Life Cycle Assessment LCA of Li-Ion batteries for electric vehicles

1. **Project goals**
2. **Presentation of a typical battery from cradle to gate**
3. **LCA results**

graphics: Empa

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Empa - Swiss Federal Laboratories for Materials Testing and Research
TSL Technology and Society Lab

2009

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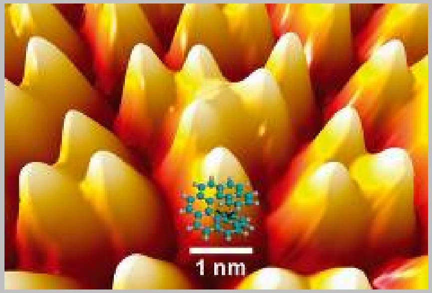
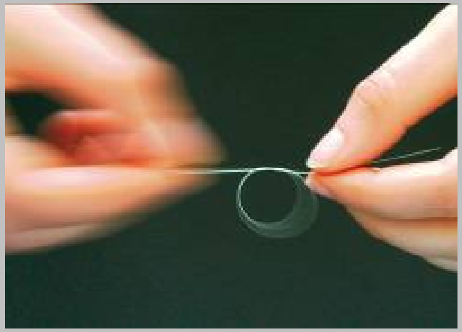


Nanotechnology

Adaptive Material Systems



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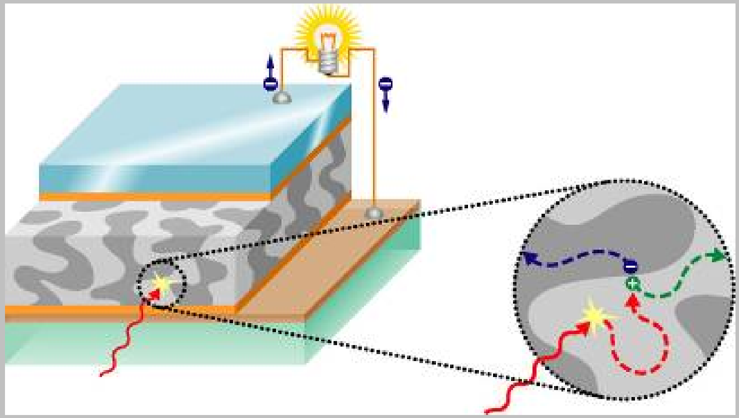


Materials for Energy Technologies

Technology and Society Lab @ Empa

- Life Cycle Assessments
- Scarce materials resources
- Energy options for transitional countries

Project goals

- Detailed cradle-to-gate Life Cycle Inventory LCI of a modern Li-Ion battery
- Special focus on Lithium mining and refining to battery-grade material
- Integration of the results in ecoinvent database
- Evaluation of the environmental impacts with Life Cycle Assessment LCA tools
  - how harmful is the battery / a vehicle / a km in comparison with a standard ICE car?

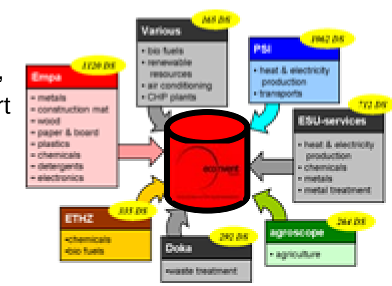
Foto: www.hypadrive.com

4 In-wheel motors (each 30 kg), > 400 PS / 160 km autonomy
Removal of drivetrain components: 1000 pounds (454kg)
Batteries LiIon 1000 pounds (40kWh),
Prototype for tuningfare SEMA Las Vegas Nov '08

ecoinvent

The most comprehensive public worldwide database for Life Cycle Inventories.

- More than 4000 process on energy supply, resource extraction, material supply, chemicals, metals, agriculture, waste management services, transport services
- Based on industry data, compiled by independent experts
- Consistent, validated and transparent



Life cycle of a battery





Life cycle assessment: The basic idea

INPUT

- Raw Material
- Energy
- Auxiliaries

product or service over entire lifecycle

OUTPUT

- Product/Service
- Emissions
- Wastes

& ecological assessment of flows

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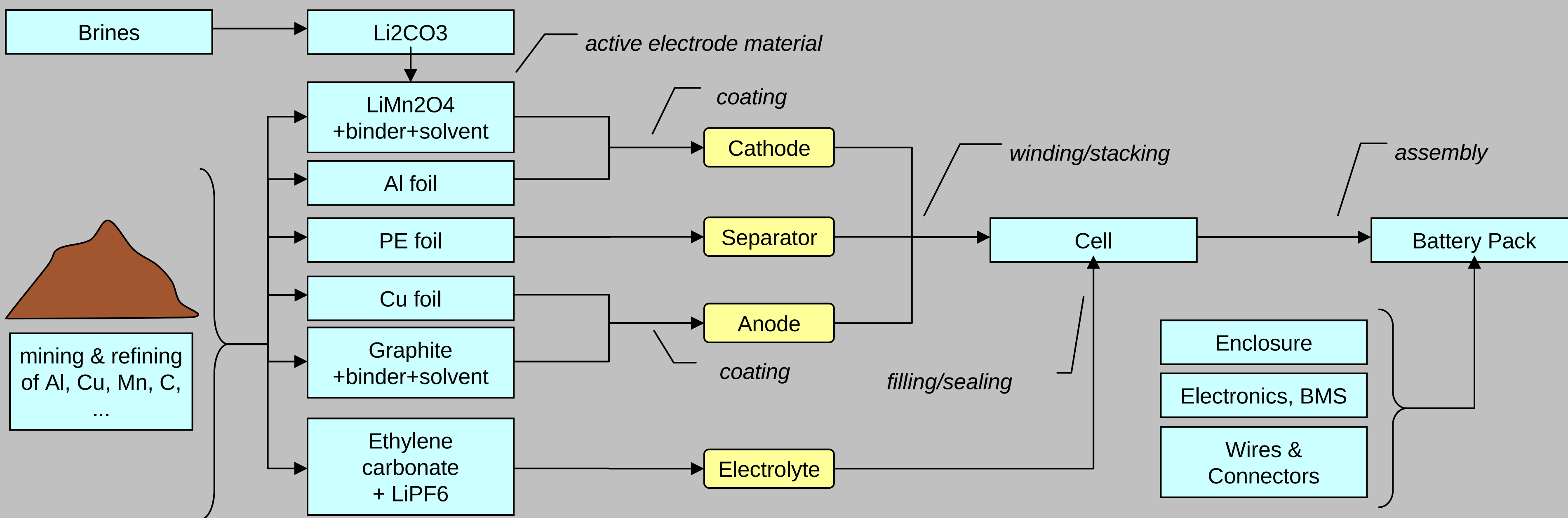
A Li-Ion Battery is built (Manganese oxide type)



- Two foils and a thin separator that is permeable to ions are wound or folded into a stack to pack a big surface into a low volume
- This stack is inserted in a pouch or case, filled with Li-salt electrolyte and sealed.
  -> The **cell** is ready (assumption for this study: 3.7V; 40Ah; 130 Wh/kg; 5C_cont.)
- These cells are combined in series or parallel and completed with a battery management system (BMS) and the necessary wirings. This assembly is fit into an enclosure
  -> The **battery pack** is ready
- Assumption for this study: 100Wh/kg, 5C_cont, 30kWh, 300kg

graphics: Empa

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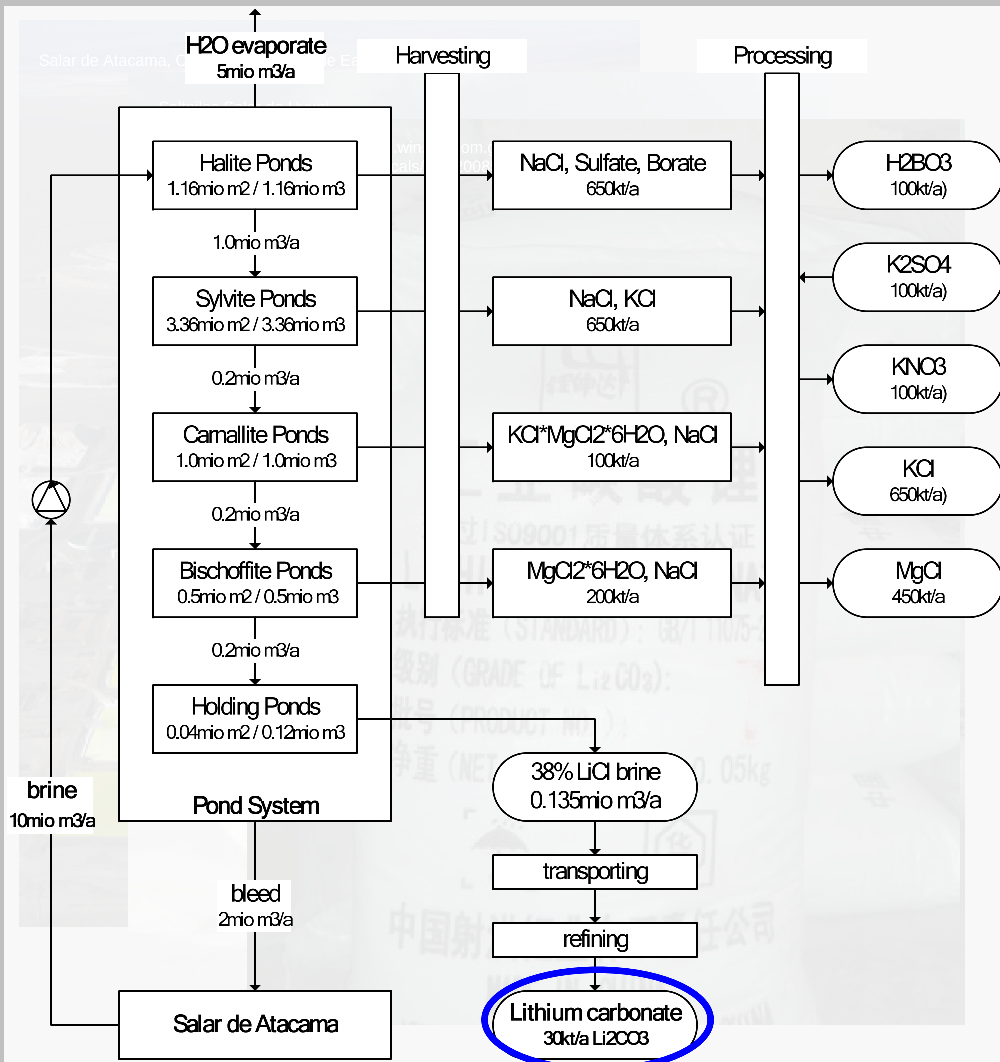
Lithium



Extraction of lithium carbonate from Atacama (CL), one of the most important worldwide Li2CO3 producers
Compilation of numbers and graphics: Empa

- Lightest metal (density 0.543 kg/l)
- Highest electrochemical potential
- Relatively abundant (more abundant than Cu, seawater content 0.17 ppm)
- Non-toxic (used as drug)
- Very reactive in metallic form (burns!)

Lithium exploitation

- Most of the lithium for batteries comes from saltlakes in the Andes (Chile, Bolivia) or in China (Tibet)
- It's extracted from salines and sold as lithiumcarbonate Li_2CO_3
- The highest energy fraction for the production of Li_2CO_3 is solar energy for the evaporation
- Most of the by-products go to fertilizer production

A Li-Ion Battery Cell (Manganese oxide type)

Picture: Empa


Picture: Empa


Picture: Empa

Cell calculation Total cell pack		per kg cell [g]
Cathode	Al collector foil	143.7
	Cathode Li-X	240.8
Anode	Cu-collector foil (spec.sheet: 8-15um)	124.8
	Anode graphite	162.3
Separator	Separator film PE	51.4
Packing	PE-Al envelope	70.2
Electrolyte	Ethylenecarbonate (w/o LiPF6 1M)	171.2
Electrolyte Salt	LiPF6 1M (152 g/mol, 1mol/l)	19.7
Electrodes	Electrode tabs Al	15.8
Total cell pack		1000.0

Table: measurements Empa

What's in it?

- Only ~1% of a Li-Ion cell is Li (resp. 5% Li2CO3) which means 0.08 kg Li for 1kWh
- ~40% of a cell is Al (~23%) and Cu (~13%) (current transducer, electrode carrier)
- ~40% is the active electrode material (cathode LiMn2O4 ~24%, anode graphite ~16%)
- ~20% is the electrolyte (lithium hexafluorophosphate LiPF6 1M in solvent ethylenecarbonate)

- The metals Cu, Al, Mn/Co/Ni/Fe are usually recycled
- Graphite, electrolyte and Li usually are not recycled for cost and energy efficiency reasons

Data based on patents plus own calculations (publ. in prep.)

How to measure the env.impacts? How ‘clean‘?

reasonable answer needs:

- A good bookkeeper, who
  - Sums up all the inputs
  - Defines the system limits
- Help from software with a database which contains all the relevant values
- Different environmental impacts can be evaluated
  (e.g. greenhouse-gas, air/water/soil-emmissions, landuse,…)
- Methods which allow to conclude all the impacts to a total environmental impact figure

picture: VW, The Golf – Environmental Commendation Background Report, 2008 (Golf V disassembled)

Result of this bookkeeping over the whole lifecycle:
-> Ecobalance

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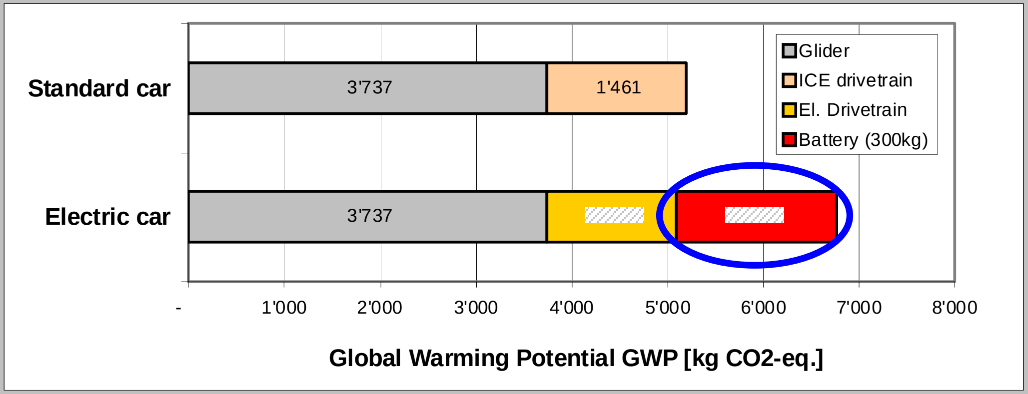
LCA result   Comparison: ICE / BEV vehicle production

Global warming potential GWP (kg CO2-eq) of the car production   (w/o operation)

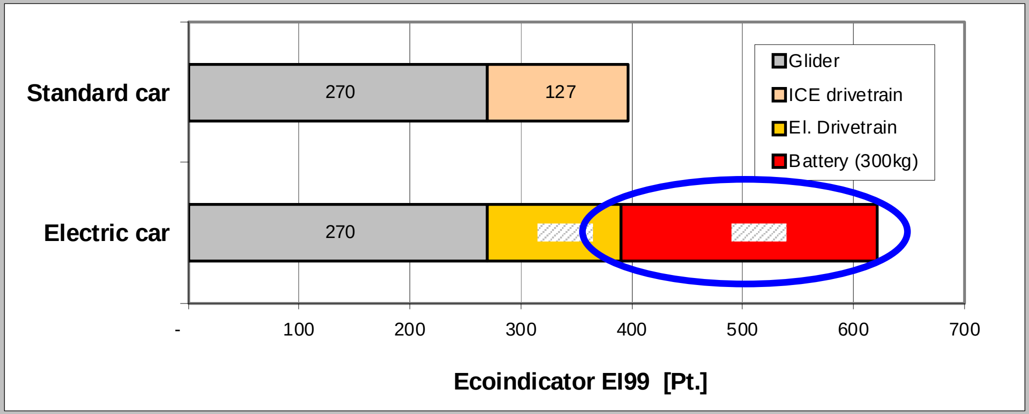
ICE, golf-class

BEV, golf-class,
300kg battery 30kWh
~200km autonomy in NEDC



plus ~30%

Total environmental impact (ecoindicator EI99 points) of the car production   (w/o operation)



plus ~57%

- Producing a BEV incl. battery causes significantly more damage than a conventional ICE car
- Producing an electric drivetrain w/o battery causes slightly less damage than an ICE drivetrain

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Data from: ecoinvent database plus own calculations (publ. in prep.)

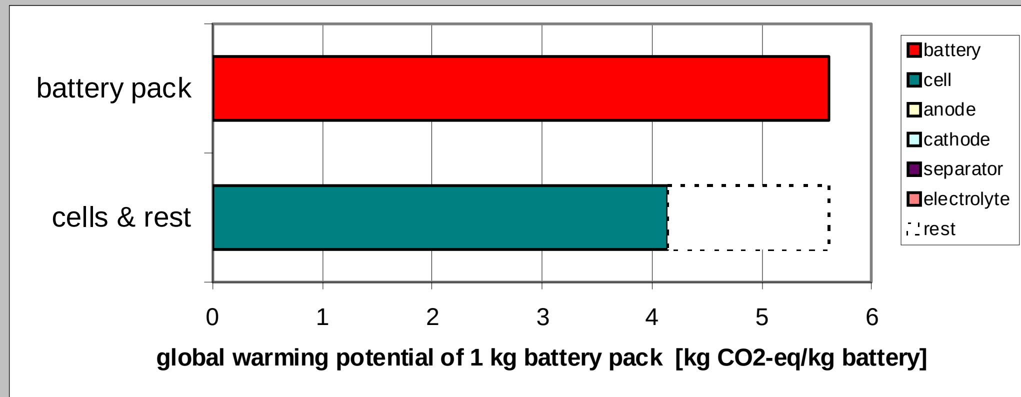
LCA result Li-Ion battery (manganese oxyde type)

Global warming potential (kg CO2-eq) for the production: 1 kg battery

battery pack compositon

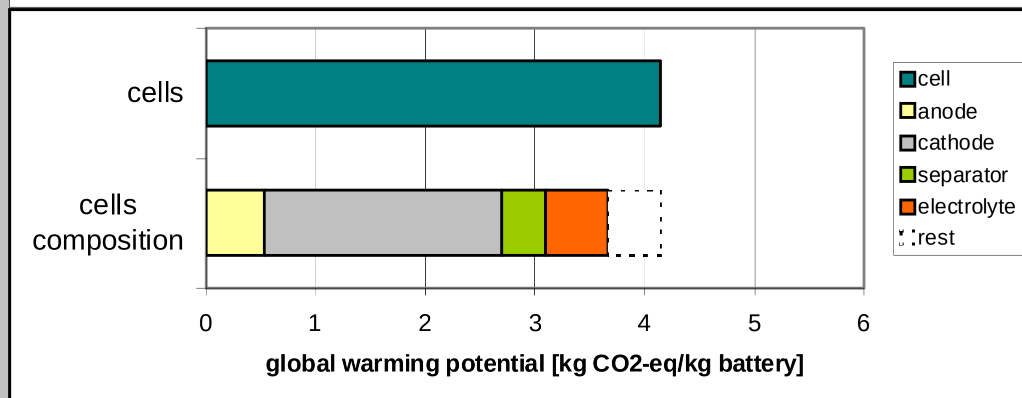
cells and assembly to a battery pack

- 74% from cells
- rest: assembly plant, BMS printed circuit board, wirings, enclosure, production energy, transport



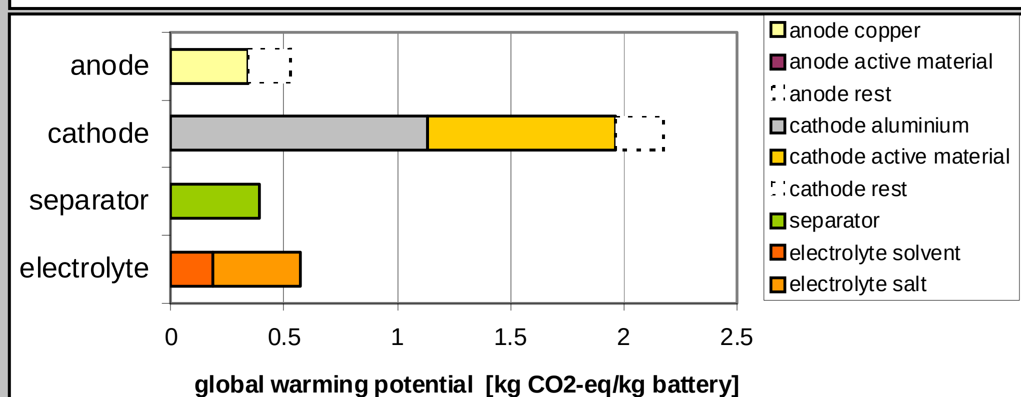
cell composition

- main impact 52% from cathode
- rest: cell plant, pouch (plastic), production energy, transport



cell details

- highest impact from Al and $LiMn_2O_4$ in cathode
- similar impacts from Cu, separator and electrolyte salt $LiPF_6$



conclusion:
optimisation of metals use

Data from: ecoinvent database plus own calculations (in prep.)

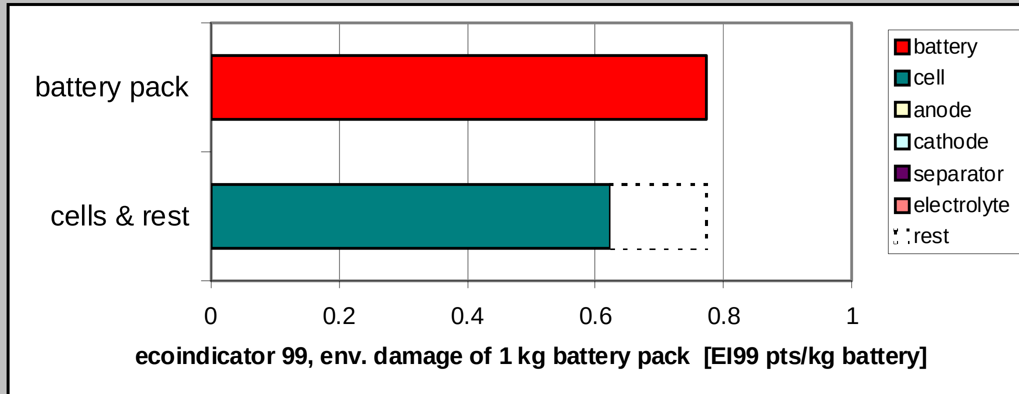
LCA results Li-Ion battery (manganese oxyde type)

Total environmental impact (ecoindicator EI99 pts) for the production: 1 kg battery

battery pack compositon

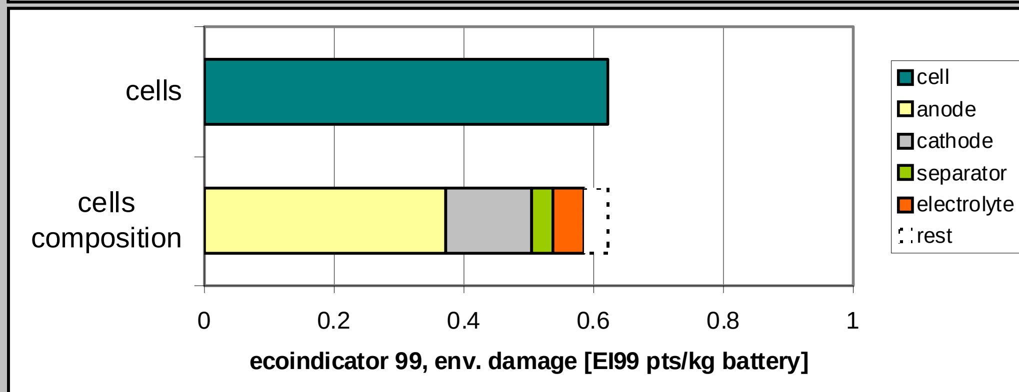
cells and assembly to a battery pack

- 81% from cells
- rest: assembly plant, BMS printed circuit board, wirings, enclosure, production energy, transport



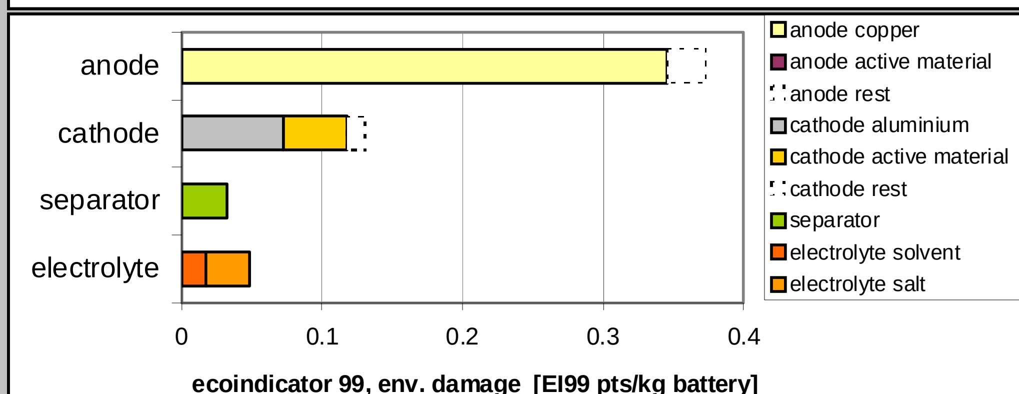
cell composition

- main impact 60% from anode
- 21% from cathode
- rest: cell plant, pouch (plastic), production energy, transport



cell details

- dominant impacts from metals: Cu and Al
- similar impacts from $LiMn_2O_4$, separator and electrolyte salt $LiPF_6$



conclusion:
optimisation of metals use

Data from: ecoinvent database plus own calculations (in prep.)

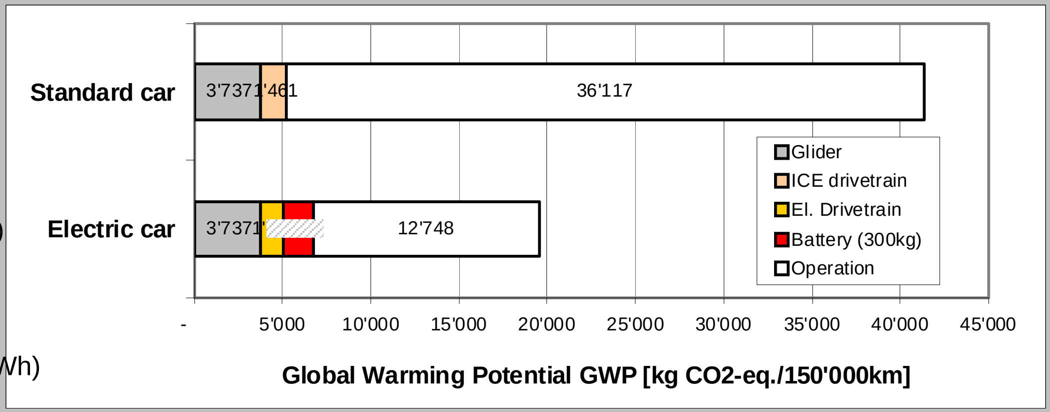
LCA: Entire lifecycle   Comparison ICE / BEV vehicle

Global warming potential (kg CO2-eq) over entire lifecycle (production + 150'000km operation)

ICE, gasoline EURO4
avg. europ. car (golf-class)

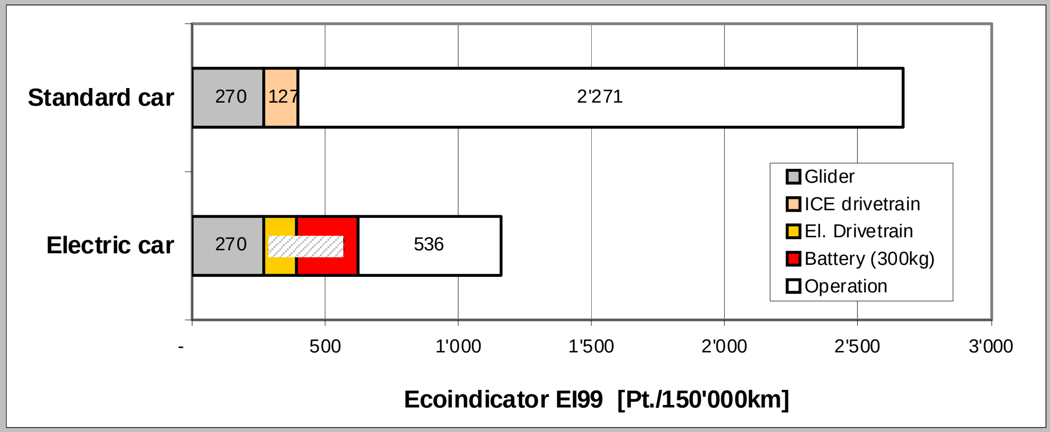
BEV, EU-electricity
(UCTE-mix, 593 gCO2eq/kWh)
300kg battery

(CH-mix, 134 gCO2eq/kWh)
(EU-coal-mix, 1095 gCO2eq/kWh)



minus ~53%

Total environmental impact (EI99 pts) over entire lifecycle (production + 150'000km operation)



minus ~57%

- Due to the higher efficiency in the operation there is a significant advantage for the BEV over the whole lifecycle, even if operated with electricity including a relatively high fossil energy fraction

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Data from: ecoinvent database plus own calculations (publ. in prep.)

Conclusion:

your feedback is welcome!
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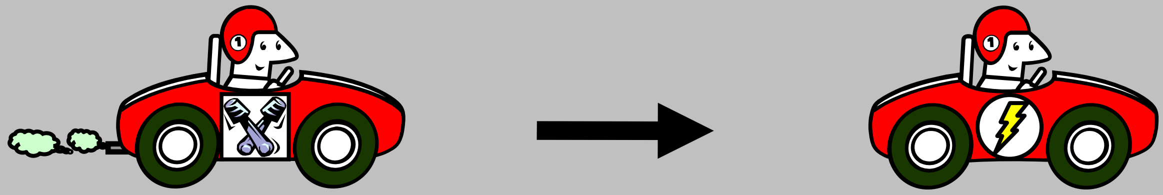
- the transition from ICE cars to BEVs looks favorable from an environmental perspective although the impact from BEV production is significantly higher than from ICE car production



- very efficient ICE cars might be competitive with BEVs operated with electricity with very high fossil footprint (pure coal power plants)
- operated with low fossil energy containing electricity, BEVs perform better than the best possible ICE car

source: unknown