# The life cycle assessment of cellulose pulp from waste cotton via the SaXcell™ process.

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# The life cycle assessment of cellulose pulp from waste cotton via the SaXcell™ process.

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**Abstract.** Recycling of cotton waste into high value products is a longstanding goal in textile research. The SaXcell$^{TM}$ process provides a chemical recycling route towards virgin fibres. In this study a Life cycle assessment (LCA) is conducted to measure the impact of the chemical recycling of cotton waste on the environment. Pure cotton waste and cotton containing 10 % of polyester are elaborated. The results show that chemical recycling via the SaXcell$^{TM}$ process can have a lower impact on climate change and other impact category than comparable pulping technologies.

## 1. Introduction

Recycling is one of the most important solutions to the environmental problems that the world will face due to increasing population and welfare [1]. While in the plastic and paper industry recycling is state of the art, the recycling of textiles is still underdeveloped and most of the textile waste is burned. Considering the enormous needs for energy and chemicals during the production of textile fibres [2], the creation of a closed material cycle for textile fibres is expected to decrease the environmental impact of textiles.

SaXcell™ (Saxion and cellulose) is a regenerated cellulosic fibre made out of 100 % cotton waste material and has recently been developed at Saxion UAS, The Netherlands. A lot of progress is made in creating a sustainable and economically valuable process for waste cotton recycling into regenerated cellulose fibres [3] (see Figure 1). In order to be able to give objective information on the environmental impact of the production of the SaXcell™ fibre, as a first step, a life cycle assessment (LCA) has been carried out of the dissolving pulp production from cotton waste as feedstock (figure 1 steps 1-5).

The goal of this LCA-study is to evaluate the environmental impact of the production of cellulose dissolving pulp via the SaXcell™ process. Pulp from two different kinds of (sorted) waste textiles is inventoried:

1. 100 % cotton
2. 90 % cotton / 10 % PET

Calculations are performed on processes that were not optimized for a low environmental impact.

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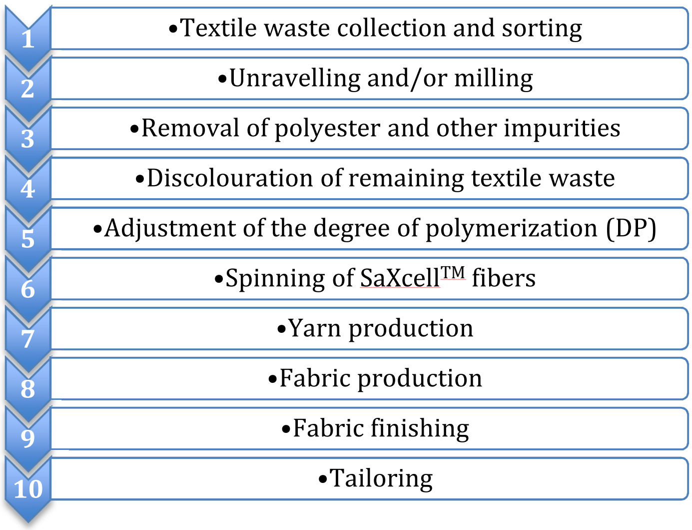


**Figure 1.** The SaXcell™ recycling process and subsequent fabric production

## 2. Methods

The LCA study is executed by CE Delft according to the ISO-standard of good LCA practice (ISO 14044:2006 'Environmental management - Life cycle assessment - Requirements and guidelines') and also reported accordingly. This investigation is a cradle-to-gate investigation, meaning that the product is evaluated from the resource extraction (cradle) to the factory gate (i.e., before transport of the pulp to the fibre production facility).

The data for the production of SaXcell pulp is collected by Saxion in consultation with textile production experts. The data is inventoried per 100 kg of SaXcell pulp. For the LCA of regenerated pulp from cotton waste, data from laboratory and pilot plant scale experiments at Saxion are used and translated to an industrial scale production. This translation is done based on literature data and experts estimations. De data is modelled in the LCA software Simapro, by making use of the environmental background data of the Ecoinvent database.

The SaXcell pulp is a feedstock for fibre production via the Lyocell process. Due to the unavailability of data on industrial fibre production via the Lyocell process, the fibre production is excluded in this study (step 6 in **Figure 1**).

The ReCiPe method (midpoint level) is selected as life cycle impact assessment method. With this method, eighteen different environmental effects and indicators are calculated. The results of five are shown in this report. As representative values, here, the climate change values in kg $CO_2$-eq. are reported. Additionally a comparison between SaXcell pulp from 100 % white cotton waste and existing sulphate pulps will be shown. Several other environmental assessments have been applied (not reported here) in order to ensure optimal comparability with other studies.

## 3. Results

### *3.1 Data collection (inventory)*

Data about the SaXcell™ process was collected based on laboratory and pilot scale experiments and translated to an industrial scale production.

*3.1.1. Energy.* The (estimated) energy requirement for pulp production at industrial scale is shown in table 1. Electricity consumption in the pulping process consists of unravelling the textile waste, milling, dewatering and stirring during the chemical processes. Heat from natural gas is required for process water heating. The process is based on an integrated plant where pulp production is directly followed by fibre production (not included in this study). For that reason for drying no electricity or heat is accounted.

**Table 1.** Electricity and heat use for industrial scale production of 100 kg of SaXcell pulp

| Process | 100 % cotton | 90 % cotton / 10 % PET |
|---|---|---|
| Electricity (kWh) | 58.4 | 63.8 |
| Heat (MJ) | 169 | 427 |

The stirring process and all heating processes are assumed to consume 30% less energy than in the lab scale situation. This was an estimation based on the effects of process optimization, integration, and up-scaling.

An uncertainty assessment is performed for the process step that adjusts the degree polymerisation (DP reduction step; see figure 1, step 5). This step was additionally calculated with the use of a biocatalyst instead of an acid as catalyst. In that case only 58 MJ instead of 169 MJ for heating was required.

*3.1.2 Transport.* Transport of waste material is based on averaged distances between the place of collection of textiles and the sorting facilities within the Netherlands. For the transport from the sorting location to the pulp production plant it is assumed that the pulp production takes place in the centre of the Netherlands and sorting occurs within the Netherlands (see table 2).

**Table 2.** Transport of raw materials

| Process | Kilometres | Transportation type |
|---|---|---|
| From collection to sorting location | 75 | Truck (<10 t) |
| From sorting to pulp and filament production | 200 | Truck (24 t) |

*3.1.3 Input materials.* The chemicals used during the pulping process are given in table 3. The water consumption is a summary of the process steps and the washing cycles. It is assumed that a water recycling system reduces the actual water consumption by 70 % (this is taken into account in the figures in table 3).

**Table 3.** Chemicals and water input on industrial scale (per 100 kg of SaXcell pulp)

| Material | 100 % cotton | 90 % cotton / 10 % PET |
|---|---|---|
| Water (l) | 1500 | 2700 |
| Sodium hydroxide pellets (kg) | 1.6 | 15.1 |
| Sulfuric acid (96%) (kg) | 5 | 5 |

*3.1.4 Wastewater.* The pulp production generates wastewater, in similar amounts of the water used (see table 4). This wastewater contains substances as sodium sulphate and organic compounds (such as glucose and ethylene glycol). The wastewater is discarded through the sewers to a wastewater treatment plant (WWTP).

**Table 4.** Waste water production on industrial scale (per 100 kg of SaXcell pulp)

| Material | 100 % cotton | 90 % cotton / 10 % PET |
|---|---|---|
| Waste water generated (l) | 1500 | 2700 |

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*3.2 Environmental impact results (selection)*

*3.2.1 Impact on climate change.* The results for the impact on climate change for different textile wastes and processes are shown in table 5. Existing LCA studies for pulping processes reported climate change values of 0.54 - 1.34 kg $CO_2$-eq. for different pulps depending on quality and feedstock, which in most cases is wood.

The SaXcell™ pulping processes based on 100 % white cotton waste has an impact on climate change of 0.48 kg $CO_2$-eq. The use of a biocatalyst in the DP reduction step reduces the impact to 0.39 kg $CO_2$-eq. The impact of the bio-catalytic process is generally small, due to the catalyst itself, but also due to the milder process conditions.

A sensitivity assessment is performed on the application of ‘green’ electricity use (from sustainable sources) for the production of pulp on industrial scale. Whereas in the base analysis, all electricity used consisted of the average Dutch electricity mix, in the sensitivity assessment electricity from sustainable sources only is applied (for instance generated by solar or wind power on the production site). When only green energy sources are used, the climate impact decreases from 0.48 kg $CO_2$-eq to 0.27 kg $CO_2$-eq.

Dissolving pulp form textile wastes with PET content has a higher impact on climate change (0.86 kg $CO_2$-eq.) than pulp based on 100 % cotton waste (0.63 kg $CO_2$-eq when green energy is used). This is due to the use of more process chemicals and the need for additional processes for the separation of PET from cellulose.

**Table 5.** The impact on climate change for 1 ton of SaXcell™ dissolving pulp using different production parameters.

| Feedstock | Climate change (kg $CO_2$-eq.) |
|---|---|
| 100 % cotton waste | 0.48 |
| 100 % cotton waste (biocatalyst)[1] | 0.39 |
| 100 % cotton waste (green energy)[2] | 0.27 |
| 90 % cotton / 10 % PET | 0.86 |
| 90 % cotton / 10 % PET (green energy)[2] | 0.63 |
| Existing pulping processes[3] | 0.54 – 1.34 |

[1] During the process biocatalyst are used instead of acids for reduction of the degree of polymerization.
[2] Green energy sources are used instead of the EU energy mix for calculation.
[3] Based on environmental data of pulp types available in the Ecoinvent Database [4].

*3.2.2 Comparison between SaXcell pulp and sulphate pulp from different sources in five impact categories.* SaXcell pulp form 100 % white cotton waste is additionally compared to existing sulphate pulps from different feedstocks. Table 6 shows that next, to the impact on climate change, SaXcell pulp shows much lower impact values than existing sulphate pulps also for human toxicity and water depletion. The most remarkable difference is found for the agricultural land occupation. Here, the traditional sulphate pulp showed the highest impact values of 4,8 $m^2a$ and the sulphate pulp from sustainable forestry gave still an impact value of 0,83 $m^2a$. The impact value of the SaXcell pulp however, is almost negligible (0,01 $m^2a$), caused by the fact that recycling processes do not require the cultivation of trees or plants.

**Table 6.** Comparison between SaXcell pulp and sulphate pulp

| Impact categories | SaXcell 100 % cotton | Sulphate pulp | Sulphate pulp sustainable[1] |
|---|---|---|---|
| Climate change (kg $CO_2$ eq) | 0,48 | 0,54 | 0,58 |
| Human toxicity (kg 1,4 DB eq) | 0,107 | 0,234 | 0,194 |
| Agricultural land occupation ($m^2a$) | 0,01 | 4,82 | 0,83 |
| Urban land occupation ($m^2a$) | 0,004 | 0,031 | 0,005 |
| Water depletion $m^3$ | 0,0100 | 0,0170 | 0,0251 |

[1] pulp made of eucalyptus wood from sustainable forest management

## 4. Conclusions

The data and results show that dissolving pulp from white 100 % cotton textile waste has generally a low impact on climate change. This impact on the environment can additionally be decreased by the use of a biocatalyst and/or green energy sources in the production process. When the textile waste contains PET, the use of process chemicals increases and so does the impact on climate change (and other environmental effects). However, especially SaXcell pulp from 100 % white cotton shows big advantages compared to sulphate pulp in the impact categories human toxicity, urban land occupation, water depletion and a large advantage in the impact category agricultural land occupation. From this it can be concluded that the use of cotton waste as pulp feedstock for regenerated cellulose fibres has clear advantages compared to most pulp qualities in terms of most impact categories investigated in this study.

## Acknowledgments

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