The need for a prospective perspective in LCA

76th LCA Discussion Forum

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Problems with conventional LCA of emerging technologies

1. Technologies might change over time
Table 1. Typical **lead-acid battery** and electric vehicle performance.

<table>
<thead>
<tr>
<th>Battery and vehicle assumptions</th>
<th>Available technology</th>
<th>Goal technology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy density of battery</strong> (Wh/kg)</td>
<td>18</td>
<td>56</td>
</tr>
<tr>
<td>Number of driving cycles per battery</td>
<td>450</td>
<td>1,000</td>
</tr>
<tr>
<td>Vehicle energy requirements (Wh/km)</td>
<td>310</td>
<td>310</td>
</tr>
<tr>
<td>Average distance per driving cycle (km)</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Energy for driving cycle (kWh)</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Battery mass for driving cycle (kg)</td>
<td>1,378</td>
<td>443</td>
</tr>
<tr>
<td>Battery life-cycle distance (km)</td>
<td>36,000</td>
<td>80,000</td>
</tr>
<tr>
<td>Lead percentage of battery mass (%)</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Battery lead mass (kg)</td>
<td>964</td>
<td>310</td>
</tr>
<tr>
<td>Battery lead per life-cycle kilometer (g/km)</td>
<td>27</td>
<td>4</td>
</tr>
<tr>
<td>Lead releases per life-cycle kilometer</td>
<td>1,072</td>
<td>155</td>
</tr>
<tr>
<td>Virgin production (4%) (mg/km)</td>
<td>536</td>
<td>78</td>
</tr>
<tr>
<td>Recycling production (2%) (mg/km)</td>
<td>268</td>
<td>39</td>
</tr>
</tbody>
</table>

Problems with conventional LCA of emerging technologies

1. Technologies might change over time

2. Production processes might change over time
Lab-scale production

• No solvent recycling

• High yields OR high quality with low yields

• Different energy requirement

• Byproducts not utilized
Problems with conventional LCA of emerging technologies

1. Technologies might change over time

2. Production processes might change over time

3. Surrounding systems might change over time
Prospective
or
ex-ante
LCA
Bonus slide!
Prospective vs Consequential and Attributional LCA

How to actually do the up-scaling / prediction / scenarios?

\[ E_{\text{stir}}(1000 \ l) = \frac{0.79 \times \rho_{\text{mix}} \times 1.417^3 \times 0.373^5 \ m^5 \cdot t}{0.9} \times 0.1 \]

= 0.0180 \ m^5 \cdot s^{-3} \cdot \rho_{\text{mix}} \cdot t
<table>
<thead>
<tr>
<th>Laboratory scale process</th>
<th>Scaled-up process according to framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction under heating</td>
<td>Heated liquid batch reaction in an insulated batch reactor with an in-tank stirrer</td>
</tr>
<tr>
<td>Mixing (magnetic stirrer)</td>
<td>In-tank stirring</td>
</tr>
<tr>
<td>Dispersing</td>
<td></td>
</tr>
<tr>
<td>Blending</td>
<td>Rotor-stator type homogenizer</td>
</tr>
<tr>
<td>Mixing (viscous solution)</td>
<td></td>
</tr>
<tr>
<td>Homogenizing (all types)</td>
<td></td>
</tr>
<tr>
<td>Dispersing</td>
<td></td>
</tr>
<tr>
<td>Pestling in mortar</td>
<td>Grinding</td>
</tr>
<tr>
<td>Grinding/milling</td>
<td></td>
</tr>
<tr>
<td>Other particle size reduction</td>
<td></td>
</tr>
<tr>
<td>Filtration (e.g. membrane, reverse osmosis, dialysis)</td>
<td>Filtration/centrifugation</td>
</tr>
<tr>
<td>Sieving</td>
<td></td>
</tr>
<tr>
<td>Centrifugation/cyclonic separation</td>
<td></td>
</tr>
<tr>
<td>Other solid–liquid separation</td>
<td></td>
</tr>
<tr>
<td>Distillation</td>
<td>Distillation</td>
</tr>
<tr>
<td>(Rotary evaporation)</td>
<td></td>
</tr>
<tr>
<td>Vacuum drying</td>
<td>(Oven) drying/vaporization</td>
</tr>
<tr>
<td>Drying</td>
<td></td>
</tr>
<tr>
<td>Rotary evaporation</td>
<td></td>
</tr>
<tr>
<td>(Manual) Transferring of liquids</td>
<td>Pumping</td>
</tr>
<tr>
<td>Waste disposal</td>
<td>Pre-treatment (case specific)</td>
</tr>
<tr>
<td></td>
<td>Solvent recycling – distillation</td>
</tr>
<tr>
<td></td>
<td>Solvent recycling – filtration</td>
</tr>
<tr>
<td></td>
<td>Co- and by-product isolation</td>
</tr>
<tr>
<td>Normally not included in laboratory process</td>
<td>Heat recovery through heat exchangers</td>
</tr>
</tbody>
</table>

Example, stirring

\[
E_{\text{stir}}[J] = \frac{N_P \cdot \rho_{\text{mix}} \cdot N^3 \cdot d^5 \cdot t}{\eta_{\text{stir}}}
\]

\[
E_{\text{stir}}(1000 \text{ l}) = \frac{0.79 \cdot \rho_{\text{mix}} \cdot 1.417^3 \cdot s^{-3} \cdot 0.373^5 \cdot m^5 \cdot t}{0.9}
\approx 0.0180 \cdot m^5 \cdot s^{-3} \cdot \rho_{\text{mix}} \cdot t
\]
## Table 2: Estimated best-case and worst-case default values of the yield (Eq. 2), the solvent recycling factor (Eq. 5), other solvent parameters (Eq. 5), the emission factor (Eq. 6), and utility inputs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Reaction phase</th>
<th>Reaction medium</th>
<th>Solvent type</th>
<th>Parameter subgroup</th>
<th>Default values</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Best-case</td>
<td>Worst-case</td>
</tr>
<tr>
<td>Yield (X)</td>
<td></td>
<td></td>
<td></td>
<td>No major side product</td>
<td>0.97</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Major side product</td>
<td>0.87</td>
<td>0.77</td>
</tr>
<tr>
<td>Solvent recycle factor ($f_{\text{recyc}}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.95</td>
<td>0</td>
</tr>
<tr>
<td>number of solvents used in a process step ($k_{\text{solvant}}$)</td>
<td>Gas phase</td>
<td>Any</td>
<td>Any</td>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Liquid phase</td>
<td>Organic</td>
<td>Organic</td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aqueous</td>
<td>Water</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aqueous</td>
<td>Organic</td>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total mass of a single solvent $j$ in a process step ($m_{\text{total solvent}}$)</td>
<td>Gas phase</td>
<td>Any</td>
<td>Organic</td>
<td></td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aqueous</td>
<td>Water</td>
<td></td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic</td>
<td>Organic</td>
<td></td>
<td>0.2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aqueous</td>
<td>Water</td>
<td></td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aqueous</td>
<td>Organic</td>
<td></td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Emission factor ($f_{\text{emission}}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$1 \times 10^{-7}$</td>
<td>0.001</td>
</tr>
<tr>
<td>Utility inputs for reaction and workup</td>
<td></td>
<td>Steam</td>
<td></td>
<td></td>
<td>1.2</td>
<td>7.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electricity</td>
<td></td>
<td></td>
<td>0.7</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling water</td>
<td></td>
<td></td>
<td>70</td>
<td>730</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$N_2$</td>
<td></td>
<td></td>
<td>0.06</td>
<td>0.4</td>
</tr>
<tr>
<td>Utility inputs for solvent regeneration</td>
<td></td>
<td>Steam</td>
<td></td>
<td></td>
<td>1.5</td>
<td>n.a.$^a$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electricity</td>
<td></td>
<td></td>
<td>0.2</td>
<td>n.a.$^a$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling water</td>
<td></td>
<td></td>
<td>80</td>
<td>n.a.$^a$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$N_2$</td>
<td></td>
<td></td>
<td>0.01</td>
<td>n.a.$^a$</td>
</tr>
</tbody>
</table>

$^a$ n.a. – not applicable because no solvent regeneration assumed

Main messages

1. Prospective perspective in LCA of emerging technologies is needed because:
   • Technologies change
   • Production processes change
   • Surrounding systems change

2. Prospective/ex-ante LCA is a useful approach for considering such possible changes

3. The big question: How can relevant up-scaling, predictions and scenario construction be done in practice?