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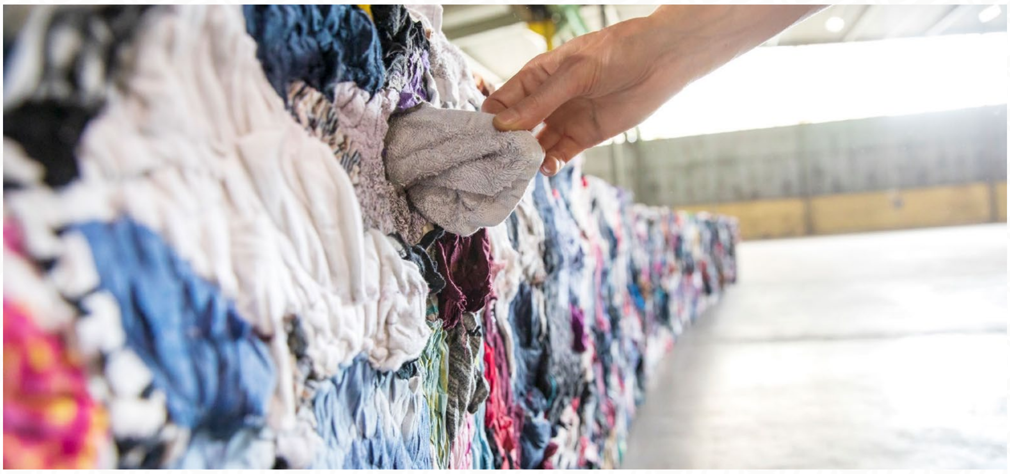

Siptex - Quality assurance report

Dämien Johann Bolinius

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Preface

Siptex (Swedish Innovation Platform for Textile Sorting) is a research project funded by Sweden's Innovation Agency's Challenge-driven innovation initiative. The first stage of the project began in 2015 with the third and final stage initiated in 2019. During this final stage of the project, Siptex, the world's first automated sorting facility for post-consumer textiles on an industrial scale, was built in Malmö.

The Siptex plant uses near-infrared and visual spectroscopy (NIR/VIS) to sort mixed pre-sorted textile waste according to market needs in terms of fibre composition and colour. As a new step in the textile value chain, Siptex aims to create the conditions for increased profitability in the handling of the ever-increasing amounts of textile waste that are collected for material recycling and an increase in fibre-to-fibre recycling of textiles.

The work with setting up Siptex was split up in several work packages covering various aspects of development needed to establish an industrial scale automated textile sorting process. This report focuses on the work carried out in the work package called "Quality assurance" and is an addition to the report: "Siptex - Swedish Innovation Platform for Textile Sorting - A summary report of the final stage of the project" which summarizes the results from the stage 3 of the Siptex project. For more information on the Siptex project in general or the environmental impact assessments performed in the Siptex project, see IVL:s webpage for Siptex[1] where all reports are freely available.

Acknowledgements

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[1] https://www.ivl.se/english/ivl/our-offer/research-projects/circular-flows/automated-sorting-will-increase-textile-recycling.html

List of abbreviations

- 6:2 FTOH: 1H, 1H, 2H, 2H-Perfluoro-1-octanol
- 8:2 FTOH: 1H, 1H, 2H, 2H-Perfluoro-1-decanol
- 8:2 FTS: 1H, 1H, 2H, 2H-Perfluorodecanesulphonic acid
- AFIRM: the Apparel and Footwear International RSL Management group. In the context of this report, we use AFIRM to refer to the restricted substance lists of AFIRM.
- Ba: Barium
- Cr: Chromium
- Cu: Copper
- DMAc: N,N-Dimethylacetamide
- DMF: N,N-Dimethylformamide
- DMFu: Dimethylfumarate
- KNIME: the Konstanz Information Miner, an analytical software package
- MCP: Monochlorphenol
- NA: Not applicable
- NDMA:N-nitrosodimethylamine
- N-ET-FOSE: N-ethyl perfluorooctane sulfonamide ethanol, part of a group of per- and polyfluorinated compounds
- NIR: Near infrared
- N-Me-FOSE: N-Methyl perfluorooctane sulfonamide ethanol, part of a group of per- and polyfluorinated compounds
- NP(EO): Nonylphenolethoxylates
- NP: Nonylphenol
- Oeko-tex: Oeko-tex is an organization consisting of 17 independent institutes in Europe and Japan. In this report we use Oeko-tex to refer to the Oeko-tex class 100 certification for textiles.
- OPP: o-phenylphenol
- PAHs: Polycyclic aromatic hydrocarbons
- PCP: Pentachlorphenol
- PFOA: Perfluorooctanoic acid, part of a group of per- and polyfluorinated compounds
- PFOS: Perfluorooctane sulfonic acid
- REACH: Registration, Evaluation, Authorisation and Restriction of Chemicals, part of EU's chemical legislation
- Refab: Sysavs assortment of quality-assured recycling products
- RSL: Restricted substance list, a list of substances set up by a company or organization with specific chemical substances and limit values. Often used to inform suppliers of which chemicals should not be present in a certain material / product above a certain concentration.
- Siptex: Swedish Innovation Platform for Textile Sorting

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Summary

Siptex (Swedish Innovation Platform for Textile Sorting) is a research project funded by Sweden's Innovation Agency's Challenge-driven innovation initiative. As a new step in the textile value chain, Siptex aims to create the conditions for increased profitability in the handling of the ever-increasing amounts of textile waste that are collected for material recycling and an increase in fibre-to-fibre recycling of textiles.

This report focuses on the work carried out in the work package called "Quality assurance". There were two main goals within this work. The first goal was to enable the establishment of a range of quality assured products. The second goal was to increase the knowledge on hazardous chemicals in post-consumer textiles in general.

Five different outbound products of specific fibre content have been developed based on market demand. The products are referred to as ReFab® by SYSAV and include Siptex sorted materials of different purities of cotton, polyester and acrylics.

For the quality assurance process, a method was developed to take representative textile samples from the bales of post-consumer materials, using a hay sampler and an extensive shredding process to product homogenous samples of shredded textile fibres. In the Siptex project, a total of 15 samples per bale was considered to be both practical as well as likely to give a good representation of the contents in a certain bale. This number is the result of a small pilot study which is described in this report. This method can be supplemented by a more routine analysis in which samples are taken by hand to monitor sorting efficiencies.

The increase the knowledge on hazardous chemicals in post-consumer textiles, the project investigated existing data on hazardous chemicals in post-consumer textiles and supplemented this with new data generated from chemical analyses on bales of Siptex sorted materials made of cotton, polyester, and acrylics.

The analysis of the literature data and the results from the chemical analysis of Siptex samples, indicate that compliance with REACH due to presence of hazardous chemicals, likely is not an issue in the sorted post-consumer textiles. Post-consumer textiles also seem to clear Oeko-tex and AFIRM requirements for the majority of the chemical substances on these restricted substance lists. But not all samples clear all the requirements from Oeko-tex or AFIRM. Bales with polyester materials were found to be most likely in breach of Oeoko-tex or AFIRM requirements.

Three remaining challenges were identified and discussed in the report. These include the need for more standards, further development of the colour sorting process and a need for more analyses and data-sharing on hazardous substances in post-consumer textiles.

Work package on quality assurance

To be of value to fibre-to-fibre and chemical recyclers, the fibre content of the Siptex sorted material needs to be of a reliable and consistent quality.

There were two main goals in the work package for quality assurance. The first goal was to enable the establishment of a range of quality assured products. The second goal was to increase the knowledge on hazardous chemicals in post-consumer textiles in general. To reach these goals, a method had to be developed to take representative samples from bales of post-consumer textiles.

Siptex aims to be able to sort on both fibre type and garment colour. However, sorting by colour has proven to be more difficult than expected and was at the time of writing this report still under development. Therefore, the focus of the quality assurance process has mostly been on fibre content quality and identification/quantification of hazardous chemical content.

Range of quality assured products

Five different outbound products of specific fibre content have been developed based on market demand. The products are referred to as ReFab® by SYSAV[2], which stands for "Renewable Fabulous Fabric". The existing ReFab products consist of the following fibre materials (by weight):

- 95% cotton
- 70% cotton
- 95% polyester
- 60% polyester
- 95% acrylic

Each of these products contains a minimum fraction of a certain fibre when looking at the average fibre content for several bales. For 95% cotton for example, this would mean that at least 95% of the average fibre content would be cotton. A bale however can still contain a t-shirt made from 100 % polyester.

Representative sampling

When developing a quality assurance program, it is important to have a sampling method that can accurately represent the contents of what is sampled. Compared to pre-consumer textiles, there are no guidelines or standards on how to take this type of representative sample of post-consumer textiles.

There are some major differences when comparing the sampling of pre-consumer textiles with that of sorted post-consumer textiles in that for example: 1) pre-consumer textiles are usually more

[2] https://www.sysav.se/foretag/material/textil--refab/refab-produkter/ . Samples were taken in the Siptex project to analyze this further, but the results were not ready by the time this report was written.

homogenous, e.g. a t-shirt of a certain model is likely to have the same properties as other t-shirt from the same batch, meaning that sending a t-shirt for analysis would often give a good representation of what all the t-shirts within the batch look like and 2) there are well-defined standards on how to take textile samples, how often to take samples and what chemicals of concern to look for in order to for example certify a certain material according to Oeko-tex or AFIRM guidelines.

Post-consumer textiles coming into a sorting facility on the other hand can be very heterogenous. Both inbound as well as outbound sorted textiles in Siptex are usually packed in large bales, with each bale consisting of roughly 300 kg of unshredded textiles of all types and colours, see Figure 1.

For each bale, there can be large differences in the type of textiles included, their fibre composition, where they were produced, when they were put on the market and therefore which hazardous chemicals could be present in the textiles. This makes taking a representative sample more difficult as taking only one or a few products at random from a bale would likely result in results that do not cover the entire bale and therefore increases the risks of overlooking something important (e.g. the occurrence of a chemical of concern over a regulatory limit).

Figure 1: An example out an outbound product of Siptex sorted materials with a 95% cotton content.

One challenge in the project was therefore to find a sampling method that was practical while giving a good representation of the content of a bale of post-consumer textiles. The ideal method would be to shred the full content of every bale, mix the materials and then send samples of this mixture for analysis. This method is however not feasible at the moment. An alternative sampling method, inspired by sampling methods used in the (recycled) paper industry and the testing of bales of hay, was used instead. The method consists of taking drill samples using a hay sampler from different places in the bale and then pooling and homogenising these samples followed by chemical analysis (see Figure 2).

Figure 2: Demonstration of the sampling method used in the Siptex project, in which drill samples are taken using a hay sampler (left picture) and an example of the shredded and homogenized samples that were send for analysis (right pictures).

Pilot study to test sampling method

Method

Two bales were assembled manually, so that each bale had a known composition of three types of fabrics with different colours. The motivation for using colours as an alternative to for example three types of fibres, was to reduce the costs and time required to send the fabrics for fibre analysis.

These two bales were only used for developing the sampling method. All other data in this report is based on sorted textiles from Siptex.

The compositions of the two bales studied in this case study are listed below, with each fraction expressed as a weight percentage of the total weight of the bale:

- Bale 1 composition: 2.5% red fabric, 2.5% white fabric, 95% blue fabric
    - This represents a bale that has 95% material purity with the remaining 5% being composed of two contaminations of 2.5% each (e.g. polyester and elastane in a cotton bale).
    - 95% material purity was chosen as it represents the highest purity that is currently included in the range of Siptex sorted materials.

- Bale 2 composition: 0.5% red fabric: 0,5% white fabric, 99% blue fabric
    - This represents a bale that has 99% material purity with the remaining 1 % composed of 0.5 % each content of a certain fabric or contaminations (e.g. polyester and elastane in a cotton bale) of 0.5%.

- 0.5% contamination was chosen as it could represent the occurrence of hazardous chemicals in higher concentrations or very small impurities.

Each bale was sampled 48 times with a drill sampler and each sample was then analysed to get the weight fractions of each type of fabric in the sample. The samples were taken according to Figure 2. With the first row of samples being taken at a distance of 100 mm from the top of the bale, the second one at 200 mm as so forth. The sixth and last row of samples was taken at a height of 200 mm from the bottom of the bale, to avoid sampling "clumped" fabrics that might form in the bottom of the bale due to the weight of the textile above. These "clumps" proved to be harder to sample with the hay sampler.

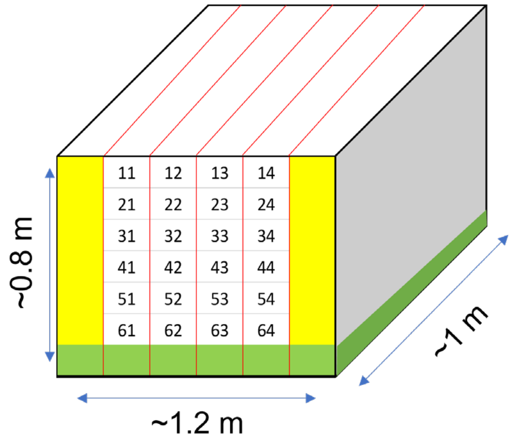


Figure 3: Illustration of where the samples were taken (the numbers represent sample IDs). Samples were taken from 2 sides of the bale. The red lines in the figure represent the wire that holds the bale together.

To take the core samples, a regular power drill was used in combination with a hay sampler (Wile Grovfoderborr, Figure 2). Core samples were taken at a depth between 300 and 380 mm. The core samples were removed from the sampler into a plastic tray and then moved by hand into plastic bags. The total time required per sample was roughly 2 minutes.

After sampling, the samples were sent to an analytical lab where they were sorted by colour and where each fraction was weighed. This made it possible to study if the sampling method gave representative samples.

Results and discussion

Sampling method

While causing some wear to the sampler, the hay sampler easily drilled through buttons and zippers. Metal and plastic bits were therefore frequently found in the samples which needed to be removed before shredding the samples as these might damage the shredder. As the hay sampler becomes warm during the sampling, it is recommended to have multiple samplers ready so that they can be switched during the sampling of multiple bales instead of waiting for the sampler to cool down.

Sample composition – studied by weight

The core samples taken weighed (after removal of zippers and buttons) on average 20,86 gram/sample (n=96) with a standard deviation of 4,70 g. Samples taken from the top, middle or bottom of the bale did not differ that much in their weight, indicating that the weight difference observed, could be due to other reasons than "packing intensity", for example the presence of zippers and buttons or the type of fabrics included in the sample.

The aggregated data on the composition for bale 1 and 2 is given in Table 1.

Table 1: The fractions calculated based on the samples taken in each bale. The nominal (known) fractions are given in brackets. E.g. in bale 1, the nominal fraction of red fabrics is 2.5 % but the measured fraction is 2.3%.

Bale	Avg. Sample weight (g)	Avg. Red fraction (%)	Avg. White fraction (%)	Avg. Blue fraction (%)
1	21,62 g	2,48 % (2,5 %)	2,61 % (2,5 %)	94,91 % (95 %)
2	20,10 g	0.81 % (0,5 %)	1,10 % (0.5 %)	98,1 % (99 %)

As is seen from the results in Table 1, the averages from the 48 samples comes close to the known composition of bale 1, indicating that the samples are likely to give a good representation of this bale. This is less so for bale number 2, where the difference between the nominal and measured values is larger. This in an indication that even taking 48 drill samples from a bale, is not sufficient to accurately measure small impurities of 0.5 %.

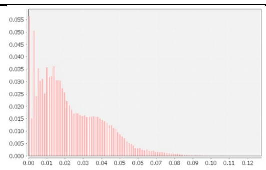
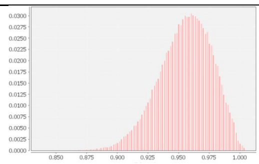
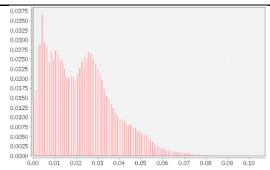
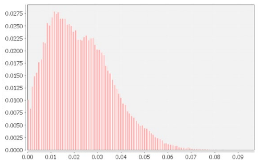
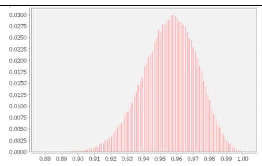
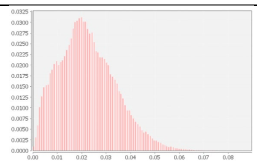
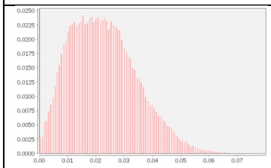
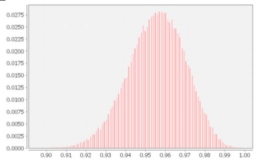
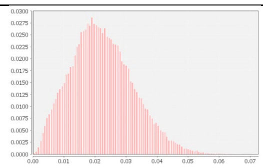
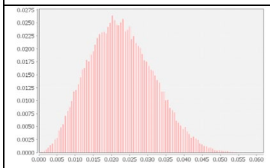
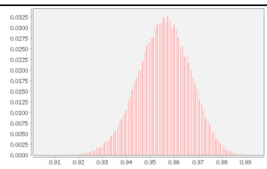
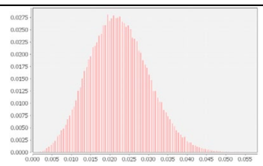
Sample representativity

Based on the results from Table 1, it was assumed that 48 samples gave a good representation of the bale contents (for bale 1). The sampling using 5, 8, 10, 15 and 20 replicates per bale was then simulated 100 000 times using KNIME (v. 4.6.3)[3], taking the required number of random samples out of 48, to see what the result distribution was like. For bale number 2, no additional analysis was performed, as the number of samples taken was found to be too low to represent the bale accurately.

When taking 15 replicates or more from bale 1 did the samples represent a normal distribution centred around the nominal fractions of each colour (See Table 2), thereby indicating that 15 samples could be sufficient to represent bales with a material purity of 95% or impurities of 2,5 %.

[3] https://www.knime.com/

Table 2: Each figure below shows the results from 100 000 simulations, in which 5, 8, 10 or 15 samples were taken randomly from the 48 samples taken from bale 1, and then used to calculate the average fraction of red, blue and white textiles in the bale

Simulated number of samples		Red fraction	Blue fraction	White fraction
5	Frequency			
8				
10				
15				
		Fraction		

Sample shredding, homogenisation and analysis

Samples were frequently taken during the Siptex project from bales of sorted materials that were ready to be shipped to customers. These samples were sent to RISE, where they were shredded multiple times (3-5) to achieve a well-mixed sample that could then be sent for analysis to certified labs. The following types of analyses performed:

- Fiber composition and quality:
  - Fibre composition (performed by AMSLab and Intertek)
  - Fibre length (performed by AMSLab)

- Hazardous chemicals
  - Compliance with REACH (performed by RISE)
  - Compliance with AFIRM (performed by Intertek)
  - Compliance with Oeko-tex 100 class 1 and 2 [4](Performed by RISE)

[4] Oeko-tex 100 class 1 is used for baby products, Oeko-tex class 2 is used for products in direct contact with skin, e.g. single layer garments or the inside of multilayer garments.

Analyses for fibre content and fibre length were done in triplicate for 24 bales of sorted textiles. For each bale samples, 15 drill samples were taken and shredded and then 3-4 subsamples were taken at random from the shredded fibres and then analysed. This was done to obtain an estimate of the variability within each sample and to see how well the sample homogenisation went.

Dominant fractions (e.g. cotton in bales of 95% cotton) had coefficients of variation (CV) ranging from 0,3 % to 20,6 % with an average of 2,56 %. While impurities (e.g. polyester in bales of 95% cotton) had CV ranging from 0,78 % to 90,73% with an average of 29 %.

The low variability between the replicates for the dominant fractions indicates that the samples were well homogenized. However, the higher variability observed for the impurities indicates that taking samples in triplicate is recommended when analysing small fractions in order to get a good measurement.

Results from the analyses of fibre content were used to monitor and optimize the automated sorting process while the results from the fibre lengths were used to have a benchmark when comparing sorted textiles from different sources[5].

For the analysis on hazardous chemicals, samples from different bales were often pooled together before sending to the lab, on the assumption that the samples were well mixed. These samples could for example contain shredded textiles of 3 different bales. This was done, as the cost for the chemical analysis of hazardous substances is much higher than that for measuring the fibre content or average fiber length. Pooling the samples therefore allowed many more bales to be screened for the presence of hazardous substances than would otherwise have been possible.

Routine manual analysis

Taking drill samples and sending the samples to certified labs as described above is both time consuming and expensive and is therefore not suitable for monitoring the sorting process on a more frequent basis. This way of sampling can therefore be complimented with an additional sampling that is performed for every 5-20 tons of material (depending on how well know the inbound material is) that is sorted out. During this sampling, 50 kg of materials can for example be withdrawn from the sorted material and checked by hand using either garment labels or a handheld NIR scanner.

The fibre composition stated on garment content labels have often been found to be inaccurate and therefore caution must be taken when using them as a tool or as a reference material[6].

[5] See for example the case study with ELIS: https://se.elis.com/sv/om-elis/nyhetsrum/nyheter/uttjanta-arbetsklader-blir-till-nya-textilier

[6] See for example the reports from https://refashion.fr/eco-design/en/clothing-labels-accurate-or-not? and https://www.circle-economy.com/resources/clothing-labels-accurate-or-not

Increased knowledge on hazardous chemicals

For the Siptex sorted materials it is not only important to ensure that a specific amount of fibre content is met but also that the materials comply with chemical regulations such as REACH and specific chemical requirements set up by customers (e.g. compliance with AFIRM or Oeko-tex criteria).

Analysing the samples according to criteria from AFIRM or Oeko-tex ensures that the analyses include hazardous substances that may occur in textiles, in line with (international) requirements from chemicals legislations. The criteria in AFIRM and Oeko-tex go beyond existing chemical legislation for potential hazardous substances, so by following them it possible to also analyse for substances not yet restricted by law. AFIRM or Oeko-tex do not cover all substances that are regulated today according to REACH but cover those that are expected to occur/be used in textile manufacturing. All substances from the Stockholm Convention and RoHS are covered by Oeko-tex and AFIRM.

Criteria from AFIRM and Oeko-tex overlap approximately 80% and where they differ, it is usually about differences in target values or the inclusion of potentially dangerous substances that are not yet restricted by legislation. With regards to the legislation, there are only a few isolated cases where criteria from Oeko-tex and AFIRM seem to differ from REACH. An example is Diazene 1,2-dicarboxamide (CAS: 123-77-3) which is included in the analyses from Oeko-tex but not AFIRM.

Due to the variability and uncertainty of composition of the inbound material, Siptex sorted materials from a sorting facility cannot currently be certified when it comes to hazardous chemicals as it would require taking samples from every bale that leaves the facility. Existing certification programs such as Oeko-tex for example can only start when the Siptex sorted materials have been turned into new yarn as the materials are then more homogenous.

To deal with this issue, the Siptex project investigated existing data on hazardous chemicals in post-consumer textiles and supplemented this with new data generated from chemical analyses on bales of Siptex sorted materials made of cotton, polyester, and acrylics. Existing data were extracted from two recent sources: A publication by RISE on post-consumer textiles[7] and a presentation by IKEA of Sweden and H&M[8]. These publications were chosen as they focus on post-consumer textiles and analysed the samples according to AFIRM or Oeko-tex.

Table 3 contains summaries of presence of hazardous chemicals for the Siptex sorted materials 95% cotton, 70% cotton, 95% polyester, 60% polyester and 95% acrylics. These summaries could be used to communicate the risk of hazardous substances occurring in sorted post-consumer materials between sorter and out-bound customers. Annex 3 contains an overview of all the substances covered by the analyses according to Oeko-tex 100, during the Siptex project.

[7] https://www.ri.se/en/what-we-do/projects/classification-and-risk-assessment-of-textile-for-material-recycling

[8] https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwi3-LHmy-76AhUrQPEDHZEyDnkQFnoECCYQAQ&url=https%3A%2F%2Fwww.naturvardsverket.se%2Fcontentassets%2Fbe04327b5a874955a5402d4f663d1632%2Fwebinar-collaborative-study-chemicals-recycled-textiles-hm-ikea.pdf&usg=AOvVaw1i6rKOUCJcTQbU3SDqKh5V

The analysis of the literature data and the results from the chemical analysis of Siptex samples, indicates that the presence of hazardous chemicals, in compliance with REACH is likely not an issue for the sorted post-consumer textiles. Only 1 sample was found in Siptex that breached the requirements for REACH for 1 substance (DMFu in a bale of 95% polyester). A large amount of hazardous additives is likely washed out or evaporated from the materials during the use phase.

Post-consumer textiles also seem to clear Oekotex and AFIRM requirements for the majority of the chemical substances on these restricted substance lists. Not all samples clear all the requirements, however.

For post-consumer textiles consisting mostly of cotton, the risk for finding hazardous substances above Oeko-tex class 2 limits seems quite small with only 1 substance found above Oeko-tex class 2 limits in 1 of the Siptex samples. Seven substances were found in concentrations over Oeko-tex class 1 or AFIRM limits.

For post-consumer textiles consisting mostly of polyester, the risk for finding substances in breach of Oeko-tex or AFIRM limits is larger than for cotton textiles. The study by IKEA of Sweden and H&M showed for example that 50% of the samples did not clear AFIRM requirements. Several of the Siptex samples also did not clear Oekotex class 1 or 2, due to the presence of chlorinated benzenes, PCP and Disperse orange 37/59/76 in some of the samples. The analysis according to Oeko-tex performed in this study did not include analyses for forbidden flame retardants as these were not expected to be present in the sorted materials in Siptex. Textiles treated with flame retardants are not accepted as inbound material to Siptex[9]. One of the screening results indicated the presence of hexabromocyclododecane in a polyester bale however, indicating the need to include flame retardants in future analyses.

For post-consumer textiles consisting mostly of acrylic, the risk for finding hazardous substances above AFIRM limits cannot be estimated as the study from IKEA of Sweden and H&M did not include any acrylic samples. The risk for finding hazardous substances in breach of Oeko-tex criteria seems to be small. PCP was found in one Siptex sample above Oeko-tex class 1 limits, but all other samples clear both Oeko-tex class 1 as well as 2. The study by RISE also indicated that contamination with wool fractions could lead to NP(EO)1-20 above Oeko-tex limits.

Caution should be taken for chemical substances that have been detected in breach of AFIRM or Oek-tex criteria and these substances should be monitored more frequently.

A more detailed overview of all the analyses performed within the Siptex project can be found in Annex 1. An overview of the data used for the assessments can be found in Annex 2.

Table 3: Summary of the assessments based on literature data as well as chemical analyses performed within the Siptex project.

ReFab product	REACH	AFIRM	Oeko-tex	Substance (groups) found below limits
95% cotton 70% cotton	Low risk for occurrence of hazardous substances above legal limits.	Low risk 5% cotton postconsumer samples analysed	Low risk for occurrence of hazardous substances above Oeko-tex class 2 limits	OPEO, BPA, Cr, Ni, Cu, Ba, NP(EO)1-20; 3,3'dimethoxybenzidine, 8:2 FTOH, PAHs, fluoranthene,

[9] See https://www.sysav.se/en/siptex/siptex---inbound-material/ for specifications ofor textiles sent to Siptex.

		by IKEA of Sweden and H&M were found breaching AFIRM limits for the following substances: OPEO, BPA, chromium and nickel	PCP was found in one Siptex sample over Oeko-tex class 2 limits. PCP, N-et-FOSE and Formaldehyde were found to breach Oeko-tex class 1 limits.	phenanthrene, PCP, N-et-FOSE, Formaldehyde, PFOS, N-Me-FOSE, Aniline, Disperse orange, Chlorinated benzenes and toluenes, DMAc, DMF, Pyrene, N-Nitrosatable substances, N-nitrosodiethanolamine, NP, NP(EO)
95% polyester 60 % polyester	Low risk for occurrence of hazardous substances above legal limits. DMFu was found in one Siptex sample over the legal limit of 0.1 mg/kg and should be included in future analyses.	High Risk 50% of cotton postconsumer samples analysed by IKEA of Sweden and H&M were found breaching AFIRM limits for the following substances: NPEO, BPA, trichlorobenzenes, dichlorobenzenes, cadmium and DEHP.	Risk for the following substances breaching Oeko-tex class 1 and 2 limits: Chlorobenzenes (mostly di- and tri-chlorobenzenes) were found over Oeko-tex class 1 and 2 limits in 3 Siptex samples. PCP was found over Oek-tex class 1 levels in 2 Siptex samples. Disperse orange 37/59/76 was found over Oeko-tex class 1 and 2 limits in 1 Siptex sample. Hexabromocyclododecane was found over Oeko-tex class 1 and 2 limits in 1 Siptex sample. Textils treated with flame retardant should not be sent to Siptex.	Cu, Ba, PAHs, Phenanthrene, Fluoranthene, Pyrene, Naphthalene, N-nitrosatable substances, MCP, OPP, 6:2 FTOH, 8:2 FTOH, N-Me-FOSE, N-Et-FOSE, Disperse brown 1, NP(EO), Dichlorotoluenes
95% acrylic	Low risk for occurrence of hazardous substances above legal limits.	Unclear risk No acrylics were analysed in the study by IKEA of Sweden and H&M	Low risk for occurrence of hazardous substances if the amount of wool can be limited. Otherwise, there is a risk of NP(EO)1-20. PCP was also found over Oek-tex class 1 limits in 1 Siptex sample	Ba, Cr, Cu, N-Me-FOSE, N-Et-FOSE, PFOA and salts, 8:2FTS, Chlorinated benzenes, chlorinated toluenes, NP(EO)

In the future, Siptex sorted materials consisting of other fibre types should undergo these same testing procedures, as different fibre compositions can contain different additives. A bale of 95% wool could for example contain other chemicals of concern.

Remaining challenges

More standards are needed

It became clear within the project that there is a lack of standards which can be used for the quality assurance of the Siptex sorted materials. For example, there is no established way of taking representative samples from bales of sorted material to test for fibre characteristics and the presence of hazardous chemicals. Nor is it possible to certify the outgoing materials with reference to hazardous chemicals as chemical certification programs such as Oeko-Tex can only be used to certify yarn and products further downstream. Standards are also lacking when it comes to defining different colour fractions of Siptex sorted materials. Reliability and consistency are of great importance for Siptex sorted materials to be able to compete with primary textile materials. It is therefore necessary to develop quality assurance standards for the above-mentioned aspects, i.e. fibre purity, colour, and chemical content.

Sorting by colour needs further work

Colour sorting is a feature that the VIS technology installed at Siptex can perform. However, the colour sorting proved to be challenging due to difficulties in categorising different colour shades and the lack of standards for how much impurity that can be accepted. Sorting trials were performed on a light and dark colour basis, but even this simplification produced variable results with some inconsistency, mainly due to how multi-coloured garments were categorised by the sensors. In addition, trials showed that colour sorting requires different calibrations for different fibre types (e.g cotton or polyester), making the sorting process more challenging. Even though colour sorting is challenging, there are incentives for sorting the textile waste based on colour. For example, an advantage of colour sorting in combination with fibre sorting is the potential avoidance of subsequent processes such as dyeing of the fibres obtained from mechanical recycling.

More data is needed on hazardous chemicals in post-consumer textiles

Most of the chemical analyses in the Siptex project were performed according to Oeko-tex criteria. These can be expensive as it requires a wide range of tests to measure the concentration of all chemical substances included in the criteria. Table 3 could be used as a first guideline for which chemical substances need more frequent monitoring in post-consumer textiles sorted in setting such as Siptex.

In the long run and with enough data, the analyses can be limited further to only include certain substances that have been shown to occur in post-consumer textiles and that need to be monitored more closely. Still, due to the costs involved with the analysis, this could require more collaboration and data sharing between actors and that the data is made openly available.

Annex 1: Summary of lab results for hazardous chemicals

Sorting Program	Pooled samples	Oeko-tex Class 1	Oeko-tex Class 2	RSL Screening (AFIRM)	REACH	Chemicals detected above limit values	Substances detected below limit values
Acrylics 95%	3	Fail (1 substance)	Pass	Pass	Pass	PCP over Oekotex class 1 levels (0.05 mg/kg, limit is below 0.05 mg/kg for class 1 and below 0.5 mg/kg for class 2)	Extractable Ba: 0.4 mg/kg N-Me-FOSE: 0.002 ug/m2 N-Et-FOSE: 0.016 ug/m2 PFOA and salts: 0.007 mg/kg 8:2 FTS: 0.016 mg/kg Chlorinated benzenes and toluenes: 0.45 mg/kg NP(EO): 20 mg/kg 1,2,3-trichlorobenzene: 0.17 mg/kg 1,2,4-trichlorobenzene: 0.28 mg/kg
Acrylics 95%	3	Pass	Pass	NA	Pass		Extractable Cr: 0.3 mg/kg Extractable Cu: 0.5 mg/kg Extractable Ba: 0.6 mg/kg
Cotton 70 %	3	Pass	Pass	NA	Pass		NPEO: 31 mg/kg N-nitrosatable substances: 0.12 mg/kg N-Et-FOSE: 0.038 mg/kg

Sorting Program	Pooled samples	Oeko-tex Class 1	Oeko-tex Class 2	RSL Screening (AFIRM)	REACH	Chemicals detected above limit values	Substances detected below limit values
Cotton 95%	3	Fail (2 substances)	Fail (1 substance)	Pass	Pass	PCP over Oekotex class 1 levels (0.09 mg/kg, limit is below 0.05 mg/kg for class 1 and below 0.5 mg/kg for class 2) N-Et-FOSE: 2.81 ug/m2 (Oekotex limit is below 1 ug/m2)	Extractable Ba: 0.5 mg/kg PFOS: 0.002 ug/m2 N-Me-FOSE: 0.041 ug/m2 8:2 FTOH: 0.099 mg/kg Aniline: 7 mg/kg Disperse orange 37/59/76: 13 mg/kg Chlorinated benzenes and toluenes: 0.13 mg/kg N-Nitrosamines: 0.1 mg/kg NP: 2.8 mg/kg NP(EO): 62 mg/kg
Cotton 95%	4	Pass	Pass	Pass	Pass		Extractable Ba: 0.8 mg/kg DMAc: 0.004 mg/kg DMF: 0.005 mg/kg NP(EO): 15 mg/kg (RSL screening) 1,2,4-trichlorobenzene: 0.28 mg/kg
Cotton 95%	1	Fail (1 substance)	Pass	NA	Pass	Formaldehyde over Oekotex class 1 levels (18 mg/kg, limit is below 16 mg/kg for class 1 and below 75 mg/kg for class 2)	Extractable Cu: 2.6 mg/kg Extractable Ba: 1.1 mg/kg PAHs (Sum 24): 1.17 mg/kg Fluoranthene: 0.34 mg/kg Phenanthrene: 0.59 mg/kg Pyrene: 0.24 mg/kg N-nitrosatable substances (NDMA)
Cotton 95%	3	Fail (1 substance)	Pass	NA	Pass	PCP over Oekotex class 1 levels (0.13 mg/kg, limit is 0.05 for class 1 and 0.5 for class 2)	Extractable Cu: 1.7 mg/kg Extractable Ba: 0.5 mg/kg

Sorting Program	Pooled samples	Oeko-tex Class 1	Oeko-tex Class 2	RSL Screening (AFIRM)	REACH	Chemicals detected above limit values	Substances detected below limit values
Cotton 95%	3	Pass	Pass	NA	Pass		Extractable Cu: 4 mg/kg Extractable Ba: 0.5 mg/kg Extractable Cr: 0.8 mg/kg N-nitrosodiethanolamine: 0.13 mg/kg
Polyester 60%	1	Pass	Pass	NA	Pass		Extractable Cu: 1.2 mg/kg Extractable Ba: 0.5 mg/kg PAHs (Sum 24): 0.42 mg/kg N-nitrosatable substances (NDMA): Phenanthrene: 0.42 mg/kg
Polyester 60%	3	Fail (3 substances)	Fail (3 substances)	NA	Pass	Chlorinated benzenes sum: 5.08 mg/kg, limit is 1. 1.4-Dichlorobenzene: 1.45 mg/kg 1,2,3-Trichlorobenezene: 1.53 mg/kg 1,2,4-Trichlorobenzene: 2.10 mg/kg	Extractable Cu: 0.4 mg/kg MCP: 0.03 mg/kg OPP: 1.4 mg/kg 6:2FTOH: 0.07 mg/kg 8:2 FTOH: 0.13 mg/kg
Polyester 95%	3	Fail (4 substances)	Fail (3 substances)	Fail (1 subtance)	Pass	PCP over Oekotex class 1 levels (0.07 mg/kg, limit is below 0.05 mg/kg for class 1 and below 0.5 mg/kg for class 2) Disperse orange 37/59/76: 235 mg/kg, limit is 50. Chlorinated benzenes sum: 3.84 mg/kg, limit is 1.	Extractable Ba: 0.4 mg/kg N-Me-FOSE: 0.005 ug/m2 N-Et-FOSE: 0.018 ug/m2 PFOA and salts: 0.003 mg/kg 8:2 FTOH: 0.055 mg/kg Disperse brown 1: 26 mg/kg NP(EO): 17 mg/kg (RSL screening) 1,2 Dichlorobenzene: 0.10 mg/kg 1,4 Dichlorobenzene: 0.15 mg/kg 2,3-/3,4-Dichlorotoluene: 0.13 mg/kg 2,5-/2,6-Dichlorotoluene: 0.12 mg/kg

Sorting Program	Pooled samples	Oeko-tex Class 1	Oeko-tex Class 2	RSL Screening (AFIRM)	REACH	Chemicals detected above limit values	Substances detected below limit values
						1,2,3, Trichlorobenzene: 1.26 mg/kg 1,2,4 Trichlorobenzene: 2.08 mg/kg Hexabromocyclododecane over AFIRM levels (73 ppm, AFIRM limit is 10 ppm)	
Polyester 95%	5	Fail (3 subtances)	Fail (2 substances)	NA	Fail (1 substance)	PCP over Oekotex class 1 levels (0.06 mg/kg, limit is 0.05 for class 1 and 0.5 for class 2) DMFu over Oekotex and REACH levels (0.19 mg/kg), limit is 0.1) Sum of chlorinated benzenes and toluenes over Oekotex levels (4.04 mg/kg and limit is 1 mg/kg).	Extractable Cu: 0.4 mg/kg PAH(Sum 24): 2.13 mg/kg Fluoranthene: 0.36 mg/kg Phenanthrene: 0.96 mg/kg Pyrene: 0.38 mg/kg Naphtalene: 0.43 mg/kg NP(EO): 23 mg/kg N-Me-FOSE: 0.014 mg/kg N-Et-FOSE: 0.024 mg/kg

Annex 2: Additional data used to make the assessments in Table 3

For 95% cotton and 70% cotton:

- In the study from IKEA of Sweden / H&M:
    - 172 samples of post-consumer cotton have been analyzed.
    - 5% of the samples showed levels above the AFIRM guidelines. Among other things for four substances: OPEO, BPA, chromium and nickel. The concentration itself is not public, so it is unknown if they also exceed limit values in the legislation.

- In the study from RISE:
    - 279 garments of post-consumer cotton have been analyzed[10]
    - 0% of the samples showed levels above Oeko-tex guidelines, however, it is unclear if the samples were tested for the presence of pesticides.
    - 0% of the samples showed levels above REACH requirements
    - Substances detected: NP(EO)1-20; 3,3'dimethoxybenzidine, chromium, copper, 8:2 FTOH, barium, fluoranthene and phenanthrene

- From analyses within Siptex:
        - See Annex 1

For 95% polyester and 60 % polyester:

- In the study from IKEA of Sweden / H&M:
    - 169 samples of post-consumer polyester have been analyzed in the study.
    - 50% of the samples showed levels above limit values from AFIRM. Among other things for the following substances: NPEO, BPA, trichlorobenzenes, dichlorobenzenes, cadmium and DEHP

- In the study from RISE:
    - 225 garments made of post-consumer polyester have been analyzed (incl. Wind and workout jackets, workout clothes and mixed garments)
    - 0% of the samples showed levels above REACH requirements

[10] Including: T-shirts, hoodies, bedlinen, shirts, denim and cotton blends (PES and other fibres: Work pants, Mixed garments

    - In the "Wind and workout jackets" fraction, 2,3,4,6-tetrachlorophenols were found in concentrations that exceed the Oeko-tex guidelines for class 1 (baby).

- From analyses within Siptex:
        - See Annex 1

For 95% acrylics:

In the study from IKEA of Sweden / H&M:

    - 0 samples of post-consumer acrylic have been analyzed in the study.

- In the study from RISE:
    - 100 garments made of post-consumer acrylic have been analyzed (incl. knitted garments and mixed garments (wool + acrylic))
    - NP(EO) occurs above the Oeko-tex limit values in mixtures of acrylic and wool.
    - 0% of the samples showed levels above REACH requirements

- From analyses within Siptex:
        - See Annex 1

Annex 3: Substances covered by the analyses according to Oeko-tex criteria in Siptex

In the Siptex project, the following chemical groups and substances were covered by the analyses according to Oeko-tex criteria:

- Formaldehyde
- Extractable metals
  - Sb
  - As
  - Pb
  - Cd
  - Cr
  - Co
  - Cu
  - Ni
  - Hg
  - Ba
  - Se
- Pesticides (Only in cotton fractions) [11]
- Chlorinated phenols
  - PCP
  - TeCPs
  - TrCPs
  - DCPs
  - MCPs
- Other chemical residues
  - Phenol
  - OPP
  - Bisphenol A (BPA)
  - Bisphenol B (BPB)
  - TCEP (Tris(2-chloroethyl) phosphate)
  - Dimethylfumarate (DMFu)
  - Quinoline
  - Benzene

[11] The individual substances are listed in Standard 100 by Oeko-tex: https://www.oeko-tex.com/en/downloads

- Phthalates
  - Diisononyl phthalate (DINP)
  - Buthylbenzylphthalate (BBP)
  - Dibutyl phthalate (DBP)
  - Di-ethylphthalate (DEP)
  - Di-methylphtalate (DMP)
  - Di(2-ethylhexyl)phthalate (DEHP)
  - Di-(2-methoxyethyl)- phthalate (DMEP)
  - Di-C6-8-branched alkylphtalates, C7 rich (DIHP)
  - 1,2-Benzenedicarboxylic acid, di-C7-11-branched and linear alkyl esters (DHNUP)
  - Di-cyclohexylphtalate (DCHP)
  - Di-hexylphthalate, branched and linear(DHxP)
  - Di-iso-butylphthalate (DIBP)
  - Di-iso-decylphthalate (DIDP)
  - Di-iso-hexylphthalate (DIHxP)
  - Di-iso-octylphthalate (DIOP)
  - Di-n-propylphthalate (DPrP)
  - Di-n-hexylphthalate (DHP)
  - Di-n-octylphthalate (DNOP)
  - Di-n-nonylphthalate (DNP)
  - Di-pentylphtalates (n-, iso- or mixed)
  - Di-n-pentylphthalate (DPP)
  - Di-iso-pentylphthalate (DIPP)
  - Isopentyl pentyl phthalate (NPIPP)
  - 1,2-Benzenedicarboxylic acid, dipentyl ester, branched and linear
  - 1,2-benzenedicarboxylic acid, di-C6-10-alkyl esters, 1,2-benzenedicarboxylic acid, mixed decyl and hexyl and octyl diesters with ≥ 0.3% of dihexylphthalate
- Siloxanes
  - Octamethylcyclotetrasiloxane (D4)
  - Decamethylcyclopentasiloxane (D5)
  - Dodemethylcyclohexasiloxane (D6)
- Organic tin compounds
  - TBT
  - TPhT
  - DBT
  - DMT
  - DOT
  - DPhT
  - MMT
  - MBT

    - MOT
    - TeBT
    - TCyHT
    - TMT
    - TOT
    - TPT
    - DPT
    - MPhT
    - TeET
    - TeOT
- PFC´S, Per-and polyfluorinated compounds
    - PFOS PFOSA, PFOSF
    - N-Me-FOSA, N-Et-
    - FOSA, N-Me-FOSE
    - N-Et-FOSE
    - PFOA and salts
    - PFHpA
    - PFNA
    - PFDA
    - PFUdA
    - PFDoA
    - PFTrDA
    - PFTeDA
    - Further Perfluorinated carboxylic acids: PFBA, PFPeA, PFHxA, PF-3,7-DMOA
    - Perfluorinated sulfonic acids: PFBS, PFHxS, PFHpS, PFDS
    - Partially fluorinated carboxylic/sulfonic acids: 7HPFHpa, 4HPFUnA, 1H,1H,2H,2H-PFOS
    - Partially fluorinated linear alcohols: 4:2 FTOH, 6:2 FTOH, 8:2 FTOH, 10:2 FTOH
    - Esters of fluorinated alcohols with acrylic acid: 6:2 FTA, 8:2 FTA, 10:2 FTA
    - PFOA Related Substances: 8:2 FTA, 8:2 FTOH, 8:2 FTS
- Colorants[12]
    - Cleavable carcinogenic arylamines
    - Aniline
    - Basic Blue 26
    - Basic Red 9
    - Basic Violet 3
    - Basic Violet 14
    - Disperse Blue 1

[12] The individual substances are listed in Standard 100 by Oeko-tex: https://www.oeko-tex.com/en/downloads

  - Disperse Orange 11
  - Disperse Yellow 3
  - Solvent Yellow 1
  - Solvent Yellow 3
  - Pigment Red 104
  - Pigment Yellow 34
  - Disperse Blue 1
  - Disperse Blue 3
  - Disperse Blue 7
  - Disperse Blue 26
  - Disperse Blue 35
  - Disperse Blue 102
  - Disperse Blue 106
  - Disperse Blue 124
  - Disperse Brown 1
  - Disperse Orange 1
  - Disperse Orange 3
  - Disperse Orange 37
  - Disperse Orange 59
  - Disperse Orange 76
  - Disperse Red 1
  - Disperse Red 11
  - Disperse Red 17
  - Disperse Yellow 1
  - Disperse Yellow 3
  - Disperse Yellow 9
  - Disperse Yellow 39
  - Disperse Yellow 49
  - Basic Green 4: Chloride, free, oxalate
  - Disperse Orange 149
  - Disperse Yellow 23
  - Acid Violet 49
  - Basic Violet 1
  - Solvent Yellow 2
  - Solvent Yellow 14
  - Basic Yellow 2: Solvent Yellow 34, hydrochloride & free base)
  - Disperse Red 60
- Chlorinated benzenes and toluenes[13]
- Polycyclic aromatic hydrocarbons (PAH)
  - Benzo[a]pyrene

[13] The individual substances are listed in Standard 100 by Oeko-tex: https://www.oeko-tex.com/en/downloads

  - Benzo[e]pyrene
  - Benzo[a]anthracene
  - Chrysene
  - Benzo[b]fluoranthene
  - Benzo[j]fluoranthene
  - Benzo[k]fluoranthene
  - Dibenzo[a,h]anthracene
  - Sum 24 PAH[14]
- Surfactant, wetting agent residues
  - NP
  - OP
  - HpP
  - PeP
  - NP(EO)
  - OP(EO)
  - 4-tertbutylphenol
- N-Nitrosamines; N-nitrosatable substances[15]

[14] The individual substances are listed in Standard 100 by Oeko-tex: https://www.oeko-tex.com/en/downloads
[15] The individual substances are listed in Standard 100 by Oeko-tex: https://www.oeko-tex.com/en/downloads

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