PlastiCircle

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D4.5 Final prototype of new film-stabilizing conveyor for plastic sorter

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Abstract

One of the objectives of the Plasticircle project is to improve the sorting of post-consumer packaging. Near Infrared (NIR) sorting is used commonly in the waste industry to recover materials of value from mixed streams. A high level review of the waste composition in the three pilot cities has been carried out, along with specification of the sorted product requirements and an initial study into the sorting efficiency of the Picvisa NIR unit.

Present document report compiling the results of the testing and validations of the sorting prototype of the new film-stabilizing conveyor for plastic sorter.

Abbreviations

HDPE	High density polyethylene
LDPE	Low density polyethylene
MRF	Materials recovery facility
NIR	Near Infrared
PET	Polyethylene terephthalate
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl chloride

Partners short names

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
21. CALAF
22. SINTEF AS

PlastiCircle
TOO VALUABLE TO WASTE

Table of contents

Publishable summary

One of the objectives of the Plasticircle project is to improve the classification of post-consumer packaging.

Near Infrared (NIR) sorting is commonly used in the waste industry to recover valuable materials from mixed streams. The technology uses differences in the wavelengths of infrared light that is reflected by polymers with different chemical structures. The wavelengths of light that are reflected depend on the covalent bonds in the polymer structure.

But it is not only on this technology that we have wanted to make improvements to equipment with the lowest recovery rates, such as lightweight materials.

It is also known that mechanical errors can affect this type of materials as much or more than other aspects of the technology.

For this reason a transport system has been developed to improve the stability of the material in the optical separation equipment. So we not only want to improve its detection but also to improve its overcoming.

In this document we detail data about the materials collected in the pilot cities and processed by the prototype separation equipment with all the improvements and developments made in the Plasticircle project..

Introduction

The initial objective of the project within WP4 is to improve the classification of post-consumer packaging. In particular the separation of 5 plastic fractions:

- Separation of 5 fractions of plastic:
  - PET Bottle.
  - PET Tray mono-layer.
  - HDPE Bottle.
  - PP rigid and flexible.
  - LDPE film.
- Loss of material <20%, classification purity >95%.
- PE Film and PP film with contaminants <5%.
- Final rejection fraction with presence of <7% PET, <6% rigid PE, and <8% PP-PE films.
- Presence of biodegradables materials and PVC <0,3% in the classified fractions.

To achieve these objectives, in the previous tasks of the WP, specific work has been done on the technology and algorithms to improve the detection and classification of optical separators.

But already in the previous task in a more preliminary way and now in this one, it is intended to improve another of the existing needs in the recycling plants. Specifically on light materials, which are the mechanical errors that limit the capabilities of the equipment to achieve good recovery and purity data.

In this deliverable we are going to report the preliminary results collected during the last test and validation task of the new film-stabilizing conveyor for plastic sorter prototype.

IPR Strategy

The PLASTICIRCLE solution corresponds to two main conceptual components: (i) a machine-vision sorter of plastic packaging issued from municipal solid waste, (ii) a pre-treatment process technology to be applied in plastic sorting facilities, including mechanical separation of materials and optical sorting at the end of the process line.

PICVISA intends to develop the IPR strategy, referred to the PLASTICIRCLE developments in material sorting, in terms of Patent and Industrial Design applications.

On the other hand, Industrial and Trade Secrecy measures are currently been carried out by the company.

Furthermore, reliable evidence will be established for a first registration in the Intellectual Property Registry of Spain and the use of the symbol ©, including software (source code, object code, algorithms, software architecture), the preparatory documentation and technical documentation concerning the methodology of material sorting, as well as the user manuals and original technical documentation of drawings, designs, graphics, procedures.

In this aim, PICVISA has identified and classified the confidential information being developed during the PLASTICIRCLE project, and has implemented an internal procedure considering the accumulated knowledge as business secrecy. Information and documentation, which is the subject of industrial secrecy, correspond to drawings, mechanical, electrical, electronic, pneumatics and hardware specifications, as well as the technical information related to the software of both the optical sorting equipment and the process line of the PLASTICIRCLE project.

Likewise, all PLASTICIRCLE improvements obtained in machine-vision and materials sorting, with applications to other materials than plastics, are also considered by the company as part of its expertise and a matter of industrial secrecy.

PICVISA already includes in its product and service contracts a regime of industrial and intellectual property rights, as well as the corresponding clauses of confidentiality according to the model of design and exploitation that are determined by the PLASTICIRCLE solution.

1 Final prototype

1.1 Optical and software upgrades

1.1.1 Optical technology

Within the project, one of the main focuses of the optimization study was to study the available technologies to determine which was the most suitable for this type of waste, which is plastic packaging.

The study, as explained in the D4.2 deliverable, concludes that the best technology in terms of resolution and spectral response is the Pushbroom. It also indicates that it would be necessary to study a system in the extended range up to 2500nm, but there is no Pushbroom system on the market in this range, so a prototype point spectrometer has been manufactured to evaluate the improvement in range extension, but it does not justify investment in new product development.

Thus the technology used in the optical separator in the Plasticircle project has been a Pushbroom system in the range 900-1700nm.

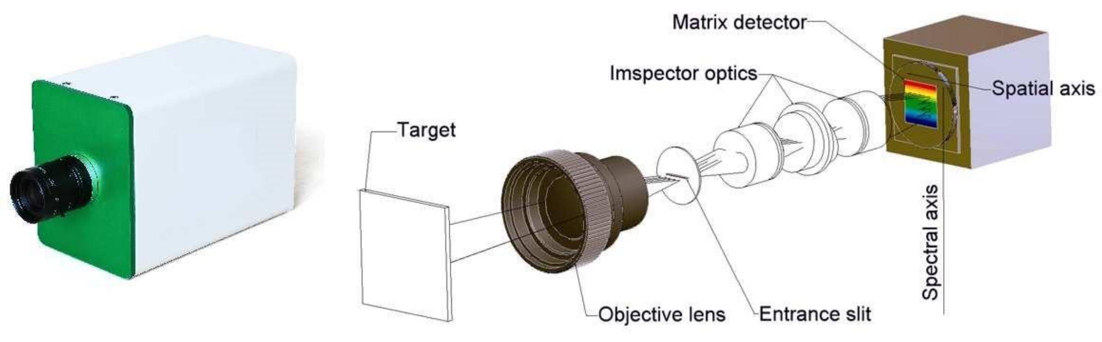

Figure 1 - Pushbroom spectrometer and capture of the visible spectrum on a matrix sensor

1.1.2 Lighting

For a Pushbroom system in the range 900-1700nm the most suitable lighting is halogen lamps, as they have very good response in the entire NIR range.

The lighting used by Picvisa's optical sorters is therefore already suitable for this application.

Figure 2 - Capsule, focus and line voltage halogen lamps

1.1.3 Adaptive segmentation software

Classification algorithms require images with the objects to be classified well defined, but in the environments where optical separators must work they are far from an ideal scenario.

For this purpose, a new method of adaptive segmentation has been developed which, as the environment changes or worsens, corrects and adapts the image to the new scene.

Figure 3 - Background image calculated

With this improvement we have managed to obtain better object detection and classification at the image level, which means more material recovery.

1.1.4 Image Preprocessing Algorithms

Another improvement developed in the software of the optical separator has been to apply different image processing algorithms.

In this project a study of different existing algorithms has been carried out and several tests and combinations between them have been made. From the results obtained it has been determined that the best combination and application of image pre-processing algorithms are: Smoothing, Detrend and SNV.

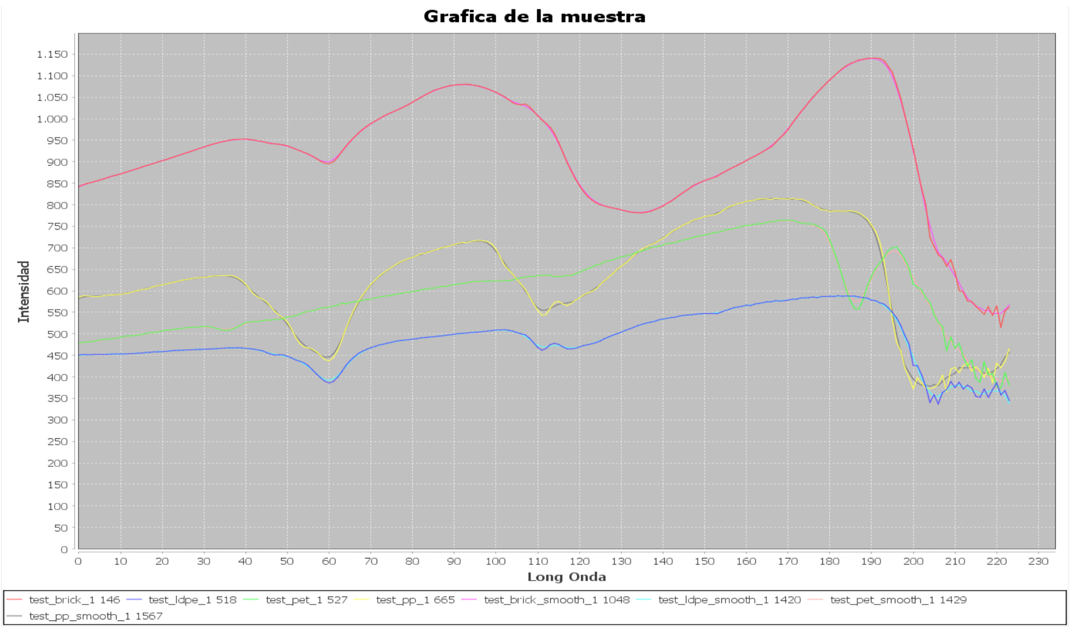

Figure 4 - Effect of applying the Smoothing filter on the spectra of some materials

1.1.5 Classifiers

Machine learning is a field of artificial intelligence that aims to provide computer systems with the ability to learn. This learning ability will be based mainly on statistical methods and previously acquired data. One of the classic applications of machine learning is classification, which consists of the system being able to classify a new unknown instance into a certain number of categories.

Simulations with spectrum libraries have been carried out in order to compare the current method, SVM with the PLS-DA, contrasting it with some studies found in the literature. Although the simple nature of the data may influence the degree of accuracy achieved by each algorithm, in general the SVM obtains better results in the different applications consulted.

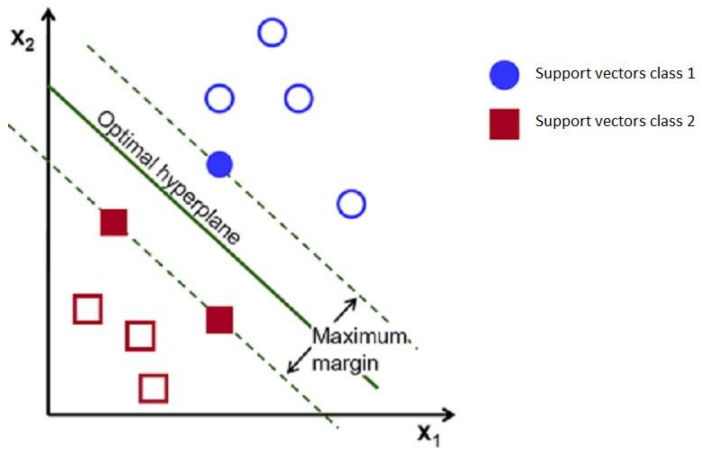

Figure 5 - SVM classification scheme in 2 dimensions

Different simulations were performed which have shown that the SVM algorithm is more suitable than the PLS-DA for our application. So Picvisa's optical separator will use this classifier to perform the different separation tests with materials from the cities participating in the Plasticircle project.

1.1.6 Improved database

The database of an optical sorter is part of its AI, it is what the machine can use to make the decision to classify a material of one type or another.

This database must be constantly fed, as the market demands new variables, changes and new materials.

Within the Plasticircle project it has been decided to implement this database with the following new materials.

1.1.6.1 Multilayers

This type of material has been in constant growth for some time now and new formats are coming onto the market from the many possibilities that multilayer packaging allows. For both rigid and flexible packaging.

It is a great technological challenge for optical sorters to be able to detect and correctly classify this type of material, as many of these combinations of layers do not allow reading between them.

The project has studied different combinations of multilayers and has focused on those that can have the most important effect on the usual waste flow.

Figure 6 - Sample tray lids.

The database could be improved with samples of trays formed by **PE-PET**, the second type being those formed by **PE-PA**.

For flexible film packaging and tray lids, the following new materials have also been added to the database: **PET-PE, PA-PE, PET-PP** and **PVC-PE.**

1.1.6.2 Bioplastics

Bio-based plastics are increasingly appearing in a range of consumption products, and after use they often end up in technical recycling chains.

Bioplastics are not just one single material. They comprise of a whole family of materials with different properties and applications. According to European Bioplastics, a plastic material is defined as a bioplastic if it is either biobased, biodegradable, or features both properties.

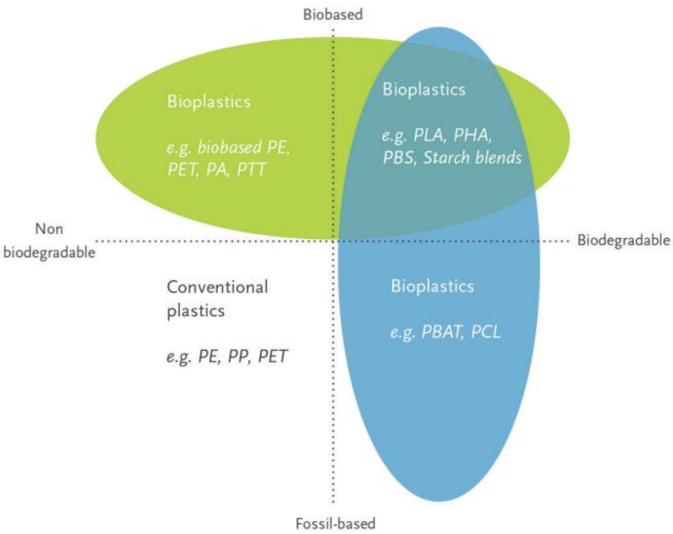

Figure 7 - Plastic classification according to their origin and biodegradability (European bioplastics, 2018)

PLA and **starch-based plastics** represent the majority of bio-based and biodegradable plastics and therefore, the main ones that could disturb the clousure of plastic cycles.

Today these materials do not have a defined flow in the recovery of materials because they are minimal and represent a large investment for treatment plants. Maybe in a few years they could be considered as extracted from their own flow to recycle these materials in a new application (and not only through compost).

So these two new types of plastic have also been added to the database to be separated from the usual flow of recoverable materials.

1.1.6.3 PET Bottle vs PET Tray

This separation of the PET bottle from the PET tray was not initially provided for in the project's DOA.

But during the separation requirement study carried out by Axion and Picvisa (T4.1), it was determined as a necessary separation to have a higher value and use PET material in the recycling market.

Initially in the project we faced this problem with the multilayer materials, because a great majority of the trays are multilayer. But the market requires a tray-free flow of PET, both monolayer and multilayer, so the initial separation was not sufficient.

Finally, the study was based on the analysis of the viscosity index (VI) of the materials, information which already allows a greater separation between bottles and trays.

However, there are both bottle and tray materials with similar VI, which means they do not have a visually clean flow.

Since then, Picvisa has developed a long study on the separation of this type of materials with the collaboration of Proplast in obtaining samples and chemical characteristics for the creation of the database. And also Itene's collaboration in the analysis of samples at laboratory level.

As a result of this work, it has been possible to implement a new specific database for the classification of these two materials that allows this separation between the two to be carried out successfully.

1.2 Flight box improvements

Within the study of the light materials stabilization system, a section was incorporated to analyze the flow of air and material inside the flight boxes.

The light material is blown inside the flight chamber and the air used can generate turbulences that modify the theoretical flight that the material should perform inside the chamber. The material without turbulence should fly to the bottom of the chamber and down once it has reached the end of the chamber.

Instead the turbulence causes the flight of the material to be random, sometimes it does what is expected but many others do unexpected things, like flying to the unblowed flow.

Thanks to this study of fluids, it has been possible to conclude that the turbulence generated inside the box can be detrimental to the correct separation of the light material.

In the same study the solution has been designed to reduce this effect of the air inside the flight box, placing an internal deflector as shown in the image of the flight box used in the Test Center demonstrator.

Figure 8 - Deflector inside the Test Center flight box

The deflector conducts the air produced by blowing the valves to the exhaust area enabled in the flight boxes, thus reducing the turbulence inside and preventing the blown material from making an unexpected flight.

1.3 Prototype of the new film-stabilizing conveyor

One of the important developments within WP4 has been the study of a stabilisation system for light materials.

The study analysed different existing solutions in the market, assessed the benefits and drawbacks, and studied new alternatives.

After an analysis of all the solutions proposed, the design of a new stabilization concept has been initiated, based on the movement of a belt over the material.

Figure 9 - Prototype of the new film-stabilizing conveyor

The basic principle of this finger conveyor is to generate a stable, guided air current over the material to stabilize it on the conveyor belt, during the entire material feed.

We have already explained and detailed in the previous deliverable D4.4, the results obtained with this new prototype are very encouraging.

Like the other developments, the tests carried out on the classification of the materials in the different pilot cities participating in the project have been applied.

2 Test pilots

All improvements and developments made within the Plasticircle project for Picvisa's optical sorters must be tested and evaluated on the material of the participating pilot cities.

To evaluate the improvements applied, the results obtained in the requirements study carried out in T4.1 and with the data reflected in D4.1, must be compared to the results obtained in T4.5 and the data reflected in this D4.5 deliverable.

Within the reading of results for each pilot city, the effectiveness of the measures applied in each city is also evaluated by contrasting the results of the area before applying the pilot and the results after applying the pilot.

2.1 Collect

The material to be collected in each city for the subsequent sorting treatment must be the one defined in the WP4, and concretely in task 4.1 Sorting requirements.

We will have to collect the material in the same zones, similar dates and times so that the comparisons can be comparable.

Dimensions shall be between 40mm and 400mm.

The materials to be separated by Picvisa Sorting Equipment must be classified into two main categories:

- 3D: It will be all ballistic rolling stock and with ferrous separation.
    - PET BOTTLE
    - PET TRAY
    - PE RIGID
    - PP RIGID

- 2D: It will be all the planar material of ballistic or aspiration, it depends on the pretreatment in the plant.
    - PE FILM
    - PLASTIC MIXES

2.2 Protocol Pre-Tractament material

In this section we detail the protocol that indicates the process that must be applied to the material once collected from the container and before passing through the Picvisa sorting equipment.

1. First of all, open the bags collected from the containers.
2. Manually remove any voluminous (>400mm) or dangerous material.
3. Screen the material with a 40mm mesh to remove all material below these dimensions.
4. At this point we can make the separation of 2D and 3D material.
    a. 2D – All lightweight material such as film or paper. It is not necessary to make thisprocess to perfection, as it is allowed on 2-3% of lightweight in 3D material.
    b. 3D -The rest of the material once the previous 2D has been extracted.
5. 2D material can now be collected in big-bags for transport
6. 3D material should be extracted from all ferrous and non-ferrous metals.
7. And finally to simulate this material at the entrance of sorting equipment, the material should be compacted or flattened so that not everything arrives as rolling.

Once the different points have been made, this material can be collected in big-bags for transport.

If it is not possible to reproduce accurately by any of the points, an alternative process should be sought with the same results as the described process.

2.3 Transport

Since the tests with the sorting equipment are carried out in a test plant and with equipment equivalent to a 1000mm EcoPack, only a small scale simulation can be carried out, approximately 2 t/h. This means that there is not enough time or the capacity to carry out tests with large volumes.

Also to facilitate the manipulation and processing of the material in plant, it is necessary to transport this in big-bags of 1m3. In this way we avoid that the material arrives compacted to the test plant of Picvisa.

Of the two types of material, the following quantities per sample have been estimated:

- 1 truck before and 1 truck during/after the pilot
- Quantities
  - 3D Big-bags quantity 2/3 truck
  - 2D Big-bags quantity 1/3 truck

2.4 Sorting of Valencia

In this section we are going to collect the result of the tasks carried out within this WP and the previous ones in the field of sorting.

Basically we treat the material collected in each pilot and process it with the equipment developed in the project.

2.4.1 SAV - Valencia

The first city to participate in the pilot and to collect the samples for analysis and further processing by Picvisa was Valencia.

The process of collecting samples and adapting to a pre-process has suffered some incidents, since the material collected was manually pre-selected without contaminants, which considerably alters the study of the results for the optical separators.

Once the errors were detected and solved, a new collection of samples was generated and duly pre-processed by SAV personnel following the indications detailed in point 2.2 of this deliverable.

2.4.2 Waste in Valencia

In Spain, all packaging waste is collected together, this is:

- Plastic – including bottles, containers and films
- Metals – including ferrous and non-ferrous
- Beverage cartons

In Spain, glass is collected separately.

In order to characterise the material collected in Valencia, test data have been collected and the fractions have been added separately.

The results are shown separately below by the collection before the pilot and during the pilot.

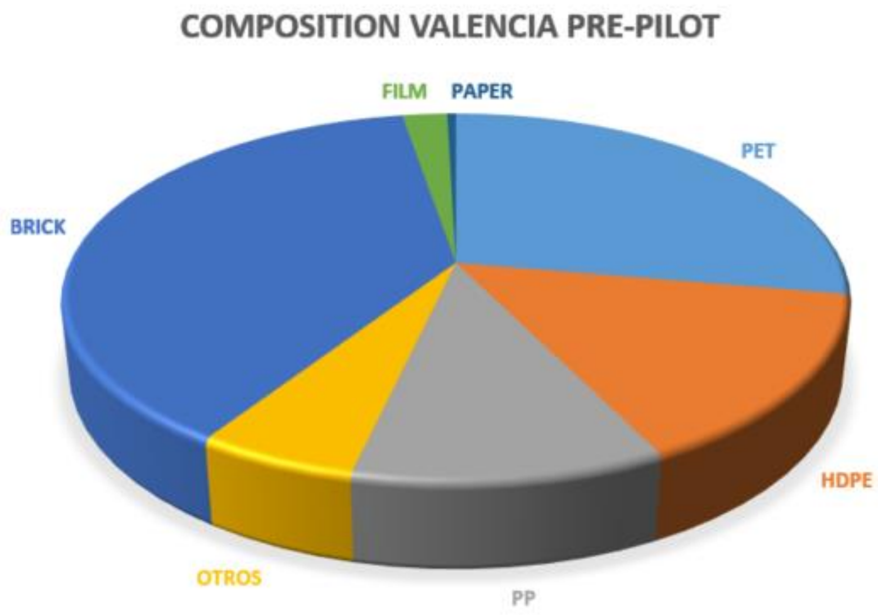

Figure 10 - Composition Valencia pre-pilot

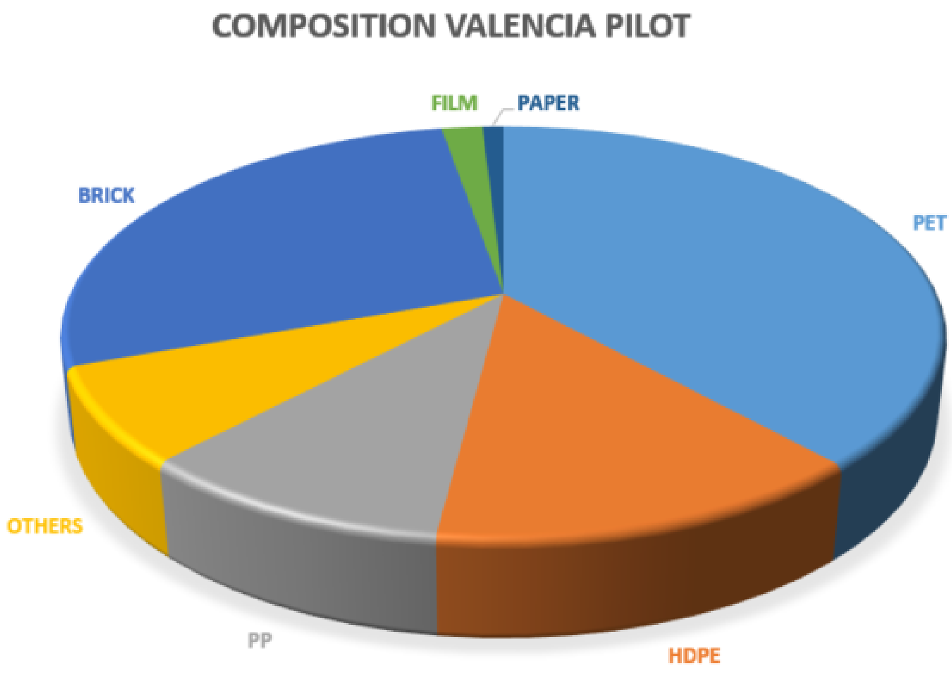

Figure 11 - Composition Valencia pilot

The first analysis that we can extract from the composition data between the two pilots is mainly the difference between two materials.

The collection before applying the pilot in Valencia had a proportion of BRICK over the total of 38% and a proportion of PET of 28%.

Fraction	% composition
PET	28%
HDPE	15%
PP	11%
OTHERS	6%
BRICK	38%
FILM	2%
PAPER	0%

During the application of the pilot, the rest of the materials remained at very similar values, but BRICK had a proportion of 29% and PET a proportion of 39%.

Fraction	% composition
PET	39%
HDPE	14%
PP	10%
OTHERS	8%
BRICK	29%
FILM	2%
PAPER	1%

Therefore, we can consider that the pilot has had a very moderate effect on the population in terms of materials collected, with the exception of PET, which has increased significantly by approximately 10% of the total.

2.4.3 Sorting pilot

The separation scheme used for the pilot tests is the same as the one used in the initial phase of requirements.

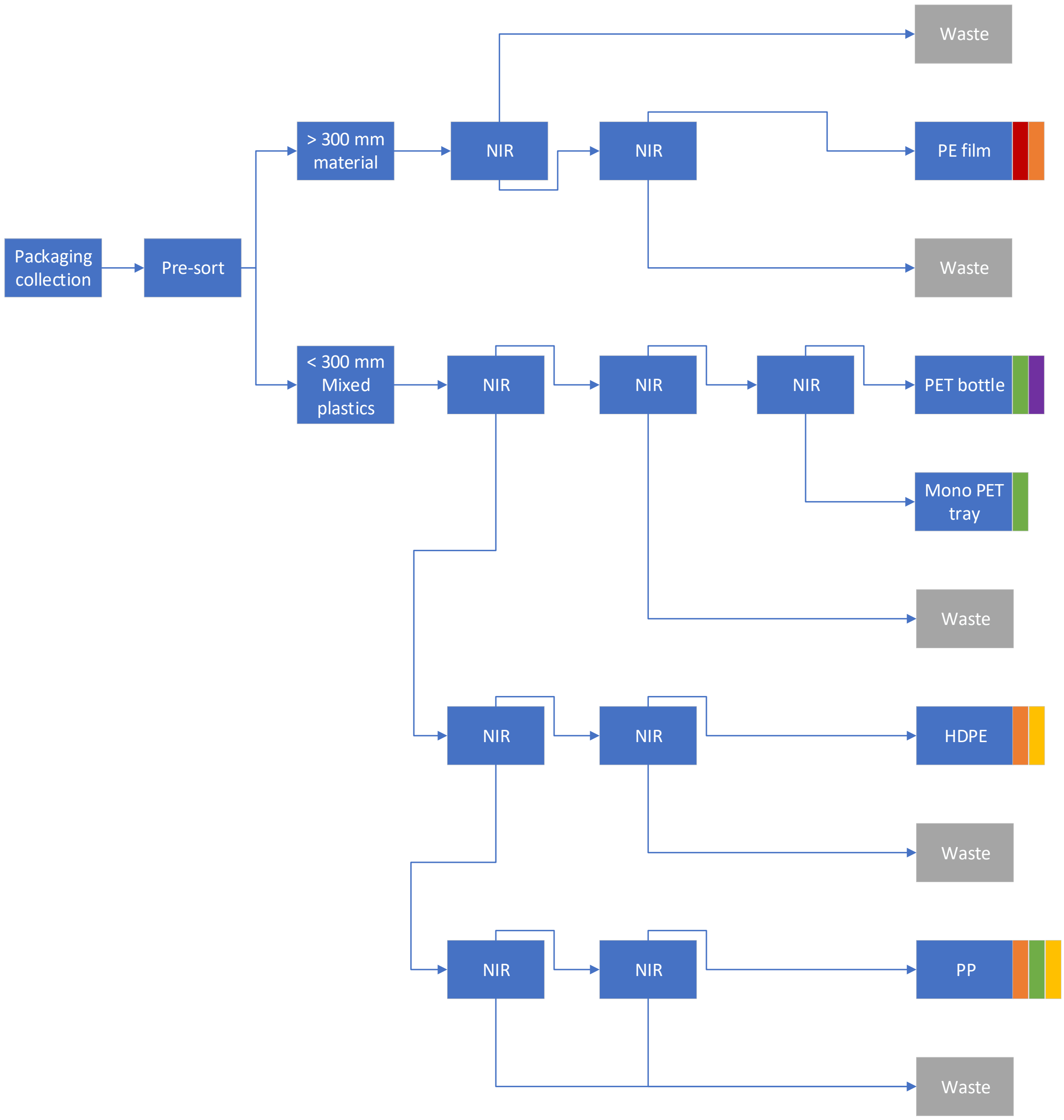

Figure 12 - Separation layout

As shown in the picture the material collected in the pilot has to be pre-processed following the indications marked in section **2.2 Protocol pre-tractament material**. Then, with the two well differentiated flows, the 2D must be processed by blowing PE FIlm in positive in two passes through the optical sorter (NIR).

And with respect to the 3D flow, the separations are made by the optical sorter (NIR) for each target material.

For the test pilot, five different products were analysed and sorted. These were:

- PET bottle
- PET trays
- HDPE
- PP
- LDPE films

The tests were carried out for each material using the following methodology:

1. A 10 - 20 kg sample was taken from the bale of material
2. NIR was set to eject either the target material, or eject the non-target material
3. Material was passed through the test NIR sorter at a steady rate
4. The ejects and rejects from the sorter were manually separated and then weighed
5. The yield and the purity were then calculated

The calculation for yield is given as:

$$\frac{Mass\ of\ target\ material\ in\ the\ product}{Mass\ of\ target\ material\ in\ the\ feed} \times 100\% = Yield$$

The calculation for purity is given as

$$\frac{Mass\ of\ target\ material\ in\ the\ product}{Total\ mass\ of\ material\ in\ the\ sample} \times 100\% = Purity$$

When using NIR sorting, there are some limitations. These are:

- Plastic with carbon black pigment cannot be identified and will always report to the drops fraction;
- If material is overlapping on the belt it will create an unclear signal and may result in incorrect sorting
- If material is compounded together (i.e. one type of plastic crushed around another type of plastic), the unit will not separate the two materials, so it will be sorted as a single item
- If material is too dirty it can prevent a clear signal
- It material is too heavy (i.e. because of product residue or liquids) then the power of the air may not be enough to eject the material

As a result, when analysing the results from the sorting test pilot

2.4.4 Sorting pilot results

In the following section we will analyse the results obtained by each target material from the tests carried out on the material collected before and during the pilot.

In this way we want to evaluate the technological improvements made by Picvisa and the effect the pilot may have had on the separation technologies.

2.4.4.1 PET results

PET is the first material to be recovered in the separation sequence of optical separators as it has the highest percentage of content in the flow.

For the correct separation of PET, Picvisa's equipment has been configured with a classification model for all types of PET, i.e. both bottles and trays.

In a second separation, the optical sorter has been configured only for blowing trays, so that we will have the result of the PET Bottle on one side and the PET Tray on the other.

Fraction	% composition PRE-PILOT	% composition PILOT
PET	92%	96%
HDPE	0%	2%
PP	0%	0%
OTHERS	3%	2%
BRICK	3%	2%
FILM	1%	1%
PAPER	0%	0%
Yield	**85%**	**92%**
Purity	**92%**	**96%**

The improvements developed in Plasticircle with respect to the sorter part have allowed us to reach values of 85% recovery and 92% purity, but we can verify with the data obtained in the pilot that the combination of technological improvements and citizen education allows us to reach values of 92% recovery and 96% purity.

2.4.4.2 *PET Tray results*

This fraction is obtained from purifying the PET bottle fraction, so the percentages are not so revealing, as we are not looking for a pure fraction in this flow.

On the other hand, the recovery has not been measured since the PET has been measured in the other fractions together.

Fraction	% composition PRE-PILOT	% composition PILOT
PET TRAY	88%	98%
HDPE	0%	0%
PP	0%	0%
OTHERS	9%	1%
BRICK	0%	0%
FILM	3%	1%
PAPER	0%	0%
Yield	**-**	**-**
Purity	**88%**	**98%**

This fraction does not yet have a market value, since recycling is complicated and expensive. Anyway, all the recovered fractions of this material have been sent to Itene where they are going to be washed and granulated to analyze what recycling possibilities it may have in the market.

2.4.4.3 HDPE results

This is the second fraction to be recovered from the sequence of optical separators. Once the PET has been extracted, it is the next most proportional material in the flow.

Fraction	% composition PRE-PILOT	% composition PILOT
PET	2%	0%
HDPE	91%	95%
PP	1%	1%
OTHERS	2%	1%
BRICK	1%	1%
FILM	3%	2%
PAPER	0%	0%
Yield	**90%**	**94%**
Purity	**91%**	**95%**

The improvement in this case is similar to the PET fraction.

2.4.4.4 PP results

This is the last material to be recovered in the 3D material fraction. The proportion of material at this point in the flow is mostly PP, but the rest of the material is mainly contaminant.

Fraction	% composition PRE-PILOT	% composition PILOT
PET	4%	1%
HDPE	1%	1%
PP	92%	95%
OTHERS	1%	2%
BRICK	1%	0%

FILM	1%	2%
PAPER	0%	0%
Yield	**75%**	**94%**
Purity	**92%**	**95%**

The important difference that we have collected between the material of the pre-pilot and the material of the pilot, can be due to some error of characterization, because there is no such difference neither in the obtained purity nor in the balances of the material.

2.4.4.5 PE Film results

This fraction is no longer obtained from the 3D material, but from the 2D material.

The separation configuration of this fraction is detailed in section 2.4.3 Sorting Pilot of this document. And the operation is a double pass through optical sorters, blowing first the material in positive and blowing second the material in negative, that is the contaminant.

Fraction	% composition PRE-PILOT	% composition PILOT
LDPE	88%	91%
OTHERS	12%	9%
PAPER	0%	0%
Yield	**85%**	**89%**
Purity	**88%**	**91%**

This material is the one that has obtained greater values of improvement in recovery and purity has obtained, thanks to the technologies applied, but above all the new prototype of stabilization of light materials.

2.5 Conclusions

From all the results obtained we can conclude that **the improvements developed during the Plasticircle project have been successful** in some cases and in others have even exceeded expectations.

The effect of the pilots must also be evaluated **very positively in the results obtained**, although in the characterizations the improvement is not directly appreciated, we can interpret that the selection of containers by the citizen corresponds better to the separation criteria for which the optical separators are configured.

And finally, we must evaluate as a **great success the results obtained in the light fraction**. Since this fraction has always been the great challenge of the sector due to the difficulties it posed at the physical level. Thanks to the development carried out by Picvisa within the Plasticircle project, it has been possible to design and manufacture **a stabilization prototype for light materials that perfectly covers the needs** for which it has been studied.

Picvisa valued positively the results obtained, we will proceed to carry out a detailed study of **the industrialization of this stabilization equipment** to be able to offer our current and future clients as an improvement in the flow of light materials.

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