Environmental impact assessment of man-made cellulose fibres and recycled polyester fibre

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Part I
Comparative LCA of man-made cellulose fibres

Why man-made cellulose fibres are interesting?

LCA of man-made cellulose fibres

• Goal:
  1) assess the impacts of man-made cellulose fibres;
  2) compare with cotton, PET and PP.

• Functional unit:
  – 1 metric tonne of staple fibre

• System boundary:
  – cradle-to-factory gate
  – cradle-to-factory gate plus post-consumer waste incineration with energy recovery
Types of fibre and data sources

- Man-made cellulose fibres
  - Viscose Asia
  - Viscose Austria
  - Modal
  - Tencel
  - Tencel 2012

- Cotton (US and China)

- PET and PP fibres (Western Europe)

- (PLA)
# Viscose, Modal and Tencel

<table>
<thead>
<tr>
<th>Fibre name</th>
<th>Pulp source</th>
<th>Process</th>
<th>Process energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscose Asia</td>
<td>Market Pulp</td>
<td>Separate production</td>
<td>Local electricity, coal, gas, oil</td>
</tr>
<tr>
<td>Viscose Austria</td>
<td>Lenzing Pulp</td>
<td>Integrated production</td>
<td>- Biomass</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Energy from MSWI</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Fossil fuels</td>
</tr>
<tr>
<td>Modal</td>
<td>Lenzing Pulp</td>
<td>Integrated production</td>
<td></td>
</tr>
<tr>
<td>Tencel</td>
<td>Mixed Market pulp &amp;</td>
<td>Separate production</td>
<td>- Biomass (30%)</td>
</tr>
<tr>
<td>Tencel, 2012</td>
<td>Lenzing pulp</td>
<td></td>
<td>- Natural gas (70%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Energy from MSWI (100%)</td>
</tr>
</tbody>
</table>
Net NREU (GJ/t fibre), Cradle-to-factory gate *plus* post-consumer waste incineration with energy recovery (recovery rate = 60% primary energy)

<table>
<thead>
<tr>
<th>Material</th>
<th>Cradle-to-factory gate</th>
<th>Recovered energy from waste incineration (energy recovery rate 60%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton (US&amp;CN)</td>
<td>-10</td>
<td>-10</td>
</tr>
<tr>
<td>PET (W. Europe)</td>
<td>-14</td>
<td>-14</td>
</tr>
<tr>
<td>PP (W. Europe)</td>
<td>-29</td>
<td>-29</td>
</tr>
<tr>
<td>PLA fibre, without wind</td>
<td>66</td>
<td>66</td>
</tr>
<tr>
<td>PLA fibre, with wind</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>Lenzing Viscose Asia</td>
<td>93</td>
<td>93</td>
</tr>
<tr>
<td>Tencel, Austria</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td>Lenzing Modal</td>
<td>66</td>
<td>66</td>
</tr>
<tr>
<td>Tencel, Austria, 2012</td>
<td>62</td>
<td>62</td>
</tr>
<tr>
<td>Lenzing Viscose Austria</td>
<td>19</td>
<td>19</td>
</tr>
</tbody>
</table>
Environmental impact categories (CML)
Cradle-to-factory gate, 1 tonne fibre (cotton = 100)
Single-score result (III)
NOGEPA weighting factors (normalised to world)
1 tonne fibre, cradle-to-factory gate, cotton =100

Weighting factors (NOGEPA)

- Climate Change 32
- Abiotic depletion* 8
- Ozone layer depletion 5
- Human toxicity 16
- Fresh water ecotoxicity 6
- Terrestrial ecotoxicity 5
- Photochemical oxidation 8
- Acidification 6
- Eutrophication 13
- Total 99

Source: Huppes et al (2003), except for abiotic depletion (marked with *), which is not excluded by Huppes et al. and is determined based on own estimation.
Part II
LCA of bottle-to-fibre (B2F) recycling

Product systems  
(FU = 1 metric tonne of fibre)

<table>
<thead>
<tr>
<th>Product systems</th>
<th>Type of fibre</th>
<th>Location</th>
<th>Data sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mechanical recycling</td>
<td>Staple</td>
<td>W. Europe</td>
<td>Company data</td>
</tr>
<tr>
<td>2. Semi-mechanical recycling</td>
<td>Filament (POY)</td>
<td>E. Asia</td>
<td>Company data</td>
</tr>
<tr>
<td>3. Back-to-oligomer (BHET) recycling</td>
<td>Filament (POY)</td>
<td>E. Asia</td>
<td>Company data</td>
</tr>
<tr>
<td>4. Back-to-monomer (DMT) recycling</td>
<td>Filament (POY)</td>
<td>W. Europe</td>
<td>Literature data</td>
</tr>
<tr>
<td>Ref. Virgin PET fibre</td>
<td>Staple/Filament</td>
<td>W. Europe</td>
<td>Literature data</td>
</tr>
</tbody>
</table>
Allocation: open-loop recycling

• Cut-off approach:
  – The first life (bottle) does not have influence on the second life (fibre)

• Waste valuation approach:
  – Bottle waste contains part of the burden from first life (economic allocation)

• System expansion approach:
  – Do not distinguish first and second life, but do assume products from 1\textsuperscript{st} and 2\textsuperscript{nd} life are functional equivalent
  – Do take into account the “grave” stage
Cradle-to-factory gate NREU & GWP100a based on the “cut-off” method

NREU (GJ/t)  GWP (kg CO₂ eq./t)

Mech. recycling (staple)  13  960
Semi-mech. recycling (POY)  23  1,880
Chem. recycling (BHET route, POY)  39  2,590
Chem. recycling (DMT route, POY)  51  3,080
V-PET (W.EU, staple/POY)  95  4,062
Cradle-to-factory gate NREU & GWP100a
Based on the “waste valuation” method

NREU (GJ/t)

GWP (kg CO₂ eq./t)
NREU and GWP100a (cradle to grave excl. use phase)

NREU (GJ/t)

GWP (kg CO₂ eq./t)

Virgin PET (staple&POY)  Mechanical recycling (Staple)  Semi-mechanical recycling (POY)  Chemical recycling, back to BHET (POY)

Virgin PET (staple&POY)  Mechanical recycling (Staple)  Semi-mechanical recycling (POY)  Chemical recycling, back to BHET (POY)

79  23  33  48

5,540

1,330  2,210  2,820

Incineration with credits

VPET fibre

RPET fibre
Bio-based and recycled polymers for cleaner production

An assessment of plastics and fibres