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

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

2009
Empa’s Research Programs

Materials for Health & Performance

Nanotechnology

Technosphere

Atmosphere

Adaptive Material Systems

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?*

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**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

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*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*
Life cycle of a battery

Life cycle assessment: The basic idea

**INPUT**
- Raw Material
- Energy
- Auxiliaries

**OUTPUT**
- Product/Service
- Emissions
- Wastes

& ecological assessment of flows

Product or service over entire lifecycle
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
Lithium

- 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 salt lakes in the Andes (Chile, Bolivia) or in China (Tibet)
- It’s extracted from salines and sold as lithium carbonate Li2CO3
- The highest energy fraction for the production of Li2CO3 is solar energy for the evaporation
- Most of the by-products go to fertilizer production
A Li-Ion Battery Cell  (Manganese oxide type)

- 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

What’s in it?

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

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

Table: measurements Empa

Picture: Empa

Picture: Empa

Picture: Empa
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-emissions, landuse,...)
- Methods which allow to conclude all the impacts to a total environmental impact figure

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

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

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 composition**
- 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 LiMn2O4 in cathode
- similar impacts from Cu, separator and electrolyte salt LiPF6

**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

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**Battery Pack Composition**

- 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 LiMn2O4, separator and electrolyte salt LiPF6

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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)

<table>
<thead>
<tr>
<th></th>
<th>BEV, EU-electricity (UCTE-mix, 593 gCO2eq/kWh) 300kg battery</th>
<th>ICE, gasoline EURO4 avg. europ. car (golf-class)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Warming Potential GWP [kg CO2-eq./150'000km]</td>
<td>3,737 1461</td>
<td>36,117</td>
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<tr>
<td>Total environmental impact (EI99 pts) over entire lifecycle</td>
<td>1,461</td>
<td>1350</td>
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<td>Operation</td>
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<td>Glider</td>
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<td>ICE drivetrain</td>
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<td>-</td>
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<tr>
<td>El. Drivetrain</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Battery (300kg)</td>
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Data from: ecoinvent database plus own calculations (publ. in prep.)

- 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
Conclusion:

- 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