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

Grant Agreement No 730292

PlastiCircle Deliverable

D5.3: Specifications required by end users and comparison with sorted material

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: D5.3: Specifications required by end users and comparison with sorted material

Responsible partner: Axion

Work package: WP5

Deliverable number: D5.3

Version: 1

Version date: 27/04/2020

Date due: M35

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 addresses the Human ethical requirements for the PlastiCircle Project.

It includes details on the procedures and criteria that will be used to identify/recruit research participants are be provide as well as the informed consent procedures that will be implemented for the participation of humans and templates of the informed consent forms and information sheet.

Partners

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

Table of contents

Publishable summary

PlastiCircle aims to develop and implement a holistic process to increase recycling rates of packaging waste in Europe. This will allow to reprocess again plastic waste in the same value chain (i.e. Circular economy; closure of plastic loop). This process is based on four axes: collection (to increase quantity of packaging collected), transport (to reduce costs of recovered plastic), sorting (to increase quality of recovered plastic), and valorisation in value-added products (i.e. foam boards, automotive parts like engine covers/bumpers/dashboards, bituminous roofing membranes, garbage bags, asphalt sheets/roofing felts and urban furniture like fences/benches/protection walls).

This short report details the requirements of the manufacturers who will be using the recycled materials, and identification of the challenges they have found through the assessment of materials available on the market today. 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	Outdoor furniture and ground retention products	Low Density Polyethylene (LDPE) High Density Polyethylene (HDPE) PP
Interval	Refuse sacks bags	LDPE

Table 2 shows the basic description of the materials already being used by the manufacturing partners, and the materials that Plasticircle will look to incorporate into production.

Table 2 Target materials

Partner	Current feed material	Target material
Armacell	PET bottle flake	Non-bottle rPET
Centro Ricerche Fiat (CRF)	Virgin PA Virgin PP	Recycled PP Recycled PET (to replace PA)
Derbigum	Virgin aPP and iPP	Recycled PP (converted to aPP if possible)
Hahn Plastics	Post-consumer household films	Higher purity PE film
Interval	Post-consumer industrial and commercial films	Post-consumer household films

Analysis by Armacell has shown that PET from a mixture of 80% bottle and 20% tray can be used at a level of 30% in the final mix, due to the need for more chain extender than 100% bottle flake. The demand for PET to go back into packaging is increasing across Europe as large brands are willing to pay a premium for recycled PET to go back into packaging.

CRF in collaboration with Proplast are developing formulations for using recycled PP and PET in automotive parts. There are challenges with the PET to ensure the material does not degrade during injection moulding, but it is an exciting potential market.

Derbigum have analysed PP and PE samples from the market, and the key for their process is to investigate how to transform crystalline PP into amorphous PP, so that more recycled content can be incorporated into the product. Already some material is suitable to directly replace the iPP portion of the product.

Hahn already recycle large quantities of post-consumer waste in Germany, and are ideally placed in this project to ensure maximum recycling rates The key factor for Hahn is ensuing low PVC and PET levels. Cold washed PE film will be incorporated into their product.

Current LDPE film products are not likely to be fully suitable for Interval, who need high purity to ensure the quality of their end product. The developments in Plasticircle should lead to higher quality material which they could use. The aim is t produce hot washed film from a higher purity PE feedstock to be used in manufacture.

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 3.

Table 3 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	Outdoor furniture and ground retention products	Low Density Polyethylene (LDPE) High Density Polyethylene (HDPE) PP
Interval	Refuse sacks bags	LDPE

This report details the requirements of the end users, and whether these requirements can be achieved from recycled polymers derived from post-consumer household packaging.

The development uses primarily material produced by existing recyclers rather than using material generated during the pilots. The main reason for this is mimicking the recycling process on a small scale is very challenging, and the quality of material produced is likely to suffer. This may lead to false conclusions in the project which may damage the overall success.

The overall sorting and recycling process been optimised over many years and utilises a wide range of equipment not available from the project partners.

Material that has been used in the development of the products is form 100% post-consumer, household packaging sources.

This deliverable should be read in conjunction with D5.2 which details the testing of materials and products at the lab stage.

1. Quality versus properties

Work Package 5 (WP5) is focused on developing polymers derived from recycling household packaging. Because of the limitations of Research and Development projects, it has been necessary to use recycled polymers that are available from existing state of the art recyclers.

This is possible providing the materials used in the project are of the same **quality** and have the same **properties** they would if they were recovered using the Plasticircle methodology.

The **quality** of a recycled polymer refers to how much non-polymer and non-target polymer contamination is present in the recycled resin. For example, a low quality recycled PP may have a small amount of PET or aluminium contamination. The resulting effect is the **properties** of the recycled polymer will suffer and be reduced.

In Plasticircle methods are being developed to produce higher quality outputs from sorting. However, in modern sorting and recycling facilities already very high levels of quality can be achieved. The difference is that by producing higher quality after sorting the overall cost associated with reaching the high quality levels may be lower. Therefore, in general, the Plasticircle approach will not create higher "quality" recycled polymers compared to state of the art facilities, but the route to get there will be optimised.

There is an exception to this in the project which is film. Film from post-consumer household sources is typically of very low quality, and it is often not economically viable to recycle this material in isolation. In the plasticircle project Picvisa are developing a method of recovering higher quality PE films using advanced stabilisation techniques during Near Infrared (NIR) sorting. This higher **quality** material should therefore be more suited to the mono-layer film investigated in plasticircle.

The **properties** of a recycled polymer are dictated by what grades of virgin material have been recycled. Properties are characteristics such as Melt Flow, strength and crystallinity.

Different products and different moulding techniques need different properties. The Plasticircle project is using recycled polymer from post-consumer household packaging.

Within the packaging there will be a somewhat narrow range of grades of polymers. For example, PP pots will use a grade of PP that has a high melt flow to allow for easy injection moulding.

As a result, this project is looking to take polymer with a distinct set of properties useful to its first life as packaging, and attempting to use these recycled polymers into a non-packaging market, often with very different requirements.

The innovation in WP5 is therefore the attempted modification of some polymers for use in the investigated applications, of id this is not possible or needed then the attempt to increase purity of the feedstock through improved sorting.

2. Foamed PET boards

Armacell produce foamed PET boards that can be used as insulation. 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 requirements

The main requirement for the recycled material is 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.

The other important characteristic for the Armacell product is the reactivity of the polymer. This is a property that Armacel

Armacell use chain extenders to increase the polymer chain length and allow for the correct formation of the foam. The PET must be reactive enough to allow the chain extender to increase the chain length.

A final property measured by Armacell is the Carboxylic End Groups (CEG). This is a measure of the number of end groups on the polymer present. Higher CEG usually means a lower IV, because the polymer chains are shorter.

Analysis of materials

Several different Pet materials have been tested. These can be split into roughly two categories:

- PET from bottles
- PET from thermoformed trays

Armacell already use recycled PET from bottles collected in Europe through the deposit return scheme. Bottle flake has a higher IV and reactivity as the polymer chains are longer. This makes it a well suited material.

However, the demand for PET bottle flake is growing massively as more and more retailers and brands wish to incorporate rPET into their bottles. The focus of the Circular Economy is also such that closed loop recycling is more desirable than open loop and so rPET from bottles should be supplied back

into bottles.

The result of this is that the Plasticircle project will not look at alternative sources of rPET form bottles, although this has been shown to be very suitable for the Armacell product.

The alternative source of rPET is from thermoforms. Thermoforms are often made with high levels of recycled content. PET will naturally degrade when reprocessed unless it is upgraded using solid state processing or polycondensation is carried out in the melt phase. Because the requirements for PET in thermoformed sheet is not as demanding as for bottles, there is no need to upgrade the rPET and a lower quality polymer can be used. This makes economic sense as the upgrading process is expensive.

Because a "lower quality" PET is used in trays, when they are recycled it causes issues. Firstly, PET thermoforms often have a PE layer used for heat sealing that causes discolouration of the PET. Secondly, because the polymer chains are shorter and the PET is a lower IV, the tray material is more brittle and has to be upgraded if it is to be used back into tray. The brittleness also means during washing the PET breaks up and is lost in the process.

There is only one commercial recycling facility in Europe processing PET post-consumer trays. The focus of this plant however is to supply the PET back into trays, and recycling into non-packaging products is not of interest.

A sample of PET containing 80% bottle and 20% tray from kerbside sources was identified. Although this still contains a high level of bottles, it is all that is available on the market for testing. If the product can be developed to use this material then higher levels of tray could be incorporated in the future.

The sample was tested as received in flake form and after extrusion into pellet. The two samples are from the same source.

Table 4 Analysis of PET samples

Lot	Reactivity flakes	Reactivity pellets	CEG	IV	nIR scan
Sample 1 80% bottles 20% tray	2.6	3.7	22.33	0.744	99.81 % PET 0.08% PES 0.1% PET with contaminants
Sample 2 80% bottles 20% tray	3.1	4.0	26.1	0.723	99.89% PET 0.04% PES 0.02% PET with contaminants 0.04% PMMA
Reference (PET bottle)	12-14		28-30	0.74	N/A

The PET from this 80/20 source can be used in the Armacell process (see D5.2 for details). The maximum quantity that can be used which is economically viable I 30%.

Updated specification

Using the results of the testing, an updated specification for Armacell can be given:

- mixed colour semi-crystalline
- hot washed PET flakes
- non-food contact grade
- no limitation regarding content of other colours, with exception for brown flakes: max. 8%
- maximum trays content: 20% by wt.
- impact of multilayer material – still to be confirmed
- particles size: 8-10 mm
- intrinsic viscosity internal testing: 0,73 dl/g (average)
- bulk density internal testing: 200 - 400 g/l
- limited amount of contaminants and residual moisture, in particular:
    - Moisture < 1,5%
    - Dust < 0,1% (<1mm)
    - Polyolefins < 0,5%
    - Polyamide < 500 ppm
    - Polyvinyl chloride < 100 ppm for full delivery and < 300 ppm for single big bag
    - Polystyrene < 200 ppm
    - Metal < 30 ppm
    - Paper < 10 ppm
    - Opaque < 3%
    - Other impurities < 100 ppm

Focus for development

The work to date has shown the increasing difficulty in obtaining PET for use in a non-packaging application. The impact of this must not be underestimated. The demand for rPET back into packaging is only growing, and with strong purchasing power from the large brands, the availability of this feedstock will dwindle.

The impact will also be that the thermoform industry who has typically used large volumes of rPET bottle flake will be forced to use rPET from thermoforms. The recycling of thermoforms is challenging but not impossible.

This leaves the project in a difficult position and suffering from an unforeseen

situation. However, Armacell will continue to focus on developing their product with a 80/20 mix of bottle/tray. The reactivity of this material is lower than the standard bottle material, and more chain extended is needed in order to achieve the correct quality. This limits the use of the tray/bottle material to 30% in the final mix.

Finally, the impact of multilayer trays could be assessed. NIR sorting can remove multilayer trays as these will contain PE (specification is <0.5% polyolefin) and could contain polyamide (specification is <500 ppm), and so it is likely multilayer trays would be very detrimental to the process.

3. 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.

Polyamide 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 requirements

CRF have 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.

Analysis of materials

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 PET was sourced from DENTIS. This is a coloured PET fraction primarily from bottle flake. The PP was sourced from Breplast. Proplast and CRF visited the recycling facilities to ensure the material was suitable as post-consumer.

The PET was supplied as a hot washed flake and the PP as an extruded pellet. Thee specification of the PP from the recycler is as follows:

Table 5 Anlaysis of recycled PP from packaging

	Median	Standard deviation
Elastic modulus (MPa)	1569	17
Yield stress (MPa)	26	0.3
Strain at yield (%)	6.5	18.3
Stress at break (MPa)	18.3	3.7
Strain at break (%)	14.8	2.9
IZOD notched impact (KJ/m2)	5.3	0.8

The specification of the PET was not tested on its own due to the instability of PET in injection moulding. The confidential appendix gives detailed information on the results

For the PP material, Proplast have investigated three parameters:

- Level of filtration – 1 mm and 200 µm used
- Influence of Polyethylene (PE) – 10% and 20% PE blends looked at
- Fillers – different levels of mineral and glass fillers

Results have been for the different blends and the results are provided in the confidential technical appendix.

The results are promising and shows that the finer filtration gives improved physical properties. Filling the PP with minerals and glass improved some properties, but recued the impact strength as expected. The PP blends have been fine tuned to meet the specification required by CRF, and so it can be concluded that PP from packaging can be successfully modified and used in the production of automotive parts.

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

Proplast have carried out a significant amount of work to modify the PET to be used in injection moulding. It is not possible to display results in this report as the specification of the automotive parts must remain confidential.

The initial results highlight the challenges with using PET in injection moulded

applications, and Proplast will continue to formulate and optimise the injection moulding parameters.

As discussed in the previous section, the demand for rPET is goring. Currently development has been carried out on coloured PET from the Italian kerbside collection. Typically coloured PET was not that desirable, but it can be used back into coloured thermoform trays. As a result the price is also increasing, and since there is a huge amount of modification needed to use the PET, economically it may no longer make sense.

Focus for development

Proplast and CRF have successfully demonstrated the production of automotive parts from Polypropylene from recycled post-consumer plastic. The formulations require a degree of filler to give the correct properties, but this is not unusual for automotive parts, many of which contain a filler.

PET is significantly more difficult. This is not a polymer that is used by CRF in injection moulding applications, and so assessing the suitability has required significant work to develop a formulation and extrusion and moulding process that yields results close to those needed.

Because of the complexity of using PET the development will continue to be carried out on coloured bottle flake. This is not as in demand as clear bottle flake although is becoming more expensive. Since IV is such an issue for injection moulding, low IV tray material is likely to be very challenging.

4. 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.

Analysis of materials

Derbigum carried out a wide and comprehensive testing of different sources of PP. The details of this can be found in D5.2. Due to the confidential nature of the results detailed results cannot be given, but a summary is available.

The test used to analyse potential feedstock are summarised in the table below.

Analysis name	Purpose
DSC (Differential Scanning Calorimetry)	This provides an indication as to how pure the polymer is. If there is contamination from a non-PP polymer it will be shown using this method. It is not fully qualitative but give an indication. Any non-PP polymer can significantly impact the performance
Viscosity	This is a measure of how viscus the polymer is and how freely it flows. The polymer needs a very specific viscosity to be used in the
IR (Infrared spectrophotometer analysis)	This identifies the polymer type of the chip/pellet and will show any non-PP contamination. It is more quantitative than DSC.

Ash rate	Ash rate determines the level or inorganic filler. Inorganic filler can be from chalk to talk to "bulk" out the polymer or from pigment or contamination

Deliverable 5.2 gives a detailed analysis of all the different materials tested by Derbigum from post-consumer packaging waste streams.

Unlike PET, there are many, many different grades of PP used in packaging. PP is used in blow moulded bottles, injection moulded containers and in film. Each of these will have quite different properties.

Atactic PP is not used in packaging, so all recycled PP from packaging will be isotactic. Derbigum only use a small percentage of iPP, which has lead to the work on reducing the crystallinity of the recycled polymer as presented in D5.2. This means that unless the crystallinity of the iPP can be reduced by 90%, only the small quantity of iPP can be substituted for recycled.

As well as aPP and iPP, PP can be split into copolymer and homopolymer.

Homopolymer is the most widely used general purpose grade for PP, and most packaging will use this type of PP. it consists only of propylene monomers. PP copolymer is made by polymerizing ethane and propene together. This introduces ethene units into the propylene chain. It makes the polymer tougher and can improve optical clarity.

Packaging should primarily be isotactic homopolymer, but there is the potential for other types of PP to be used.

There are two other difficulties when considering PP from packaging:

1. Separation efficiency from PE: PP and PE are both polyolefins and both float in water. Therefore the only way to separate the two is using NIR or by hand. Neither of these methods are perfect, and it often leads to considerable levels of PE in recycled PP streams. Some recyclers may use more advanced equipment than others, and so there would be a difference in quality between the recyclers
2. The definition of "packaging" for PP can be quite loose. It ranges from primary food packaging to secondary or even transit packaging. As a result recyclers may target slightly different types of PP packaging, which could lead to quite a difference in properties for the recycled polymer. In plasticircle every effort has been made to ensure the PP is from household, post-consumer packaging.

Table 6 shows the analysis of different sources of PP.

Table 6 Summary of analysis of different sourced of recycled PP

Source	Comment	Outcome
Netherlands	Some PE contamination Lab blends show poor penetrability, rigidity and viscosity	Not suitable for production scale

Belgium	Levels of PE too high	Lab blend not feasible
Bulgaria	Polymer will not melt in blenders	Lab blend not feasible
Serbia	Levels of PE too high MFI too low	Lab blend not feasible
Italy	Low MFI	Can be used in production
Romania	Low MFI	Could be used to replace 50% of the iPP in the product blend
Polyolefin	Low MFI	Could be used to replace 25% of the iPP in the product blend

All recycled polymers were isotactic, and can therefore only replace the iPP portion of the final product blend. Work is ongoing in Plasticircle to reduce the crystallinity of iPP to make it potentially possible to replace some of the aPP in the blend.

The other limitation to the recycled materials were the presence of PE and the low Melt Flow Index (MFI). This varied from recycled to recycler. This is likely to be because of the efficiency of the recycling process in removing PE contamination and also the exact types of packaging that are being targeted for recycling.

Focus for development

Derbigum is continuing to work with Sintef to develop a method of reducing the crystallinity of iPP to make it more suitable to replace aPP.

Already, some proportion of the iPP can be replaced with the identified recycled PP sources. However, because this is only a limited quantity of the overall mix (<5% by mass), in order to see a significant benefit some of the aPP must also be replaced.

Focus is therefore on the development of crystallinity reduction. Initial results show some success when using virgin iPP but it is known that the additives and pigments in recycle PP may reduce the effectiveness.

5. Outdoor furniture

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.

Whilst HAHN are already making products from recycled plastics collected from domestic and industrial sources, Hahn see the Plasticircle project as an important project that will drive a better collection system potentially across the whole of Europe.

In this project flexible PE is one of the most challenging material streams. Current quality of PE film from materials sorting facilities is quite low. This project is looking at improving the quality of PE film after sorting.

Once sorted there are then two options for the film which will be investigated in plasticircle through Hahn and interval. These are:

- Hot washing of the film to remove contamination and produce a recycled PE that should be suitable for use back into film
- Cold washing of the film to remove some of the contamination but not enough to enable new film to be produced. Instead this can be used in the manufacture of plastic lumber products

By having two options for the PE film, it means a balance can be reached between cost and environmental impact.

Product requirements

The requirements for Hahn are relatively low in comparison to the other partners, which is why their placement in the project is so vital as it means a mixed waste stream can be used.

Hahn's recycling facility in Germany can accept dirty waste straight from a Materials Recovery Facility (MRF). The main requirement for Hahn is for the material to be predominantly polyolefin (either PE or PP). Providing Hahn know what the material is, they can tailor the product blend to ensure a high-quality product can be created.

PVC is unacceptable, and PET is not desirable. PP, HDPE and LDPE are the target materials.

Analysis of materials

PE film from households is not a well recycled product in Europe, and as a result there is very little data available

Ecoembes would be suitable for their recycling supervised facilities. The specification of this film is given in Table 7 below.

Table 7 Ecoembes film specification

Material	Specification
Flexibles (LDPE, HDPE, PP)	>82.00%
Contamination	<18.00%
PET	<1.00%
Metals	<1.50%
Rubber	<0.05%
Paper/carton	<2.50%
Other impurities	<9.00%
Moisture	<5.00%

Although this film is believed to be of sufficient quality of the existing process in Germany, Hahn in the UK do not have a sorting and cleaning plant, and would require significantly higher quality of material.

Work undertaken by Picvisa has sown that a single further sort on this fraction can increase the purity to 87%. A further sort on this material takes the purity to 91%, with the contamination being 5% PP film and 2% "other" (e.g. paper).

Focus for development

The focus for development is to understand the quality of the cold washed PE film when used in the production of wood replacement products in the UK. Picvisa have already sorted 700 kg of PE films to be washed hot and cold by a third party.

Due to the outbreak of COVID-19 across Europe this task has been significantly delayed.

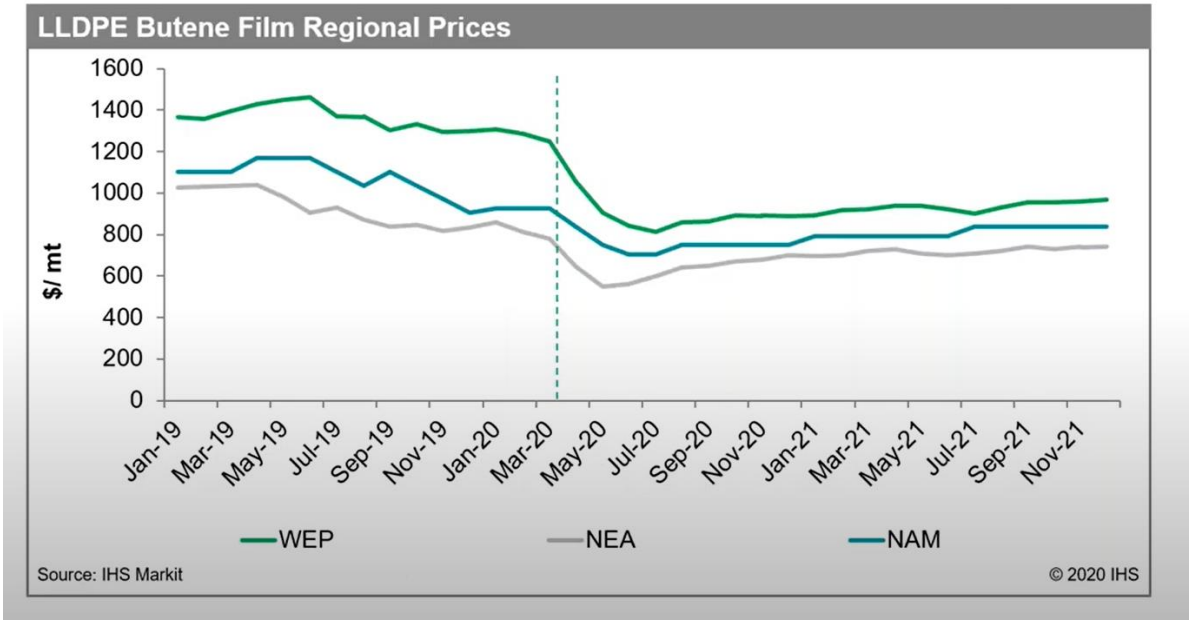
6. Refuse sacks

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.

The plan for this product is to use the hot washed fraction of PE film from the project.

IT should be noted that there is the added complication of an oversupply of virgin PE globally. This means that the economics of washing and processing post-consumer material becomes even harder to justify.

HIS Markit are predicting a significant fall in the price of virgin PE to around $800/tonne, which is €740/tonne. Producing a high quality recycled polymer for much less than this would be very, very challenging. The global economics in terms of oli price and polymer oversupply cannot be ignored when looking at supply recycled resin into non-packaging markets.



Product requirements

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 though 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.

Analysis of materials

Interval have inspected the film produced from MRF in Spain (as per the specification in Table 7). This film would not be suitable for the interval plant as the levels of contamination are far too high.

Materials from countries such as Germany with higher quality standards on the LDPE products from MRFs may be more suitable. The DSD standard for the film fraction is >92% film. Testing plans are being developed to test this type of material at the Interval facility, but obtaining a reference sample outside of the pilots is difficult.

Axion have discussed with Lindner Washtec the possibility of a visit, however this has been declined has they have previously been in touch with Interval.

Conversations have progressed well with SOREMA in Italy who were due to carry out a trial on hot and cold washing PE film from the project. A visit was carried out to the SOREMA facility with Interval in September 2019. However due to the outbreak of COVID-19 this trial is to be delayed.

7. Conclusions

Work in WP5 is ongoing and there are still technical challenges to overcome. There is however a very clear idea of what the issues are and the requirements of each of the manufacturing partners.

The is a growing demand for recycled polymer form packaging to be supplied back into packaging applications. This is particularly evident in PET where it has been very difficult to identify a source of material available for the end applications. This has a knock on effect as to the economic feasibility, as often big brands will be willing to pay a premium for recycled materials to meet their own sustainability goals, as well as mitigate potential future taxation on virgin packaging.

Armacell are able to use PET bottle flake, and can use up to 30% of flake that contains 20% PET tray and 80% bottle. Higher levels of tray reduce the reactivity and high levels of chain extender are needed which impacts the economics of the process.

CRF can successfully use recycled PP from packaging, but there is still more work needed on the PET due to the difficulty in injection moulding this polymer. As the price of recycled PET increases, the economic justification of using it along with additives to make it suitable for injection moulding becomes more difficult.

Derbigum are able to use recycled PP from packaging to replace some of the crystalline PP, however in order to replace larger quantities it must be demonstrated that crystalline PP can be converted to amorphous. This has not yet been demonstrated on recycled polymers.

To progress for Interval and Hahn the washing test must be carried out on the increased purity film produced by Picvisa. This is on hold due to COVID-19.

The properties of post-consumer recycled plastics can make then challenging to use in the end applications. The innovative developments should enable a certain level of increased recycled content. Quantifying the additional cost and impact of any additives and additional processes is vital to ensure there is an overall benefit of using the post-consumer recyclate.

Global economics and the potential for a global recession due to COVID-19 cannot be overlooked when discussing recycling and end markets. There is not yet the discussion of mandating recycled content in non-packaging applications. As a result, the price of recycled polymer form packaging may become higher than virgin, and unless there is another economical incentive to use recycled, companies will not be able to justify it.

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