DOI: https://doi.org/10.23634/MMU.00633698

Publisher: Interreg NW Europe

Version: Published Version

A Business Model for AM Plant Replication

A Business Model for AM Plant Replication

This report is a circular economy business model for a commercial waste processing and AM filament production plant. It uses single use single polymer waste plastic that is at this time not widely recused.

Date May 2023

Authors Moshe Kinn

Deliverable WPLT D2.4 A Business model for AM plant replication.

This research has been conducted as part of the TRANSFORM-CE project. The Interreg North West Europe support for the production of this publication does not constitute an endorsement of the contents which reflects the views only of the authors, and the Programme cannot be held responsible for any use which may be made of the information contained therein. More information about the project can be found on: **www.nweurope.eu/transform-ce**. TRANSFORM-CE is supported by the Interreg North West Europe programme as part of the European Regional Development Fund (ERDF).

Interreg North-West Europe TRANSFORM-CE

Table of contents

List of Abbreviations/Acronyms

AI	Artificial Intelligence
AM	Additive Manufacturing
C&I	Commerce and Industry
CE	Circular Economy
DIY	Do It Yourself
EfW	Energy from Waste
EPRS	Extended Producer Responsibility Schemes
eq.	equivalent
GHG	Greenhouse Gasses
HDPE	High Density Polyethylene
HWRS	Household Waste Recycling Centre
IEM	Intrusion Extrusion Moulding
Kt	kilo tonnes, 1000 tonnes
LDPE	Low Density Polyethylene
MIR	Mid-range Infra-red
MRF	Material Recovery Facility
MSW	Municipal Solid Waste
Mt/a	Million Tonnes per annum
NGOs	Non-Government Organisations
NWE	Northwest Europe
PAYT	pay-as-you-throw
PET	Polyethylene Terephthalate
PMC	Plastic, Metal and Drinks cartons (Belgium)
PMD	Plastic, Metal and Drinks cartons (The Netherlands)
PP	Polypropylene
PRF	Plastic Recovery Facilities
PPF	Plastic processing facility
PTT	Pots, Tubs and Trays
RFID tag	Radio Frequency Identification tag
RDF	Refuse Derived Fuel
RCV	Refuse collection vehicle
SPI	Society of Plastics Industry
SUP	Single Use Plastic
WfH	Waste from Households

1. Executive Summary

TRANSFORM-CE is an Interreg NW Europe funded project focused on transforming single-use plastic waste into valuable, new products for a circular economy. The types of polymers and the grade of the waste was such that until this project, these types of plastics were not generally recycled. The waste ended up in landfill or being burned to make energy, which is a loss of valuable resources to the European economy. The challenge was to reduce this loss of processed plastic, by upcycling it from end-of-life waste into durable long-life products. To this end, two innovative recycling technologies were employed: Additive Manufacturing (AM) and Intrusion-Extrusion Moulding (IEM). This business model presents important insights gained during the TRANSFORM-CE project, from the AM pilot plant and identifies the key criteria necessary for starting a full size commercial business that will use single use waste plastics and make filaments for additive manufacturing, also known as 3D printing.

Originally this project was going to open and operate a waste sorting and an AM filament extrusion facility with an output capacity of 80 tonnes over three years, with the capacity to ramp up to 100 t. However, due to the withdrawal of the strategic partner, it was never constructed, therefore, this business module uses the design and the original cost of the proposed plant. It employs the use of a business model canvas to structure the key activities needed to open and operate a filament production plant. The potential market for AM filaments and the 3D printing market in general, is discussed. The potential for adding value to a waste stream that usually has a cost associated with its disposal by upcycling it into rolls of filaments is discussed.

Since the plant was not constructed within this project, the actual profit potential is not known. However, as, there are international large manufacturers who supply filaments made from virgin plastic, they have shown that their business model can be profitable. Therefore, further work needs to be carried out to assess the profit potential of using negative valued waste plastic to make AM filaments for the 3D printing market.

2. Introduction

2.1 The background to this project

Single use plastic (SUP) causes enormous pollution in our environment. Each year 8 Mt of SUP leaks into our oceans ending up as microplastics affecting our ecosystems (European Commission, 2021). Northwest Europe (NWE) generates the biggest source of SUP (40% of Europe). In the past the EU generated 27 Mt per year of waste plastic, of which 31% was recycled, 41% was sent for energy from waste (EfW) and 27% was landfilled. This is a loss of valuable resources to the European economy. The challenge is to reduce this 68% loss of processed plastic, by upcycling it from end-of-life waste into durable long-life products.

By 2019, EU plastic production was 53.6 Mt with 29.5 Mt collected for recycling (55%), of which only 10.1 Mt was actually recycled (19%) and only 4.6 Mt (8.5%) were used in new plastic products (Plastics Europe, 2020). The rest of the waste, 14.8 Mt, was exported. The EU is reliant on imports of virgin plastic yet there is a huge opportunity to valorise low and high grade recycled SUP as an alternative to virgin plastic imports. The EU has set an ambitious 2025 recycling target of 65% for packaging materials, which includes SUP, with an increase to 70% by 2030. Existing lack of infrastructure capacity and viable links to secondary material markets across NWE, forces pre-segregated and mixed waste plastics into landfill and or energy-from-waste (EfW) plants. This approach is not resource efficient, will not enable EU recycling targets to be achieved and clearly does not promote a circular economy (CM) approach. There are real environmental and resource security issues, but currently NWE lacks the economic incentives to solve them.

The plastic import ban to China in 2018, meant the closure of a huge market for the export of European plastics for recycling. With this reduction in the offtake market, this created a reduction in the export demand for the waste plastics, while at the same time the supply of waste plastics continues to increase. In response, EU plastic is being stockpiled and higher levels of SUP are now being sent to energy from waste plants and landfill. This is an economic loss to the EU and reinforces the wasteful linear economic model of 'use once and discard'. The EU Packaging Waste Directive (EU Commision, 1994) and Extended Producer Responsibility (EPR) policy, aims to reduce plastic production and make manufacturers more responsible for the waste they produce. Therefore, there is urgency for NWE to develop its own plastic recycling economy, to reduce reliance on import markets, to repurpose, to revalue existing SUP waste and to upcycle, while at the same time diverting valuable plastic away from EfW and landfill.

Since it is technologically feasible to segregate, re-engineer and repurpose SUP, one of the pilot projects of the TRANSFORM-CE is the Additive Manufacturing (AM) pilot project at Manchester Metropolitan University and the facilities at Materia Nova in Belgium. It focuses on the repurposing of high-grade single polymer post-consumer single use plastic from within the waste system. Additional plastic waste materials, commonly used in AM e.g., polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS), were also included for initial process trials. These are less common in municipal waste streams but are more well established within the AM industry. For a full list of the different types of plastics used within the AM industry see Appendix 2 below.

NWE is a region of mixed economy, with variable levels of wealth and employment. Its consumers produce significant quantities of plastic waste, in part due to affluent and urban lifestyles. The region contains some of the largest urban conurbations in Europe. Several are sufficient to provide consistent and large feedstocks for supplying one or more 30 t per annum capacity plants. The higher valued plastics i.e., pre-sorted drinks and cleaning bottles, and food trays and containers, are processed into filaments to be used to make AM products. AM provides opportunity for integration into complex products, that could not be produced using the sister technology of this project, intrusion extrusion moulding (IEM) manufacturing.

2.2 Size of AM filament production plant

One of the goals for a circular economic model is to reduce as much as possible transportation distances that the feedstock and products go through. To achieve this goal, the production of the filament should be as near as possible to the scouse of the waste plastic, and near to a 3D printing marketplace. There are many facilities that collect and sort waste plastic, and in large cities there may be several. Therefore, to achieve a circular economy goal the AM production facility should be of a size where it can be economical, but not too large, such that its' production volume saturates the local market and therefore the filaments need to be transported long distances to customers further away. Therefore, a yearly volume of under 30 tonnes capacity was chosen as the size of the production facility. This could provide approximately 30,000 1kg rolls of filament for the local market yet has the capability to grow to a 100 tonnes capacity per year. The distance to and size of the local market will depend on the location of the filament production facility and will therefore vary for each plant. This business model is one of multiple small facilities located near the source of supply and demand, rather than a few very large facilities that can process hundreds of thousands of tonnes and manufacture millions of 1 kgs rolls per year, and requires large travel distances for both the feedstock and the filament.

2.3 Focus of this report

This business model for the AM recycling and filaments manufacturing plant, is the third report in a series of three, that address the dissemination of the TRANSFORM-CE manufacturing plants across NWE. The Second report in this series looked at the circular economy business model of a 2000 tonne intrusion extrusion moulding manufacturing plant. The TRANSFORM-CE project was initially supposed to have a large filament manufacturing facility attached to a waste processing plant in Manchester UK. The production facility had an initial operating output of 80 tonnes over three years with the ability to scale up to 100 tonnes per year. This is an initial production capacity of 26.6 tonnes per year, that can produce 26,666 1kg reels of filament. When the production is ramped up to 100 tonnes per year the production would be 100,000 1kg reels per year.

However due to circumstances outside the boundaries of this project, the company that was going to operate the plant pulled out of this project and the plant was never constructed. This puts a constraint on this business model, as there was no working plant within the project to gather the data to determine the financials for this AM business model. However, the original blueprint plans are used to provide some details for a future potential plant.

2.4 The Business Model Canvas

This AM business model is based on the Harvard Business School Business Model Canvas, which can be found in Appendix 1 below.

The basic business model canvas has been in use for more than 13 years. It is divided up into nine segments or steps (headings). These nine segments can be ordered in different ways depending on the focus of the model. The numbering given here focuses first on the reason for the business, followed by who are the customers and what the company offers the customers, and then how they will be served. Then it looks at the company structures and finally at the financing. In the next nine sections of this document each of the segments will be discussed. The business model canvas is populated with relevant questions that an entrepreneur, and ultimately a financier would ask about the nine segments of the business, see Figure 1 below.

<table>
<tr><th>7. Key Partnerships</th><th>8. Key Activities</th><th>1. Value Proposition</th><th>4. Customer Relationships</th><th>2. Customer Segments</th></tr>
<tr>
<td rowspan="3">7.1 who will supply the waste plastic?
7.2 Who is the local waste authority (council), will it partner with the company?
7.3 What trade, NGOs or societal organisation can help with the promotion and proliferation of products?</td>
<td>8.1 To make products from recycled waste plastic.
8.2 Sell them for 3D printing.
8.3 To provide good customer care.
8.4 To provide education about this recycling and sustainability proposition</td>
<td rowspan="3">1.1 How can this company solve the recycling problem of plastic waste within a circular economy business model?
1.2 Do our products help customers fulfil their sustainability goals?</td>
<td>4.1 How will the company get, retain, and grow its customer base?
4.2 How will customers be contacted?
4.2 What sales channels will be employed?</td>
<td rowspan="3">2.1 Who are the groups of customers for the company’s products?
2.2 Who are the customers and is the customer base big enough to support the business?</td>
</tr>
<tr><th>6. Key Resources</th><th>3. Channels</th></tr>
<tr>
<td>6.1 What capital equipment is required?
6.2 what personnel and skills are required?</td>
<td>3.1 How will the products reach the customers?
3.2 How does localism within a circular economy fit into the business model?</td>
</tr>
<tr><th colspan="2">9. Cost Structure</th><th colspan="3">5. Revenue Streams</th></tr>
<tr>
<td colspan="2">9.1 Initial set up of plant, approximately £1 million
9.2 Investment in personnel and training
9.3 Running costs including energy bills
9.4 Other fixed and variable costs</td>
<td colspan="3">5.1 What added value is the company offering to customers for choosing its products?
5.2 What price premium are customers willing to pay for such sustainable products?
5.3 How will products be prices when sold as projects?
5.4 Possible value added from waste to products</td>
</tr>
</table>

Figure 1 The Business Model Canvas for an Additive Manufacturing circular economy business

3. Value proposition

3.1 What is the problem this business model is trying to solve?

There are millions of tonnes of waste plastic that are generated each year across Europe. Much of this ends up being burned to generate energy for electricity and heat or ends up in a landfill. This valuable resource is therefore lost forever. This means that it is used once and discarded. If it could be used at least once more or many more times, then there will be benefits for society, consumers, and for the economy.

New plastic products can be made from virgin plastic, with recycled plastic or with a combination of both. Each year the global production of new plastics from fossil fuels is more than 330 Mt, while less than 33 Mt are recycled see Figure 2 volumes of virgin plastic produced each year (Plastic Europe, 2022) bellow. Some countries have a rule that at least 30% recycled plastic should be used, e.g., the UK plastic packaging tax (GOV.UK, 2022) is only on products with less than 30% recyclant in them. The goal of this project is to decrease the number of products made exclusively from virgin plastic filaments and substitute filaments made from recycled plastic from the waste management system. This can be both post-consumer and post-industrial waste.

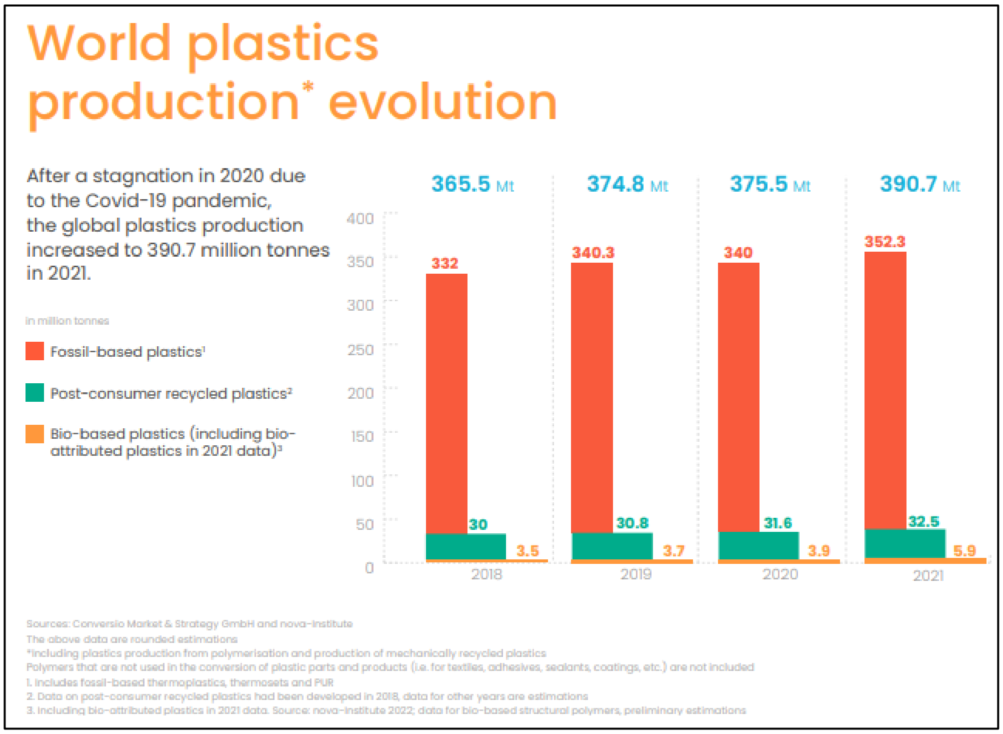


Figure 2 volumes of virgin plastic produced each year (Plastic Europe, 2022)

Within the recycling system there are two grades of plastic that end up as feedstock for plastic products, food grade and non-food grade. Much of the food grade plastic comes into the recycling system through deposit return schemes, as in Germany and the Netherlands, and through special plastic collection routes. The non-food grade plastic comes from the residual of the food grade plastic that has been contaminated and can't be used again for food, or from other consumer products. However, there is a huge amount of plastic that is rejected from or never makes it into, the recycling system. This plastic enters the waste system, via residual waste collections or as plastic rejected by the recycling system and end up in either landfill or waste for energy generation, (or as what is sometimes termed 'refuse derived fuel').

While it has been shown that the volume of plastics across the regions within this project is approximately 6 Mt, Table 2 from LT2.1 '*Plastic waste available for pilot plants*', this is for all types of polymers. What is not known is the available volume of any single polymer type. Furthermore, as the most prevalent plastic used for 3D printing in the UK (95%) is PLA (Fillamentive, 2021) it Is not known the distribution of this polymer across the NEW waste management system.

3.2 What need is an AM plant fulfilling for its suppliers?

Waste plastic is a burden on local resources to deal with. The local municipality must collect it and a waste management company must sort and dispose of it. There are monetary costs for this process and if it is not put into the local circular economy, there will be a loss of the value of the plastics to the economy. If it has to be sent to a UK landfill the gate fee is £90.00 + VAT per tonne for 2022 (WRAP, 2022). If is sent to an EfW the gate fee in the Netherlands, will be between €100 and €150. Turning local waste into AM filaments that stays local is something that appeals to local people and saves costs for the MRF. Locally produced 3D printed items made from local waste, gives the community a good-feel-factor, and is a good selling point to local consumers. If the local municipality uses 3D printed art or products it shows that the local politicians care about the environment, and about sustainability.

3.3 What are the societal needs when using recycled plastic to make filaments for AM?

Making virgin plastic has a carbon footprint, due to the use of energy and resources to take the crude oil out the ground and to process it into plastic. However, once it is plastic, all that is needed to use it for a second time, is to grind it up, heat it, and extrude it with the addition of some additives. Therefore, when the plastic is used for the second time, the carbon footprint is much lower than virgin plastic as the carbon footprint of extraction is not applicable. This means that each time the AM product is ground up and reused, not only is there savings of virgin plastic, that is not used, but the overall reprocessing carbon footprint is lower. It has been shown in the laboratory that without chemicals to elongate the polymer chains, the plastic used for AM can be reused three more times. This therefore means that the virgin plastic can have a minimum of 4 lifecycles before it needs to be chemically treated or mixed with a large quantity of virgin plastic. The reusing of the materials in a product for the same or similar use is part of a circular economy business model.

3.4 Circular economy business models

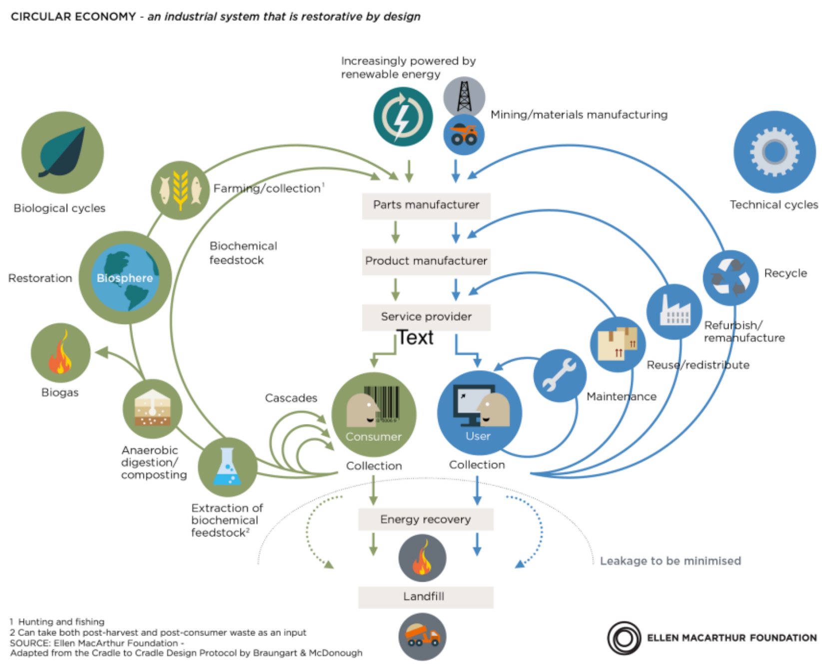


Figure 3 the circular economy butterfly diagram (Ellen MacArthur Foundation, 2023)

The linear economy is shown down the centre of the diagram, manufacture, use and then discard. The goal of the circular economy is to be at the bottom of the right hand side, with plastic products being in constant use. What this shows is that recycling takes a product out of the market and then it is reintroduced as another product. While this is preferable than energy recovery or landfill it involves energy usage and in many cases a loss of materials in the recycling process.

The circular economy doesn't just look at the materials flow of products throughout their lifetime, but it also looks at the interplay between the manufacturer, the consumer, and the product. The hardest part of the circular economy is to close the circle. What mechanisms are used to get back the product so that it can be remanufactured into the same or a different product? Furthermore, how will the AM product be able to be in service to its capacity lifespan, i.e., who and how will it be maintained or repaired if needed?

There are five circular economy business models,

1. Product as a service – instead of the customer buying the product outright, the ownership of the product is retained by the manufacturer. Therefore maintenance, replacement parts and after use disposal are all carried out through the manufacturer.
2. Sharing platform – mainly for the information technology sector.

3. Circular supplies – usually a company may have a limited number of suppliers that provide the feedstock for the business. However, in the circular economy all customers are the suppliers of their waste as a feedstock to the company. Therefore, in order to keep up the supply of the input materials, the company has to educate their customers about the routes available to them to send the products back. The company has to set up it supply chain, i.e., the route through which customers can send back the products. There is a need to identify the type of product and the materials or composite of the products. This can be carried out in a number of ways, via a QR code, RFID tag, or a new plastic identification sign. This identification should allow a unique identification for the product.

4. Product life extension, this is about fixing products so that they can continue to be used for the same purpose that they were made for. A sister project to TRANSFORM-CE is ShaRepair (Print City, 2023),

5. Resource recovery, products are designed to easily be disassembled into their constituent components. This means the design uses interlocking components rather than bonding then together, and with minimum usage of screws, and no nails.

3.5 The circular economy for AM filaments and 3D printed products

In the lab it was shown that the filaments were able to be reprocess up to 3 times, before there was a large reduction in the polymer chains that drastically reduced the workability of the plastic. This means that after four uses the plastic can be recycled through other pathways other than filament production. Chemicals that lengthen the polymer chain can be used or the plastic can be mixed with virgin plastic to make a few more production cycles.

The purity of the polymer for AM must be almost 100% otherwise there will be problems with the structure of the filament and its tensile strength. This level of purity is only needed when fine filaments of less than 2.85 mm diameters. However, there are other AM production processes that do not use filaments. For example, 10-XL in the Netherlands (10-xl, 2022) that make very large 3D printed plastic products. Their process uses a print head of up to 30mm, which is within a robot arm. For their printing process they use compounds rather than single polymers. Their large 3D printer is directly fed from a large extruder. This type of printing does not use filaments; therefore, the purity has to be high but is lower than ordinary AM filaments.

It has been shown, through experimentation at MMU, that during the experimental manufacturing process there was approximately a 20% waste factor. This waste factor cannot be directly used again in the extruder without going through the pelletisation process. However, the 20% waste can be used directly in the same process used by 10-XL where the plastic is extruded to produce and AM product, thus continuing the circularity of the plastic.

As the TRANSFORM-CE project has shown, it will be possible to forward any plastic that is unsuitable for AM production to the IEM industry to continue the circular economic model.

4. Potential customers

The TRANSFORM-CE pilot project showed that it is possible to make filaments from recycled plastics. The industry for AM filaments that are made from recycled plastic is very small, yet companies seek to comply with their corporate social responsibility as part of their sustainability agenda. Therefore, now is the time to produce these filaments to fulfil the market need to become more sustainable.

4.1 The AM market analysed

The financial data available for the AM industry is for the whole industry and covers the whole range of activities, from the printer manufacturers, software producers, service providers, and filament producers, to the final printed products. The data also includes all the printable materials of which plastic is only one of them. At this time, in volume, plastic is used the most, however the value in monetary terms for plastic is low compared to the monetary value of the other parts of the AM industry. In 2019 of the 582 companies surveyed 72% used polymers and 49% used metal, (Ernst & Young 2019). Filamentive (2021) provide some data analysis for the UK. At the time of writing this business plan, detailed data about the other three partner countries is not yet available. For the UK Filamentive estimate that by end of 2021 there was 232,000 3D printers in the UK, which on average use 12 kg of filament annually. This equates to 2.8 million 1kg reels or a market of 2800 tonnes of filament. The estimated yearly growth for the whole AM industry is given my Ernest & Young, and HUBS (2022) as approximately 25%. If this is assumed across the whole industry equally, then the plastic AM industry can be assumed to have a compound annual growth of 25%. This means, with an annual compound growth of 25%, the amount of filaments required in the UK for 2025 will be 8.544 million 1kg reels, and for 2030 it will be 26.077 million 1kg reels. This is an exponential growth just for the UK. There is no breakdown of the types of polymers that are projected to be used in 2025 or 2030.

At the time of writing this business plan, the manufacturing capacity for AM recycled filaments in the UK is very small, and most is imported. Filamentive, is one of the larger companies selling filaments in the UK, yet their product is manufactured in the Netherlands by a conglomerate based outside the EU. This means that the filament production expansion within the partner countries from local waste plastics has a huge potential.

4.2 Potential for additional plants in partner countries

The full-scale plant envisaged by this project, has the maximum capacity of 100 tonnes per year. There was no indication which polymer types the plant was to produce. However as shown in Appendix 2, there are many types of plastics that can be used for AM. From data published by Filamentive (2021), their research found the most used plastic in 3D printing was PLA, which according to them was more than 95% of their market. The problem is that good clean PLA can usually only be found from post industrial waste, which is of high grade with low levels of contaminants and therefore easily recycled into filaments. The PLA from municipal waste is available but it is quite contaminated and costly to recycle to the purity needed to make sub 2mm filaments.

Axion polymers (axiongroup, 2022) in Manchester England, recycle approximately 200,000 tonnes of mixed plastics, and produce ABS, PP and polystyrene pellets that are used as a replacement for virgin plastics. Their plastic waste comes from motor vehicles and electrical and electronic consumer products. They only make the recycled plastic pellets, but do not turn them into filaments for AM. Just this one facility has the potential to provide feedstock for many 100 tonne filament plants in the UK. Furthermore, they recycle only 200,000 tonnes a year which is a fraction of the waste plastic potentially available in the UK. Attero (Attero, 2022) is a company in the Netherlands that recycles plastic foils and produces 24,000 t of high quality LDPE pellets that have the potential to be used to make filaments.

Therefore, there are great opportunities across NWE to partner with existing plastic pellet manufacturers and continue the recycling process by turning the pellets into filaments for the AM industry. Furthermore, given the amount of waste plastic that is not currently recycled, there is opportunity for many 100 tonne capacity plants to be set up all over NWE. The business model could be to focus on a small range of polymers like Axion and Attero and become a specialist filament manufacturer.

Any small city that has the capacity to provide the waste plastic needed to supply a 100 tonnes capacity plant can be a potential city for a plant. What is currently unknown, is the plastic AM offtake or product market, i.e., where the exact market is for the filaments, as a wide range of commercial entities as well as hobbyists use the filaments. Given the projected compound growth of 25% per year, there is the potential for early producers to help grow the market using a supply push model. Therefore, while it is not possible to put a number on the amount of 100 tonne facilities that could be made in NWE, given the millions of tonnes of waste plastic that are not yet recycled, the potential is very large.

This project is based on a circular economy business model, which focuses on local recycling opportunities. This means that the waste plastic for the pellet feedstock and for the filament manufacture should come from local municipal waste thus reducing the distance travelled. There is also the added benefit that local users know that they are using locally manufactured filament that was made form plastic saved from incineration or landfill. The 100 tonne size of the plant is chosen so that multiple smaller plants can be dotted around Europe rather than a few huge plants. However, if the need arises this is not a limit, and the output capacity could grow over time.

5. Distribution channels

With direct sales, the distribution of the 100 m filament rolls will depend on who the end user will be. For the hobbyist or very small 3D manufacturer who only needs 1 or a few rolls, ordinary currier or postal service is the best way to deliver the products. however, for industrial users, who may order large quantities, they can pick them up or it will be sent on a pallet. There are online marketplaces that sell filament, these third party websites will be distributers for the filaments, which will be sent to the customers via the channels used by the website.

A method of closing the loop to receive back products made from the filament will have to be introduced. The mechanism for this is not known at this time.

6. Customer procurement

The first methods will be via direct sales using internal salesmen and the company website, and social media. The second method will be via third party companies and websites.

Promotional videos and the full use of social media will be used to promote the products, procure new customers and keep customers coming back to make repeat purchases.

7. Revenue streams

The AM market is a multibillion-dollar market that includes many different materials with which to manufacture products. The biggest sector by monetary value is the metal sector. However, the most prolific and cheapest AM sector for both the technology and the production materials is the polymer desk-top 3D printing market. The European sector happens to be the largest region in terms of its geographical footprint. It is home to several additive manufacturing industry players, which hold strong technical expertise in additive manufacturing processes. Hence, the European market emerged as the second-largest regional market in 2021, (grandviewresearch.com, 2022).

Ernst & Young (2019, p. 5) found that the West is losing ground to Asia for the amount of businesses being exposed to the use of 3D printing. They found the market is expanding fast, because AM is boosting competitiveness and brings the production process closer to customers. It is helped by governments in Asia supporting and nurturing this sector with greater input than that of Western governments. They calculated the compounded annual growth rate (CAGR) between 2011 and 2019 to have been 25% and extrapolated this average of 25% until 2023. This is approximately the same as what HUBS (2022, p. 6) predicted for 2026 of 24%, which they circulated based on the average of ten different market reports. The CAGR prediction from Ernst & Young for 2019 to 2023, ranged between 18% and 30%. Based on the HUBS CAGR of 24%, the overall market for AM in 2026 is predicted to reach $44.5 billion. Note, the overall market includes technology, software, feedstock and product manufacture.

There has also been a significant increase in the percentage of companies using 3D printing service providers. The reason for this is that the companies lack the internal expertise and are not willing to invest in capital equipment until they can better understand the advantages their company can gain with the use of AM. They start by using third party providers, then they invest in desktop technology and only later do they consider investing in industrial machinery, (Ernst & Young 2019, p. 24).

Industry developments in 2021 and 2022 positioned the technology to surpass its role in functional prototyping and become a viable solution for end-use parts and serial production, (HUBS, 2022). From their 2021 survey 11% of their respondents said that they would be making production runs between 100 to 1000 items. Ernst & Young (2019, p. 15), define AM as becoming a production technology, which is reliable and mature enough to produce end parts and components, and produce spare parts made on demand from digital warehouses, i.e., more than prototypes they become functional parts. The advantage of using AM to manufacture closer to customers, and on demand, can have a huge financial impact since it saves handling and transportation costs and reduces potential customer downtime, (Ernst & Young 2019, p. 21).

The two products that the 100 tonne a year plant will be selling will be a full range of different diameter and colour filaments and the pure single polymer pellets produced in the first stage of the production of the filaments. They could further vertically integrate by becoming 3D product printers, I.e., manufacture and sell end user printed products.

7.1 How will profits be made?

Under the law or regulations, across the four regions that this project is relevant, there is a cost to the waste management system for handling and processing a tonne of waste plastic. A MRF will receive money from the Producer Responsibility Schemes, or deposit schemes to offset costs for the recycling the waste. Part of their cost will be the gate fee for the WfE and/or landfill charges. Therefore, the gate fee or disposal fee can become the first income to the AM manufacturer. Waste management companies, as part of their corporate social responsibility (Lindgreen & Swaen, 2010), should rather pay the gate fee to an AM filament manufacturer who is doing proper recycling, than to send it to landfill or to be burnt to generate electricity. Therefore, the first income to the AM business is the value they are paid per tonne to recycle it. This is £90.00 per tonne for a UK landfill the gate fee in 2022 (WRAP, 2022). If it is sent to an EfW the gate fee in the Netherlands, will be between €100 and €150. It is not known how this will develop in the future as charges change and offtake markets develop.

A second stream of income is from the manufacturing sector. The plastic by-products leftover from the manufacturing process, costs the company for disposal. This waste plastic is clean and ideal for AM manufacturing. If a deal can be made with the business to collect or send the waste to the AM plant at a price more competitive than sending it to a MRF, this is another way to get plastic very cheaply. This will help the manufacture fulfil its corporate social responsibility.

As this business plan is not based on an actual operational plant the fixed and variable costs are not known and therefore a breakeven price for selling the product is not known.

8. key resources

The full-scale plant was never built, but a desk top laboratory installed pilot production facility was set up. The feedstock was bought in as pure single polymer pellets, which were extruded to make filaments. The pilot plant was then used to recycle the filaments to identify how many times the plastic could be recycled before it lost its mechanical properties and could not be used in desktop 3D printing. This business plan will look at the original blueprint to determine the machinery needed for the plant to operate. Actual costings i.e., the breakdown of the how much capital will be required is not available. However, the original costing was about £800,000, and at today's prices about £1M will be needed to get the plant operational.

8.1 Plant layout

The layout of the proposed plant was set out in a floor plan drawing that is reproduced here in Figure 4 Commercial sized granulator and mixer and Figure 5 layout of a commercial filament production facility below. The filament production process begins with stage two, which is the pelletisation of the clean plastic flacks received in from the MRF.

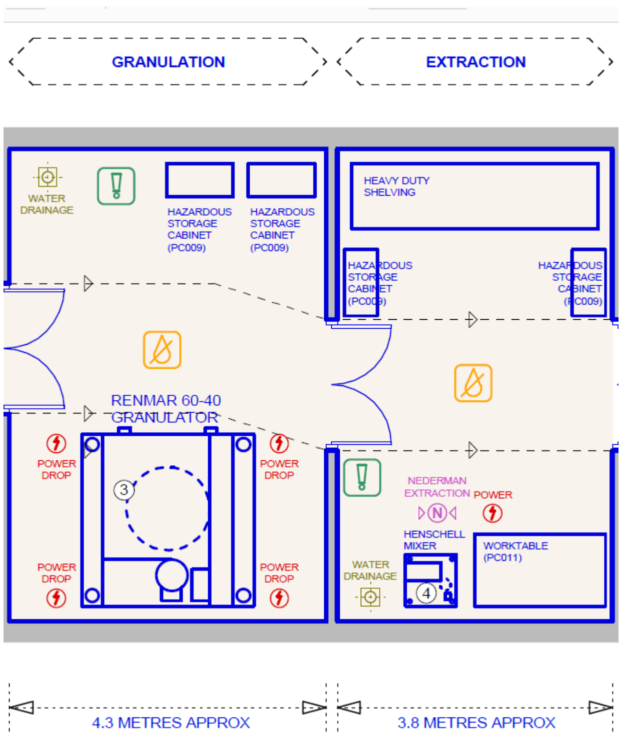


Figure 4 Commercial sized granulator and mixer

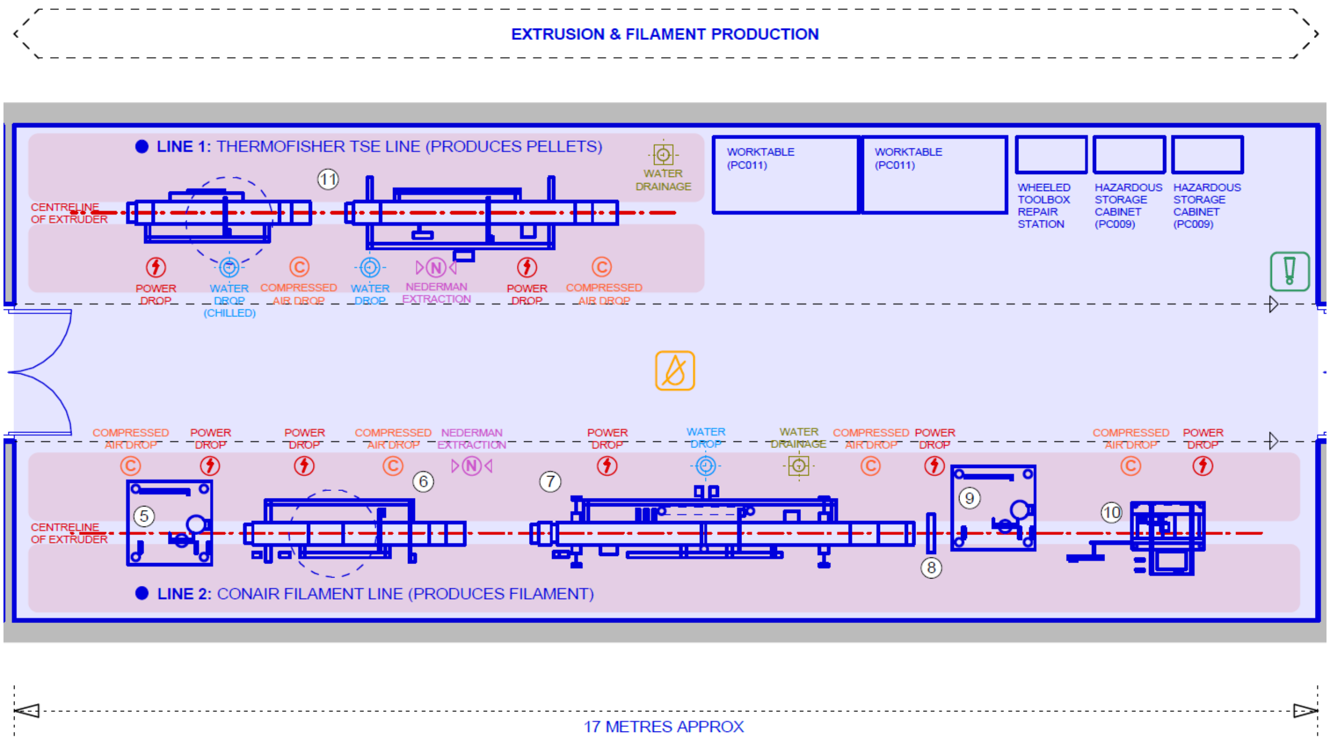


Figure 5 layout of a commercial filament production facility

8.2 Granulation of the plastic flacks and mixing the additives

The plastic chips are received in from a MRF. They should be almost 100% free of any contaminants and be almost moisture free. However, the feedstock may need some visual inspection to remove any impurities found. A Renmar 60-40 granulator is used to grind the plastic to a maximum size of approximately 3 mm.

Figure 6 Renmar 60-40 granulator #3 in Figure 4 Commercial sized granulator and mixer

The Henschell mixer is used to mix the required additives into the plastic. This is carried out before the plastic is inputted to the extruder.

Figure 7 Henschell Mixer #4 in Figure 4 Commercial sized granulator and mixer

8.3 The manufacturing process of pellets

This process uses the Thermo Fisher TSE24 twin-screw extruder equipment which has an output of 50 kg/h. At the initial output of 26.6 tonnes per year, the production was predicted to be 26,666 1 kg reels of filament. At the rate of 50 kgs per hour this would take 534 hours over one year. When the production is ramped up to 100 tonnes the production would be 100,000 I kg reels, this will take 2000 hours to produce over a single year. It is not known if this machine is able to produce this amount of output on a yearly basis, or if a larger version is needed.

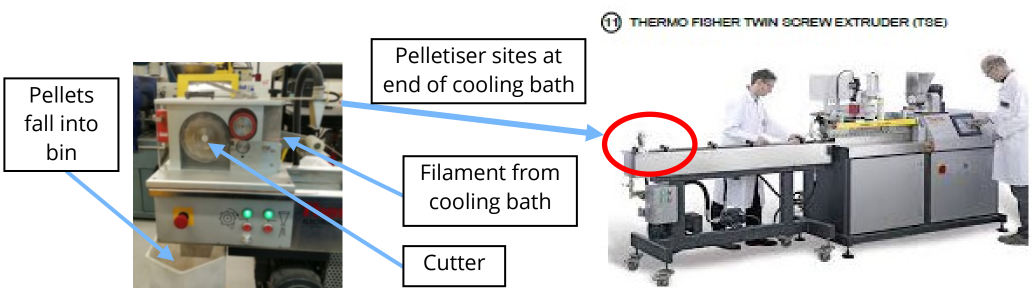


Figure 8 Thermo Fisher twin screw extruder and pelletiser

The pelletiser in mounted on the end of the cooling bath and has a cutting wheel that produces the pellets. This is the configuration at the moment in the lab. However, in a 100 tonne a year plant the pelletiser will be of a larger size that can produce 100 kg per hour. Its extruder head will produce up to 10 filaments that feed into a large standalone pelletiser Figure 9. For example, the ASG SHJ50 model, (ASG, 2023).

Figure 9 The extruder head, extruding 10 filaments that will be cut into pellets.

8.4 Drying the pellets

This project specified six pieces of equipment from Conair that make up the filament extrusion and reel production processes, see the bottom half of Figure 5. The first piece of equipment is the pellet drier.

The pellets are of approximate 5mm in diameter while the filaments are produced with less than 1 mm in diameter. In order to successfully extrude at below 1 mm, the plastic must be very dry, or have no water moisture. The reason for this is that at 300 plus Celsius the water moisture vaporises and forms bubbles within the plastic. At the extrusion head, bursting bubbles cause breaks in the filament and deformities in the thickness of the extruded filaments. It was also found that moisture in the filament is one of the causes of poor adhesion of the printed layers, otherwise known as 'poor lamination'. Poor lamination leads to the printed item splitting or breaking. Therefore, a drier is specified to reduce the moisture of the pellets before they are put into the extruder. At the MMU pilot plant the pellets are heated to 60ºC for a few hours to remove all the moisture.

The DH Series Insulated Hoppers from Conair offers large volume air drying for the plastic pellets.

Figure 10 Conair DH Series Insulated Hopper

8.5 Filament production & testing

The filament production line consists of Conair products (Conairgroup, 2023). It consists of a filament extruder, water cooling bath, a laser measuring device to check the diameter of the filament, a puller machine to move the filament along, and a coiler machine that winds the filament onto the reel.

Figure 11 Conair filament extrusion line

To test the quality of batches of filament there will be a need for a small test facility with a few 3D printers. The printers will be of the type shown in Figure 12 two types of desk top 3D printers below.

Figure 12 two types of desk top 3D printers

8.6 Air quality – Fumes extractors

A Nederman extraction unit is used in three places to extract fumes that are given off from hot plastic. The first is used above the mixer, and the other two are used above the two extruders. It is assumed that the extraction unit is centralised with extraction arms coming down from the roof.

8.7 HR and labour costs

The facility will need polymer experts in order to successfully manufacture commercial volumes of AM filaments. Also, the company will need, sales staff, office staff, cleaning staff, forklift driver etc. the costing for these are not known.

9. Strategic partners

The local MRF and the local council members associated with waste management are important people to partner with in order to secure a steady supply of good feedstock. Similarly, local commercial manufacturers who may have a steady supply of clean single polymer plastics will be strategic partners within a sustainable supply chain. There are many private enthusiasts that have a 3D printer in their home and make things for their utility or as a hobby. These people have an online presence that will be tapped into, to showcase and promote filaments made from recycled plastic. The products make by these customers will be used to showcase what can be produced using recycled plastic. These customers will be used as ambassadors for the circular economy model for AM. Third party wholesalers, with strong online presence, will be sought as channels to sell the filaments.

10. Key Activities

10.1 Site location for plant

The full-scale plant would have been in Manchester UK, where the tonnage needed to fully supply the plant with up to a 100 tonnes per year would have been ample. As this is a circular economy project, the site chosen for the production of the pellets and the filament should be situated as near as possible to the collection of the plastics, usually a MRF, in order to reduce transportation to a minimum.

10.2 AM end products

For the above printers, Figure 12, the plastic filament must be of very pure single polymer and the nozzle size is usually less than 2 mm. However, there are larger format printers that use a robotic arm to print with a width of up to 30 mm and create pieces of up to 12 meters long. The robot arm moves on rails as it prints the product. Figure 13 3D printing technology using a large robotic, shows a lounge sofa being printed by a robotic arm, (10-xl, 2022).

Figure 13 3D printing technology using a large robotic arm to print a sofa (10-xl, 2022)

The advantage of printing with a print head of up to 30mm is that the purity of the plastic does not need to be at the level of ordinary 3D printing. Therefore, all the waste from ordinary printing can be recycled in a circular manor by reusing it in a large format printing like that used by 10-XL. As these are very large objects reinforcing fibres are used to strengthen the product. In such a printer, the clean dry plastic flakes are put into a hopper fed extruder, which feeds the molten plastic directly to the print head. This has the advantage that no pelletisation or filament production is needed. Multiple heating cycles of the plastic cause the shortening of the polymer chains. Short polymer chains make it difficult to extrude the filament as breakages occur. The less the plastic is heated the more times it can be reused before it needs to be mixed with virgin plastic or depolymerised using chemical recycling, (Jeswani et al., 2021; Jiang et al., 2022; Kusenberg et al., 2022) .

While the prevalence at the moment is to print one-off items, in the future 3D printing will be used to produce runs of up to 1000 products (Ernst & Young 2019).

10.3 Auxiliaries

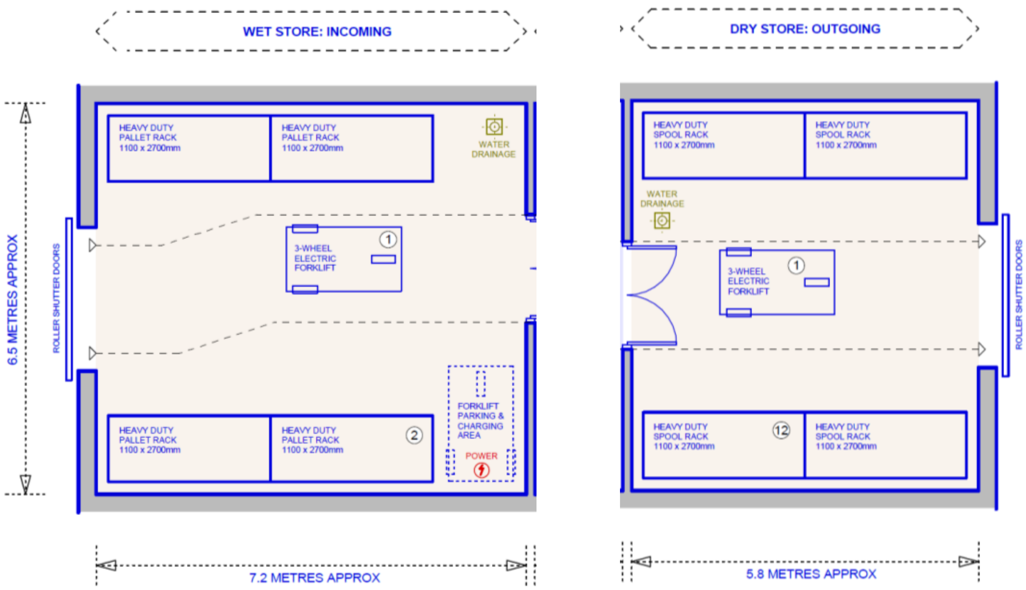


Figure 14 The auxiliary storage areas

Capital investment is needed for pallet shelving to store the inward bound wet/moist plastic flakes and for the finished reels of filament. Also required is a vacuum sealing machine to stop the filament absorbing moisture from the air as it waits to be used. A forklift is needed to move raw materials and products around the plant.

10.4 Capital expenditure and size of plant

Actual costings are not available. However, the original total cost in 2019 was estimated to be £800k for full plant. The initial yearly capacity was to have been about 26.66 tonne, which could have be ramped up to 100 tonnes per year. The 26.66 tonnes equates to 26,666 1kg rolls per year. If they sell at £24 each that is a gross sales of £639,984 sales per year. If the plant is working to capacity, it can produce 100,000 1kg rolls per year which equates to £2.4M.

The return on investment and the breakeven point are not know as the fixed and variable cost are not know.

11. Conclusion

This business model, which is based on the business model canvas, discussed the nine elements of the business model. From desktop research, the overall AM industry is very large, with a compound yearly growth of approximately 25%. In the UK there are over 200,000 desktop printers that can be use the plastic filaments produced through this project.

Since the plant was not constructed within this project, the actual profit potential is not known. However, as, there are international large manufacturers who supply filaments made form virgin plastic, they have shown that their business model can be profitable. Therefore, further work needs to be carried out to assess the profit potential of using negative valued waste plastic to make AM filaments for the 3D printing market.

Based on successful production of filaments from a range of different 100% recycled plastic polymers, it was show that the products can be re-extruded up to three more times. Thus, eliminating four amounts of virgin plastic, and having a reduced carbon footprint of the three iterations, over the first lifecycle of the plastic.

12. References

10-xl. (2022). https://10-xl.nl/

ASG. (2023). *Plastic pelletizer for PET flakes*. https://www.plasticrecyclingmachine.net/plastic-pelletizer-for-pet-flakes/

Attero. (2022). *AGANFOILS: Upcycling post-consumer film into high quality LDPE granulate*. Retrieved 2022 from https://bit.ly/2ungMyb

axiongroup. (2022). *Working towards a world where nothing goes to waste*. Retrieved 2022 from https://axiongroup.co.uk/

Conairgroup. (2023). *Never worry about your plastics processing equipment again*. Retrieved 2023 from https://www.conairgroup.com/

Ellen MacArthur Foundation. (2023). *The butterfly diagram: visualising the circular economy*. Retrieved 30/03/20223 from

Ernst & Young (2019). 3D printing: hype or game changer?

EU Commision. (1994). *Packaging and packaging waste EUROPEAN PARLIAMENT AND COUNCIL DIRECTIVE 94/62/EC*. https://bit.ly/3XmNvz7

European Commission, D.-G. f. E. (2021). *Turning the tide on single-use plastics*. Publications Office. https://doi.org/doi/10.2779/800074

Fillamentive. (2021). *The UK 3D Printing Filament Market in 2021*. https://www.filamentive.com/the-uk-3d-printing-filament-market/

Garmulewicz, A., Holweg, M., Veldhuis, H., & Yang, A. (2018). Disruptive technology as an enabler of the circular economy: what potential does 3D printing hold? *California Management Review*, *60*(3), 112-132.

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science advances*, *3*(7), e1700782. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5517107/pdf/1700782.pdf

GOV.UK. (2022). *Plastic Packaging Tax: steps to take*. https://www.gov.uk/guidance/check-if-you-need-to-register-for-plastic-packaging-tax

grandviewresearch.com. (2022). *3d-printing-industry-analysis*. https://www.grandviewresearch.com/industry-analysis/3d-printing-industry-analysis

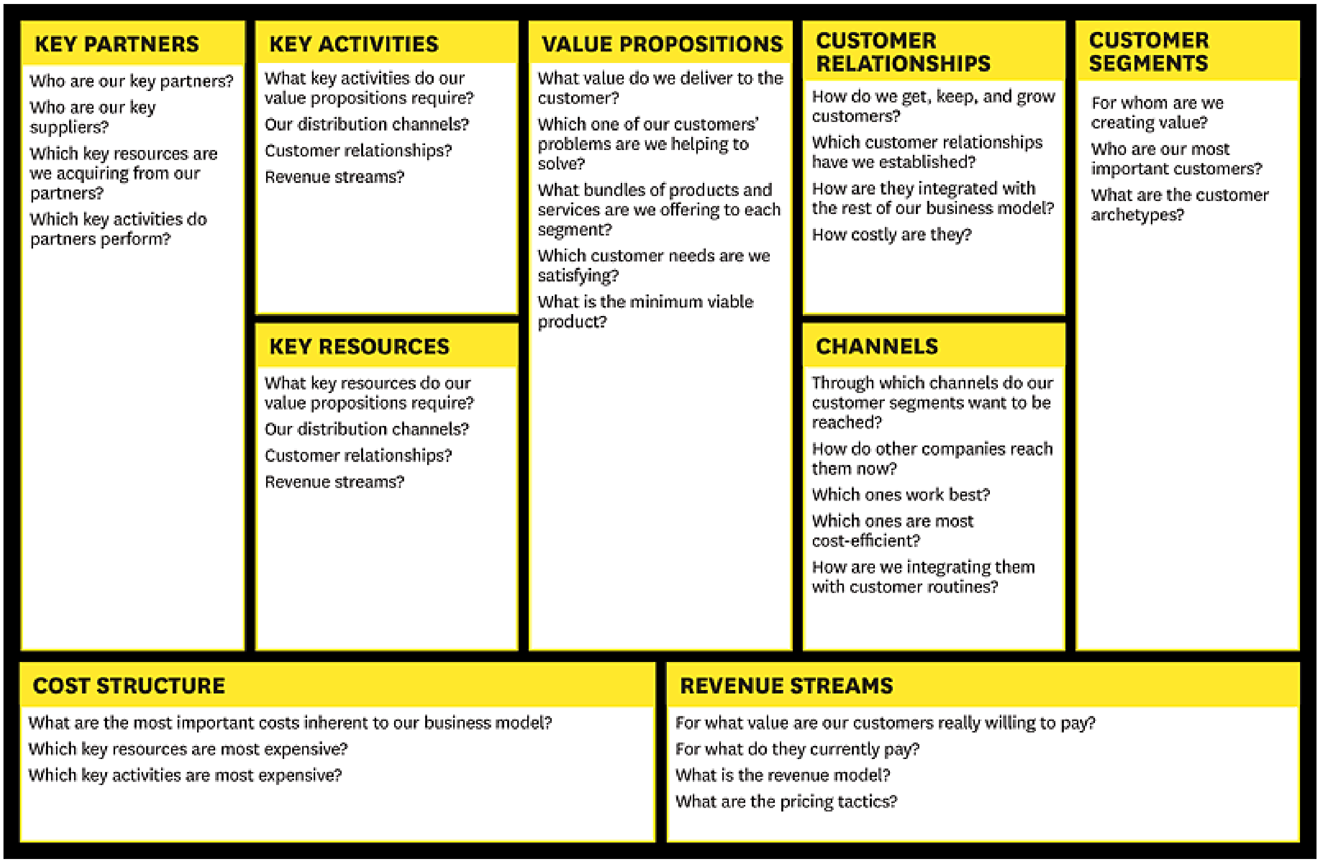
HUBS. (2022). *3D printing trend report 2022*. https://bit.ly/3W5ihwA , https://www.hubs.com/get/trends/

Jeswani, H., Krüger, C., Russ, M., Horlacher, M., Antony, F., Hann, S., & Azapagic, A. (2021). Life cycle environmental impacts of chemical recycling via pyrolysis of mixed plastic waste in comparison with mechanical recycling and energy recovery. *Science of the Total Environment*, *769*, 144483.

Jiang, J., Shi, K., Zhang, X., Yu, K., Zhang, H., He, J., Ju, Y., & Liu, J. (2022). From plastic waste to wealth using chemical recycling: A review. *Journal of Environmental Chemical Engineering*, *10*(1), 106867. https://www.sciencedirect.com/science/article/pii/S2213343721018443
Kusenberg, M., Roosen, M., Zayoud, A., Djokic, M. R., Dao Thi, H., De Meester, S., Ragaert, K., Kresovic, U., & Van Geem, K. M. (2022). Assessing the feasibility of chemical recycling via steam cracking of untreated plastic waste pyrolysis oils: Feedstock impurities, product yields and coke formation. *Waste Management*, *141*, 104-114. https://doi.org/https://doi.org/10.1016/j.wasman.2022.01.033
Lindgreen, A., & Swaen, V. (2010). Corporate social responsibility. *International journal of management reviews*, *12*(1), 1-7.
Plastic Europe. (2022). *Plastics – the Facts 2022*. https://bit.ly/3EGk0Rz
Plastics Europe. (2020). *The Circular Economy for PLastics, A European Ovewrview*
Print City. (2023). *ShaRepair*. https://printcity.mmu.ac.uk/business/sharepair/
Simplify3D. (2022). *Ultimate 3D Printing Materials Guide*. https://www.simplify3d.com/support/materials-guide/
WRAP. (2022). *Comparing the costs of alternative waste treatment options*. https://bit.ly/3znL9qx

Appendix 1: Business Model Canvas

The Harvard Business school business model canvas, from https://hbr.org/2013/05/a-better-way-to-think-about-yo



Appendix 2: Types of plastics used in the AM industry

The list below makes up the types of plastic filaments used in AM (Geyer et al., 2017; Simplify3D, 2022).

ABS (Acrylonitrile Butadiene Styrene)

It is a low-cost material with good mechanical properties. It is tough and impact resistance, and therefore good for printing durable parts that will hold up to extra usage and wear. It can withstand much higher temperatures before it begins to deform. This makes ABS products good for outdoor or high temperature applications. When printing with ABS, good ventilation is necessary, as the material tends to have a slight odour. ABS also tends to contract quite a bit as it cools, so controlling the temperature of the environment can have major benefits.

High-Density Polyethylene (HDPE)

It is light, flexible, easy to dye and mould, has good insulating property, and has a non-absorbent property that can be used for everyday materials. However, Garmulewicz et al. (2018, p. 118), explain that the thermal properties of HDPE make it hard to work with, and as of 2018 HDPE "… *commercially available HDPE filament from recycled materials is still hard to find*."

Low-density polyethylene (LDPE)

It is a polymer used in many different types of packaging. It can be used when wear resistance is a critical issue; for example, the soles of shoes also require hardness, plasticity, elasticity, and more. LDPE can also be used as a near-surface filler or in creating products like sliding pads (commonly used with furniture).

Polyethylene Terephthalate (PET)

It is used to manufacture water bottles. It is a semi-rigid material with good impact resistance, but it has a slightly softer surface which makes it prone to wear. The material also benefits from great thermal characteristics, allowing the plastic to cool efficiently with almost negligible warpage.

Polylactic Acid (PLA)

It is the filament of choice for many extrusion-based AM, because it is used at a low temperature and does not require a heated bed. It is inexpensive and creates parts that can be used for many applications. It is derived from crops such as corn and sugarcane, it is biodegradable and is therefore considered one of the most environmentally friendly filaments. For the PLA to be compostable it must be able to compost according to the European standard EN 13432. However, the conditions for composting under this standard are only suitable for commercial or industrial type composting and not ordinary ambient temperature garden composting.

Polypropylene (PP) – used in AM

It is a semi-rigid and lightweight material used in storage and packaging applications. It is a challenging metrical to use for AM, however it is tough and has a good fatigue resistance making it ideal for low strength applications like living hinges, straps, leashes, etc.

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