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TRANSFORM-CE
European Regional Development Fund

Business support – case study 3Devo

Injection Printing

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As part of the TRANSFORM-CE project, several case studies will be done to assess the conditions that foster the uptake of recycled plastic feedstock in (new) products. This document covers the results of the case study at 3Devo, based in The Netherlands. A total of 20 case studies will be done, each representing one product to be (re)designed with recycled plastic. In depth support will be given to five cases per country (The Netherlands, Germany, Belgium and the United Kingdom).

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	WPT3	D3.7	Redefining Circular Economy business models

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1. Introduction and method

1.1 Goal of case study

TRANSFORM-CE is an international research project about the uptake of recycled single use plastic (SUP) feedstock. A core part of this project is to provide in-depth business support to businesses willing to use recycled plastic materials in (new) products. The uptake of SUPs implies that companies in the plastic industry must make a major transformation. In order to gain a better understanding of the support required for the wider uptake of recycled plastics (such as SUP) by companies, 20 different case studies will be completed, documenting the conditions that foster the uptake of recycled feedstock. In line with the technologies of the pilot plants from the TRANSFORM-CE project, cases will represent either IEM[1] technology or AM[2] technology.

Thus, the aim of these case studies is twofold; 1) to support the case study company with their specific request to help foster the uptake of recycled plastic feedstock into one of the company's products, and 2) to gather insights into the conditions necessary to support the wider uptake of recycled plastics by using IEM and AM technologies. The case studies also present a unique opportunity to study the technical requirements for (re)designing products with IEM and AM. The learnings of the various cases and (re)designed products could serve as a proof of concept that provides the entire value chain with the insight and confidence to uptake recycled feedstock, creating circular economy opportunities for all stakeholders.

1.2 Case study process

The case studies are being carried out between September 2021 and December 2022. The case study process is structured in four steps[3], with an iterative approach at the end of each step. The first step (*initial diagnostic*) aims to establish a starting point and describes the challenge to be addressed. The second step (*circular product development*) captures basic information about the product (re)design and describes prototyping and testing leveraging IEM and/or AM technologies. The third step (*circular product management*) covers how to commercialise the new (or redesigned) product and describes the product's relevance for business and environment, creating a successful circular business model. The last step involves a wrap-up of the results and concludes with strengths of the redefined business model, an overview of the barriers and enablers for circularity, and learned lessons from the case study. The final result is a case study report, covering the previously established information.

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[1] IEM: Intrusion-Extrusion Moulding (for low(er) value recycled material), a combination of two techniques to produce plastic products/components. With extrusion the polymer is being melted, thereafter the polymer is being forced into a shape (by using a mould).

[2] AM: Additive Manufacturing (for high(er) value recycled material), method of creating objects layer by layer according to a digital design.

[3] This work uses insights derived from other activities of TRANSFORM-CE, in particular the case study method of WPT3 D2.1: *Case study methodology - Researching good practices of circular economy business models.*

The total case study can be seen as a package of business support (all steps). Yet, a specific type of 'in-depth support', chosen from the menu-card[4], will be done for each case study. This support differs from company to company and will be selected based on a first analysis of the case. Examples of in-depth support include: material testing, prototyping and production trials, implementation of technology and use of recycled filament.

An overview of the case study analysis process is shown in figure 1 on the next page. In order to obtain the results, a 'collaborative/participative' assessment is used to collect further information, which gives insights in the overall innovation process. At the end of the case study, an iteration will be done to validate the results. The reported results will be send to the contact person by email, so this person can validate the results and check if something is still missing or if information has been misinterpreted. Any comments will be processed and the results will be adjusted accordingly. Table 1 gives an overview of the people that have been interviewed during the case study.

Table 1: Overview of interviewed people

	Interviewed person	**Function**
Step 1: Initial diagnostic	Timo van der Laak	Materials Department Manager
Step 2: Circular product development	Timo van der Laak Floris Wardenier	Materials Department Manager R&D manager
Step 3: Circular product management	Timo van der Laak	Materials Department Manager

[4] An extensive list of the support possibilities is presented in a separate document '*Transform-CE support Summary*', describing the menu-card.

Step 1. Initial Diagnostic

- First assessment of company
- Establish starting point
- Describe challenge to be addressed
- State project goal

Step 2. Circular Product Development

- Describe product to be (re)designed
- Assess context in which product will be produced, used and marketed
- Design product
- Describe product’s relevance for business and environment
- Create successful circular business model
- Prototyping and testing leveraging IEM and/or AM technologies

Step 3. Conclusion

- Wrap-up of results
- Strengths of redefined business model
- Summarise barriers and enablers for circularity
- Describe learned lessons

Report

- Succinct, yet informative case study report
- Excellent exposure opportunities for business

Figure 1: *Overview of case study process*

2. Step 1 – Initial diagnostic

The first step focusses on an initial diagnostic of the case study, which includes outlining the company profile, its wishes and the project goal.

2.1 Company profile

3devo is a tech company founded by young inventive engineers in the Netherlands. They develop and produce equipment for enabling 3D printing, like filament extruders and shredders. A short overview of 3Devo is given in table 2.

Table 2: *Overview of company [1]*

Topic	Information
Company name	3Devo
Website	www.3devo.com
Country	The Netherlands
Size of company (0-10, 10-200, 200-500, 500+ employees)	10-200
Mission/vision	3Devo's mission centers on developing accessible and high-quality products to empower innovators and creators
Value proposition	We are dedicated to helping our customers improve their competitive advantage through the customization of enhanced 3D printing filament. We offer the tools and knowledge — all you need to do is use it.
Main activity	3devo offers high-performance products and services, that transform filament extrusion into a closed-loop circle. By working with some of the biggest brands in the world, we dare to say that nobody excels in filament extrusion the way we do.

2.2 Current situation & challenge

3Devo produces desktop extruders for making polymer filaments suitable for FDM (fused depostion modelling) 3D printing. Typically the extruder is fed with granulate matter such as pellets and regrind material. They want to skip this filament making step, and be able to print directly from granules. A clear target here is the use of recycled plastics to directly feed such a printer.
Currently they control all the individual steps in the process, but now need to put everything together. Here, there are two main challenges that coincide: the first is that with printing directly from pellets the control over the deposited wire is less precise, potentially leading to reduced (dimensional) quality of the printed product. On top of that, especially with respect to recycled materials: a large amount of that are polymers which were optimised for other production techniques than 3D printing (such as injection moulding), and those materials are less suitable. They are more challenging for 3D printing due to warpage and shrinking. Since 3Devo aim to use their ecosystem to really produce parts (and not just 1-off prototypes), there is a clear challenge to make their technique work with recycled plastics and produce good quality components.

Description of support

Transform-CE has offered support in designing and testing (proof of principle) ideas to enable fast production cycles by combining aspects of 3D printing and injection moulding (and IEM). Several proof of concepts were prepared by printing into a simple mould, with the aim of better controlling the (dimensional) quality of the products thus produced.

The design of the products can be so called 2.5 D which makes it easier to create a mould with stacked layer of material. Very low costs from acrylic or wood with a lasercutter or a bit more advanced from aluminium with a waterjet or industrial laser cutter.

3. Step 2 – Circular product development

After creating a first analysis of the company and project, a more detailed assessment of the (re)designed product is made. This includes basic information about the product and an assessment of the context in which the product will be produced and used, as well as an analysis of the circularity of the product. Moreover, a more detailed design of the product is created, which goes hand in hand with prototyping & testing.

3.1 Circular product canvas

The new (or redesigned) product is investigated by using a circular product canvas (CPC). This model is created for the purpose of this study and covers the main aspects to consider in circular product design. The CPC of 3Devo is visible in figure 2 and a description of each element is given below.

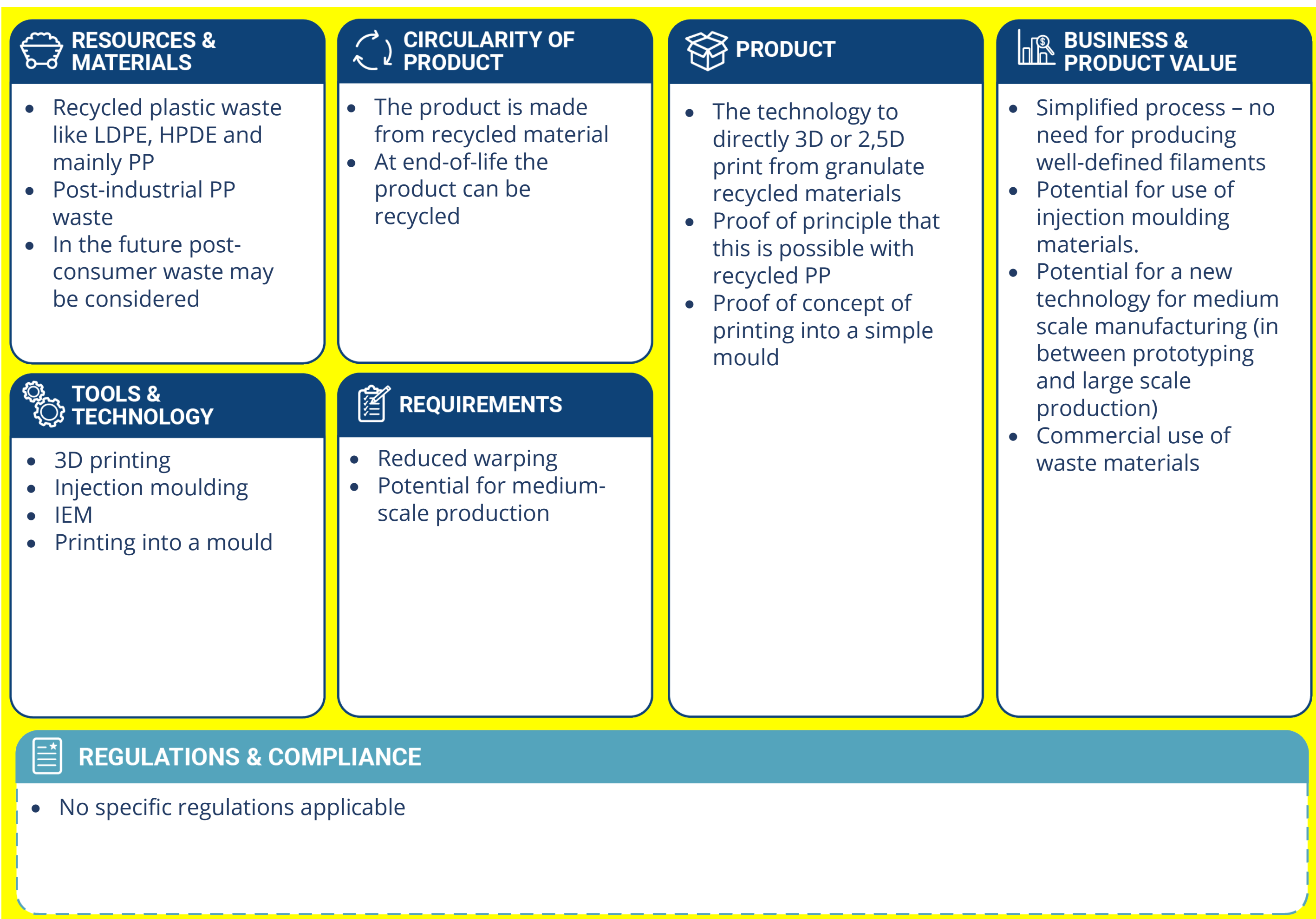


Figure 2: CPC for 3Devo

Product

The product in this particular support case is not a physical product as such, but a technology (proof of principle&concept) that combines with their printing technology & choice of (recycled) materials, to enable production of good quality components.

Resources & materials

Currently 3Devo has a business case with an industrial (automotive) partner to recycle their post-production waste. This is typically PP. However, other waste-streams are expected to be used, such a HDPE or mixes of materials. Post-consumer waste may be tested/used in the future.

Tools & technology

Direct-from-pellet 3D printing (FDM technology), thereby eliminating the need to first producing a filament from pellets or shredded recycled material. Printing directly into a mould ('injection printing') to reduce warpage and shrinking. For producing the moulds, techniques such as laser-cutting and a water-ject can be used in conjunction with materials like aluminum and plastic (acrylic).

Circularity of the product

As stated under resources and materials, the current case uses post-production waste (PP) from an automotive manufacturer, with the intention to recycle this into simple one-time use tools used in the automobile construction process. The idea is then to keep on recycling those tools in this process.

Requirements

Not clearly defined at this point, but obviously the proposed addon-technology needs to be compatible with the 3Devo print technique and the materials used, and should result in reduced warping when compared with the 'naked' process, and show potential for medium-scale production

Business and product value

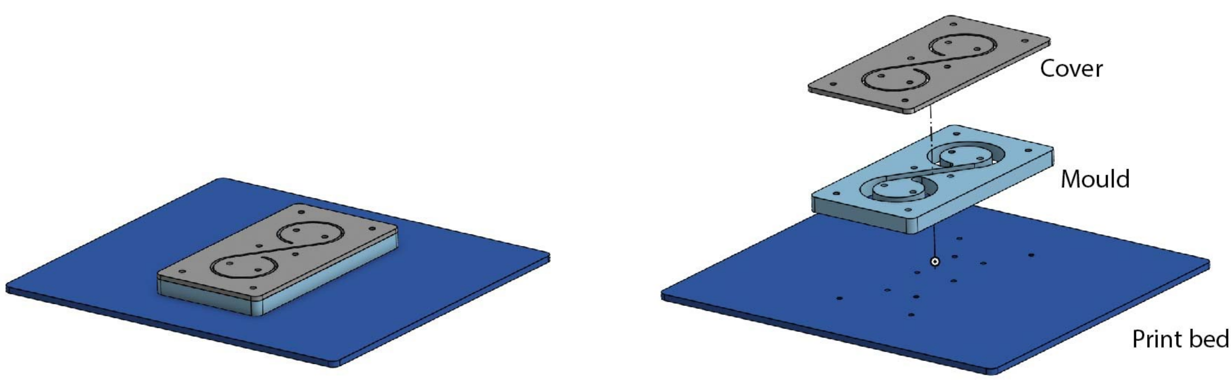
The technology proposed would enable the use of direct-from pellet 3D printing to enable medium-scale production of items from (recycled) plastics. This enables printing without the use for very well-defined filaments. The technology enables the use of injection moulding materials, that are normally not well-suited for 3D printing. Furthermore, easier upscaling is made possible as multiple printers can be used with one shredder/extruder/pelletizer combination.

In the future, the technology could remove one process step from the current process, *i.e.* the need to first produce a filament from pellets or shredded material, thereby simplifying the process. In addition, since both the making of a filament and the subsequent printing both require a high-temperature step that will lead to polymer degradation upon repetition, the effective usable lifetime of the materials thus recycled can be extended: they can be recycled more often before the materials degrade too much.

Regulations and compliance
Given that this case is about technology development, any regulations for this process would be ones already existing for AM/IEM and 3D printing.

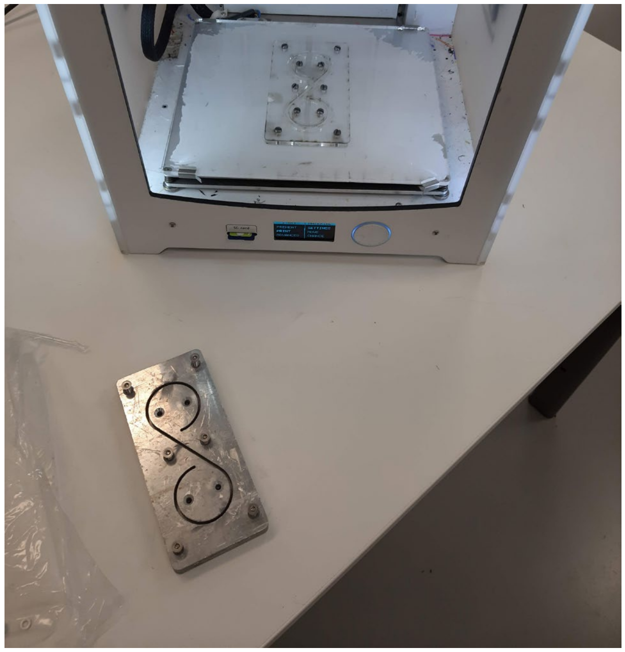
3.2 Design, prototyping & testing

Transform-CE has offered support in designing and testing (proof of principle) to enable fast production cycles by combining aspects of 3D printing and injection moulding (and IEM), which we will refer to as 'injection printing' for now. Several proof of concepts were prepared by printing into a simple mould. The most important part in the business support is maybe not this description, but the tests were made in real live to get a feeling what can be possible.
The design of the products can be so called 2,5 D which makes it easier to create a mould with stacked layer of material. Very low costs from acrylic or wood with a laser cutter or a bit more advanced from aluminium with a waterjet or industrial laser cutter. The mould is conceptually shown below.



Simple 2,5D mould (left) and exploded view (right)

First tests
The very first test were made manually. A mould was made with aluminium plates and pushed agains a nozzle from a 3D printer. The result was quite disappointing since the material was not able to enter mould. Main reasons for this were that the mould was too cold and therefore the material was already solidified before it entered the next layer.



First attempt at manual 'Injection printing' with an aluminum mould and the next attempt computer controlled in an acryllic mould.

First iterations

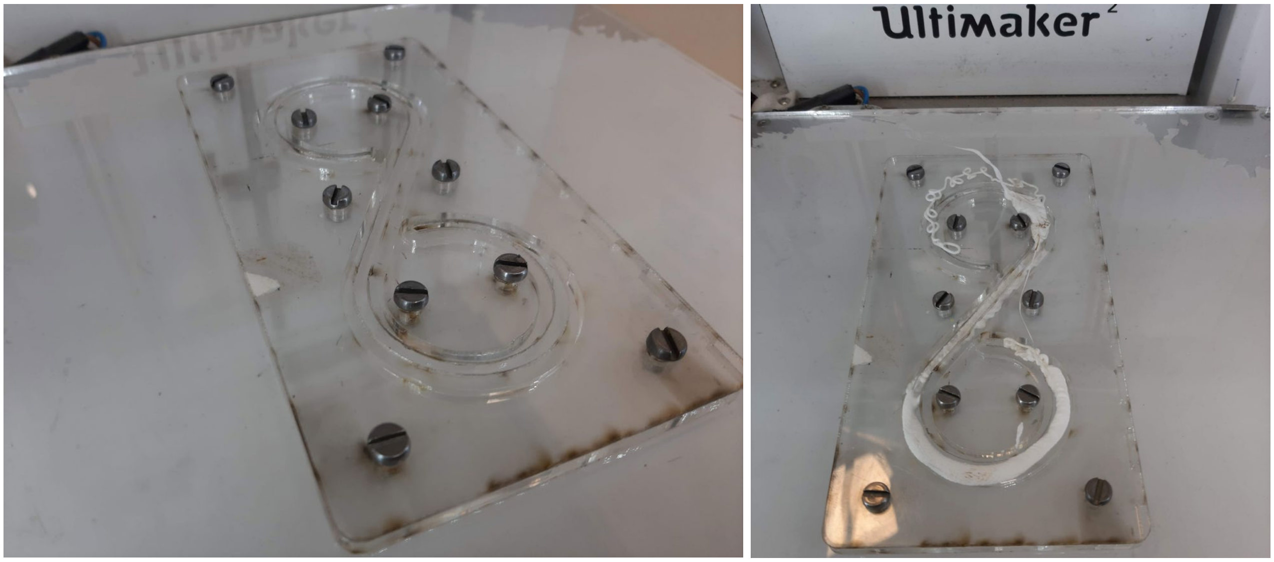
The next tests were done with a acrylic mould. The reasons for this where 2-fold: easier to produce and the possibility to see where the material is going when entering the mould.
For this step also the motion was automized. A gcode was generated to drive the 3D printer.

Mould

If the mould making gets too expensive and has too much lead time, the advantage gets less. For these experiments we where testing to make the mould with relatively low-cost digital fabrication tools as laser cutters desktop CNC milling machines. As well as low cost materials for the mould e.g. sheet material from acryllic, wood, steel or aluminium.

Positioning

The mould for the 3D printer was made the same size as the build platform for an Ultimaker 2. For testing the original build plate is replaced with the 'mould build plate', Aligning the mould is challenging, but on the 3D printer there are option to live adjust the position of the nozzle. After a few iterations it is possible to get the nozzle follow the right path.
The same iterations are made for the amount of material needed to fill the mould.



'Injection printing' tests with an acrylic mould

Flow

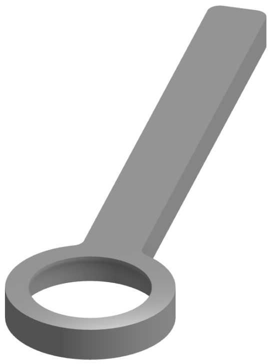
To get the material flow into the mould, the material is not supposed to get solid before it is in the right cavities. In the first test the mould is made of aluminium and was manually push against the nozzle. The aluminium cooled the material too fast and therefore the mould was not filled. A wooden mould is cheaper and can possibly avoid this problem.

Other options to avoid this is to mount the mould on the heated bed of a 3D printer. The bed will heat the mould as well.

The hypothesis is that when using pellet extrusion more material is extruded per minute and therefore more heat is going from the material within the mould.

Product

What kind of product can be made? 3Devo delivered some 3d files to see if they could possibly printed with this technique. Most models however are designed for fdm 3d printing and therefore not straightforward compatible with 3D printing IEM (injection printing). One model can be adjusted for some tests. In that case the model will be made flat and afterwards one part of the model will be bent to get the final shape.



Potential product to be made with 'Injection printing'. The 2,5D flat product (left) can be bent into the final 3D shape (right) in a later step.

Design constraints

Injection printing lends itself more for 2D and 2,5D printing. The more three dimensional the shape the more complex the mould and therefore more expensive. There are options to make a more 3D mould with an affordable 3-axis CNC milling machine, the main constraint is that the top of the mould should be horizontal and flat.

4. Step 3 – Conclusion and recommendations

After going through the previously described steps, a wrap-up is presented in this chapter. This includes identifying the strengths of the redefined business model in regards to circularity, describing the learned lessons from the case study project and providing recommendations for the next steps.

4.1 Strengths of the redefined business model

Circular product and use context

First tests show that 3D printing directly into a mould (injection printing) shows some promise, although several issues obviously still remain. If those can be solved, and reduced warping and shrinkage is indeed observed, this may be a interesting way to reuse recycled materials that are not optimised for regular 3D printing.

Product (re)design, testing and/or prototyping

Effectively, this whole support case is about redesign, testing and prototyping. Injection printing was possible, but more tests still need to be run. Temperature control of the printed product (and hence the mould) appears key, since otherwise premature cooling and hardening of the printed material occurs. Hence, choice of material of the mould, actively heating the mould and/or adjusting printing parameters will be key. These appears feasible to solve.
Injection printing lends itself more for 2,5D printing, limiting the products that can be made. However, with clever redesign of products, 3D objects may still be made by bending a 2,5D object into shape. Alternatively, separate parts may be injection printed and later assembled, but this may not be a preferred solution.

4.2 Lessons learned

See section above on product redesign, testing and prototyping: temperature control of the mould and/or mould material is likely key, as are the printing parameters that do not necessarily need to be the same as for regular printing (*e.g.* higher throughput of material). 3D objects may be made from 2,5D by smart design followed by bending into shape.

4.3 What's next

Continuing the injection printing tests with different mould materials and/or heated moulds. Show proof of principle that the technique is possible, and show proof of principle that is is usable for (small-scale) production of parts, with reduced warping/shrinking. Do some tests with 2,5D objects that can be shaped into 3D later.

References

[1] www.3devo.com website of 3Devo

About the project

The problems associated with plastic waste and in particular its adverse impacts on the environment are gaining importance and attention in politics, economics, science and the media. Although plastic is widely used and millions of plastic products are manufactured each year, only 30% of total plastic waste is collected for recycling. Since demand for plastic is expected to increase in the coming years, whilst resources are further depleted, it is important to utilise plastic waste in a resourceful way.

TRANSFORM-CE aims to convert single-use plastic waste into valuable new products. The project intends to divert an estimated 2,580 tonnes of plastic between 2020 and 2023. Two innovative technologies – intrusion-extrusion moulding (IEM) and additive manufacturing (AM) – will be used to turn plastic waste into recycled feedstock and new products. To support this, an R&D Centre (UK) and Prototyping Unit (BE) have been set up to develop and scale the production of recycled filaments for AM, whilst an Intrusion-Extrusion Moulding Facility, the Green Plastic Factory, has been established in the NL to expand the range of products manufactured using IEM.

Moreover, the project will help to increase the adoption of technology and uptake of recycled feedstock by businesses. This will be promoted through research into the current and future supply of single-use plastic waste from municipal sources, technical information on the materials and recycling processes, and circular business models. In-depth support will also be provided to a range of businesses across North-West Europe, whilst the insights generated through TRANSFORM-CE will be consolidated into an EU Plastic Circular Economy Roadmap to provide wider businesses with the 'know-how' necessary to replicate and up-scale the developed solutions.

Lead partner organisation
Manchester Metropolitan University

Partner organisations
Materia Nova
Social Environmental and Economic Solutions (SOENECS) Ltd
Gemeente Almere
Save Plastics
Technische Universiteit Delft
Hogeschool Utrecht
Hochschule Trier Umwelt-Campus Birkenfeld Institut für angewandtes Stoffstrommanagement (IfaS)
bCircular GmbH

Countries
UK | BE | NL | DE

Timeline
2019-2023

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