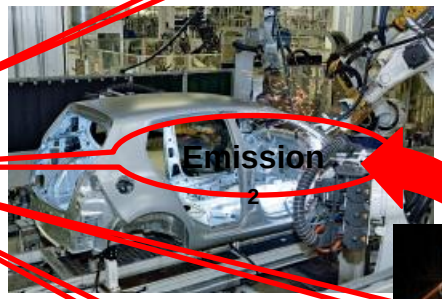
Scope / Impact assessment methods considered

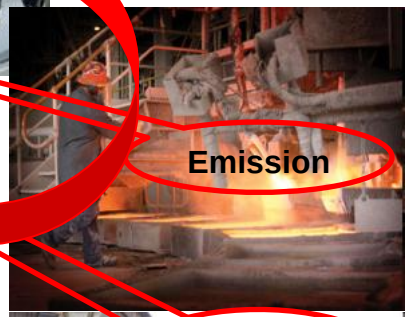
- Human health damage: Ecoindicator 99 H
  - Climate change: IPCC 2007
  - Toxic emissions: CML 01 HTP
  - Smog formation: CML 01 POCP
- Damage to ecosystem: Ecoindicator 99 H
  - Climate change: IPCC 2007
  - Land use / land use changes: CML 01 LUC
  - Eutrophication: CML 01 EP
- Damage to resources: Ecoindicator 99 H
  - Non renewable energy demand: CED fossil, nuclear
  - Exergy demand: CEDx metals, minerals
  - Resource dissipation: Loss of several scarce elements (kg)
- Others
  - Radioactive waste: Inventory (m^3)

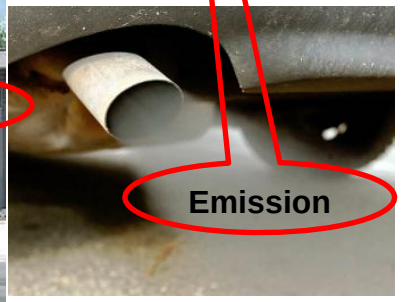
System boundaries



Environmental Impact



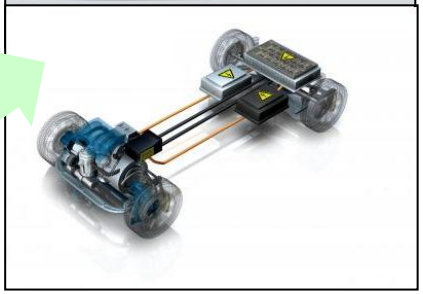




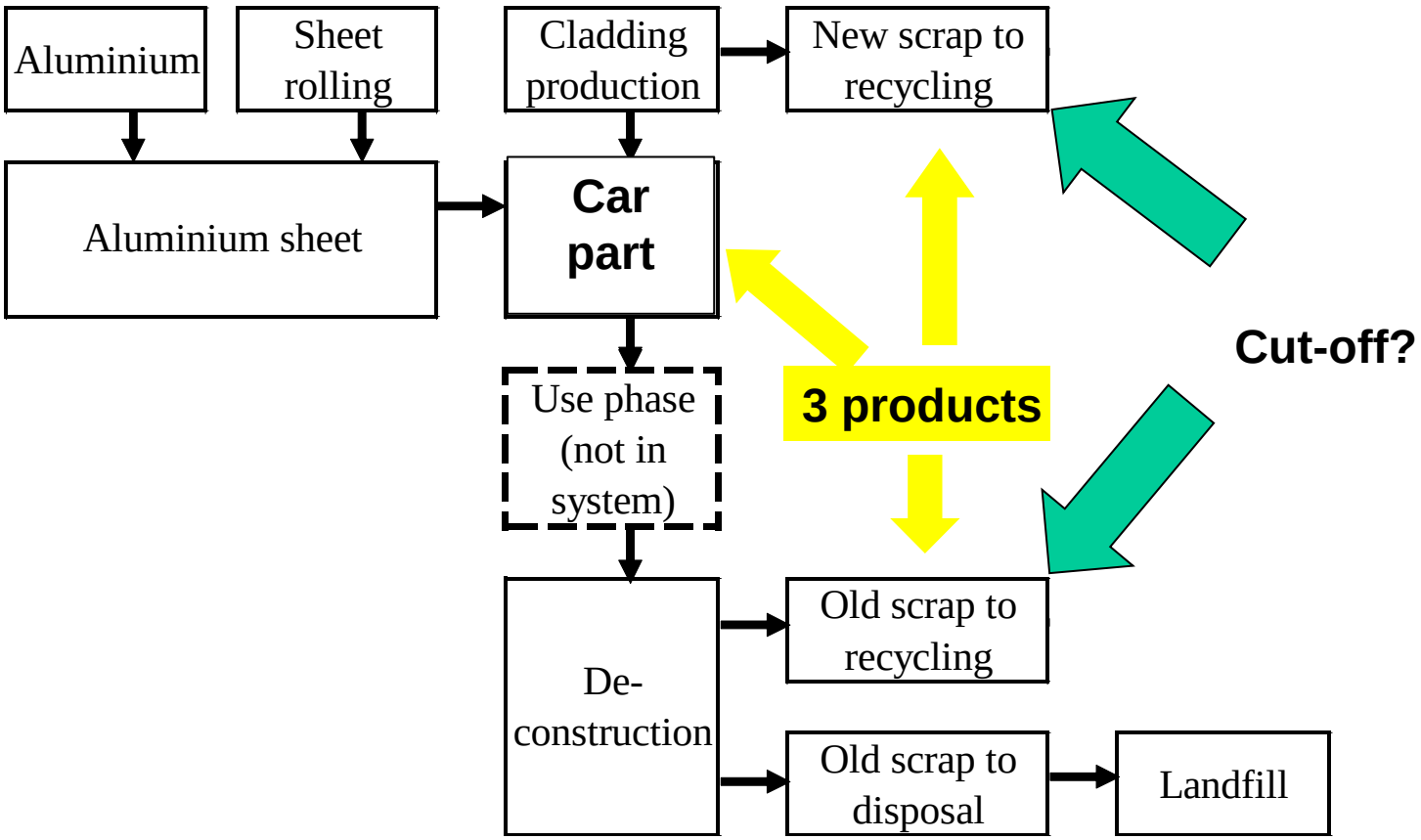
System boundaries

Scope / Life Cycle Model

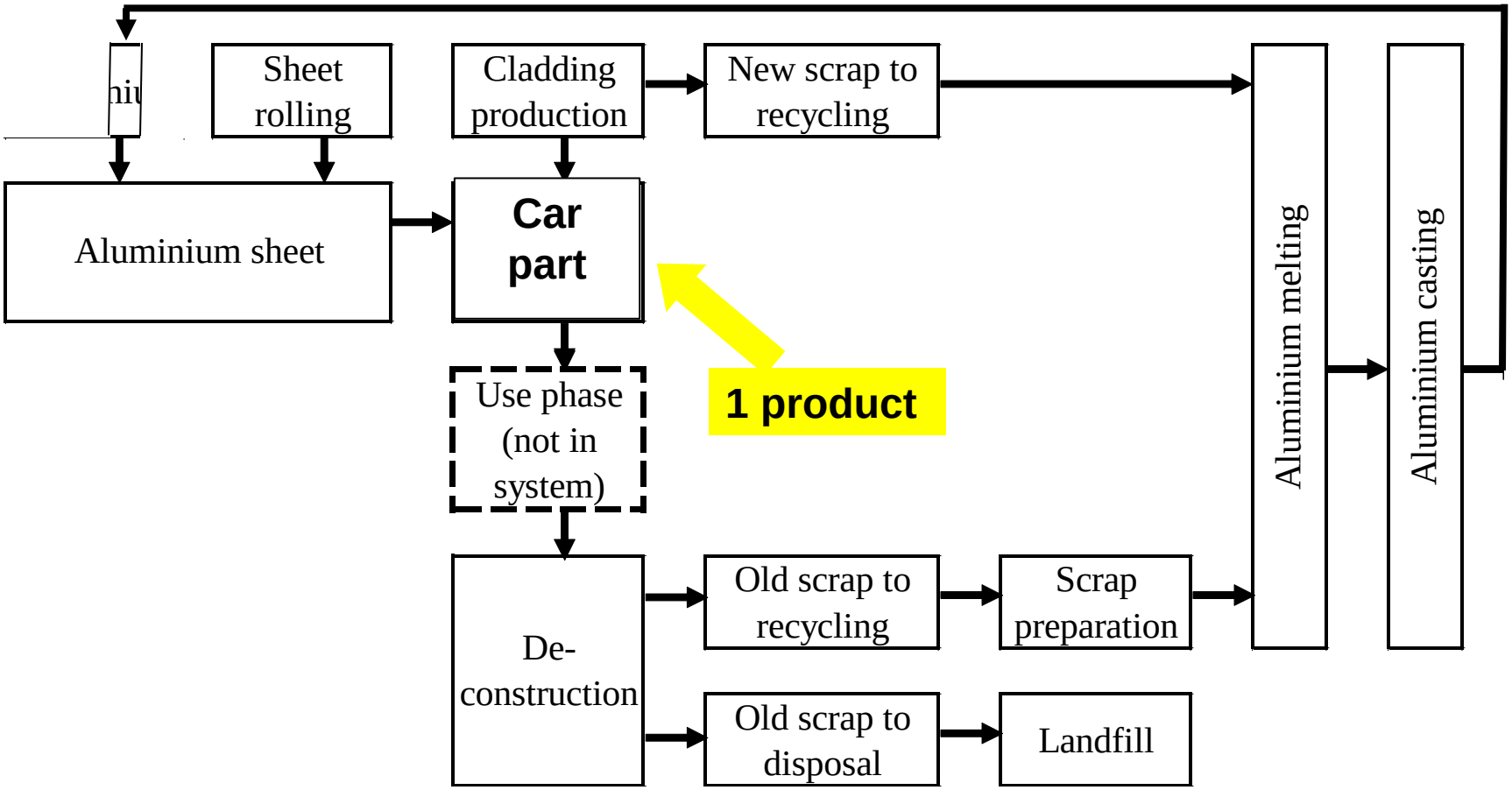
- Functional unit: 1 vehicle kilometer (vkm) per year 2015



Scope / End of Life Model



This LCA uses system expansion and substitution to avoid allocation



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

Conventional car

Body & glider

Axles, breaks, wheels, suspension
Cockpit, A
system,
doors
ente …

…rain

…e, gearbox,
…ng system,
…el system,
starter, exhaust,
lubrication, …

Golf IV, scaled to weight of Golf VI BlueMotion

Golf IV body, scaled to weight of Golf VI BlueMotion body

Electric car

Body & gli…

Ax…
…on,
…pit, A/C-
…ystem, seats,
doors, lights,
entertainment, …

Drive train

Electric mo…
gear…
…ies,
…g system,
…

Drivetrain from existing Brusa components

Scaled from existing KOKAM battery
(… kWh)

How is mobility modelled: Energy consumption

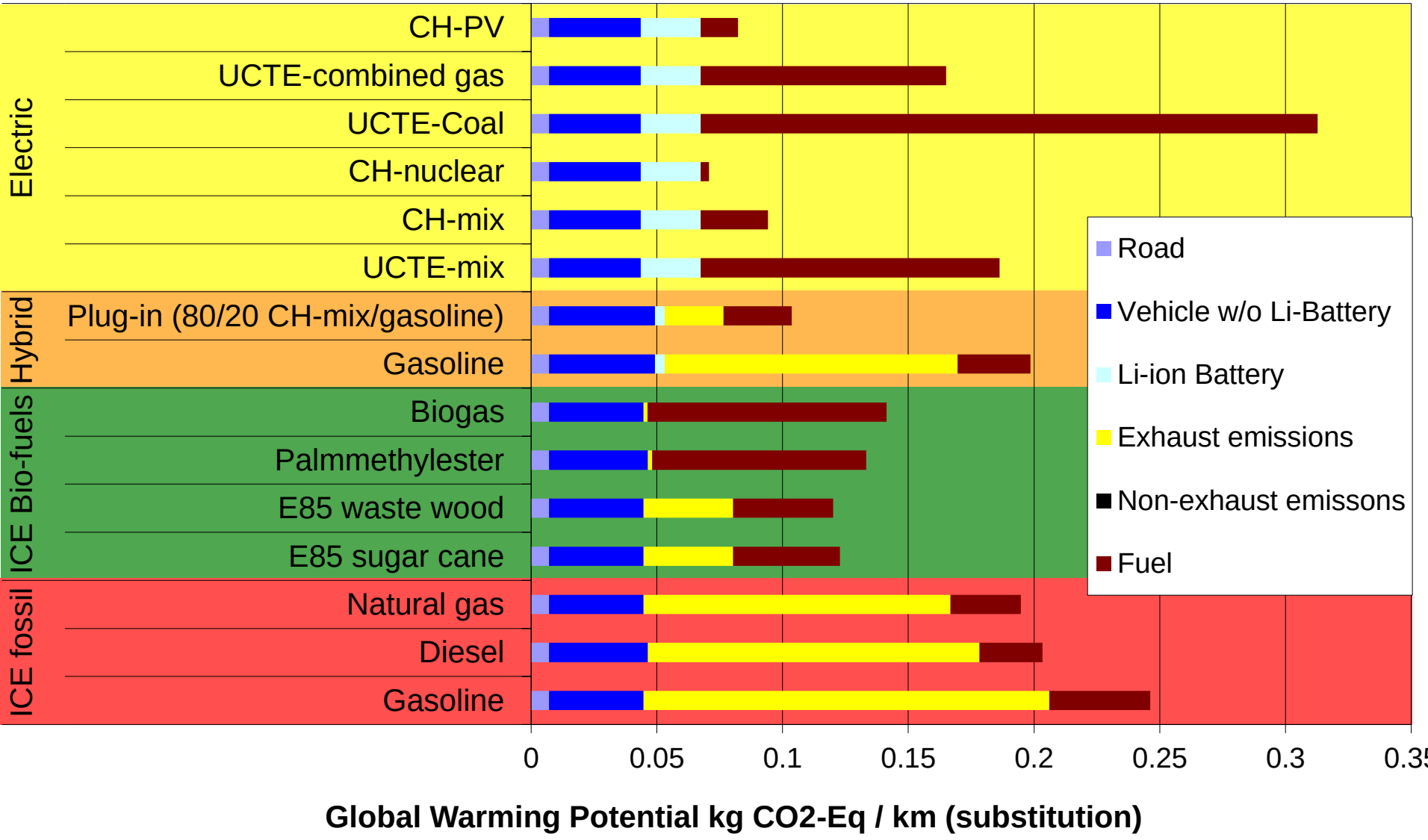
- Golf-Class vehicles with different (hypothetical) drive-trains
  - Life time / mileage: 12 years / 150‘000 km
  - Energy demand calculated: NEDC + real world addition
  - Break wear reduced for electric & hybrid cars
  - Maintenance: spare & wear parts. Batteries are replaced in every second electric vehicle
  - Use on Swiss road network

Golf BlueMotion → best in class!

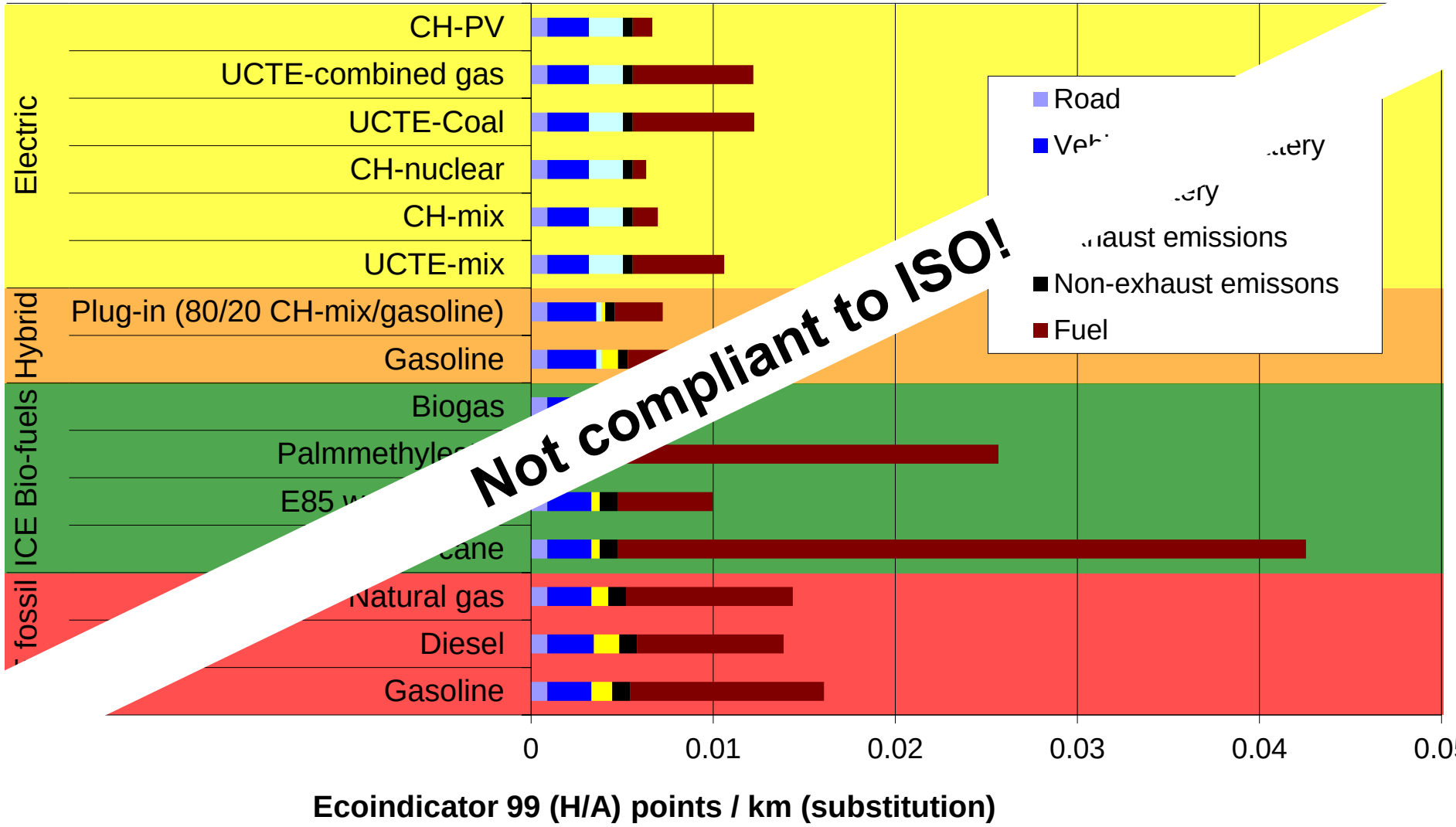
Energy carier / Drive train	Electricity[1]	Diesel	Gasoline	Natural gas	Palmmethyl-ester PME (Maleysia)	E85 from sugar cane[2] (Brazil)	Biogas (Swiss Kompogas)
Electric	20 kWh/100km 0.72 MJ/km	-	-	-	-	-	-
Plug-In hybrid	Mix CH (80%) 16 kWh/100km 0.58 MJ/km	-	Hybrid (20%) 0.98 l/100km 0.31 MJ/km	-	-	-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



Results: Ecoindicator 99 (H/A)



Results: GWP and Ecoindicator 99 safeguards

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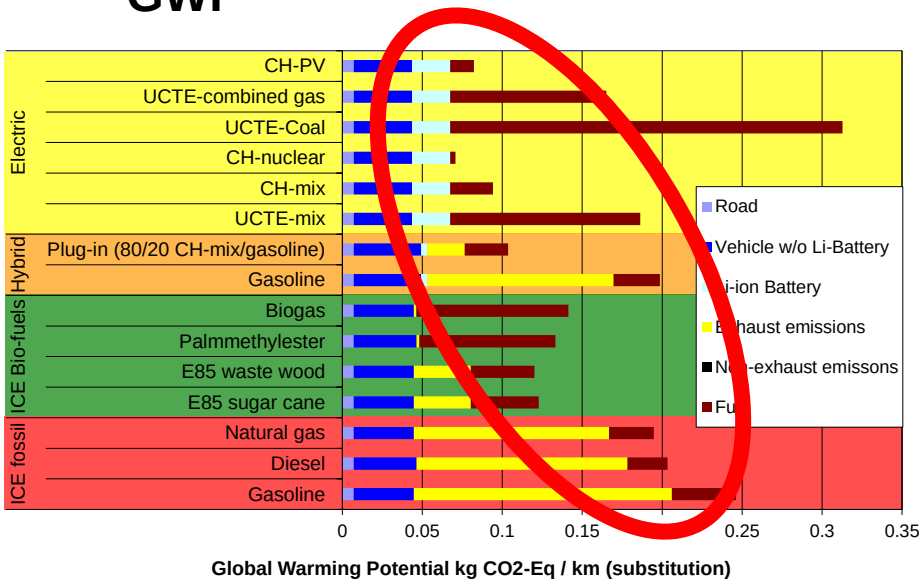
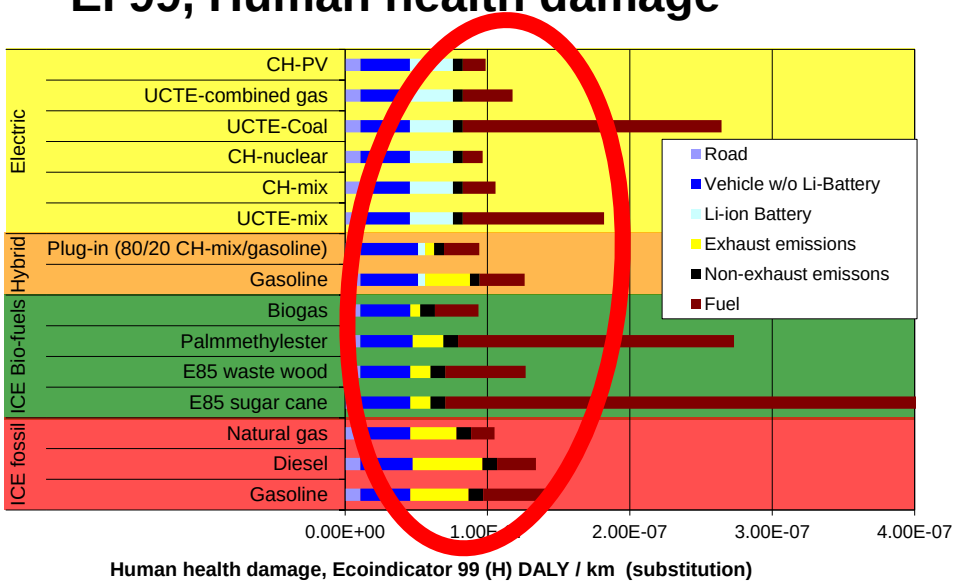
GWP



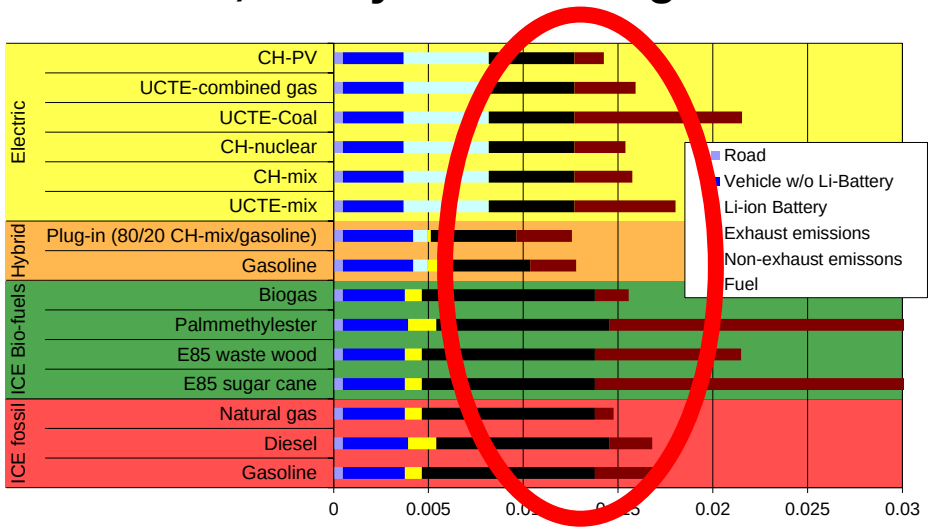
Global Warming Potential kg CO2-Eq / km (substitution)

EI 99, Human health damage



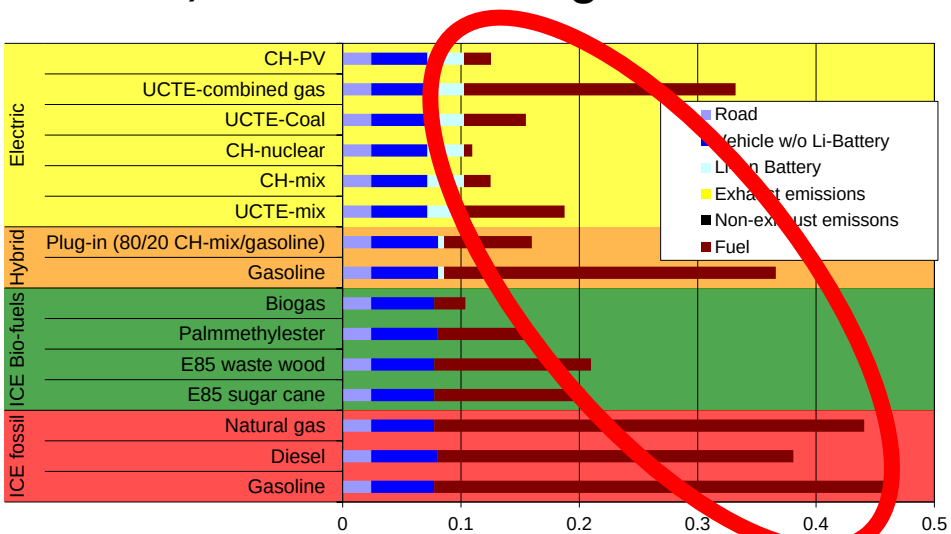
Human health damage, Ecoindicator 99 (H) DALY / km (substitution)

EI 99, ecosystem damage



Ecosystem damage, Ecoindicator 99 (H) pdf*m2*a / km (substitution)

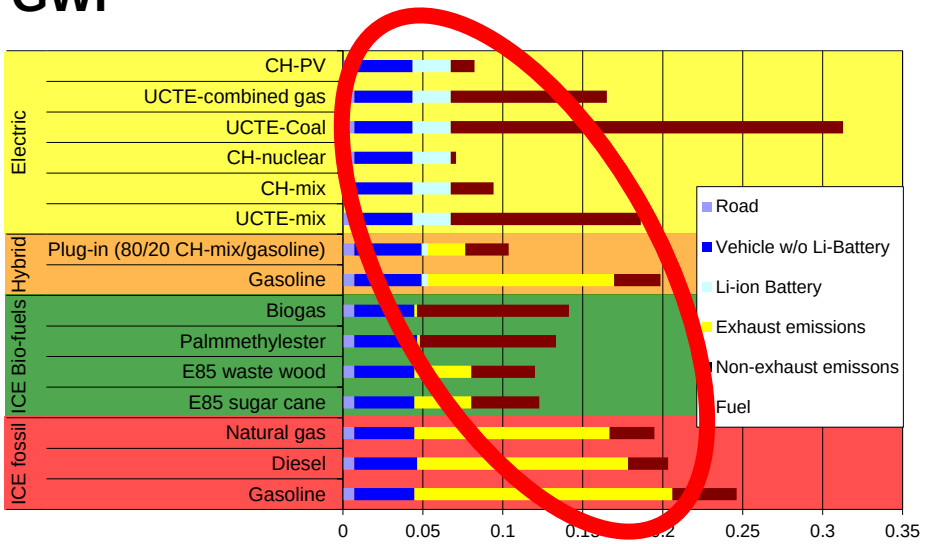
EI 99, Resource damage



Ressourcenschaden, Ecoindicator 99 (H) MJ-surplus / km (substitution)

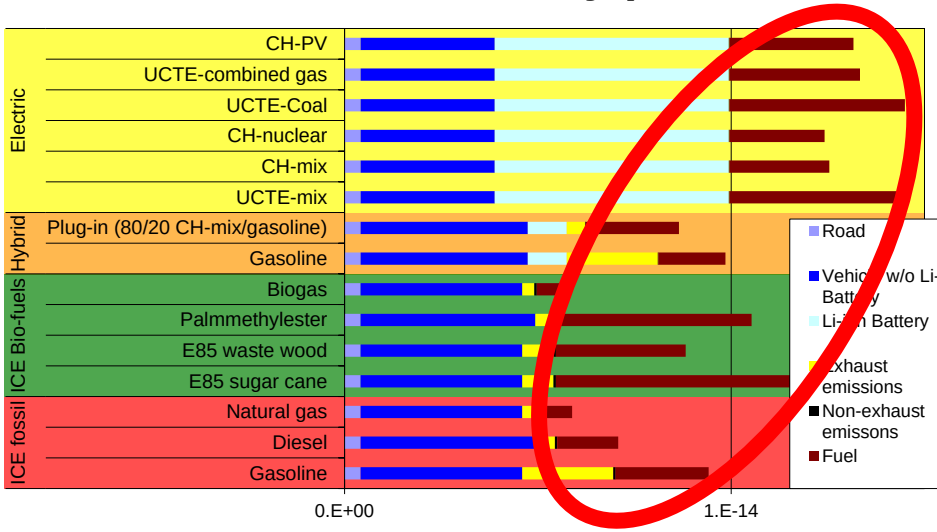
Results: GWP and human health indicators

GWP



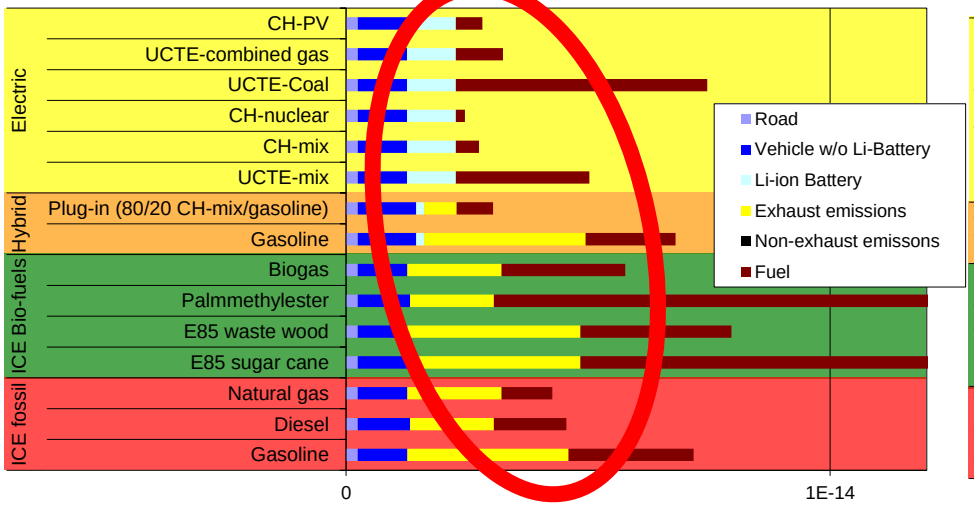
Global Warming Potential kg CO2-Eq / km (substitution)

CML 01, Human toxicity potential



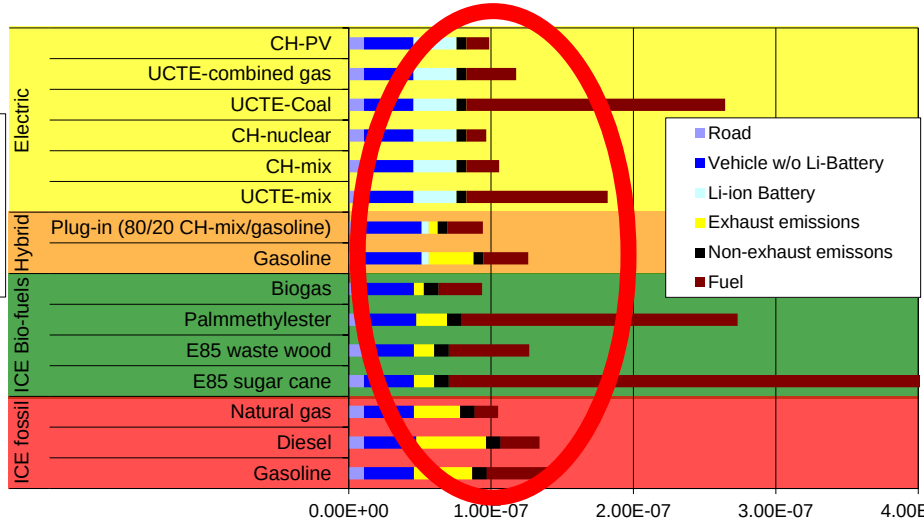
CML01 Human toxicity potential (normalized) / km (substitution)

CML 01, photochemical oxidation potential



CML01 photochemical oxidation potential, normalized / km (substitution)

EI 99, Human health damage



Human health damage, Ecoindicator 99 (H) DALY / km (substitution)

Results: GWP and ecosystem indicators

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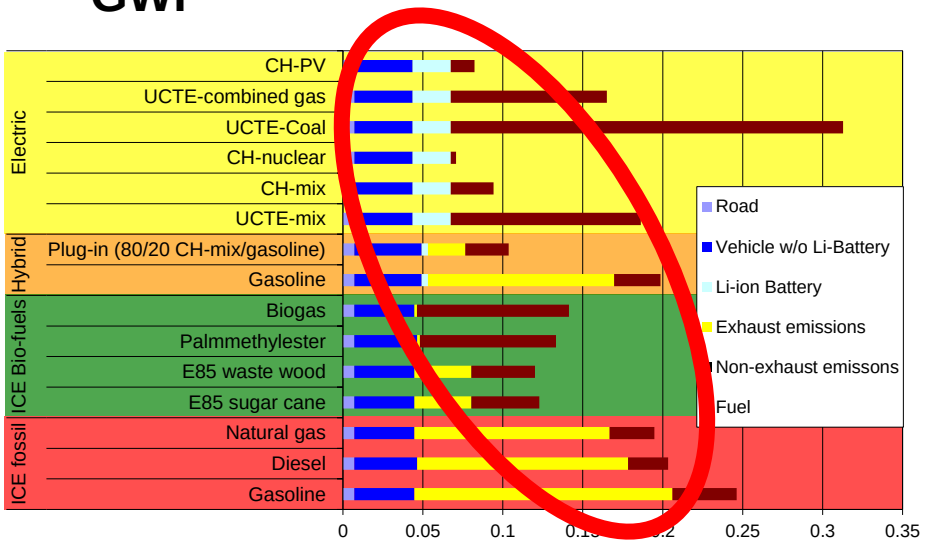
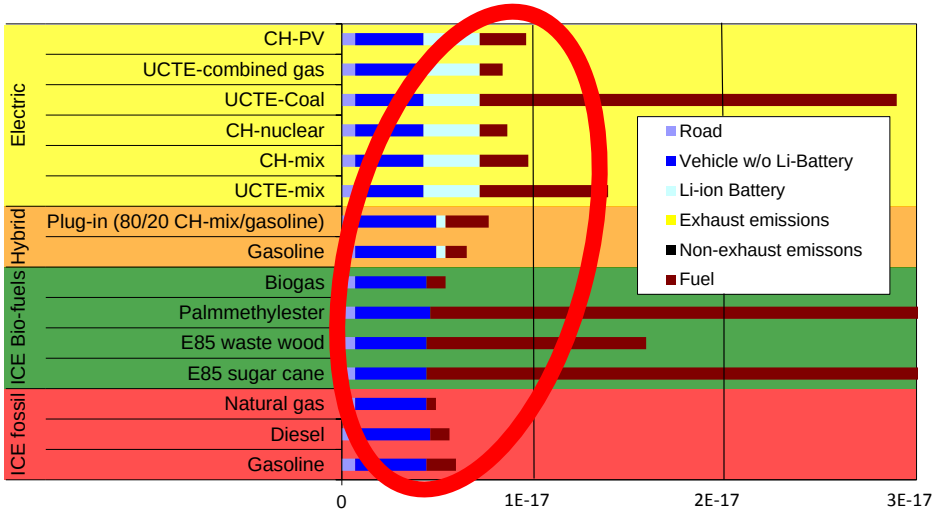
GWP



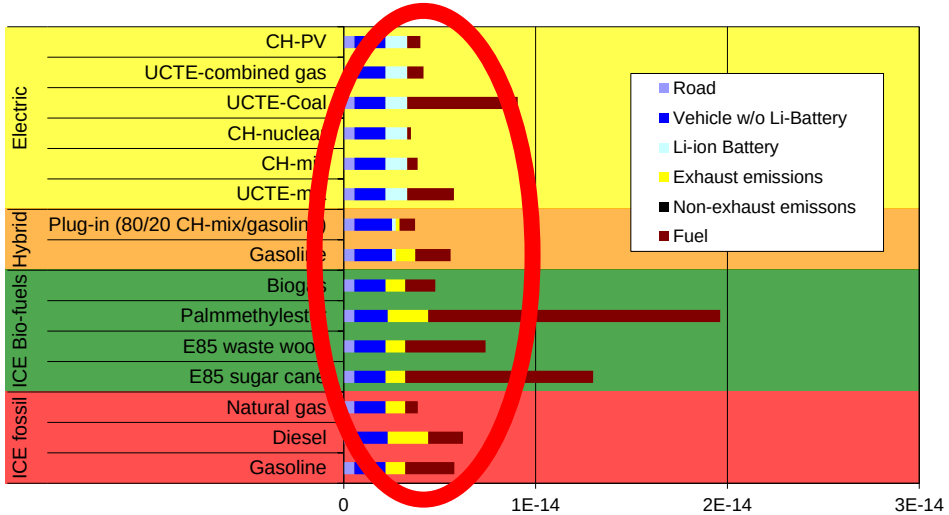
Global Warming Potential kg CO2-Eq / km (substitution)

CML 01, Land use



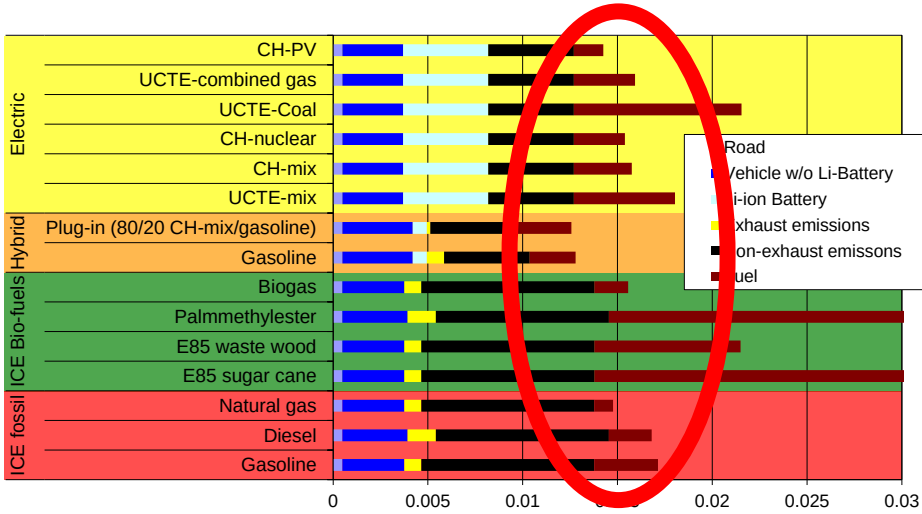
CML01 land use, normalized / km (substitution)

CML 01, eutrophication potential



CML01 Eutrophication, normalized / km (substitution)

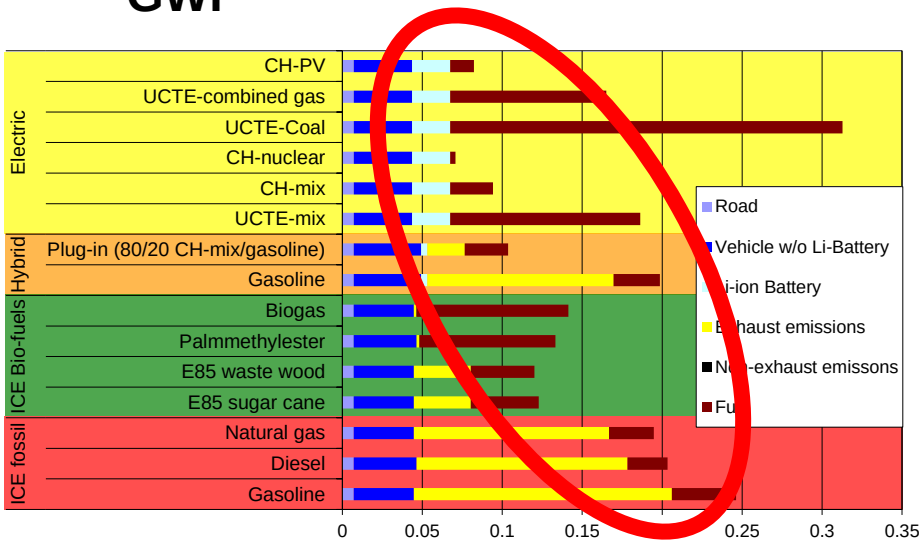
EI 99, ecosystem damage



Ecosystem damage, Ecoindicator 99 (H) pdf*m2*a / km (substitution)

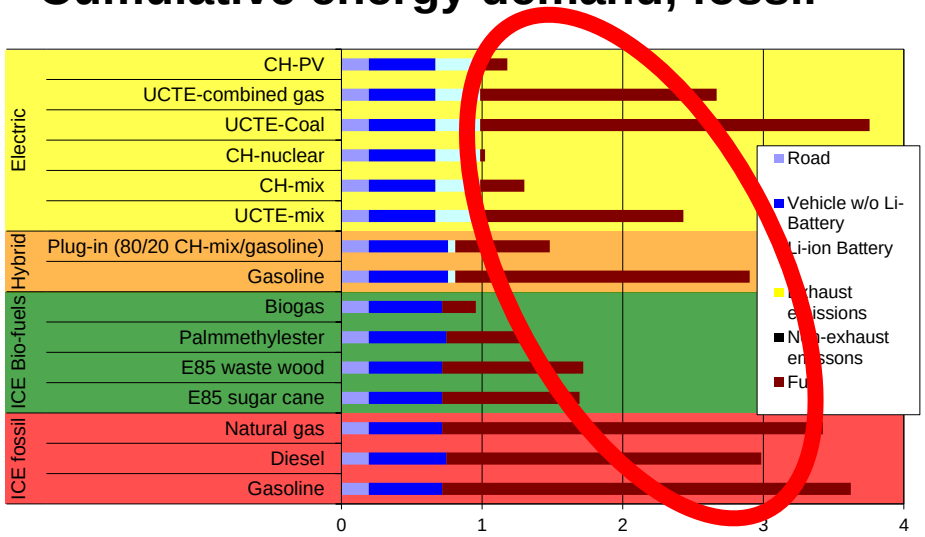
Results: GWP and resource indicators

GWP



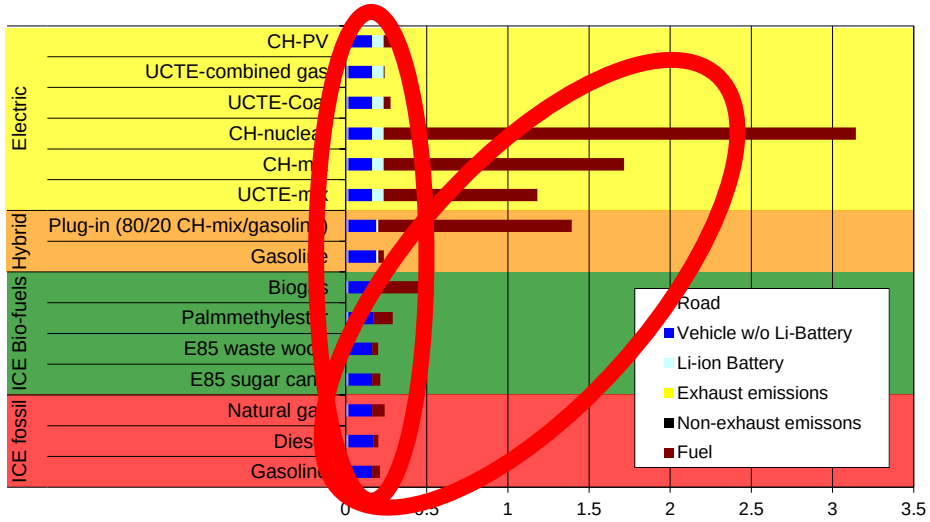
Global Warming Potential kg CO2-Eq / km (substitution)

Cumulative energy demand, fossil



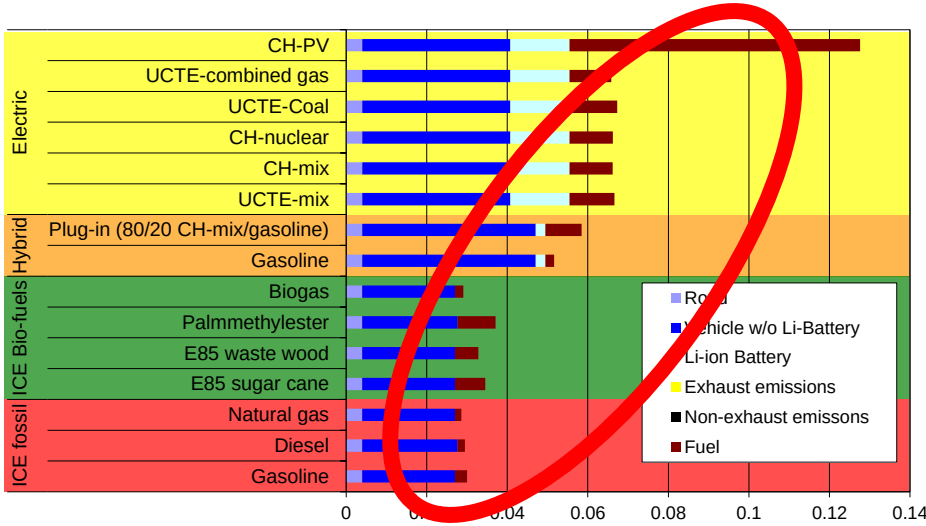
Cumulative energy demand, fossil MJ-Eq / km (substitution)

Cumulative energy demand, nuclear



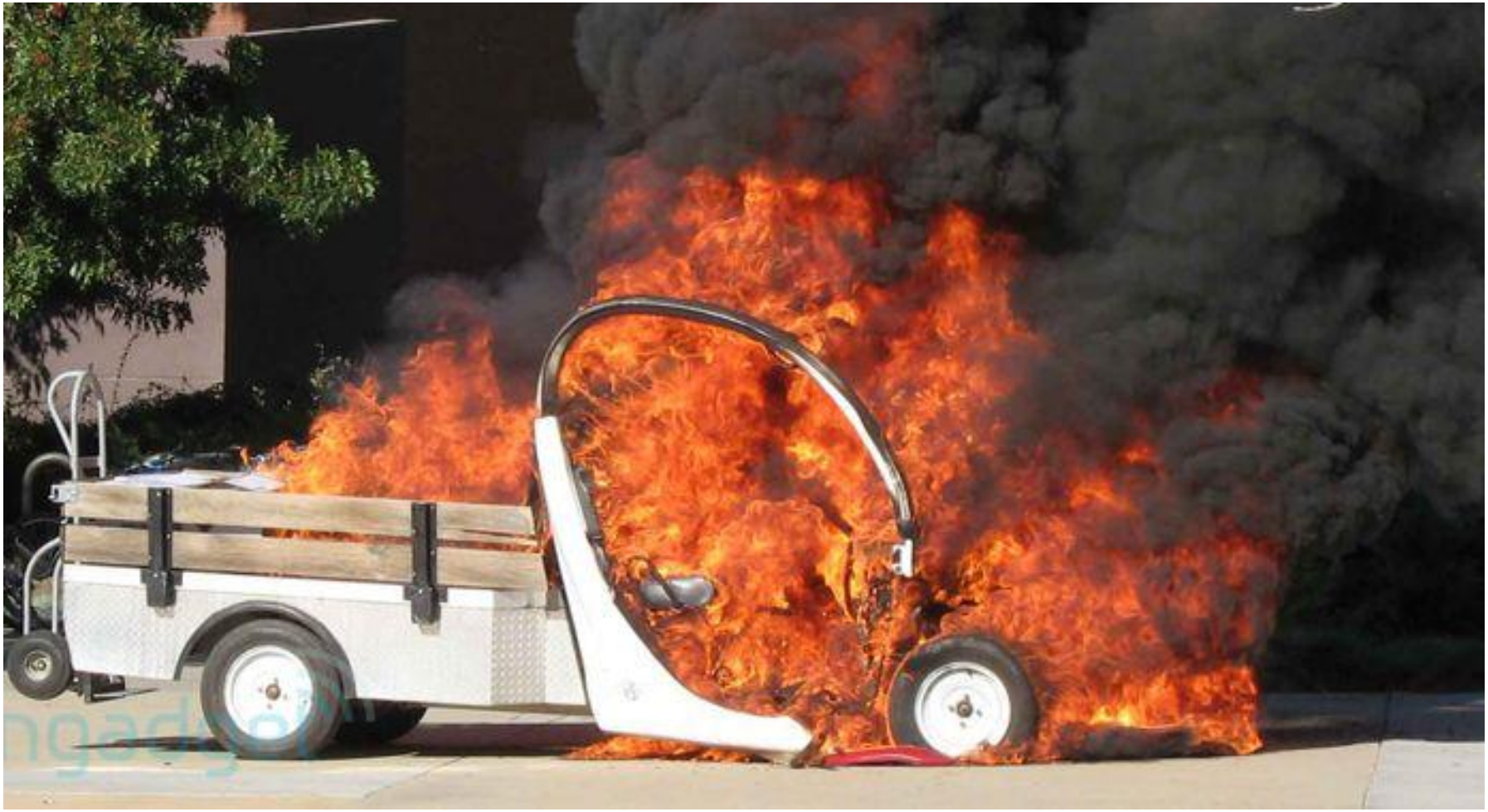
Cumulative energy demand nuclear MJ-Eq / km (substitution)

Cumulative exergy demand, metals



Cumulative exergy demand, metals MJ-Eq / km (substitution)

Uncertainties



Variability of environmental impacts

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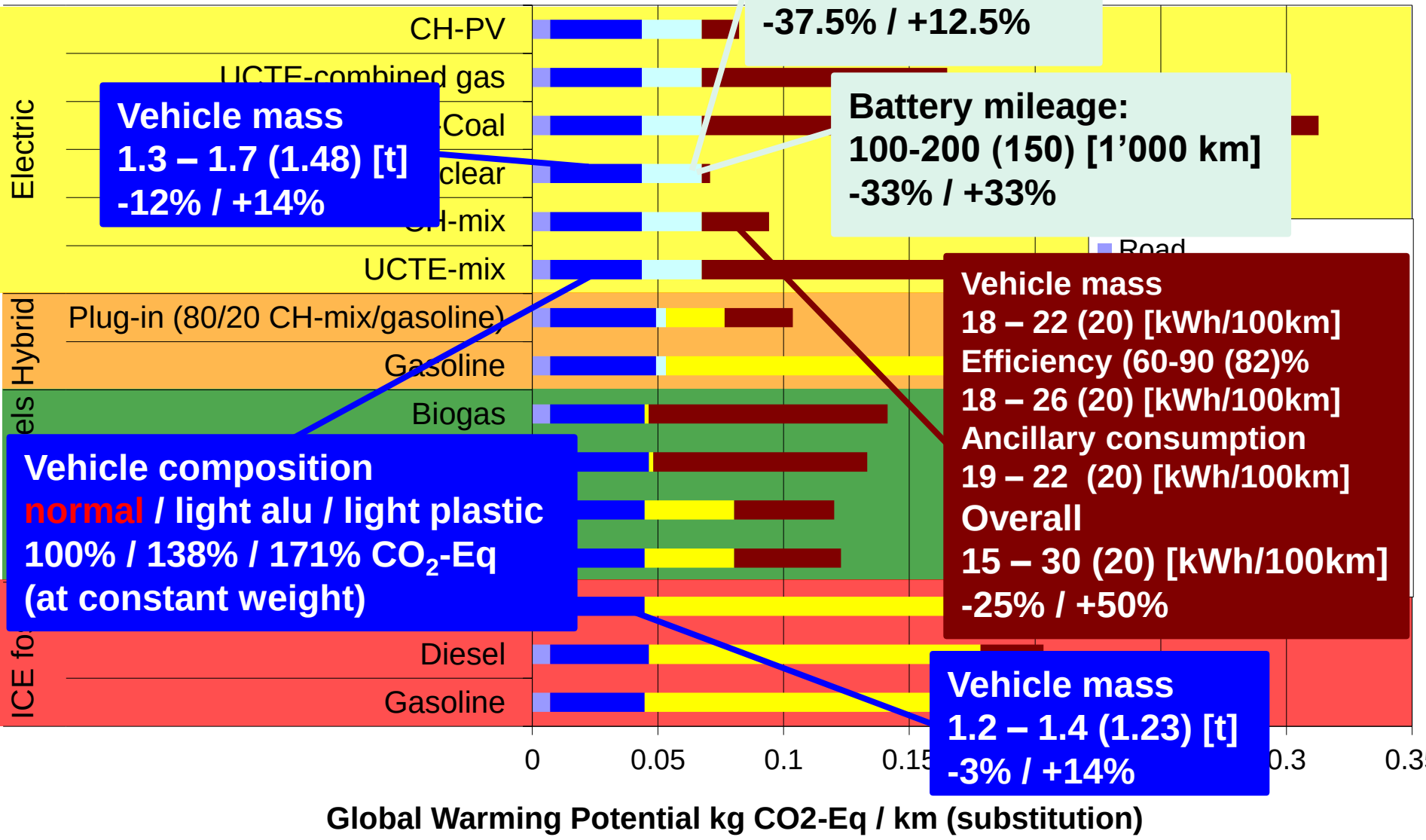
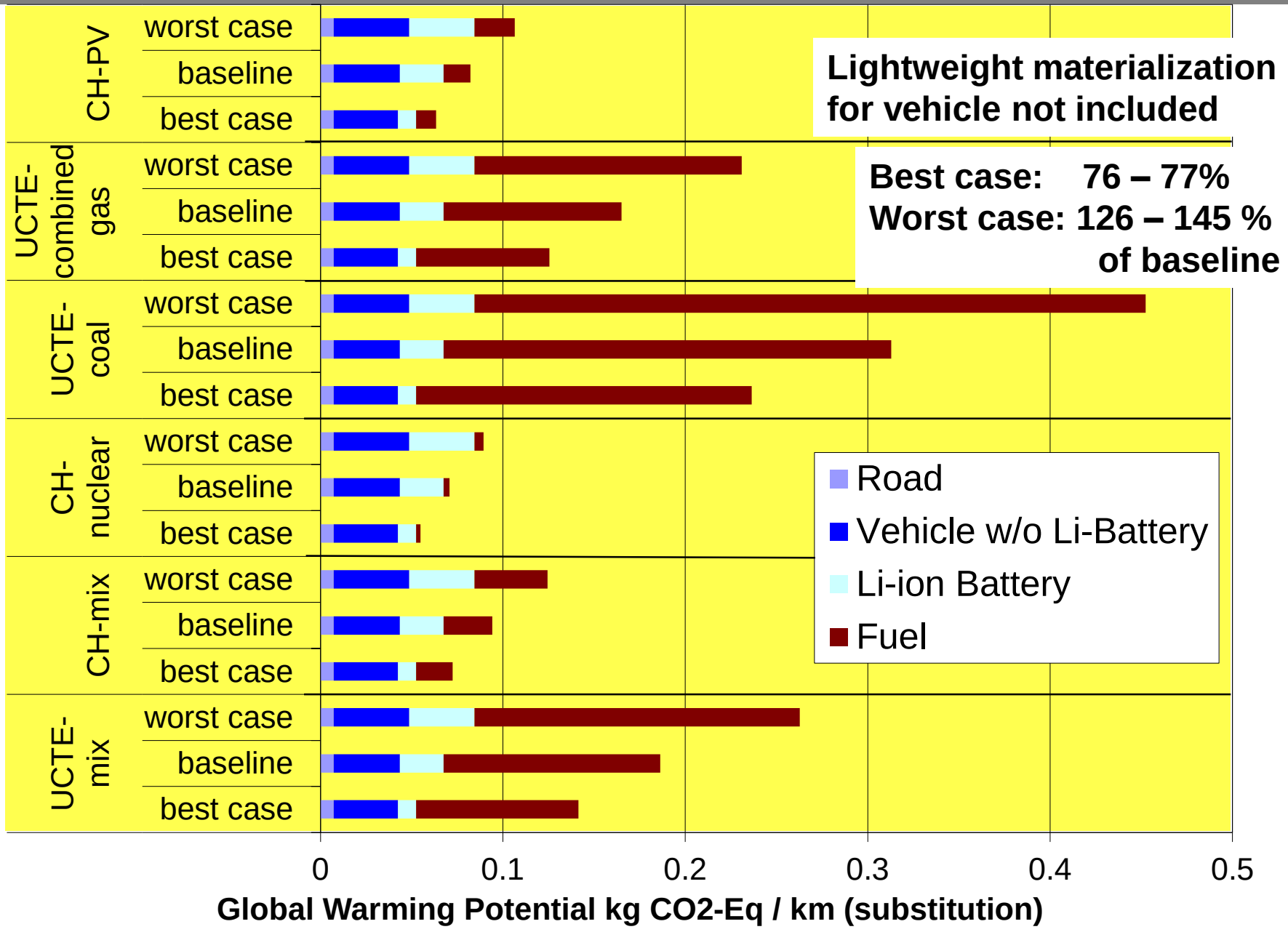
- Variability within Golf-Class

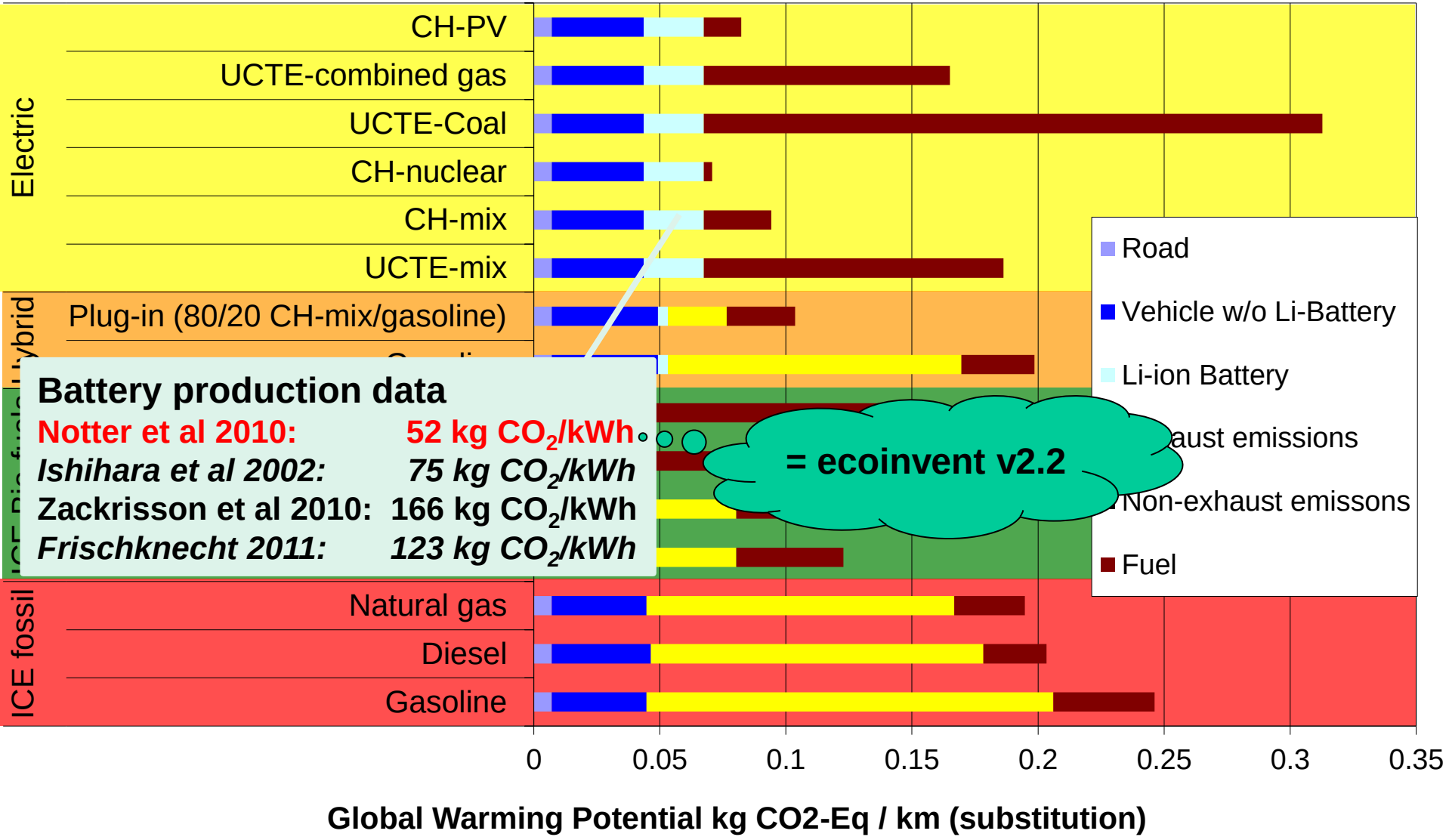


Variability of Global Warming Potential (GWP)



Uncertainty of environmental impacts

- Uncertainty of battery production data



Battery production data

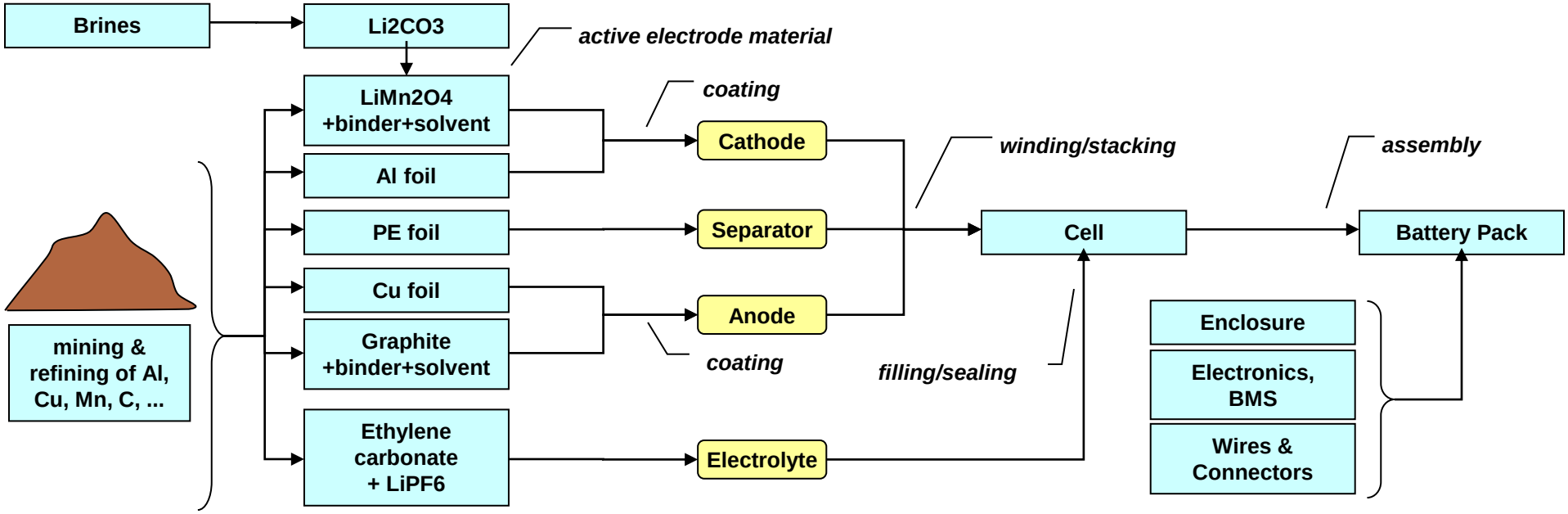
Notter et al 2010:	**52 kg CO_2/kWh**
Ishihara et al 2002:	***75 kg CO_2/kWh***
Zackrisson et al 2010:	**166 kg CO_2/kWh**
Frischknecht 2011:	***123 kg CO_2/kWh***

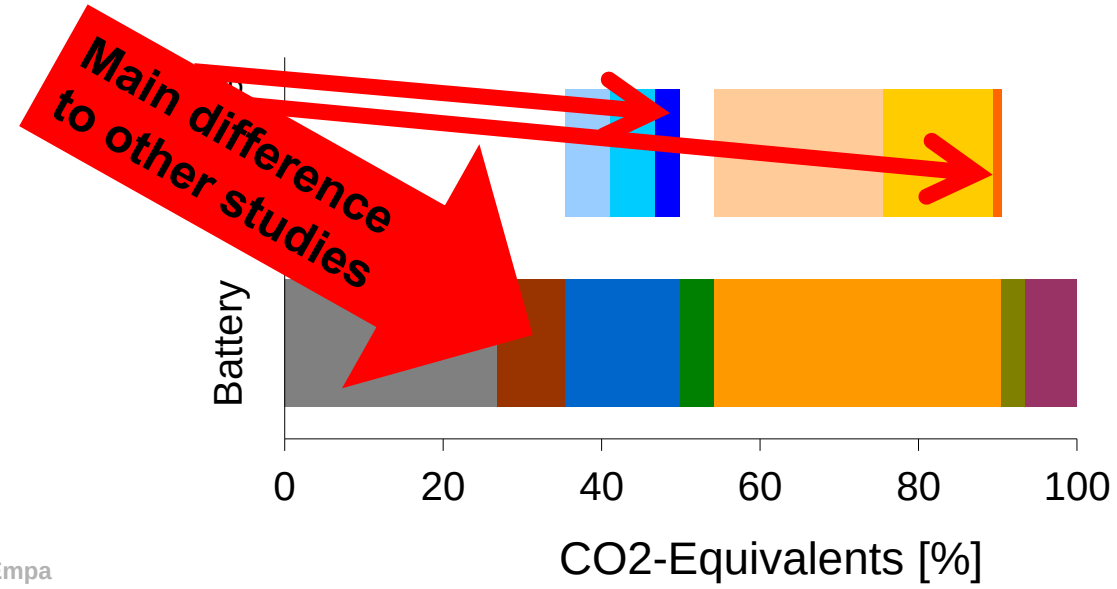
= ecoinvent v2.2

Energy consumption in cell / battery production

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

Production of a Li-Ion battery: Notter et al 2010





graphics: Empa

Variability Battery data: main differences

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Energy consumption in cell / battery production

- Notter et al / Ishihara et al: bottom up modelling of processes
- Energy demand measured or calculated from 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)

Variability Battery data: main differences

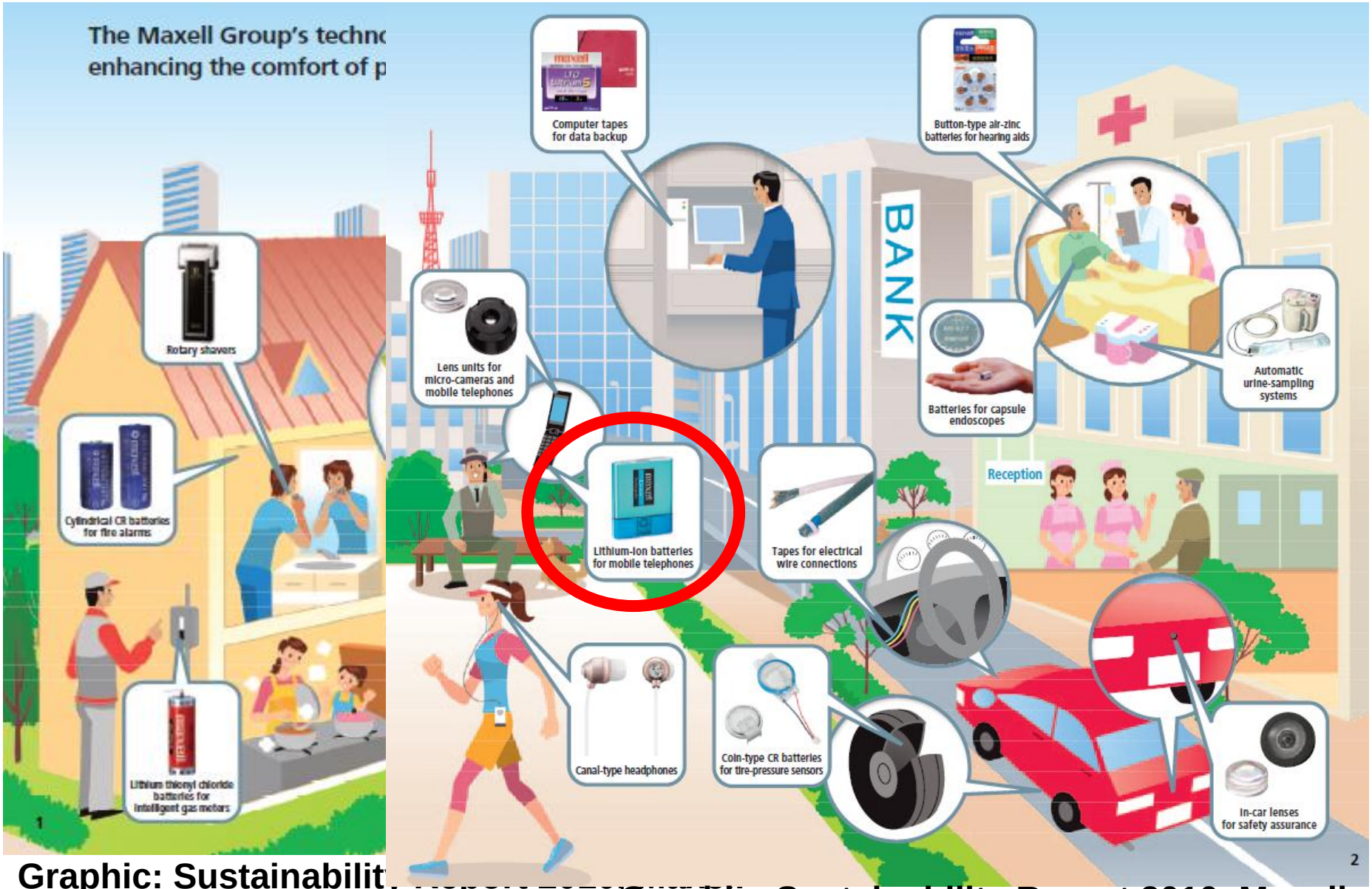
t al / Frischknecht:
m producers

demand from
y report" of producer

tween various
is producer by
battery price

Graphic: Sustainability Report 2010, Maxell

Variability Battery data: main differences



Graphic: Sustainability Report 2010, Maxell

Variability Battery data: main differences

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

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

150 Wh/€ el.
2.3 ml/€ oil

Price:
500 €/kWh

75 kWh/kWh el.
11.5 l/kWh oil

Price:
- Raw material cost
- Energy cost
- Capital cost
- Marketing cost
- Benefit

Energy consumptio

echt:

ducer

Ma

Variability Battery data: main differences

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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

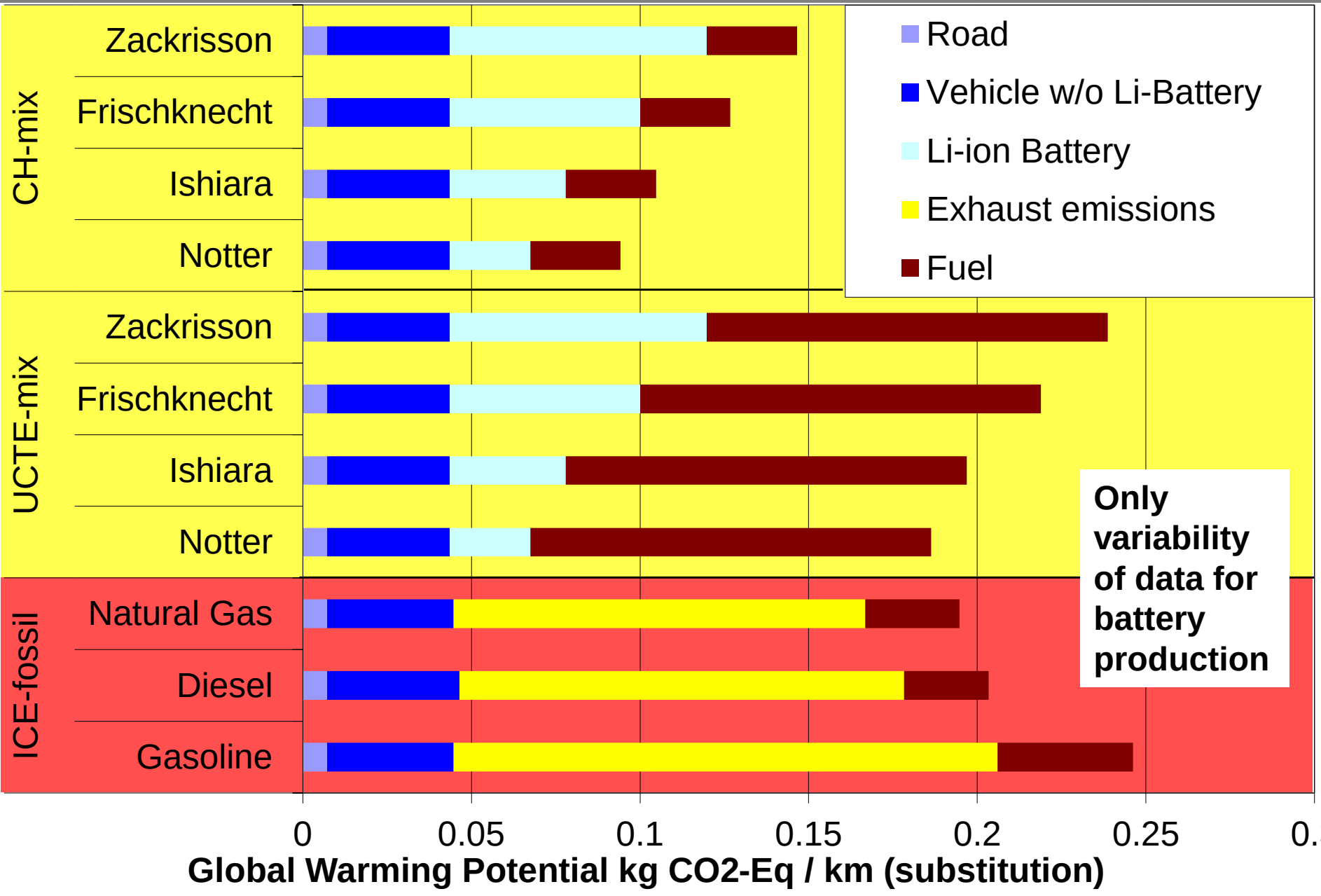
- Zackrisson et al / Frischknecht: top down from producers
- Total energy demand from “sustainability report” of producer
- Allocation between various products of this producer by turnover and battery price

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 amortisation of infrastructure is important

Variability of Global Warming Potential (GWP)



All results

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All results			Ecoindicator 99 (H) Damage to human health [DALY / km]	Ecoindicator 99 (H) Damage to ecosystem quality [PDF*m2*a / km]	Ecoindicator 99 (H) Damage to resource quality [MJ-surplus / km]	Global warming potential [kg CO2-eq / km]	Human toxicity [1 / km]	Photochemical oxidation [1 / km]	Land use [1 / km]	Eutrophication [1 / km]	Radioactive waste [m3 / km]	Cumulative energy demand nuclear [MJ-eq / km]	Cumulative energy demand fossil [MJ-eq / km]	Cumulative exergy demand metals [MJ-eq / km]	Cumulative exergy demand minerals [MJ-eq / km]
ICE fossil	Gasoline	best case	1.20E-07	1.61E-02	3.69E-01	1.96E-01	8.23E-15	5.70E-15	5.58E-18	4.87E-15	8.89E-10	2.00E-01	2.90E+00	2.93E-02	1.09E-02
		baseline	1.41E-07	1.71E-02	4.66E-01	2.46E-01	9.42E-15	7.18E-15	5.96E-18	5.76E-15	9.42E-10	2.12E-01	3.62E+00	3.00E-02	1.13E-02
		worst case	1.83E-07	1.93E-02	6.61E-01	3.47E-01	1.18E-14	1.01E-14	6.73E-18	7.55E-15	1.05E-09	2.35E-01	5.07E+00	3.15E-02	1.21E-02
	Diesel	best case	1.15E-07	1.59E-02	3.06E-01	1.64E-01	6.56E-15	3.74E-15	5.38E-18	5.24E-15	8.64E-10	1.94E-01	2.43E+00	2.90E-02	1.11E-02
		baseline	1.34E-07	1.68E-02	3.81E-01	2.03E-01	7.08E-15	4.55E-15	5.63E-18	6.22E-15	8.98E-10	2.01E-01	2.99E+00	2.95E-02	1.14E-02
		worst case	1.72E-07	1.87E-02	5.31E-01	2.82E-01	8.12E-15	6.17E-15	6.13E-18	8.18E-15	9.66E-10	2.16E-01	4.10E+00	3.04E-02	1.20E-02
	Natural gas	best case	9.28E-08	1.43E-02	3.50E-01	1.57E-01	5.58E-15	3.51E-15	4.79E-18	3.44E-15	9.89E-10	2.22E-01	2.75E+00	2.82E-02	1.02E-02
		baseline	1.05E-07	1.48E-02	4.41E-01	1.95E-01	5.89E-15	4.26E-15	4.91E-18	3.86E-15	1.07E-09	2.41E-01	3.42E+00	2.86E-02	1.04E-02
		worst case	1.29E-07	1.57E-02	6.22E-01	2.70E-01	6.50E-15	5.76E-15	5.16E-18	4.70E-15	1.25E-09	2.79E-01	4.78E+00	2.94E-02	1.07E-02
ICE biofuels	E85 sugar cane	best case	6.41E-07	1.56E-01	1.73E-01	1.03E-01	3.08E-14	7.35E-14	2.92E-16	1.03E-14	9.00E-10	2.02E-01	1.45E+00	3.26E-02	1.58E-02
		baseline	8.36E-07	2.04E-01	2.04E-01	1.23E-01	3.95E-14	9.76E-14	3.87E-16	1.30E-14	9.57E-10	2.14E-01	1.69E+00	3.45E-02	1.78E-02
		worst case	1.23E-06	3.00E-01	2.68E-01	1.62E-01	5.69E-14	1.46E-13	5.79E-16	1.84E-14	1.07E-09	2.39E-01	2.18E+00	3.83E-02	2.18E-02
	E85 waste wood	best case	1.09E-07	1.93E-02	1.77E-01	1.01E-01	7.78E-15	6.29E-15	1.30E-17	6.09E-15	8.51E-10	1.91E-01	1.47E+00	3.14E-02	1.11E-02
		baseline	1.27E-07	2.15E-02	2.10E-01	1.20E-01	8.82E-15	7.96E-15	1.59E-17	7.40E-15	8.91E-10	2.00E-01	1.72E+00	3.28E-02	1.15E-02
		worst case	1.62E-07	2.58E-02	2.76E-01	1.58E-01	1.09E-14	1.13E-14	2.16E-17	1.00E-14	9.72E-10	2.18E-01	2.22E+00	3.57E-02	1.24E-02
	PME	best case	2.19E-07	1.46E-01	1.37E-01	1.12E-01	9.14E-15	2.05E-14	1.73E-16	1.53E-14	1.16E-09	2.60E-01	1.20E+00	3.47E-02	1.64E-02
		baseline	2.73E-07	1.90E-01	1.56E-01	1.33E-01	1.05E-14	2.68E-14	2.29E-16	1.96E-14	1.29E-09	2.90E-01	1.35E+00	3.71E-02	1.85E-02
		worst case	3.81E-07	2.79E-01	1.93E-01	1.77E-01	1.33E-14	3.96E-14	3.41E-16	2.83E-14	1.56E-09	3.49E-01	1.65E+00	4.18E-02	2.26E-02
	Biogas	best case	8.43E-08	1.49E-02	9.72E-02	1.17E-01	5.35E-15	4.64E-15	5.17E-18	4.12E-15	1.87E-09	4.18E-01	8.96E-01	2.86E-02	1.03E-02
		baseline	9.37E-08	1.56E-02	1.04E-01	1.41E-01	5.58E-15	5.77E-15	5.42E-18	4.77E-15	2.26E-09	5.03E-01	9.56E-01	2.91E-02	1.05E-02
		worst case	1.12E-07	1.69E-02	1.17E-01	1.90E-01	6.03E-15	8.02E-15	5.91E-18	6.06E-15	3.02E-09	6.72E-01	1.07E+00	3.01E-02	1.09E-02
Hybrid	Gasoline	best case	1.10E-07	1.17E-02	2.96E-01	1.62E-01	8.83E-15	5.51E-15	6.25E-18	4.86E-15	1.01E-09	2.27E-01	2.38E+00	5.11E-02	1.09E-02
		baseline	1.26E-07	1.28E-02	3.66E-01	1.99E-01	9.85E-15	6.81E-15	6.53E-18	5.58E-15	1.05E-09	2.35E-01	2.90E+00	5.16E-02	1.12E-02
		worst case	1.59E-07	1.60E-02	5.06E-01	2.71E-01	1.19E-14	9.40E-15	7.08E-18	7.01E-15	1.13E-09	2.53E-01	3.95E+00	5.27E-02	1.17E-02

best 30% within indicator

worst 30% within indicator

All results

best 30% within indicator

All results

worst 30% within indicator

			Ecoindicator 99 (H) Damage to human health [DALY / km]	Ecoindicator 99 (H) Damage to ecosystem quality [PDF*m2*a / km]	Ecoindicator 99 (H) Damage to resource quality [MJ-surplus / km]	Global warming potential [kg CO2-eq / km]	Human toxicity [1 / km]	Photochemical oxidation [1 / km]	Land use [1 / km]	Eutrophication [1 / km]	Radioactive waste [m3 / km]	Cumulative energy demand nuclear [MJ-eq / km]	Cumulative energy demand fossil [MJ-eq / km]	Cumulative exergy demand metals [MJ-eq / km]	Cumulative exergy demand minerals [MJ-eq / km]
Plug-in-hybrid	50/50 CH-mix/gasoline	best case	9.52E-08	1.16E-02	1.99E-01	1.18E-01	8.27E-15	3.74E-15	6.79E-18	3.99E-15	3.46E-09	7.70E-01	1.71E+00	5.43E-02	1.07E-02
		baseline	1.06E-07	1.27E-02	2.37E-01	1.39E-01	9.10E-15	4.45E-15	7.24E-18	4.41E-15	4.31E-09	9.59E-01	2.01E+00	5.59E-02	1.08E-02
		worst case	1.29E-07	1.58E-02	3.13E-01	1.82E-01	1.08E-14	5.87E-15	8.15E-18	5.26E-15	6.02E-09	1.34E+00	2.62E+00	5.91E-02	1.12E-02
	80/20 CH-mix/gasoline	best case	8.63E-08	1.15E-02	1.41E-01	9.11E-02	7.93E-15	2.68E-15	7.11E-18	3.47E-15	4.93E-09	1.10E+00	1.31E+00	5.62E-02	1.05E-02
		baseline	9.42E-08	1.26E-02	1.60E-01	1.04E-01	8.65E-15	3.04E-15	7.67E-18	3.72E-15	6.27E-09	1.39E+00	1.48E+00	5.85E-02	1.06E-02
		worst case	1.11E-07	1.57E-02	1.97E-01	1.29E-01	1.01E-14	3.75E-15	8.80E-18	4.22E-15	8.95E-09	1.99E+00	1.82E+00	6.30E-02	1.09E-02
	95/5 CH-mix/gasoline	best case	8.18E-08	1.15E-02	1.12E-01	7.77E-02	7.76E-15	2.15E-15	7.27E-18	3.20E-15	5.66E-09	1.26E+00	1.11E+00	5.72E-02	1.04E-02
		baseline	8.82E-08	1.25E-02	1.21E-01	8.59E-02	8.43E-15	2.33E-15	7.89E-18	3.37E-15	7.25E-09	1.61E+00	1.21E+00	5.97E-02	1.05E-02
		worst case	1.02E-07	1.56E-02	1.39E-01	1.02E-01	9.77E-15	2.69E-15	9.12E-18	3.70E-15	1.04E-08	2.31E+00	1.42E+00	6.49E-02	1.07E-02
Electric	UCTE-Mix	best case	1.47E-07	1.49E-02	1.56E-01	1.49E-01	1.13E-14	4.00E-15	1.13E-17	4.76E-15	4.32E-09	9.21E-01	1.96E+00	5.89E-02	1.11E-02
		baseline	1.82E-07	1.80E-02	1.88E-01	1.86E-01	1.45E-14	5.03E-15	1.39E-17	5.75E-15	5.41E-09	1.18E+00	2.43E+00	6.66E-02	1.25E-02
		worst case	2.43E-07	2.37E-02	2.40E-01	2.54E-01	1.88E-14	6.74E-15	1.82E-17	7.35E-15	7.60E-09	1.68E+00	3.26E+00	7.71E-02	1.40E-02
	CH-Mix	best case	8.97E-08	1.32E-02	1.09E-01	7.96E-02	9.87E-15	2.29E-15	8.13E-18	3.34E-15	6.04E-09	1.32E+00	1.12E+00	5.86E-02	1.11E-02
		baseline	1.06E-07	1.58E-02	1.25E-01	9.42E-02	1.25E-14	2.75E-15	9.74E-18	3.85E-15	7.71E-09	1.72E+00	1.30E+00	6.62E-02	1.24E-02
		worst case	1.28E-07	2.03E-02	1.47E-01	1.16E-01	1.59E-14	3.32E-15	1.20E-17	4.50E-15	1.10E-08	2.48E+00	1.56E+00	7.64E-02	1.39E-02
	CH-nuclear	best case	8.29E-08	1.30E-02	9.76E-02	6.20E-02	9.78E-15	2.07E-15	7.31E-18	3.08E-15	1.05E-08	2.39E+00	9.06E-01	5.86E-02	1.09E-02
		baseline	9.66E-08	1.54E-02	1.10E-01	7.08E-02	1.24E-14	2.46E-15	8.64E-18	3.51E-15	1.36E-08	3.14E+00	1.02E+00	6.62E-02	1.22E-02
		worst case	1.15E-07	1.98E-02	1.23E-01	8.04E-02	1.57E-14	2.89E-15	1.03E-17	3.98E-15	1.99E-08	4.62E+00	1.14E+00	7.65E-02	1.36E-02
	UCTE-coal	best case	2.09E-07	1.76E-02	1.32E-01	2.44E-01	1.13E-14	5.83E-15	2.26E-17	7.26E-15	1.18E-09	2.42E-01	2.96E+00	5.94E-02	1.12E-02
		baseline	2.64E-07	2.15E-02	1.55E-01	3.13E-01	1.45E-14	7.46E-15	2.90E-17	9.07E-15	1.23E-09	2.77E-01	3.76E+00	6.73E-02	1.26E-02
		worst case	3.66E-07	2.90E-02	1.91E-01	4.43E-01	1.88E-14	1.04E-14	4.08E-17	1.23E-14	1.33E-09	3.22E-01	5.25E+00	7.81E-02	1.42E-02
	UCTE-gas	best case	9.87E-08	1.34E-02	2.64E-01	1.33E-01	1.05E-14	2.66E-15	7.13E-18	3.57E-15	1.06E-09	2.15E-01	2.14E+00	5.83E-02	1.11E-02
		baseline	1.18E-07	1.59E-02	3.32E-01	1.65E-01	1.33E-14	3.24E-15	8.40E-18	4.16E-15	1.06E-09	2.40E-01	2.67E+00	6.58E-02	1.24E-02
		worst case	1.46E-07	2.06E-02	4.57E-01	2.22E-01	1.71E-14	4.07E-15	9.98E-18	4.96E-15	1.07E-09	2.67E-01	3.62E+00	7.59E-02	1.39E-02
	CH-PV	best case	8.45E-08	1.21E-02	1.09E-01	7.06E-02	1.03E-14	2.34E-15	8.05E-18	3.45E-15	1.20E-09	2.47E-01	1.02E+00	1.05E-01	1.11E-02
		baseline	9.87E-08	1.42E-02	1.25E-01	8.22E-02	1.32E-14	2.82E-15	9.63E-18	4.00E-15	1.26E-09	2.83E-01	1.18E+00	1.28E-01	1.25E-02
		worst case	1.18E-07	1.81E-02	1.47E-01	9.76E-02	1.68E-14	3.43E-15	1.18E-17	4.72E-15	1.37E-09	3.32E-01	1.38E+00	1.69E-01	1.40E-02

Conclusions

- Environmental impacts of electric mobility can be dominated by infrastructure or by operation depending on electricity source
- Electric vehicles with sufficient battery capacity for “normal” use and a range extender for special use perform better than electric vehicles with larger batteries
- Different data sources for carbon footprint of batteries can lead to different interpretations of carbon footprint of electric mobility
- Variability of environmental impacts within the “Golf-class” is rather high (ca. 75% - 150% of baseline) and of the higher than difference to other technologies. → Specific vehicle demand for specific assessment!
- 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!

Sources for this presentation:

Thank you

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www.empa.ch/mobility


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Materials Science & Technology

Vergleichende Ökobilanz individueller Mobilität:

Elektromobilität versus konventionelle Mobilität mit Bio- und fossilen Treibstoffen

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Marcel Gauch

Life Cycle Assessment and Modelling Group,
Technologie und Gesellschaft,
Empa

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