PlastiCircle: *Improvement of the plastic packaging waste chain from a circular economy approach*

Grant Agreement No 730292

PlastiCircle Deliverable

D5.10: Report on technical and economic validation of products

Richard McKinlay (Axion)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730292.

Factsheet

Document name: D5.10: report on technical and economic validation of products I

Responsible partner: Axion

Work package: WP5

Deliverable number: D5.10

Version: 2

Version date: 03/06/2021

Date due: February 2021

Dissemination level	
X	PU = Public
	PP = Restricted to other programme participants (including the EC)
	RE = Restricted to a group specified by the consortium (including the EC)
	CO = Confidential, only for members of the consortium (including the EC)

Author: Richard McKinlay

Reviewers: All partners

Abstract

This deliverable summarises the technical and economic assessment of the products made during the PlastiCircle project.

Five different products have been successfully produced using recycled post-consumer packaging, showing the potential for incorporating recycled content into non-packaging applications.

In some cases the use of post-consumer recycled content represents a small financial saving for the manufacturers, and in other cases a slight increase in cost. This shows the importance of additional economic incentives for manufacturers to use recycled content in non-packaging applications.

Partners

1. ITENE: INSTITUTO TECNOLÓGICO DEL EMBALAJE, TRANSPORTE Y LOGÍSTICA
2. SINTEF: STIFTELSEN SINTEF
3. AXION: AXION RECYCLING
4. CRF: CENTRO RICERCHE FIAT
5. UTRECHT: GEMEENTE UTRECHT
6. Las Naves: FUNDACION DE LA COMUNITAT VALENCIANA PARA LA PROMOCION ESTRATEGICA EL DESARROLLO Y LA INNOVACION URBANA
7. ALBA: PRIMARIA MUNICIPIULUI ALBA IULIA
8. MOV: MESTNA OBCINA VELENJE
9. SAV: SOCIEDAD ANONIMA AGRICULTORES DE LAVEGA DE VALENCIA, Spain
10. POLARIS: POLARIS M HOLDING
11. INTERVAL: INDUSTRIAS TERMOPLÁSTICAS VALENCIANAS
12. ARMACELL: ARMACELL Benelux S.C.S.
13. DERBIGUM: DERBIGUM N.V.
14. PROPLAST: CONSORZIO PER LA PROMOZIONE DELLA CULTURA PLASTICA PROPLAST
15. HAHN: HAHN PLASTICS Ltd.
16. ECOEMBES: ECOEMBALAJES ESPAÑA S.A.
17. KIMbcn: FUNDACIÓ KNOWLEDGE INNOVATION MARKET BARCELONA
18. PLAST-EU: PLASTICS EUROPE
19. ICLEI: ICLEI EUROPASEKRETARIAT GMBH
20. PICVISA: PICVISA OPTICAL SORTING
21. CALAF
22. SINTEF AS

Table of contents

Publishable summary

Successful development of recycled materials for the manufacture of 5 different products has been carried out as part of the PlastiCircle project. This deliverable gives a summary of the technical and economic assessment of the products made during the PlastiCircle project. The table below summarises the products investigated in WP5

Partner	Product	Polymer
Armacell	Foamed boards	Polyethylene Terephthalate (PET)
Centro Ricerche Fiat (CRF)	Automotive parts	Polypropylene (PP) PET
Derbigum	Bitumen roofing	PP
Hahn Plastics	Ground retention products	PP (flexible)
Interval	Refuse sacks bags	Low Density Polyethylene (LDPE)

All manufacturers were able to use recycled post-consumer household packaging in their products. By using different levels of recycled material, the products were able to meet the technical requirements and end user needs.

The table below summarises the % recycled content achieved and the Plasticircle value add. A negative value add shows an increase in cost to make the product.

Partner	Product	% post consumer recycled content	Plasticircle value add
Armacell	Foamed boards	100% (80% bottle 20% tray)	-€5,10 (1 m³ of foam)
CRF	PP Automotive parts	100%	-€0.03 (1 tonne of compound)
CRF	PET Automotive parts	100%	+€0.36 (1 tonne of compound)
Derbigum	Bitumen roofing	4%	+€4.50 (1 tonne of blend)
Hahn Plastics	Ground retention products	50%	+€5,20 (100 units)
Interval	Refuse sacks bags	50% for 35 µm film	-€25,00 (1 tonne polymer)

Armacell were able to use a recycled PET source that had elevated levels of PET trays. The formulation required slightly different additives to their standard product, but the final product met end user needs. The product may not be

suitable for all PET foam applications, but certainly has a market. Due to the additive requirements there was a slight increase in cost when using the tray rich material, although this is likely to change when more post-consumer tray rich recyclate is available.

CRF used post-consumer PP and PET to produce automotive parts. Through careful formulation by Proplast the raw materials were used successfully in moulding trials. The PP part represents a very good opportunity for CRF. The PET part is more challenging, again as the supply of recycled PET is difficult to secure at a price that is attractive for non-packaging applications.

Derbigum use a mixture of crystalline and amorphous PP. The amorphous portion of the product is much greater, and therefore a significant amount of work was carried out to attempt to convert crystalline PP to amorphous. All post-consumer recycled PP is crystalline. This work was not successful however and it was not possible to convert crystalline PP to amorphous. Therefore, Derbigum focused on replacing as much of the crystalline PP with post-consumer recycled PP. This was successful at a 4.5% addition in to the final product mix, which gave a saving of 4.5 Euros per tonne. Although this is a modest saving it shows there is not an increase in cost, making it feasible long term.

Hahn have demonstrated the injection moulding of PP from film into a ground retention product. This is an important development as PP from post-consumer household film currently does not have a well established recycling route. The product was made using 50% recycled PP from film with the remainder being post-industrial granulate. This shows huge potential for PP from film into injection moulded applications.

Interval produce various film products and in the PlastiCircle project have been evaluating recycle PE available on the market and carrying out an additional washing test with Sorema. The results from the washing test were not favourable, however material from Attero showed great potential. The quality was very good, although the cost of using it is slightly higher than their standard material.

All partners have been able to produce a product that meets end user requirement and product specifications, albeit with a slight increase in cost in some cases. In most cases, the quality was a little lower when using the post-consumer recycled material. It may be that these products are suitable for certain applications and not all applications.

The demand for recycled packaging is very high due to the tax on packaging without recycled content that is due in the UK and EU. This tax means that packaging manufacturers can pay more for recycled polymer as there is the economic incentive of not having to pay the tax.

In addition, the packaging industry has a much closer link to public perception and brand reputation. This is seen by large companies such as Coca Cola using very high levels of recycled PET.

Although this is a good thing from a circular economy point of view, it means there is less material available for recycling into long life products, and the material that is available from packaging is more expensive.

There is scope for the 5 manufactures to use these materials today, but as time goes on and more closed loop recycling is achieved, recycling packaging into long life product may not be viable from an economic point of view.

To combat this, a tax on long life products without recycled content could also be considered. This would encourage more recycling of long life products which are typically not captured at end of life in a very controlled manner.

Overall, the outcome of the PlastiCircle project is very positive for the manufacturers, but more effort will be required by the whole recycling and manufacturing supply chain to ensure there is a future for recycled content in long life products.

.

Introduction

The PlastiCircle project aims to develop additional end markets for recycled polymers derived from post-consumer household packaging waste.

Already there is successful recycling of post-consumer packaging, however in order to create more demand for recycled products, and therefore stimulate the industry further, research has been conducted in this project focused on five different products.

The PlastiCircle project partners, products and polymers that are used in the products are given below in Table 1.

Table 1 PlastiCircle partners and products investigated in study

Partner	Product	Polymer
Armacell	Foamed boards	Polyethylene Terephthalate (PET)
Centro Ricerche Fiat (CRF)	Automotive parts	Polypropylene (PP) PET
Derbigum	Bitumen roofing	PP
Hahn Plastics	Ground retention products	PP (flexible)
Interval	Refuse sacks bags	Low Density Polyethylene LDPE

The use of recycled polymers must make both technical and commercial sense. If the product is not fit for purpose, or the cost of incorporating recycled content is too high, there is no business case for using recycled materials.

The PlastiCircle project focuses only on post-consumer, household packaging. Being recycled into long life non-packaging products. The current drive within Europe is to move to closed loop packaging to packaging recycling.

In Europe a tax on packaging without recycled content will soon be coming into effect. This means that the price packaging converters are able and willing to pay will exceed that which non-packaging manufactures can justify, as they will not be subject to a tax.

Furthermore, packaging is very closely linked to brands and there is much more of a focus here to appeal to consumers but using recycled content. The most obvious example of this is in PET, where many big brands such as coca cola are targeting very high recycled content in their packaging.

Since there is only a finite amount of post-consumer, household packaging collected and recycled, this creates strong competition which again drives up the price. These things have an effect on the economics of using this material in non-packaging applications, such as those investigated in PlastiCircle.

The economic evaluation carried out in this report is intended for publication, and to ensure commercially sensitive information is not shared, only the difference in cost between standard material and production and PlastiCircle material and production will be reported. More detailed information will be present in WP7 and WP8.

In addition to the competition and higher price able to be paid by large brands to mitigate the coming tax, there is the technical consideration of using recycled polymer from packaging. Because the polymer in the packaging was specified for a specific application, changing that application can come with difficulties. It is important therefore to ensure the end products are technically suitable and meet the requirements of the end user.

This short report summarises the individual technical evaluations of the products (D5.5 to D5.9) and also summarises the economic implications in a more qualitative manner. A more indepth economic assessment is carried out in Work Package 7 and WP8. Details of manufacturing processes can be found in D5.4.

1. Foamed PET boards

Armacell produce foamed PET boards that can be used as insulation or core boards for composite parts. Currently Armacell use washed PET flakes from PET bottles. Armacell use both clear PET and coloured PET, as the product is not usually visible to the consumer.

The aim of PlastiCircle is to ensure Armacell can use the PET generated from the project in the engineered foams. More specifically, the challenge is to determine whether PET from thermoforms can be used as well as PET from bottles.

Product Information

The main requirement for the recycled material was to produce a stable, even foamed structure.

There are certain characteristics of recycled PET that can affect the foam and therefore quality of the end product. These are:

- Intrinsic viscosity of the PET (0.73 average)
- Level of polyethylene or polypropylene (<0.5% polyolefin)
- PVC (<100 ppm)
- Polyamide (<500 ppm)

These contaminants can effect the reactivity of the foaming process and prevent an acceptable product from being made.

Figure 1: Example of a prefabricated foam board

The recycled content in the boards came from tray and bottles – from yellow bin collection in Germany. The boards are made out of 100% recycled content, including up to 20% tray

There is a need to use PET from tray as the PET form bottle is in such high demand, and the aim of the circular economy is to ensure this polymer goes back into bottle applications.

However, obtaining PET from tray is very difficult for two reasons:

- PET trays are not widely recycled today. In some instances (such as with the material used in PlastiCircle) a blend of PET tray and bottle is recycled together. This is because PET tray material is far more brittle and cannot be processed using the same technology. Only one facility in Europe is currently designed to process only PET tray
- There is also a strong demand for the PET from tray to go back into tray. The operator of the PET tray recycling facility was unable to provide material as they felt it went against the circular economy and the PET from tray should go back into tray

The PET from tray has its own issues. Testing by Armacell showed the polymer was less reactive in their process, and required more chain extender due to the shorter polymer chains in PET.

Anecdotally, PET from tray can contain higher levels of contamination, such as PE. This may be because there is no deposit system for trays and the packaging has to be recovered from a mixed stream. Also, PET trays can have a PE layer on for heat sealing that isn't easy to remove.

Armacell were able to formulate a product using the following recipe:

- 94.8% rPET
- 5.2% foaming additives (blowing agents, nucleation package, modifiers package)

Technical Evaluation

Armacell produced and tested a foamed board using PET from the German kerbside collection system. The production trial was successful and more information can be found in D5.4.

Table 2 Physical properties of foam

Density	96 kg/m³
Compression Strength (x-direction)	1.3 MPa
Compression Modulus (x-direction)	52 MPa
Shear Strength (y-direction)	0.7 MPa
Shear Modulus (y-direction)	15 MPa
Tensile Strength	2 N/mm²
Tensile Modulus	68 N/mm²

In terms of meeting the user specification, the product meets the minimum general requirements. For shear modulus and tensile modulus the minimum general requirements cannot be met.

However, the mechanical properties are sufficient for a large part of end users. Some high-end applications would require further optimisation.

This means that although the PET with tray can be used, it may not be suitable for all applications.

Economic Evaluation

In order to protect commercial sensitivity, only the difference in cost will be reported in this deliverable. More detailed costing will be carried out in WP7 and WP8.

The evaluation is done on a unit basis. The unit will be different depending on the manufacturer.

The economic evaluation considers three aspects:

1. Difference in raw material cost: This will include any difference in the polymer when using recycled polymer and any difference in additive cost based on the formulation developed
2. Difference in production cost: This includes any impact from slower production or increased energy consumption from higher temperatures or pressures required
3. Difference in product value: Depending on the product, it may be that incorporating recycled content increases the value of the product if it can be marketed differently. Conversely, it may be that the product with recycled content cannot be sold at the same price due to a difference in properties, and therefore the value of the product reduces

The sum of all the differences can be calculated to give an overall PlastiCircle value add

Table 3 gives the high-level economic evaluation for the Armacell product. This is done on a basis of 1 m^3 of foam (i.e. unit = 1 m^3 foam)

Table 3 Armacel economic evaluation

Difference in raw material cost (€/unit)	+€5,10
Difference in production cost (€/unit)	0
Change in unit cost (€/unit)	+€5,10
Change in unit value (€/unit)	0
Plasticircle value add (€/unit)	-€5,10

Overall, with the current supply of PET tray rich material the cost increases. The production conditions (i.e. temperature, rate of product) are ineffective, but the material cost increases. This is because:

- There is currently no secure source of tray rich material, and the recycler who can provide these charges the same as for PET bottle material due to the difficulties on processing PET tray

- The reactivity of the PET tray material is lower, and therefore different chain extenders and additives are required in different quantities which increases the overall cost[1].

As PET tray recycling increases, as it must to meet recycling targets, the belief is the feedstock will be more widely available and affordable. These additional markets for non-bottle PET will help drive the circular economy and provide a basis for further investment in recycling.

Armacell already market their product on its recycled content, and so there is no scope to increase the value of the product based on the inclusion of PET tray rich material. Overall therefore using the tray rich material increases the cost.

The situation and supply of tray rich material must be closely monitored by Armacell going forwards, such that when a supply of material does become available at a more attractive cost

[1] The exact additives and quantities is proprietary information and cannot be shared in this report

2. Automotive parts

Centro Ricerche Fiat (CRF) is a research institute for Fiat, the automotive company. CRF investigate how to develop parts from new materials. In the automotive industry there is a significant usage of Polypropylene (PP) and Polyamide (PA).

Recycled PP is available from post-consumer packaging waste, but the usage back into automotive parts can be limited due to the levels of R&D that must be put into using this material. For recyclers alone they may not be able to justify the cost of R&D, and will therefore target lower value add products such as drainage piping.

Polyamine is not used in consumer household packaging in significant quantities, and so to investigate alternative feedstocks, CRF will be investigating using PET in place of nylon.

Product Information

CRF initially selected three parts to focus on in the PlastiCircle project:

- Interior cap made currently using PA but will be made with PET in PlastiCircle
- Dashboard air duct made using PP
- Bumper bracket made using PP

These products do not contain recycled material as standard, so the PlastiCircle project will focus on incorporating recycled content.

The technical requirements of these parts are provided in the confidential technical appendix.

As the scope of the project developed the products changed and the two final products selected are shown below:

- An rPP based automotive central console bracket (interiors) by injection moulding. The rPP came from bottles, containers and caps from Italy and the product uses 100% recycled content
- an rPET based automotive bracket formed by injection moulding for exterior and engine compartment. The rPET came from recycled bottles in Italy and the product used 100% recycled content

Figure 3: rPP product

Figure 2: rPET product

Technical Evaluation

CRF have worked closely with Proplast to obtain and test samples of PET and PP for post-consumer household waste. A sample of coloured PET and coloured PP has been supplied by recyclers in Italy.

The additives and quantities used in the PP product can be seen below:

PP - (T15%+GF15%) + 3% block copolymer additive + 3% PE/PP compatibiliser

- Talc: H4 IMIFABI
- Glass fibers: Lanxess CS7952

The properties of the formulated polymer used in the production of the automotive part can be seen in Table 4.

Table 4 Properties of formulated PP

Density	1,12 g/cm³
Tensile Modulus	3530 MPa
Tensile Yield Stress	34,5 MPa
Tensile Strain at yield Stress	3,2%
Tensile Stress at break	29.4 MPa
Tensile Strain at break	3,8%
IZOD Impact Strength, notched (23 °C) – Fracture type	8,7 kJ/m² - C
IZOD Impact Strength, unnotched (23 °C) – Fracture type	19,5 kJ/m² - C

PET is being investigated to replace PA. Coloured PET bottle is being used in this study as there is not sufficient availability of PET from tray, and clear bottle is in high demand for closed loop recycling.

The PET is a more challenging material to use in injection moulding applications. Because PET is unstable when molten (will absorb moisture and degrade), the key to processing is to have the shortest possible cycle time in the injection moulder.

There are several additives that can be incorporated into the PET to improve the properties:

- Nucleating agent
- Processing aid
- High reinforcing filler
- Chain extender
- Stabilizers

The additives and quantities used in the PET product can be seen below:

PET + 1%P130 + 0.5%P252 + 20%GF + 5% Lotader AX8900

• Bruggolen P130 (processing aid) - Brüggemann

• Bruggolen P252 (nucleating agent) - Brüggemann

• Glass fibers - Lanxess CS 7967 (26/1493) D

• LOTADER AX8900 (a random terpolymer of ethylene, acrylic ester and glycidyl methacrylate-24% acrylate)

The properties of the PET product can be seen in Table 5 below:

Table 5 Properties of forumlated PET

Density	1,52 g/cm³
Tensile Modulus	6896 MPa
Tensile Yield Stress	102 MPa
Tensile Strain at yield Stress	2,2%
Tensile Stress at break	100 MPa
Tensile Strain at break	2,5%
IZOD Impact Strength, notched (23 °C) – Fracture type	8,4 kJ/m2 - C
IZOD Impact Strength, unnotched (23 °C) – Fracture type	40,3 kJ/m2 - C
HDT 1,8 Mpa	172 °C

In terms of meeting the use specifications, the PP product meets the minimum general requirements. The tensile modulus is slightly lower than the virgin counterpart is, but all other values are in line with requirements.

The mechanical properties are sufficient to pass the design validation of component of FCA standard. The same approach was used to compound other FCA grades with the same results allowing wider application range.

For the product which uses rPET, the product meets in general the minimum general requirements for user specification. The IZOD impact is still lower than the virgin counterpart is, but all other values are in line with requirements. The mechanical properties are sufficient to pass the design validation of component of FCA standard.

Economic Evaluation

The economic evaluation has been completed based on 1 kg of compound. Note that the PET would replace virgin polyamide, and the PP would replace virgin PP. More information is available in work package 7 and 8, with a summary given below in Table 6.

Table 6 Summary of economic evlauation of CRF parts

	PP part	PET part
Difference in raw material cost (€/unit)	+€0.03	-€0.39
Difference in production cost (€/unit)	€0.00	+€0.02
Change in unit cost (€/unit)	+€0.03	-€0.36
Change in unit value (€/unit)	€0.00	€0.00
Plasticircle value add (€/unit)	-€0.03	+€0.36

For the PP part, the use of the post-consumer recyclate results in a slight increase in cost per kg of compound. This is because of the additives required to improve the impact strength. This cost increase is very marginal.

For PET there is a slight saving on using the recycled PET over virgin PA. The benefit comes from the substitution of material, as although various additives are needed, overall the cost is lower. There is a slight increase in processing cost as the cycle time for the PET parts is slightly higher meaning more energy per part is used.

Overall this demonstrated a positive impact for the use of recycled polymers, that could be improved with additional incentives for using recycled content.

3. Bitumen roofing membrane

Derbigum produce polymer modified bitumen roofing membranes. The polymer used to modify the bitumen is Polypropylene (PP). The polymer prevents the bitumen from becoming too soft in high temperatures or too brittle in low temperatures.

Product requirements

Derbigum use a mixture of amorphous (or Atactic) PP (aPP) and crystalline (or Isotactic) PP (iPP). The amount of polymer used in the bitumen blend is approximately 20%. In the blend aPP is the predominant component.

Amorphous polymer means the structure is less ordered, and polymer is more flexible and blends more easily with the bitumen. Crystalline PP is more rigid and brittle and has a higher melting point.

Derbigum ideally require amorphous PP in order to use a large quantity of recycled polymer.

Aside from the crystallinity, the level of PE must be very low as this can act as a nucleating agent and cause the polymer to become more crystalline. A melt flow index of 15 g/10 minutes is also needed.

Derbigum have sourced post-consumer PP from packaging that has been evaluated and tested in replacing the crystalline portion of the product. More information on this is within D5.4.

Technical Evaluation

Work carried out to reduce the crystallinity of recycled PP has not been successful. The additives needed and the process are not feasible at scale, and so the possibility has not been considered further. More information on this is available in D5.4.

Derbigum have produced sheeting with the base sheet containing recycled post-consumer crystalline PP.

The formulation for the base sheet is as follows:

- 4% of iPP post-consumer
- 7% of aPP
- 10% bitumen
- 42% recycled bitumen
- 37% fillers

The properties of the final product can be seen in the table below:

Table 7 Properties of bitumen roof membrane

On bituminous blend	Viscosity	10.800 cPs
	Cold flexibility	-10°C
	Penetrability	70 dmm
On finished product	Cold flexibility	-10°C

In terms of user specification, the product (ipp post consumer) is currently usable for base sheets formulations; the bituminous blend and the finish product have properties in their range.

Concerning the top sheets, Derbigum need to work with the formulation because the recycled polymer increases a lot the viscosity and prevents them to reach the range of cold flexibility. Derbigum can already say that they will not be able to put as much recycled polymer in the formulation of top sheets as in the formulation of base sheets.

Economic Evaluation

The high-level economic assessment is shown in Table 8. A unit in this case is 1 tonne of blend.

Table 8 Derbigum economic assesment

Difference in raw material cost (€/unit)	-4.5€
Difference in production cost (€/unit)	0€
Change in unit cost (€/unit)	-4.5€
Change in unit value (€/unit)	0€
PlastiCircle value add (€/unit)	4.5€

The total value add based on the formulation and material supply is 4.5€ per tonne of blend. This shows a small saving by using the recycled material, and since there is no additional costs in terms of production it makes economic sense to incorporate this material.

A greater benefit could be realised if more recycled content could be incorporated into the bottom sheet, however because it has not been possible to reduce crystallinity, there is not much scope for increasing it further.

4. Ground retention products

Hahn plastics are a leading manufacturer of outdoor furniture, such as benches and tables, as well as retention and ground work products.

Hahn use an intrusion moulding process to create plastic boards and planks, which can then be used to create a wide range of end products. The intrusion moulding process is less sensitive to contamination and so the process is ideal for recycled content.

Hahn operate a large recycling facility in Germany which takes in material collected from the kerbside of households through the DSD system. They also have a plant in the UK which takes in post-industrial material for recycling.

Originally Hahn were to use film from the PlastiCircle project into their urban furniture. However this is already done commercially at scale, and since the pilots did not produce enough material for testing by Hahn the focus has been changed.

Instead, Hahn is now focusing on using recycled PP from film into ground retention products.

Product Information

Hahn manufactures the Hanpave grid for ground reinforcement. This product has historically made from 100% recycled PP from industrial sources and the aim of the PlastiCircle project is to make the product with post-consumer recycled content.

This is an injection moulded product, for which rigid recycled PP could easily be used. However because there is already a big demand for recycled rigid PP, the test is being done on PP film.

PP film currently does not have a well established recycling route, partly because PP film is used almost exclusively in food packaging. Therefore, this looks at using the film in an injection moulding applications.

Technical Evaluation

Using film to make rigid products is not standard, as the melt flow of film is much lower than in rigid products. A low melt flow is more difficult to injection mould as the polymer is stiffer and does not flow as freely. This leads to needing a higher pressure, increase cycle times and incomplete mouldings where the polymer has not filled the mould completely.

This is seen mostly in PE, where the MFI of PE film is <1 g/10 minutes. In PP, the melt flow of film can range between 1 and 5 g/10 minutes, meaning injection moulding is more feasible. Also, PP from film is stiffer than PE from film, making it more suited to injection moulded applications.

Hahn sourced washed and compressed PP film from the German kerbside household collection. Since it had not been compounded in an extruder the price was more competitive with the post-industrial regrind typically used in these applications.

Hahn trialled the recycled PP at different levels and found that 50% PP from film and 50% PP from post-industrial regrind gave a product that could be moulded. This product is shown in Figure 4.

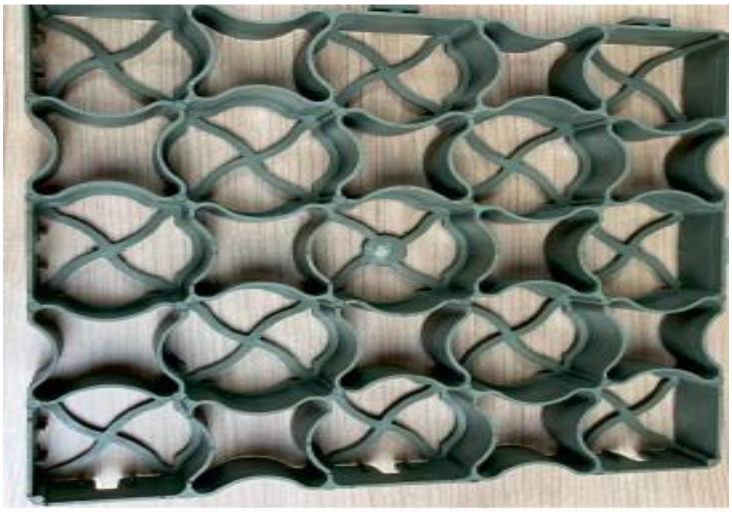

Figure 4 Hahnpave made with 50% recycle PP film

At higher quantities of post-consumer PP (greater than 50%) it led to rejection of product due to the mould not being filled and the product coming out incomplete. In addition, it excess gas was released. The 50% post-consumer blend led to no rejections and comparable processing to standard material.

Hahan classify the product in three ways:

- A class – roadside use
- B class – car park use
- C class – pedestrian use

The difference between the classes is how brittle the product is and this is measured using a drop test.

- A class – dropped from 3 metres
- B class – dropped from 2 meters
- C clad – dropped from 1 meter

In order to be classified the product must not break on impact from the drop test. Table 9 shows the results of the drop tests.

Table 9 Drop tests

Sample	1m	2m	3m
Ave. of Previous Test Batch (Hanpave)	Not tested	Not tested	2.3
100% post-industrial material	0	2	2
50% Post-consumer	0	1	3
70% Post-consumer	1	3	3
80% Post-consumer	0	2	3
100% Post-consumer	0	2	2

When including the post-consumer materials all blends fail the drop test at 2m and 3 m, and all apart from the 70% pass the 1 m drop test. The reason for the failure could be either from a variation in the material or it could be that the 70/30 blend does not mix well leading to overall weaker properties.

The moulding process therefore can handle 50% recycled content with no negative impact on the production of the parts as well as meeting the Class C requirements for pedestrian use.

Economic Evaluation

The product made with 50% recycled PP from film achieves the necessary quality requirements. The economic assessment is based on the production of 100 units (each unit weighing approximately 0.5 kg) and is shown in Table 10

Table 10 High level economic evaluation for Hahn

Difference in raw material cost (€/100 units)	-€5.2
Difference in production cost (€/100 units)	€0
Change in unit cost (€/100 units)	-€5.2
Change in unit value (€/100 units)	€0
Plasticircle value add (€/100 units)	+€5.2

When using the recycled PP form film at 50% there is no impact on the production cost but there is a reduction in raw material cost. By sourcing a compressed pellet rather than an extruded compound, the feed can compete more easily with widely available post-industrial PP regrind.

This is very positive to show the potential of PP from film in the production of injection moulded products.

5. Refuse sacks

Interval operate a recycling and production facility in Valencia. They recycle predominantly post-industrial LDPE films, and some agricultural LDPE films. A wet process is used to carry out a basic clean on the material, which is then extruded into pellet. The pellet is then blown into film products such as refuse sacks.

Product Information

Interval produce a wide range of products. The most important criteria for the raw material used to produce the blown film are:

- No odour: Recycled LDPE film from post-consumer, household sources often has an odour once recycled. The odour can be minimised
- Maximum 5% PP: Typically, recycled film applications can handle up to 5% PP in the LDPE. Above this it is not possible to form a bubble during extrusion
- No PVC: PVC will degrade during extrusion and release gas
- Low levels of solid contamination: The recycled polymer will be put through a melt filter, but any contamination such as metal or glass could seriously impact the quality of the end product.

The level of moisture and contamination such as paper and organics that is acceptable for Interval is still being defined. Since their plant was designed for agricultural plastics the required process to recycle this material may be different from that which is currently in place.

In the PlastiCircle project Interval are testing two potential feedstocks:

1. Recycled LDPE film produced by Attero in the Netherlands. This is post-consumer PE recovered from the residual waste prior to incineration. It is one of the most advance sorting and washing facilities for film in Europe
2. Film separated by Picvisa and then washed by Sorema. This trial has been carried out to better understand what the quality of material would be if Interval were to invest in a washing line for post consumer films.

Technical Evaluation

Sorema material

Material from Sormea was tested by Interval. The 2D fraction from the packaging waste collection (yellow bin) was first sorted by Picvisa to increase the purity before sending to Sorema who used a who used both a hot and cold washing process to produce a washed flake. This flake was then extruded by Interval. This flow is shown in Figure 5.

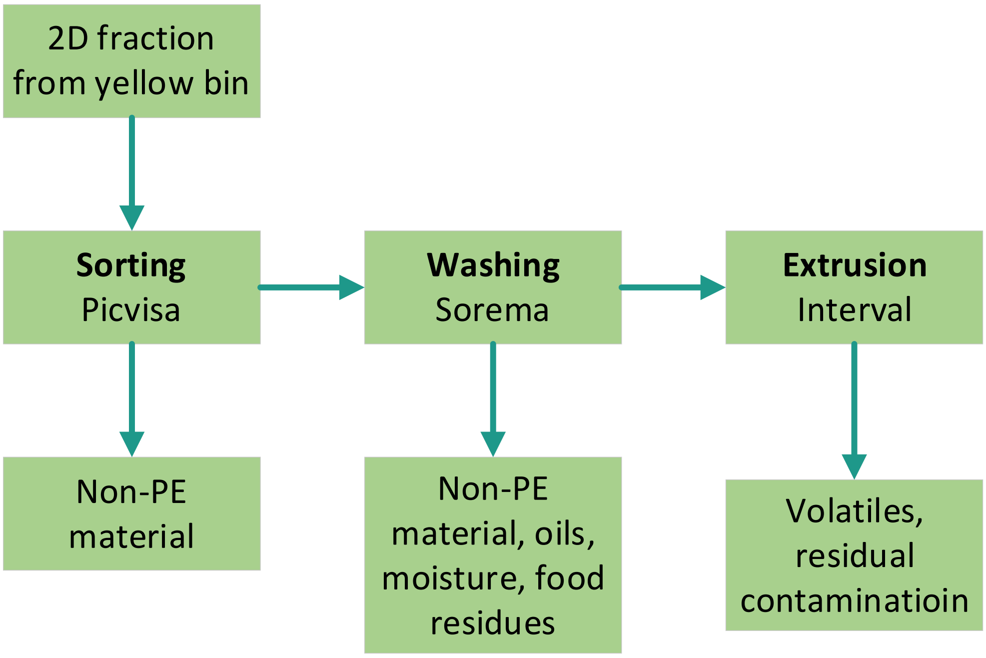

Figure 5 material flow for Sorema material

Picvisa processed the 2D fraction form the yellow bin (packaging material collected in Spain) to recover a fraction of higher purity PE. This material is typically 80% PE however Picvista increased this to 95% purity (as analysed by Picvisa). 50% of the infeed was recovered as sorted film.

Figure 6 film recovered by Picvisa

On arrival at Sorema, the material was characterised before washing. Figure 7 shows examples of the material found in the bale and Figure 8 gives the composition measured by Sorema.

Fig 3: PO stretch clear film

Fig 4: PO non-stretch clear film

Fig 5: PO stretch coloured film

Fig 6: PO non-stretch col. film

Fig 7: PET

Fig 8: Rigid PP-HDPE

Fig 9: Nonwoven fabric

Fig 10: Metals

Figure 7 Material in film bale

COMPREHENSIVE BALE ANALYSIS		
	Weight (g)	**%***
PO stretch clear film	3065	**28,6**
PO non- stretch clear film	2028	**18,9**
PO stretch coloured film	2981	**27,8**
PO non- stretch coloured film	2169	**20,2**
PET	175,2	**1,6**
Rigid PP/HDPE	75,6	**0,7**
Nonwoven fabric	54,9	**0,5**
Metals	54,1	**0,5**
Tetra Pak	46,2	**0,4**
PP film with aluminum layer	35,5	**0,3**
Expanded polystyrene	18,5	**0,2**
Polystyrene	8,9	**0,08**
Paper	7,2	**0,07**
Wood	2,5	**0,04**
Total sorted amount	**10721,6**	**100,0**

Figure 8 Composition of film measured by Sorema

The composition is comparable with that measured by Picvisa with 95.5% polyolefin film. Sorema did not differentiate between PP and PE as this is very difficult to do manually.

Half of the material received was cold washed and half was hot washed. Table 11 shows the mass balance for the washing process. In each case about 30% of material was lost as contamination, dirt or moisture.

Table 11 Sorema mass balance

	Cold washing	Hot washing
Input	212	199
Product	148.2	137.5
% waste	30.1%	30.9%

The film was received by Interval for extrusion. Figure 9 shows the washed flake. Interval commented the film was contaminated with metallised film that caused the metal detector to trigger.

Figure 9 Washed flake with aluminium film contamination

The film was extruded by interval. This process was very challenging due to the high levels of contamination. The materials viscosity was also very inconsistent suggesting a large range of grades of polymer. There was also a very strong odour from the film when being processed. Figure 10 shows the extruded pellet. This will be characterised by Proplast and Axion but is not though to be fit for Intervals purpose.

Figure 10 Extruded pellet

Attero material

Interval also carried out an extensive testing procedure to determine the level at which the Attero material can be used in their product. This information is found in D5.4.

The Attero material could be used successfully up to 100% post-consumer recycled content, however the thickness of the film had to be increased. When making a film comparable with a more standard product at 35 µm, the Attero material was used at 50% successfully.

Interval produced 3 samples of film made using the Attero material at different thicknesses and these were tested by Proplast and compared with their standard 35 µm product.

ASSESSMENT	STANDARD	UNIT	Sample 6 (Std. Dev.)	Sample 7 (Std. Dev.)	Sample 8 (Std. Dev.)	Sample 9 (Std. Dev.)
% Attero material			**50%**	**50%**	**50%**	**0%**
Thickness			35 µm	25 µm	20 µm	35 µm
Tear strength (TD)	ISO 6383-1:2015	g	659 (76,2)	591,5 (91,4)	329,2 (19,4)	889,7 (196,6)
Tear strength (MD)	ISO 6383-1:2015	g	527,2 (75,7)	380,7 (28,6)	294,7 (31,4)	538,9 (31,7)
Tensile stress at Yield (TD)	ISO 527-3:2018	MPa	11,3 (0,8)	10,2 (0,9)	10,9 (0,8)	9,9 (0,8)
Tensile stress at Yield (MD) (10% ε)	ISO 527-3:2018	MPa	11,7 (0,8)	11,6 (0,9)	11,6 (0,6)	10,0 (0,6)
Tensile strength (TD)	ISO 527-3:2018	MPa	17,3 (1,8)	15,3 (3,3)	17,0 (2,7)	17,2 (2,2)
Tensile strength (MD)	ISO 527-3:2018	MPa	16,2 (1,2)	16,4 (1,4)	18,2 (0,8)	16,8 (1,5)
Elongation at break(TD)	ISO 527-3:2018	%	459 (52)	390 (98)	485 (61)	516 (38)
Elongation at break (MD)	ISO 527-3:2018	%	234 (51)	182 (51)	140 (20)	380 (51)
Punture Resistance E_B	EN 14477	mJ	2,68 (0,30)	1,81 (0,37)	1,34 (0,22)	2,56 (0,29)
Punture Resistance F max	EN 14477	N	1,33 (0,09)	0,87 (0,12)	0,70 (0,11)	1,11 (0,14)

The data shows in the majority of tests the film made with Attero material is comparable with the standard product. As the thickness decreases, as does the strength which is to be expected. The two properties where there is a difference in strength is the tear strength and elongation at break. The Attero film is still suitable for the end markets but it is unlikely it would be used in a film thinner than 35 µm.

This demonstrates there is real potential in post-consumer film, however the sorting and washing steps are integral for success. This washing process is costly, both in capital and operational expenditure.

Economic Evaluation

Interval used material supplied by Attero to manufacture film products. The trial was also carried out with Sorema on the washing of film.

The investment in a process such of the Sorema one with all the associated equipment and installation cost, including NIR sorting would be in the region of €10 million for a 2 tonne per hour plant[2]. The operating cost of such a plant would be in the region of €300/tonne of product for the associated chemicals, energy, labour and maintenance. This level of investment is not feasible for Interval, and significant assistance would need to be given to fund such a project.

In comparison, Attero have been able to build a state-of-the-art facility with the support of the Dutch government, and the quality of the recycled PE is indicative of this. Therefore, the economic feasibility is based on the use of the Attero material.

The Attero material has limited uses because of its colour, however is comparable in cost to the standard material used by Interval. One challenge is the transport cost as the material has be to moved from the Netherlands to Spain which can be expensive. The sales price for the Attero material is commercially sensitive and so cannot be reported.

There is no difference in the production cost as the pellet is used in the same way as the standard material. There is also no need for additional additives. The overall material cost is estimated to be €25 more for the Attero material, but this is market driven and could change, and is largely due to the transport. Overall there is therefore a slight increase in cost for Interval to use this recycled material.

Difference in raw material cost (€/tonne)	+€25
Difference in production cost (€/tonne)	€0
Change in unit cost (€/tonne)	+€25
Change in unit value (€/tonne)	€0
Plasticircle value add (€/tonne)	-€25

Because the material is black, there is little scope to develop a new product range that has more value. This is one of the major limitations of post-consumer recycled film. Some plants are looking to separate coloured from clear film to produce material that can go into more applications, but this then also increases cost.

As with all cases, additional incentives to use recycled content into non-packaging applications would help justify paying more for post-consumer material.

[2] See Appendix for estimate of cost

6. Conclusions

All partners have been able to produce a product that meets end user requirement and product specifications.

In most cases, the quality was a little lower when using the post-consumer recycled material. It may be that these products are suitable for certain applications and not all applications.

In some cases (Armacel, PP automotive parts and PE for film) there was a slight increase in cost associated with using the recycled material from packaging. This is because of the additional additives needed to meet the end user requirements, or the cost of the process to produce a good quality material. For Derbigum, Hahn and the PET automotive part there is a slight reduction in cost.

The demand for recycled packaging is very high due to the tax on packaging without recycled content that is due in the UK and EU. This tax means that packaging manufacturers can pay more for recycled polymer as there is the economic incentive of not having to pay the tax.

In addition, the packaging industry has a much closer link to public perception and brand reputation. This is seen by large companies such as Coca Cola using very high levels of recycled PET.

Although this is a good thing from a circular economy point of view, it means there is less material available for recycling into long life products, and the material that is available from packaging is more expensive.

There is scope for the 5 manufactures to use these materials today, but as time goes on and more closed loop recycling is achieved, recycling packaging into long life product may not be viable from an economic point of view.

To combat this, a tax on long life products without recycled content could also be considered. This would encourage more recycling of long life products which are typically not captured at end of life in a very controlled manner.

Overall, the outcome of the PlastiCircle project is very positive for the manufacturers, but more effort will be required by the whole recycling and manufacturing supply chain to ensure there is a future for recycled content in long life products.

Appendix A – film plant costing

	Equipment				
	Number required	Unit cost	Total purchase cost	Installation factor	Installed cost
Sorting stage					
Shredder	1	£200,000	£200,000	40%	£280,000
Screen/trommel	1	£75,000	£75,000	40%	£105,000
2D/3D	1	£75,000	£75,000	40%	£105,000
Magnet	1	£50,000	£50,000	40%	£70,000
ECS	1	£50,000	£50,000	40%	£70,000
NIR	2	£200,000	£400,000	40%	£560,000
Conveyors	9	£8,000	£72,000	40%	£100,800
Total			£922,000		£1,290,800
Washing and extrusion stage					
Wash line	1	£3,500,000	£3,500,000	15%	£4,025,000
Water treatment	1	£750,000	£750,000	40%	£1,050,000
Dryer	1	£120,000	£120,000	40%	£168,000
Extruder	1	£1,250,000	£1,250,000	15%	£1,437,500
Bagging station	1	£10,000	£10,000	40%	£14,000
Screws	2	£20,000	£40,000	40%	£56,000
Pneumatic conveyors	2	£20,000	£40,000	40%	£56,000
Total			£5,710,000		£6,806,500
Installed equipment grand total	£8,097,300				

Civils	
Roads	£ 30,000
Drainage	£ 100,000
Buildings	£ 500,000

Total Civils Cost	**£ 630,000**

Steelwork	
Items	**Cost**
Conveyor supports	£ 10,000
Process equipment enclosures	£ 75,000
Access platforms	£ 25,000
Total Steelwork Cost	**£ 110,000**

Electricals	
Electrical installation (as % of equipment purchase cost)	5%
PLC installation (as % of equipment purchase cost)	3%
Total Electricals Cost	**£647,784**

Office and laboratory costs	
Office/facilities setup	£200,000
Laboratory setup	£300,000
Total setup costs	**£500,000**

Maintenance spares inventory	
Maintenance (as % of equipment purchase cost)	3%
Total cost	**£198,960**

Engineering/Design	
Items	**Number**
% of CAPEX	5%
Total Engineering/Design Cost	**£509,202**

Insurance of works

Items	Number
% of CAPEX	1%
Total cost	**£106,932**

Contingency	
Contingency (% of CapEx)	10%
Contingency (£)	**£1,080,018**

Total capital cost (2 tph plant)	**£11,880,197**

	Equipment				
	Number required	**kW**	**Loading**	**Total kW**	**Running cost**
Sorting stage					
Shredder	1	200	60%	120	£10.80
Screen/trommel	1	50	70%	35	£3.15
2D/3D	1	50	70%	35	£3.15
Magnet	1	50	70%	35	£3.15
ECS	1	50	70%	35	£3.15
NIR	2	50	70%	70	£6.30
Conveyors	9	20	70%	126	£11.34
Total					£41.04
Washing and extrusion stage					
Wash line	1	50	70%	35	£3.15
Water treatment	1	100	70%	70	£6.30
Extruder	1	500	70%	350	£31.50
Bagging station	1	0	70%	0	£0.00
Screws	2	20	70%	28	£2.52

Pneumatic conveyors	2	20	70%	28	£2.52
Total					£45.99
Total hourly electricity cost	£87				
Annual electricity cost	£522,180				

	Per tonne of feed	Tonnes per year	Per year
Washing (bulk cost)	20	11695	**£233,910**
Extrusion (screens etc)	20	11695	**£233,910**

Chemical cost, washing	
Mass flow to washing stage	11695
% Detergent	**N/A - included in bulk cost**
% Caustic	**N/A - included in bulk cost**
Chemical cost (£/te feed to washing)	**N/A - included in bulk cost**
Total (£/year)	**£0**
Chemical cost, deinking	
Mass flow to deinking stage	0
Chemical cost (£/te feed to deinking)	£40.00
Total (£/year)	**£0**

Water effluent disposal cost	
Cost (£/te feed to wash plant) of disposal to drains	£2
Total (£/year)	**£23,391**

Maintenance spares	
Total (£/year)	**£100,000**

Office and plant running costs (internet, heating etc.)

	Cost (£/year)
Total (£/year)	£ 350,000

FLT cost		
	£/month	Number required
	£650	3
Total (£/year)		£23,400

Working capex	
Total (£/year)	£404,865

Employees						
Role	Number required per shift	Number of shifts	Additional on days	Total	Cost	Total cost
Plant Manager	1	1		1	£70,000	£70,000
Business Development	2	1		2	£50,000	£100,000
Admin/office manager	1	1		1	£40,000	£40,000
Office support staff	3	1		3	£30,000	£90,000
Shift Leader	1	4		4	£40,000	£160,000
Maintenance Engineer/electrician	1	4	2	6	£40,000	£240,000
Yard	1	4	1	5	£25,000	£125,000
Operator	3	4		12	£25,000	£300,000
Lab staff	1	1		1	£30,000	£30,000
Total cost (£/year)						£1,155,000

Total operating cost (£/year) (per process)	£3,046,656

PlastiCircle
TOO VALUABLE TO WASTE

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant Agreement No. 730292.