TRASH 2 CASH

Utilising zero-value waste textiles and fibres with design-driven technologies to create high quality products

Third Milestone Report

D9.4

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 646226

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Third Milestone Report

Work package	**WP9**
WP Leader	**RISE**
Date of submission	**2018-11-30**
Number of pages	**29**
D. lead beneficiary	**RISE**
Type	**R = Document, report**
Dissemination level	**PU = Public**

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1. Summary

Trash-2-Cash is an EU funded project under the Horizon 2020 research programme. The project started in June 2015 and will be running until the end of November 2018. It applies Design-Driven Material Innovation (DDMI) as a tool for development routes within design, materials research and manufacturing of new materials, services and products. The overall objective of the Trash-2-Cash project is to develop new materials and products via creative design from waste materials and industrial side-products or by-products from the textile and paper industries and to promote development within the creative sector by providing technology solutions for exploitation of waste streams and design for recycling. 18 partners from 10 countries formed a cross-disciplinary team of designers, material researchers, and manufacturers in combination with specialists on behavioural research and cost and environmental assessments. Having all these specialists on board means that waste materials can be used to create new fibres that can be spun and woven, knitted or formed, into high performance textiles and composites, which can then be made into innovative new products. The full chain is represented within the project.

The design team drives the material innovation in close collaboration with the material R&D and manufacturer teams. The project flow has three iterative phases called "Cycles" that repeat specific steps. The end/beginning of each Cycle corresponds with a milestone, the delivery of prototypes. The prototypes were finalized during the third and final Cycle of the project, the refinement Cycle into full product prototypes or Master Cases. These Master Cases are now ready and have been displayed for a broader audience during the Dutch Design Week in October 2018.

2. Introduction

The Trash-2-Cash project

Trash-2-Cash is an EU funded project under the Horizon 2020 research programme that started in June 2015 and will be running until November 2018. The full title for the project is “Designed high-value products from zero-value waste textiles and fibres *via* design-driven technologies”. The project applies Design-Driven Material Innovation (DDMI) as a tool for development routes within design, material research and manufacturing of new materials, services and products.

The budget for the project is € 8,928,995 and the European Commission is supporting the project with € 7,933,461.

Objectives

The overall objective of the Trash-2-Cash project is to develop new materials and products *via* creative design from waste materials and industrial side-products or by-products from the textile and paper industries and to promote development within the creative sector by providing technology solutions for exploitation of waste streams and design for recycling.

The general goals of the project are to:

- Integrate design, business and technology into a coherent discipline to establish new creative industries
- Develop new material and product opportunities *via* creative design from waste or process byproduct
- Reduce the utilization of virgin materials; improve material efficiency, decrease landfill volumes and decrease the energy consumption
- Use design for recycling with the vision of closing the material loop
- Create new business opportunities by adding the return loop of the discarded goods to be recycled into attractive products
- Promote development of the creative sector by providing technological solutions for exploitation of waste streams
- Demonstrate viable technical routes for value chains in the creative industry.

Consortium

A design-driven cross-disciplinary consortium combining science, technology, design and end-users was formed for the development of creative interior and fashion products from waste textiles, waste paper fibres and industrial by-products and scraps. Industrial and academic partners from the areas of textile and paper waste, processing, retailing and design set up this consortium. The full value chain is represented: academic and industrial designers defining the demands and initiating the material development processes, researchers applying new technologies to bring about new material solutions from the waste materials (provided from textile waste suppliers and paper waste suppliers), and industrial partners, both SMEs and larger companies, connected to various end-production sectors.

List of partners

COUNTRY	PARTNERS	EXPERTISE
Sweden	RISE Research Institutes of Sweden	Development of new cellulosic materials, LCA
	TEKO	Swedish Textile & Clothing Industries' Association
	SCA Obbola	Personal care and forest products
	Swerea IVF	Research on fibrous, polymeric materials
Finland	VTT Technical Research Centre of Finland	Material Science
	Reima	Children's outdoor clothing
	Aalto University	Lignocellulose and cellulose fibre. Design research
Italy	Grado Zero Innovation	Advanced materials research and prototyping
	Material ConneXion Italia	Research and consulting on materials
	SO.F.TER SPA	Production of thermoplastic materials
Spain	Cidetec	Industrial innovation
	Maier	Aesthetical plastic component supplier for the automotive industry
Netherlands	VanBerlo	Design agency
UK	University of the Arts London	Arts, fashion and design
Denmark	Copenhagen Business School	Sustainable consumer behaviour
Turkey	Söktas	Designer and producer of cotton and blended fabrics
Slovenia	Tekstina	Supplier of design & engineered fabric solutions
Germany	Soex Group	Used textile marketing and recycling

3. Project description

The Trash-2-Cash project aims to advance us towards the sustainable textile industry of the future, one that benefits all three aspects of sustainability, people, profit and the planet. Growing problems with paper fibre waste from the paper industry and textile fibre waste, originating from continuously increasing textile consumption, is challenged through design-driven innovation.

Every year we throw away over 3 million tonnes of textiles in the EU28 countries.

In this unique collaboration between designers, scientists and manufacturers, the Trash-2-Cash project tackled the growing problem of textile waste by developing state-of-the-art fibre recycling methods to create profitable new high-performance fibres that people like and that are kind to the environment.

Designers, design researchers, scientists, raw-material suppliers and end-product manufacturers from across Europe made up this cross-disciplinary and cross-sectorial consortium. 18 partners, from 10 countries, worked on this Design-Driven Material Innovation (DDMI) project, where the whole supply chain was represented. Having all these specialists on board meant that new fibres were spun and woven, knitted or formed, into high performance textiles and composites. These can then be made into innovative new products.

The partners worked together to develop state-of-the-art textile recycling technologies to produce new fibres that were “designed” for the kinds of products people want. The aim was that the new Trash-2-Cash fibres would not only “be made from waste” but would also be desired and used well before going into future recycling processes. This report describes the consortium’s success in achieving these goals.

Together the collaborators defined material properties and evaluated newly developed eco-efficient cotton fibre regeneration processes and polyester recycling techniques. Novel materials were constructed – starting at the molecular level – in order to generate new textile fibres and other products that are compatible with the environment for a sustainable future. Prototypes – for high quality fashion, performance textiles and automotive applications – were produced in a realistic test production environment. A schematic representation of the Trash-2-Cash concept can be found in Figure 1.

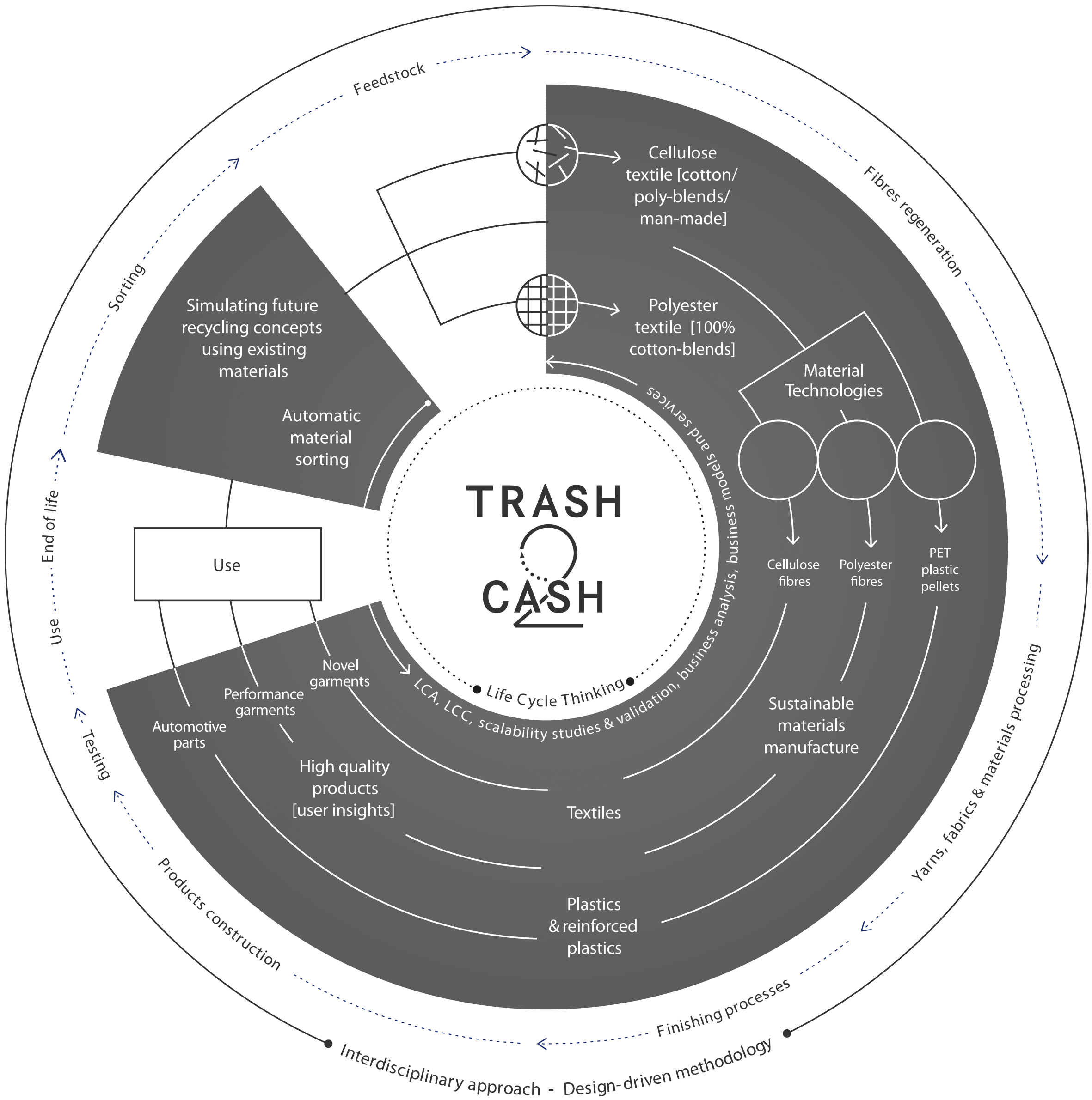

Figure 1 Schematic overview of the Trash-2-Cash circular concept

The Trash-2-Cash (T2C) team aimed not only to create amazing new regenerated fibres, but also pioneered Design Driven Materials Innovation (DDMI) and a whole new approach to developing materials.

The design team drove the material innovation in close collaboration with the material R&D team and manufacturing team. The project flow had three iterative phases called “Cycles” that repeated specific steps. The end/beginning of each cycle corresponded with a milestone, the delivery of a prototype. Figure 2 shows a schematic overview of the work packages and the iterative Cycles.

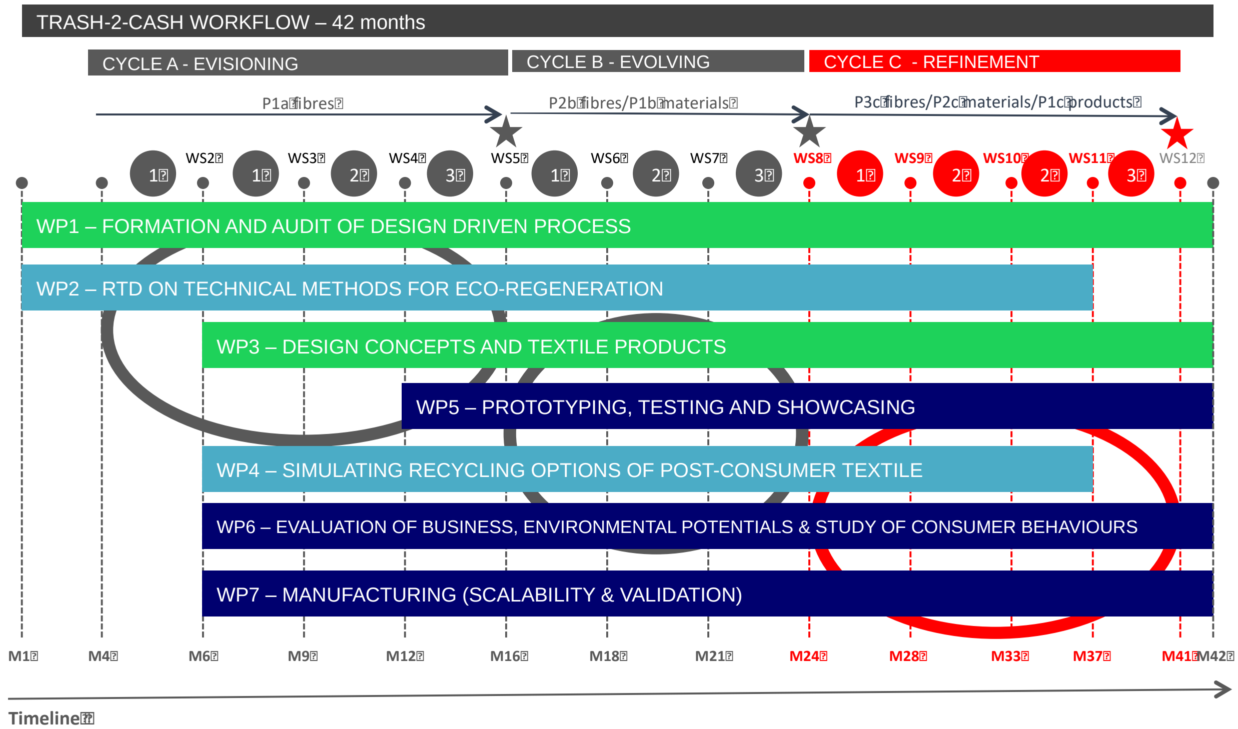

Figure 2 Schematic overview of the Trash-2-Cash workflow (including Milestone 3/ Cycle C)) basing on workshops in relation with months, Cycles, steps, and work packages

4. The third Cycle and the third Milestone

Overall work

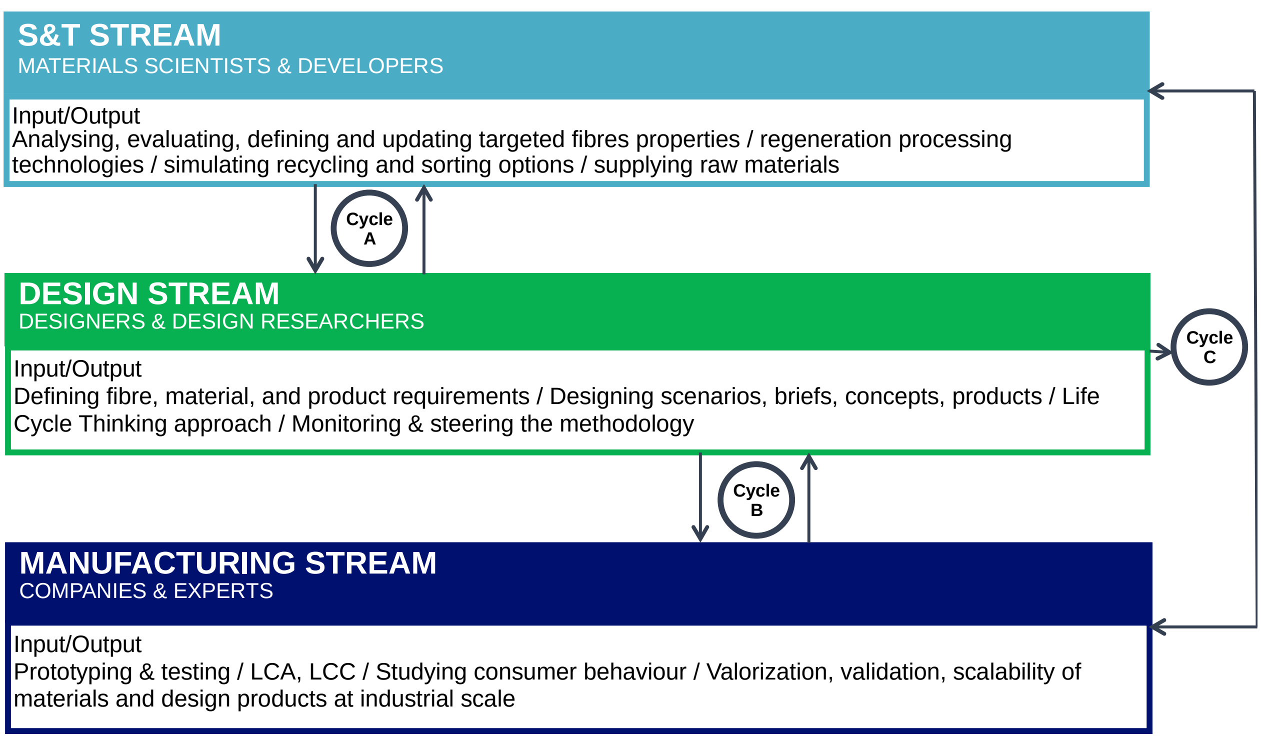

Figure 3 General T2C process: three streams in collaboration and iteration

The core of the T2C methodology is represented by three main streams (Figure 3) involved in three iterative phases called "Cycles", and each cycle is characterized by 3 iterative steps, the whole process is marked by 12 interdisciplinary workshops set up during the whole project (Figure 4). The end/beginning of each Cycle corresponded to milestones and specific outcomes both related to R&D and design and manufacturing stream:

<u>1st milestone</u>

1st generation of lab-scale material prototypes (R&D) and design scenarios.

<u>2nd milestone</u>

2nd generation of lab-scale material prototypes, 1st generation of related manufactured material prototypes (R&D) and design concepts.

<u>3rd milestone</u>

3rd generation of lab-scale material prototypes, 2nd generation of related manufactured material prototypes, 1st generation of product prototypes (R&D) and design Master Cases.

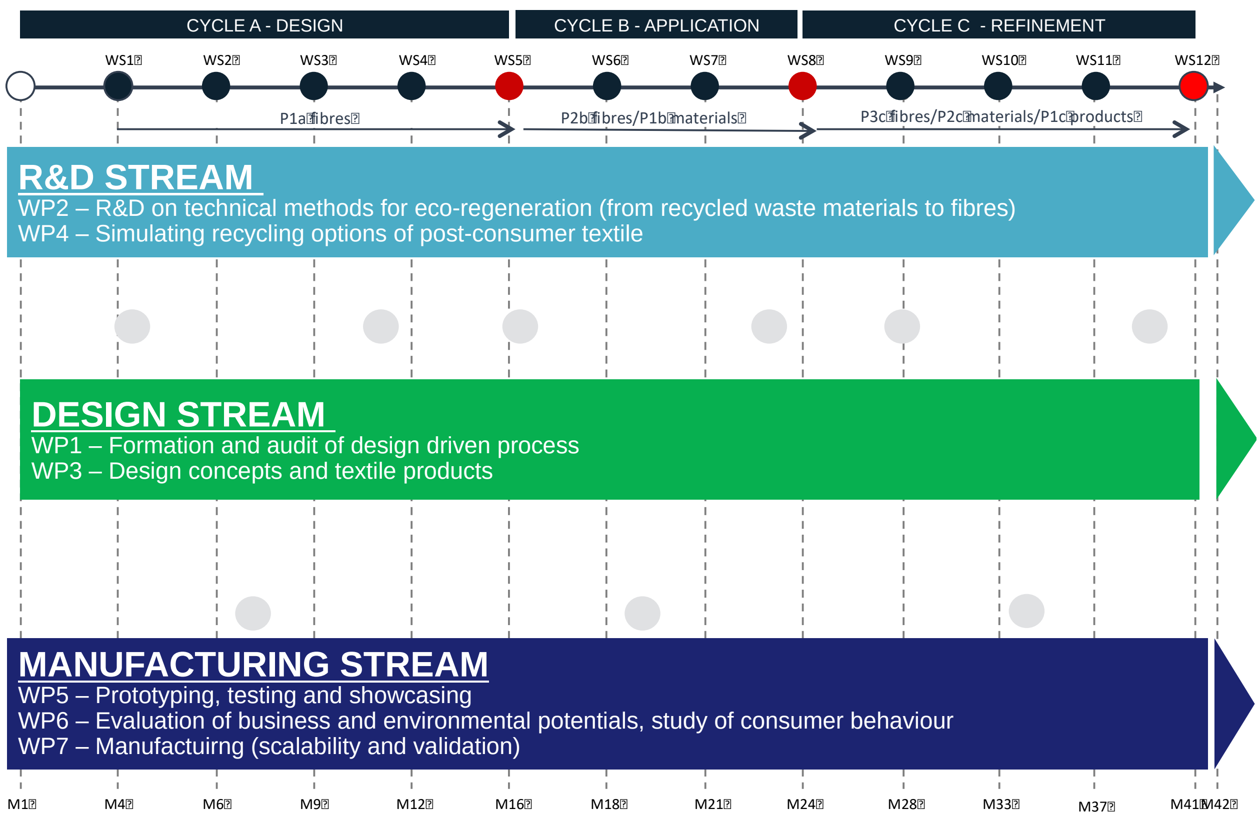

Figure 4 General T2C methodology: 3 main streams of competencies (and 7 Work Packages) with exchanges into 3 iterative cycles, characterized by 3 iterative steps each, during 12 interdisciplinary workshops

In order to create a more systematic and controlled process, the partners take three steps in each cycle: starting with the analysis of the potentialities, moving in the definition of new requirements, and ending with the development of solutions related to the level of each cycle (Figure 5).

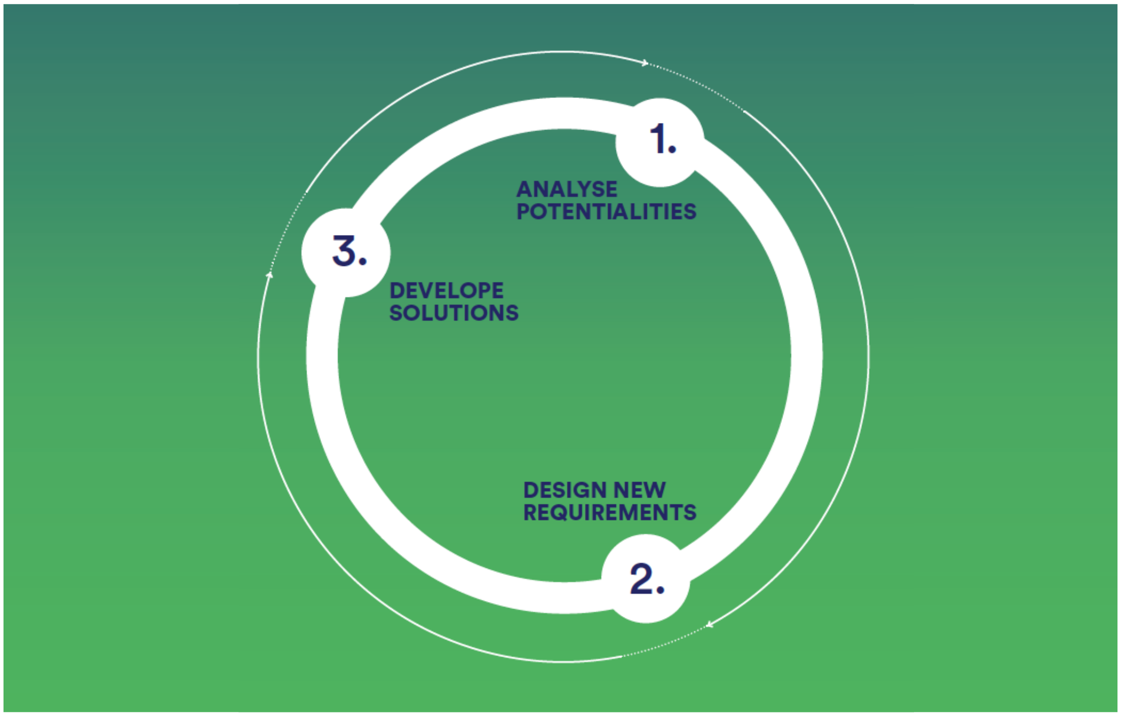

Figure 5 Three iterative steps in each iterative cycle

During Cycle A, the design Cycle, the overall work focused on setting up the activities and connecting the work-packages in a beneficial way as well as on aligning the three different streams: Design Research Stream, S&T Stream, and Manufacturing Stream in order to be coherent and to work towards the same objectives. The outcome of Cycle A was reaching the first Milestone[1] and producing the first prototype consisting of regenerated cellulose fibres (CEL) and regenerated polyester fibres (PES) made from waste materials.

The overall work during Cycle B, the application cycle, was focused on analysing the outcome of Cycle A and reaching the new requirements for the development of the next prototypes. The work within the second Cycle combined the knowledge of the three streams, designers, materials R&D, and manufacturers, and resulted in the second prototype. The consortium thus achieved the second Milestone of the project[2]. The prototypes completed during Cycle B were samples of fabrics (woven, non-woven, knitted) and reinforced plastics. The fabrics produced are based on cellulose, polyester, or a combination of the two in order to tailor specific fabric properties. The reinforced plastics consist of different fabrics in combination with plastics making them suitable for the specified applications.

Cycle C, the refinement Cycle, was the third and final cycle of the project. The work was based on the outcome of Cycle B and resulted in full product prototypes or Master Cases. These Master Cases are now ready and were displayed for a broad audience during the Dutch Design Week in October 2018. Below is a short summary of each Master Case[3].

0º SHIRT

Our goal was to design a shirt that had as close to a 0° impact on the environment as possible. The result is a shirt made from Ioncell-F fibres, a material produced from waste cotton textiles. Its

[1] D9.2 First Milestone report
[2] D9.3 Second Milestone report
[3] D5.16 Finished Prototypes 3 for showcasing at WS11

pale blue colour comes from the blue cotton feedstock, meaning no bleaching was needed, further reducing the material's impact.

REBORN – REWORN

Polyester fleece was revolutionary in the 80's but is now known to be hugely harmful to the environment due to the shedding of microplastic particles. The T2C reborn-reworn fleece is a soft and warm natural fleece made of cellulosic micro-fibres, produced from recycled cotton textiles that will not accumulate in the environment.

REACT MID-LAYER

Performance layers are soft and functional, wicking moisture away from the wearer's skin. But unfortunately, the materials currently used for mid-layer garments have large environmental impacts. The T2C alternative mid-layer material made from recycled cotton has hydrophobic properties added to the fibre, ensuring that design for sustainability does not compromise performance.

DENIM NATURE JEANS

Polyester-Cotton blends are the most common materials used in clothing. Elastane, added for the manufacture of stretchy jeans, seriously disrupts textile waste sorting and recycling. Denim NAture Jeans are made from yarn that is both recycled and recyclable. Trash-2-Cash researchers have replaced the troublesome elastane with stretchy, recycled polyester, and used an innovative elastic weave structure, ensuring that the comfort and performance of the garment is maintained.

R3 COAT

The R3 raincoat is made from recycled materials is recyclable and breathable. To make sure the materials get back to where they need to be for recycling at end of life, an innovative business model was developed based on renting, not owning these raincoats.

FASHION FASCIA

By law, cars of the future will be increasingly required to use recycled and recyclable materials in their production. The Trash-2-Cash recycling technologies make possible several new modes for manufacturing visually appealing, high-quality automotive interior plastics using recycled plastic pellets, recycled textiles and recyclable resin.

Work within the work packages

A summary of the work performed within the work packages (WPs) 1-9 can be found below.

WP1 Formation and audit of design driven scenarios

WP leader: Material ConneXion Italia

Aim of WP

In the third phase of the project (Cycle C) WP1 aimed to continue to set up and manage the interdisciplinary dialogue among the different competencies involved into the project (R&D, design, manufacturing and other expertise) fostering the design-driven methodology in the T2C workflow. This objective was mainly executed during specific meetings (workshops) and also supporting the dialogue and main actions between meetings. WP1, with the formation of a Methodology Team, had the role to develop the right background, tools, approaches related to design culture in order to develop a design-driven process.

If WP1-task 1 focused on applied methodology (workshops planning, set up of tools, general process and steps, specific audit) the WP3-task 5 had the role to capture and analyse the process and to feed back to WP1 and inform decision-making by the Methodology Team. This team was composed of representatives from design research - UAL and Aalto Arts, the project coordinator and materials R&D - RISE, the facilitator - Material Connexion Italia, design industry - VanBerlo, and manufacturing - Reima.

The applied methodology aimed to enable designers, supported by manufacturers and other experts, to affect the R&D decision-making in which they usually do not have the possibility to be involved. For this reason, the process is named Design-Driven Material Innovation (DDMI).

The project structure (Cycles, steps, workshops) helped WP1 to audit the knowledge transfer processes, with the proper interdisciplinary exchange of information in accordance with activities and tasks, as well as the overall project approach based on a design-driven methodology.

The 12 interdisciplinary workshops aimed to execute interdisciplinary activities and promote dialogue among partners. The workshops were aligned with significant steps in the project where knowledge exchange was particularly important or when key results would be ready. The experimental and exploratory workshops (2-days meetings) were set up as hands-on session and "platforms of discussion" referring to design culture and tools. Each workshop was planned case-by-case with specific aims and based on the specific step and progress of the project, considering specific tasks and outcomes.

Achieved during Cycles A and B

In Cycle A, 5 tasks of WP1 were executed. With task 2 (Knowledge sharing activity to feed design and R&D with market and end-users needs) and task 3 (Explore potentialities and properties - technology challenge) the partners initiated the knowledge-sharing activities. The design investigation and problem setting activity received the initial inputs from technological, manufacturing and business perspectives: state-of-the-art for processing technologies involved in the project (limits and potential), market trends, user perception, and material trends in the field of eco-fibres. The execution of Task 4 (Envisioning of primary scenarios for the application sectors) and task 5 (Identify and define primary design-driven material requirements and characterization of the eco-fibres) analysed and summarised these inputs, thus providing design scenarios and primary design-driven material requirements. Task 1 (Set up and monitor the material researcher-designer-manufacturer exchanges) was developed during the whole project, achieving in Cycle A and B 8 workshops which in turn resulted in the identification and development of related activities and the tools to be used. The task 1 actions and workshops were continuously implemented and refined in order to support step-by-step the knowledge sharing and the interdisciplinary interactions among the disciplines for the progress of the Design-Driven Material Innovation methodology.

Tasks during Cycle C

In Cycle B the Task 1 aimed to align the various disciplines so that inputs and outputs were received at appropriate times for the project work to progress in a ‘design-driven’ manner. In Cycle C, the WP1 partners organized and set up 4 workshops, from month 24 (September 2017) to month 41 (October 2018), associated with the start/end of the 3 steps of the cycle (1-analyse potentialities; 2-define requirements; 3-develop solutions).

In Cycle C, all the workshops focused in specifying and implementing the Design Master Cases from the various competencies and perspectives as well as through a Life Cycle Thinking approach. The Master Cases were design concepts selected to be ready for new product development, prototyping and in-depth analysis in the industrial scalability and validation phase. The workshops were: WS09-Master Cases Analysis (LCA) in Helsinki, Finland, in September 2017; WS10-Master Cases Specifications (storytelling) in Ajdovscina, Slovenia, in February 2018, WS11-Master Cases Implementations in Borås, Sweden, in June 2018, WS12 Process Reflections and showcasing results in Eindhoven, The Netherlands, in October 2018.

Results

The main results of WP1 are the workshops themselves and their outcomes, including the generated input/output dynamics, the developed tools, activities, homework, as well as the structure of the hands-on sessions. All of the 12 workshops developed during the T2C project together with how the project as a whole was managed represent the applied DDMI methodology. A full description of this applied methodology and how the interdisciplinary collaboration was enabled is summarised in a public report (D.1.7 “White paper for design driven methodology”) entitled “In Search of DDMI”.

The report also contains the summary of the new knowledge about DDMI acquired during the project as result of the design research developed in WP3. It provides core recommendations on how the design-driven approach and explorative methods can enhance the collaboration aspect between disciplines to achieve DDMI and includes the strengths and weaknesses of the applied methodology.

WP2 R&D on technical methods for eco-regeneration (from recycled materials to fibres)

WP leader: VTT Technical Research Centre of Finland

Aim of WP

The aim of the WP is to provide required raw material samples for demonstrator preparation and develop required technologies for refining and spinning.

Achieved during Cycles A and B

Two main raw material streams were explored in this WP; cellulose and polyester. In the cellulose stream, refining, dissolution and spinning of regenerated cellulose fibres from different raw-material sources were studied. Regeneration technologies were cold sodium hydroxide dissolution technology, cellulose carbamate technology and Ioncell-F technology.[4] The used raw materials were recycled paperboard, pre-consumer cotton fabrics and post-consumer cotton-polyester blend textiles. Refining procedures to remove dye from the cotton fabrics were developed as well as a procedure to fractionate polyester and cotton fractions from the blend textiles. Ioncell-F yarn from pre-consumer cotton waste material was spun for prototype 2 testing. In the polyester stream, a new recyclable nanocatalyst for depolymerisation of polyester was synthesized, tested and recovered. The set-up configuration of the melt-mixing plant for the feeding and compounding of post-consumer PES waste were evaluated. Pellet materials were prepared with a melt mixing process for injection trials and for melt spinning trials. The properties of the feeding material such as particle size, bulk density and moisture content, were found to be critical for processing.

Tasks during Cycle C

During Cycle C the concept to retain colour for reactive and vat dyed cotton materials was developed. Ioncell-F fibres and yarns were spun from the vat dyed materials for prototype 3 (to be used in design concepts). Dry and wet tenacity of the fibres were at high level, 44.4 ± 3.3 cN/tex (dry) and 40.2 ± 3.0 cN/tex (wet). A summary of the yarn spinning parameters and the fibre properties can be found in Table 1. Ioncell-F fibres having hydrophobic properties were also developed and yarn spun. Several technical papers based on the T2C results are under preparation.

Table 1. Vat dyed Ioncell-F yarn spinning parameters and the fibre properties

Twist	Count (Nm)	Count (Ne)	Twist multiplie	Linear density (tex, g/1000m)			Breaking force (cN)			Elongation at break (%)			Breaking tenacity (cN/tex)		
				AVG	ST. DEV.	CV%	AVG	ST. DEV.	CV%	AVG	ST. DEV.	CV%	AVG	ST. DEV.	CV%
700	56	33	3.09	17.83	1.53	8.61	445.63	82.97	18.62	7.56	0.86	11.34	24.99	4.65	18.62

Results

During the project several process development achievements were reached. The development of cotton textile waste refining procedures to either remove impurities and dyes or to treat the waste material while maintaining the original colour are important parts of textile fibre recycling and utilization. They also ensure the material quality in the subsequent process steps. The first procedure totally resets the existing history of the waste material and the latter, together with colour retaining Ioncell-F fibre production, minimizes the processing steps and environmental load when further dyeing of textiles is not needed. By making the fibres hydrophobic, the functionalization of Ioncell-F fibres widens the usability of the fibres and simplifies textile production technologies. The fractionation procedures for cotton-polyester blends and further utilization of these fractions will provide wider use of textile waste streams for recycling. The

[4] D2.22 Comparison of the cellulose dissolution technologies

recyclable nanocatalyst developed for depolymerisation of polyester increases the effectiveness of the polyester recycling.

WP3 Design concepts and textile products

WP leader: Aalto University, School of Arts, Design and Architecture

Aim of WP

The aim of WP3 was to create innovative textile and automotive plastics and composite product concepts via multidisciplinary collaboration. The base for the creative work was the design-driven approach. WP3 (Design) fed to WP2 (Fibre forming) and WP5 (Prototyping) by creating design briefs about material properties and product concepts in cycle A and B. The 3rd brief illustrated Design Concepts called Master Cases which then input to all WP's which again fed back to the design of products (Cycle C). Thus, the design input to R&D/S&T streams, again, after refining, input back to the design stream. Generally, every task in WP3 needed high-level collaborative actions from each WP and partner.

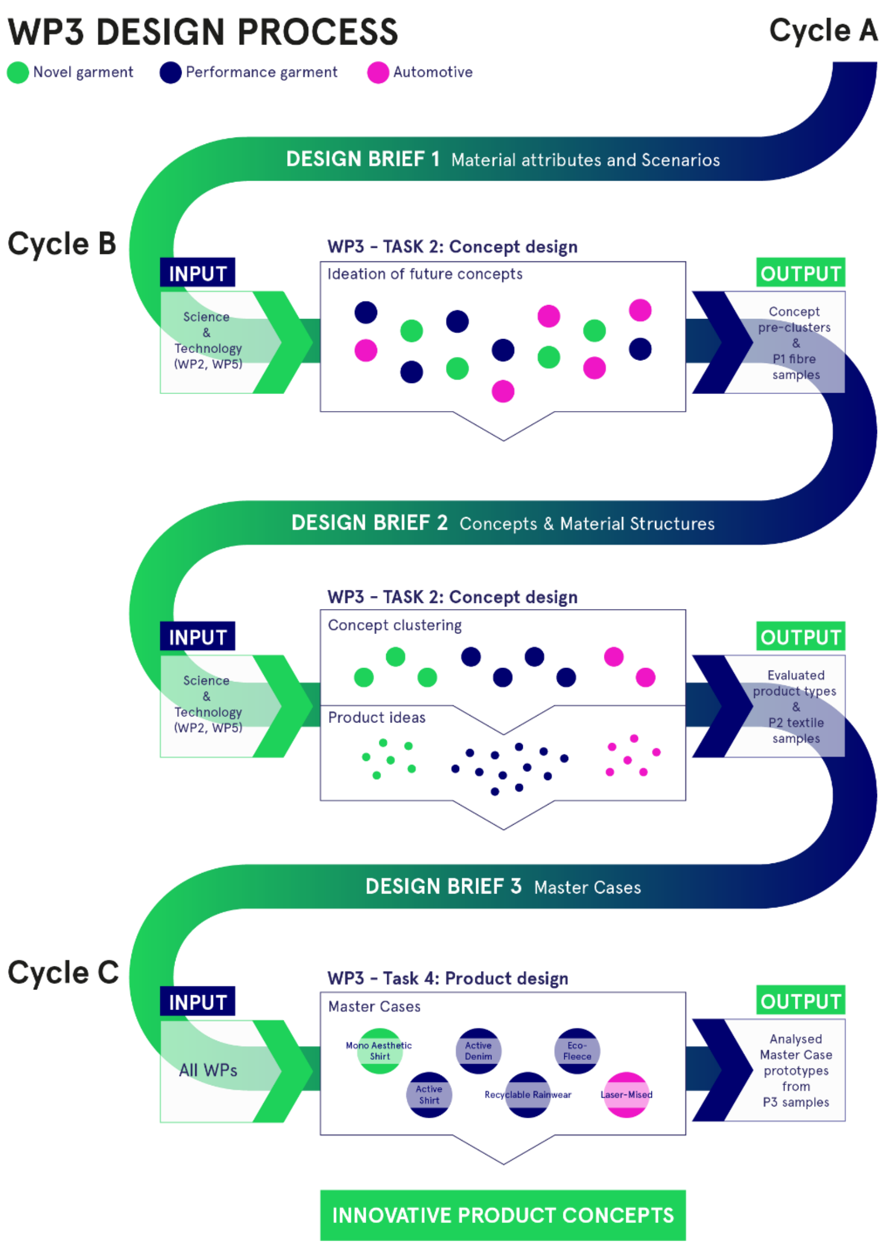

Figure 6 Design process.

Achieved during Cycles A and B

After cycle A, the first design brief was produced. It gathered the data (visions and pre-scenarios) from WS1 to WS4 and from meetings with scientists, designers and end-user companies and translated that to the most innovative and valuable material attributes for the yarn spinning and fabric manufacturers.

In Cycle B, the second brief was delivered in January 2017, which provided the clustered concept ideas and material attributes. After the creation of the concepts, the ideas were evaluated and cut down by identifying similarities from the material property perspective. These material properties were transformed to input for prototyping of fibre and textiles. After the evaluation, six final concepts, or Master Cases, were selected to be prototyped in cycle C.

Tasks during Cycle C

During cycle C the main aims in the design process were to design products from design concepts, which were prototyped and showcased during Dutch Design Week 2018. Manufacturers of the prototype fibres, textiles and end-products were also supported by this task. Each Master Case concept had an owner (one partner), who was responsible for product designing. In the applied methodology task, the aim was to gather reflections from partners about their experiences in the project. Two sessions were conducted. The first, in WS10, asked partners to think about 'DDMI Ingredients', what would they recommend is needed to make a project like T2C work (T2C recipe). The second session, in WS11, asked participants to 'find DDMI' in the master cases. They were asked to think about how other disciplines in the project had affected their work, and then to identify which master case best represented the interdisciplinary work. The other main objective in this period was to finalise the data collection and draft the report sections for an internal report on product designs A plan was made with the main partners, UAL, AA and MCI and all researchers collaborated to create a draft document that was shared in August 2018. The report was finalized and delivered on schedule in November 2018.

Results

Cycle C produced six innovative product concepts (Master Cases) with around 10 product prototypes where innovations can be realized in material properties, production process and/or business models. The outcomes of the methodology are a number of recommendations and the White Paper: "In search of DDMI – White paper on applied design-driven material innovation methodology"[5]. In addition, WP3 produced the T2C general scheme of the project process, which was developed by MCI in collaboration with the Methodology team and a graphic designer.

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[5] D1.7 White paper for design-driven methodology - public version

WP4 Simulation recycling options of post-consumer textiles

WP leader: RISE

Aim of WP

Textile-to-textile recycling generally requires high-quality sorted textile waste fractions. One way to obtain this is by utilizing pre-consumer waste of high quality and sorted waste fractions. Nevertheless, the strategy to target pre-consumer waste for textile-textile recycling does not promote a circular system as the textile ultimately becomes post-consumer waste. Therefore, strategies to handle the post-consumer waste must be explored in order to achieve a circular textile-to-textile recycling system. However, utilizing post-consumer waste presents challenges such as weakened end-of-life fibres after long-time service as well as unsorted textile waste streams. The aim of this WP was to evaluate the quality of post-consumer textile fibres subjected to wear and laundering after long-time service to see if they can be regenerated into new fibres in the Trash-2-Cash regeneration processes (Tasks 1 and 2). One important aspect of this was also to simulate the post-consumer quality of the developed Trash-2-Cash fibres to understand if they would be of sufficient quality to be regenerated again. Furthermore, this WP analysed the potential of employing a fully automated sorting system for post-consumer textile waste streams for textile recycling (Task 3).

Achieved during Cycles A and B

Task 1 and 2 were connected to the purpose of evaluating the effect that service-time has on the macromolecular quality of cellulosic textile fibres as well as the cellulose content in polycotton blends when the fabric has been subjected to extensive washing. In Task 1, cellulosic textiles and polycotton blends were subjected to simulated laundering and chemically analysed for their molecular molar mass. The study also included discarded hospital sheets taken out of rotation from a textile service company. In Task 2, obtained data from the study was discussed with a focus on the consequences for the circularity of the fibres. This contributed to optimizing the feedstock flows in the Trash-2-Cash processes.

To fulfil an effective value circle, sorting technologies to sort by fibre composition need to be adapted and optimized. Task 3 of WP4 assessed the potential of state-of-the-art near-infrared technologies for automated sorting of discarded post-consumer textiles. Having in mind that clothing can consist of rather complex materials when many layers or many blends are used that have different attributes. In this evaluation only monolayer garments were considered. The feedstock and sorting aspects based on the test results were fed into Cycle B for the evaluation of the Trash-2-Cash concepts/prototypes.

Tasks during Cycle C

Finalizing two reports describing the work and the results of this WP.

Results

The WP resulted in two public reports:

• D4.2 "Evaluation and sorting of post-consumer cellulosic textile waste for chemical textile recycling based on degree of polymerization". The report gives a better understanding of which end-of-life cellulosic textiles can be used for chemical recycling based on their composition, type of wear life and laundering. This was done by generating end-of-life textiles and looking at the cellulose content, chain length and molecular weight distribution before and after laundry. It was discovered that post-consumer textiles laundered under household conditions only had a similar or slightly lower degree of polymerisation, DP, (up to 15 % decrease) than virgin textiles. However, post-consumer textiles laundered under industrial conditions resulted in a substantially lowered DP (up to 80 % decrease). A larger relative decrease in DP can be expected for cotton compared to man-made cellulosic textiles. Furthermore, no significant decrease in cellulose content could be observed for laundering of CO/PES and Lyocell/PES blends. Therefore, it is reasonable to assume that the garments will retain the original composition stated on the label at the end-of-life. Cotton-based post-consumer waste that was laundered under household conditions resulted in having the most suitable molecular weight distribution for chemical textile recycling using Lyocell-type processes.

• D4.1 “Best available techniques for large scale operational technology to automatically sort non-traceable recycled textiles”. The report describes utilizing NIR technology as an automated online tool for an increased sorting quality of post-consumer textiles collected for recycling. It was discovered that garments having a pure fibre typeof either PES, PA, acrylic, wool, man-made cellulosic or silk can be identified and sorted accordingly. Some polycotton blends could also be identified whereas other blends were often not recognized by the system. In particular, blends containing a minor fibre constituent, mainly elastane, remained unidentified. Further, it was also observed that multi-layered garments, with layers of different material and/or composition, were difficult for the automated NIR system to sort. These challenges cannot be met only by improving the sorting system, a systemic change must be encouraged where designing for circularity is at the heart of textile development and commercialization. Fibre blends must be considered not only for the functionality/comfort of the garment but also for their ability to be sorted correctly after use.

WP5 Prototyping testing and showcasing

WP leader: Cidetec

Aim of WP

WP5 aimed at running two iterations of prototyping activities. The first iteration, corresponding to the application cycle (Cycle B) had as an objective to generate material prototypes, named Prototypes 2 (P2), and to realize a preliminary screening of finishing treatments. Subsequently, the second iteration, corresponding to the refinement cycle (Cycle C), intended to generate, ready-to-product materials with final finishing treatments to be used for the validation of the manufacturing value chains. The development of these final materials, named Prototypes 3 (P3), is based on the improvement of the P2 materials.

Both iterations implied a direct collaboration between WPs, especially between WP5 and WP2 (Fibres regeneration toward cellulose [r-CEL] and polyester [r-PET] yarns), WP3 (Design concepts definition & specifications) and WP7 (Manufacturing processes).

The end of these iterative prototyping activities corresponded to the fabrication of selected products for showcasing, and to their dissemination (exhibitions, photographs/videos) to non-expert audiences, and their evaluation through the feedback received by consumers and designers.

Achieved during Cycles A and B

During Cycle A, Tasks 1, 2 & 3 started with a preliminary valorisation plan for r-CEL and r-PET to be used for P2, a preliminary finishing testing plan for material samples based on r-CEL and r-PET, and the organization of the production to create different typologies of material samples for P2.

During Cycle B, the tasks were continued with the testing of P1 r-CEL- and r-PET-derived material samples in order to provide improvement guidelines for the manufacturing of P2. A first tuning/testing of preliminary finishing treatments to be applied on P2 was also made, starting from the input of Task 1, and the design specifications coming from WP3. Finally, different P2 material samples based on r-CEL and r-PES were manufactured in the form of fibres/yarns, knitted, woven and non-woven fabrics, and reinforced plastics. Preliminary finishing treatments coming from the first iteration were applied to them.

Tasks during Cycle C

Cycle C started with setting and carrying out a testing campaign of the various typologies of P2 materials (fibres, yarns, fabrics, fabrics, plastics, reinforced plastics) to provide guidelines for the production of improved Prototypes 3 (P3). In the meantime, a second step of the finishing technologies study was run, according to the needs of each design concept for functionalizing, colouring, and decorating.

Once the guidelines resulting from these first tasks were defined, Cycle C proceeded with the production of P3 material samples and their finishing, from the fibre level to the final fabrics/plastics/reinforced plastics. To do so, the specifications defined by WP3 for each of the seven selected design concepts, called Master Cases, were strictly followed.

Finally, Cycle C ended with the fabrication of ready-to-product prototypes for showcasing.

Results

An important step of Cycle C was the selection of six Master Cases to be developed. From this selection, the prototyping activities were organized from the fibre level to the full garments/full plastic parts. At the r-CEL fibre level, blue r-CEL fibres were successfully obtained through the Ioncell-F process from blue model textile waste (cotton specifically coloured to study process feasibility). This demonstrated the possibility to keep the waste textile colour during the recycling process, and thus avoid a dyeing step during the new product manufacturing. On these blue fibres, a spin finish applied to the recycled fibres provided great progress in the yarn spinning process, resulting in a good quality yarn, which was then used for weaving and knitting at industrial scale.

Regarding r-CEL fibres, it was demonstrated that the Ioncell-F process can lead to microfibers, to obtain fleece-type fabrics based on cellulose. It should also be noted that hydrophobic fibres were produced by using different bio-based hydrophobizing agents, and spinning trials were realized, showing that a balance must be found between hydrophobicity and spinnability.

From r-CEL fibres, full garments were obtained at the end of the prototyping chain: a man's shirt made from the previously obtained blue woven fabric; and a toddler outer layer from the formerly produced blue knitted fabric.

As for r-PET fibres, coming from the depolymerization/repolymerization process of PET-based textile waste, several batches were produced and spun into yarns with different characteristics (dtex, f, tpm), according to the specifications defined by WP3 for the corresponding Master Cases. From these yarns, fabrics were produced by weaving. The content of r-PET yarn in these fabrics depended on the final application: in one case, a 100% of r-PET based fabric was fabricated by weaving; in the other case, fabrics using r-PET yarn only for the weft were produced, showing the possibility to use r-PET fibres to replace elastane fibres in stretch fabrics. This result opens up interesting new possibilities. On the 100% r-PET fabric, a recyclable polyurethane coating was optimized and applied to obtain a waterproof textile. In addition to fabric weaving, the r-PET produced using this process was also transformed into an r-PET non-woven, through melt-blowing, to explore the potential use for design purposes (decorative reinforced plastics) of printed non-wovens in a bio-based recyclable epoxy resin.

From r-PET fibres, full garments were obtained at the end of the prototyping chain: a pair of jeans and a pair of mittens for kids.

Concerning the melt-mixing stream, various formulations of upgraded r-PET were prepared and tested at lab-scale to achieve the mechanical properties, laser-marking sensitivity and colour grade meeting the specifications defined in WP3. The achievement of an adequate r-PET pellets formulation validated the feasibility of PET textile waste up-grading for use in high quality products. In this development stream, the full demonstrators consisted of plastic parts for the automotive industry, obtained through injection-moulding of r-PET pellets.

WP6 Evaluation of the business, environmental, and consumer potential of developed design concepts

WP leader: Copenhagen Business School

Aim of WP

The aim of WP6 is to explore the potential of the developed prototypes and to integrate the individual processes into complete value chains. Special attention to achieve this aim is put on reproducibility, quality assurance, cost effectiveness, environmental performance and consumer potential. WP6 also explores how to bridge the gap from lab to pilot scale, to industrial production.

Achieved during Cycles A and B

Task 1 of WP6, to ensure the industrial relevance and impact of the research efforts, was conducted mainly by collecting the life cycle data, in terms of materials and energy flows, and life cycle costing data. Two iterations were performed for the life cycle inventory data, while only one iteration was achievable for the life cycle costing data, due to a lack of internal costing references - within the Trash-2-Cash project - about the technological developments proposed.

Task 2 of WP6 was to ensure the developed designs are competitive in environmental terms. The major part of the work was centred around creating a common understanding of life cycles of concerned sub-processes. The work was performed in two iterations - iteration zero included a review of database and literature data of relevance for further LCA work whereas iteration one utilized LCC data for screening the LCA of processes included in the Trash-2-Cash project.

Regarding consumer potential (Task 3), we identified attitudes and barriers towards clothes made of regenerated material and distinguished, with the aid of internal and external experts, which barriers are objectively given (such as price) and which are only perceived by consumers (for example, hygiene). This knowledge was then used to develop communication strategies to increase demand for such products.

Tasks during Cycle C

For Task 1, the second and final iterations of the life-cycle costing were carried out. The main achievements include the assessment analysis on reproducibility and prototypes' quality assurance, the manufacturing handbook for the most promising prototypes realized, as well as the final market analysis - including the business cases - of the previously analysed prototypes. The work in Task 2 was performed in two iterations. Iteration two concerned a preliminary cradle-to-gate LCA of one of the chosen Master Cases whereas iteration three concerned full LCAs of the four chosen Master Cases.

For the consumer communication strategies, we employed several experiments to enhance consumers demand for products made of regenerated fibres and to enhance their willingness to pay.

Results

For Task 1, the two iterations for the materials and energy flows, as well as the three iterations of the life cycle costing data, and the assessment analysis on reproducibility and prototypes quality assurance, have delivered confidential data. Even though, it has to be highlighted that we experienced lack of real production data on the processes and technologies subjected to research and development in the Trash-2-Cash project, along all the project run. This has compromised a careful evaluation of the environmental and industrial impact of the project results, which are not yet ready to be demonstrated at the level of an operating environment. The handbook for the most promising prototypes realized, as well as the final market analysis report, have delivered public results for four of the conceptual products realized, and their related expected business models.

Regarding Task 2, the four selected Master Cases from the third iteration LCA-work were expected to provide background into further analysis of the consequences of applying the Circular

Footprint Formula of the EU PEFCR work in LCAs of products using recycled material as input as well as sending used materials to further recycling. It became evident that a major barrier in ensuring the environmental competitiveness of the developed design concepts is to assess the potential consequences of up-scaling. A suggestion for further work is hence to widen competencies to include expertise on general scaling-up of chemical processes.

For Task 3, we found, in a willingness to pay experiment, that a minor price premium is accepted by consumers for products made of regenerated fibres, but no major price increase. Another outcome is that sustainable fibres and regenerated fibres could be used interchangeably. We also found that added values to the garment could increase the acceptance, but it strongly depends on whether consumers perceive the added value as a true added value. In a second set of experiments, we addressed the perceived barriers by designing and applying marketing strategies to bridge them. We built on results from the willingness to pay study, which illuminated how framing effects can help improve the attractiveness of recycled clothing products. The communication strategies - identified from the psychological research literature - were tested in three independent studies. Study 1 illustrated how inducing a mindset of resource scarcity can increase consumers' perception of regenerated jeans' functionality, although doing so might create a backlash in the form of a lower willingness to pay. This finding suggests that a strong communicative focus on the resource-saving benefits of regeneration may not be an ideal communication strategy to promote clothes made from regenerated fibres. Study 2 demonstrated that communicating the country of origin of the material input used in the regeneration process can influence consumers' perceptions of quality. Study 3 - employing a framing technique - indicated that emphasizing the economic consequences of overconsumption and waste production in the clothing industry can result in a greater willingness to pay for regenerated jeans compared to emphasizing the environmental consequences. As such, the true effectiveness and employability of this framing communication strategy remains uncertain and needs further empirical exploration. An interesting, and cross-cutting finding is that consumers consistently perceived regenerated jeans to provide better environmental benefits compared to conventional jeans.

WP7 Manufacturing

WP leader: Grado Zero Innovation

Aim of WP

The work package had the main aim to understand the potentialities and limitations of upscaling the Trash-2-Cash developments from lab to pilot and full industrial scale, validating and verifying the quality of the prototypes manufactured. Material, process and business model level were taken into account. The work package was divided into three tasks: 1) identify at conceptual level the prerequisites for investigating upscaling parameters required for the final prototypes; 2) analyse the scalability for the manufacturing of the new products from pilot to industrial scale; 3) validate and verify the quality of the prototypes manufactured in work package 5. The data collected in this work package and in WP5, were used for the Life Cycle Assessment and for the Life Cycle Costing analyses in WP6.

Achieved during Cycles A and B

The objectives of task 1, that is the identification at conceptual level the prerequisites for investigating upscaling parameters required for the final prototypes, were achieved in cycles A and B. The basis to analyse the scalability of the manufacturing of the new products from pilot to industrial scale was also established.

Tasks during Cycle C

During the cycle C, task 2, related to the scalability of the manufacturing of new products, was finalized. The validation and verification of the quality of the prototypes manufactured - as expected in task 3 - was completed.

Results

All the deliverable reports submitted by this work package are confidential, only for members of the consortium.

Both the Ioncell-F and the depolymerisation of polyester recycling technologies are still on laboratory scale. However, this project showed the potential of these two techniques for future upscaling. The chain extension polyester recycling is now performed on a small pilot scale and reached TRL 6 (Technology demonstrated in relevant environment (industrially relevant environment in the case of KETs)).

WP8 Dissemination, exploitation and networking

WP leader: University of the Arts London

Aim of WP

The aim of this work package is to deliver a coherent project identity which builds both external awareness of the project as well as a sense of unity within the consortium. The aim is also to create impact in the dissemination by engaging stakeholders and general interest groups as well as using established academic and industry routes. The work package also aims to build a robust exploitation path for the Key Exploitable Results. The connection between WP8 and the other work packages is via the workshop sessions at consortium meetings and the Dissemination Board meetings. The WP8 team also works directly with partners on leveraging stories for the blog and through podcast interviews, via emails, skype and 1:1 meetings.

Achieved during Cycles A and B

During Cycle A the project identity and logo, a brochure, the website and social media channels, and slide template were all set up for the partners. A communication strategy was created which proposed a ‘podcast first’ approach. A project ‘suitcase’ was also created – to encourage the collection and regular transportation of useful materials and to increase a sense of the project identity. During Cycle B a new project portal (Project Place) and revised version of the website and concept diagram were created. A revised communication strategy increased social media and podcast audiences. The partners hosted 4 events and workshops, including: Dynamic Duos in London (UAL); Material Village, Milan Furniture Fair in Milan (MCI); Global Change Awards (AA/AChem) in Stockholm; and Solutions Lab at Copenhagen Fashion Summit (AA/AChem).

Tasks during Cycle C

The primary tasks during Cycle C were the continued dissemination and promotion of the project, its activities and outcomes to a public audience of academics, industry professionals, press, individuals with a special interest and the general public. This was achieved through a variety of digital and analogue channels. Online channels included the project website, social media (Twitter, Instagram and Facebook) and Soundcloud. The other major task was the curation, design and production of the final project results exhibition and seminar at Dutch Design Week (DDW), 20-28 October 2018. Numerous Dissemination Tools and Products were also created for these purposes in this Cycle: 12 press releases, a new slide template, revised project concept diagrams, professional photography of the master cases and a new visual language and communication of the project and its outcomes for DDW and subsequent events, which also provided the final content created for website and social media. The Dissemination Board meetings in this period focused on the timeline to completion and successfully achieving Dutch Design Week exhibition.

Results

15 items were published in this period - across scientific papers, journals and conferences, and design items/prototypes. 2 journal articles, 1 book chapter, 7 prototypes, 2 posters and 3 conference papers. Several more publications are planned for after the project ends. The partners presented new work at 41 events, workshops and exhibitions: the key events being the Material Village at Salone del Mobile Milano (17-22 April 2018), Avantex Paris (17-20 Sept 2018 and Maison & Objet Paris (7-11 Sept 2018), which all had large visitor numbers. The final six Master Cases were shown at Dutch Design Week (20-28 October 2018) on a large stand in the Klokgebuow building, with a half day seminar held at the VanBerlo offices. The six final Master Cases were presented on the stand at Dutch Design, Week 20-28 October 2018. During this Cycle C, social media engagement increased considerably, in total by +247%. Twitter increased by +258%, Instagram by 274% and Facebook by 168%. The podcast series published 2 new interviews in this period achieving an increasing in audience by 175% (only Soundcloud allows the measuring of metrics in this regard, iTunes does not, meaning the actual audience reached is

larger). During this period, 25 blog posts were published to the project website, which attracted 8,797 unique visitors with 24,600 page views. The Trash-2-Cash project was featured in 10 international print and press publications and was broadcast on Finnish TV news channel Arena.

WP9 Management and coordination

WP leader: RISE

Aim of WP

The aim of the work package was handling the management and coordination of the Trash-2-Cash project. It included all aspects of the management: legal and financial management, reporting and planning and also communication with the project partners and the European Commission. RISE was also in charge of leading the decision-making bodies such as the Steering Committee and the Stakeholder relationship group.

Achieved during Cycles A and B

Tasks during Cycles A and B included setting up the workshops in collaboration with WP1 and the planning and reporting of deliverables to the European Commission. Handling of the financial and IP management were also major tasks during this part of the project.

Tasks during Cycle C

During Cycle C the work continued with setting up the workshops in collaboration with WP1. The planning and reporting of the finalization of the project was also a major task during Cycle C as the finalization included some minor changes to the work plan in terms of providing the possibilities to arrange the exhibition of the Dutch Design Week and also to arrange the Stakeholder meeting in Prato during the last month of the project.

Results (only public results)

There are no results that can be reported from the management and coordination WP.

5. Conclusions

The third Milestone marks not only the end of Cycle C, but also the end of the project. The Trash-2-Cash project has generated a lot of valuable results in different areas. The Master Cases are probably the most tangible results as they can symbolise the innovation that was generated within several disciplines. These include design and material processing technology, but also less obvious ones such as new business models, behavioural research and sustainability assessment. Results of confidential character, and hence not reported in this public report, helped partners better understand key issues and contribute to increasing the level of the current state-of-the-art. These are very important to the partners in the project and will be further developed by each partner after the end of the project.

The value that was generated throughout the project is not only measured in the Master Cases but can also be seen in the new Design-Driven Material Innovation methodology that was applied and evaluated in the project.

Chapter 6 lists the impact that we can expect as a result of the project.

6. Impact beyond the project

The project has achieved a wide range of results in different areas and we can expect to see their impact after the project's end. Below is a list of achievements the project partners expect will have lasting impact.

New knowledge about the DDMI methodology

The DDMI methodology is the most generic of the project results but it can have an important impact as it can be applied to different emerging materials technology development processes. It can inspire creative companies and industries to undertake a DDMI process, provide new knowledge to design community and researchers, as well as foster new experiences aimed to improve the knowledge about DDMI.The report is available on the T2C webpage (D1.77 White paper for design-driven methodology - public version).

Product development achievements

Six innovative product concepts were produced while taking into account the innovations that could be realized in material properties, production process and/or business models. The Master Cases are each a summary of the potential and possible innovations that were identified throughout the project for that specific product.

Behavioural research and the consumer's attitude towards recycled textile products

With regards to consumer potential, it was found that wording is very important. An important lesson from WP6 was that rebranding recycled clothing into regenerated clothing might counteract the partially undesirable connotation surrounding recycled clothing. Consumers in the study - a large U.K.-based sample - attributed greater monetary value to a t-shirt and a pair of jeans made from regenerated cotton compared to conventional cotton, thus contrasting the findings of Gwozdz, Nielsen, and Müller (2017)[6]. Moreover, we found that the communication strategies must be carefully selected and tested before being implemented.

Technology achievements

The material processing and prototyping activities led to several technological achievements that could have some impact on society after the project, provided some more research/technological transfer is carried out to bring them to higher TRLs. These achievements are listed below:

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[6] W Gwozdz, K Steensen Nielsen, T Müller, An Environmental Perspective on Clothing Consumption: Consumer Segments and Their Behavioral Patterns, Sustainability 2017, 9(5), 762.

- The developed pre-treatment, fractionation and spinning technologies will provide wider utilization of different waste materials not only mono component waste but also utilization of textile blends. This might help the sorting and collection of waste textiles.

- Use of a low-impact method to regenerate waste cotton into new Ioncell-F fibres.

- "Retaining colour" technological concept, which consists of leaving in the initial colour of the textile waste during the recycling process, to avoid bleaching away the colour and later recolour the regenerated fabric during the new product manufacturing. This saves both chemicals and energy.

- Use of zero-waste pattern-cutting techniques to reduce textile scrap during garment construction.

- Modification of the Ioncell-F technology to regenerate cotton waste into microfibers that replicate the softness of polyester fleece, thereby providing a possible substitution material that would be much less problematic in terms of pollution/microplastics.

- Brushing treatment of knitted fabric made from Ioncell-F microfibers to imitate soft polyester.

- Hydrophobic fabrics obtained from hydrophobic Ioncell-F fibres, instead of applying a finishing treatment employing additional chemicals to fabric. Indeed, Ioncell-F fibres were made hydrophobic through the use of bio-based hydrophobizing agents.

- A new, sustainable method for separating polyester and cotton so that they can be used again in new yarns for new clothes.

- Use of depolymerized polyester to obtain recycled polybutylene terephtalate (PBT) that can be used as a stretchy alternative to elastane, thus making jeans recyclable.

- Adaptation of a recyclable polyurethane material usually used to make sealants for the aerospace industry to make fabrics waterproof.

- Upgrading of PET waste textile with chain extending agents, through extrusion compounding, to get new high-quality plastic parts.

Recycling options of post-consumer textiles

The sorting study emphasized the importance of designing for circularity. In order to facilitate automatic sorting, it is recommended to avoid inhomogeneous multilayers, which should be considered already at the product development stage. Another important aspect is to investigate sustainable substitutes for elastane. In WP4 it was discovered that elastane is hard to detect and in WP2 it was discovered to cause problematic clogging of the spinnerets in the regeneration process making it an unfit polymer for designing recyclable garments, which confirms earlier findings.

The end-of-life study provides cellulose content degree of polymerisation (DP) and molecular weight distribution (MWD) for common textile garments after long-time services. This finding provides recyclers who want to target post-consumer waste with expected minimum specifications. It covers the current knowledge gap concerning polymer properties of end-of-life man-made cellulosic fabrics, viscose and Lyocell.

Manufacturing of recycled textiles

Major findings from the manufacturing point of view are related to the necessity to push over the applied research on textile recycling and on how this will impact the new related models of supply and production. Large investments are needed to reach at least an adequate technology readiness level to assess and demonstrate the technology in an operational environment. The concentration in the far east for the production of almost all fibres, yarns and fabrics limits the development of a profitable economy on textile recycling. According with the findings of the Trash-2-Cash project, it would be beneficial that the investments mentioned above be directly destined to European companies (mainly SMEs) already directly or indirectly involved in textile recycling, especially in the validation - manufacturing and economic - of those pilot activities.

Dissemination and networking

DDW is a key event in the international design calendar. It attracted an estimated 355,000 visitors this year. Large numbers of visitors from industry, academia, NGO's, press, banking and the general public came to the T2C stand and were able to see and feel the work; they were able to speak with the researchers themselves through a series of planned interactions. An exhibition book logs business cards and conversations which took place across all ten days.

This broad dissemination continued with several events in November 2018: a special issue of the podcast series selected for the Disruptive Innovation Festival, hosted by the Ellen MacArthur Foundation; a final event in Prato (20.11.18) disseminated the project to a technical audience. Several academic publications and press interviews are also in the pipeline right into mid-2019.

The final dissemination kit will help partners continue to create impact: the final website[7], a short film, PowerPoint slides, academic publications and press article are all planned. A printed brochure will be created for the partners and will also be a downloadable PDF on website.

To the extent of the Consortium's experience and knowledge, this extensive reach to such a wide audience and dissemination through so many varied channels has been unique for a project of this complexity. This has been primarily noted through conversations with the audience, their engagement, feedback, and interest in the project in general and in specific details of its innovations. The Consortium is greatly encouraged by this and are of the conviction that the impact and influence of the project will remain with the audience and persist throughout the many industries touched upon. Discussion are on-going for finding and setting up suitable follow-up projects.

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[7] www.trash2cashproject.eu

7. Further reading

For further reading, please have a look at the public deliverables of the project. These deliverables are available through the project website, www.trash2cashproject.eu/#/trash-2-cash-publications-page, or through CORDIS, cordis.europa.eu/project/rcn/196847_en.html.

D1.7	White paper for design-driven methodology - public version
D2.1	To provide textile waste and recycled paperboard for the tasks 2-5
D2.2	Report on availability, price, composition and quality of waste textiles and recycled paperboard
D2.22	Comparison of the cellulose dissolution technologies
D4.1	Best available techniques for large scale operational technology to automatically sort non-traceable recycled textiles
D4.2	Evaluation and sorting of post-consumer cellulosic textile waste for chemical textile recycling based on degree of polymerization
D5.16	Finished Prototype 3 for showcasing at WS11
D6.15	Handbook on optimised manufacturing protocols for the most promising (at least three) design concepts
D6.16	Market analysis including business cases
D6.17	Publishable manuscript of LCA results and/or experiences of integrating LCA work for the benefit of design-driven product development
D8.1	Dissemination kit - Project Brochure, Multimedia Project Presentation
D8.2	Trash-2-Cash project portal, blog and social media channels established
D8.5	Updated Dissemination Kit: Project Brochure, Multimedia Project Presentation
D8.6	Collection of Magazine articles, newsletters, video clips
D9.1	Final workshop plan set
D9.2	First Milestone report
D9.3	Second Milestone report
D9.4	Third Milestone report