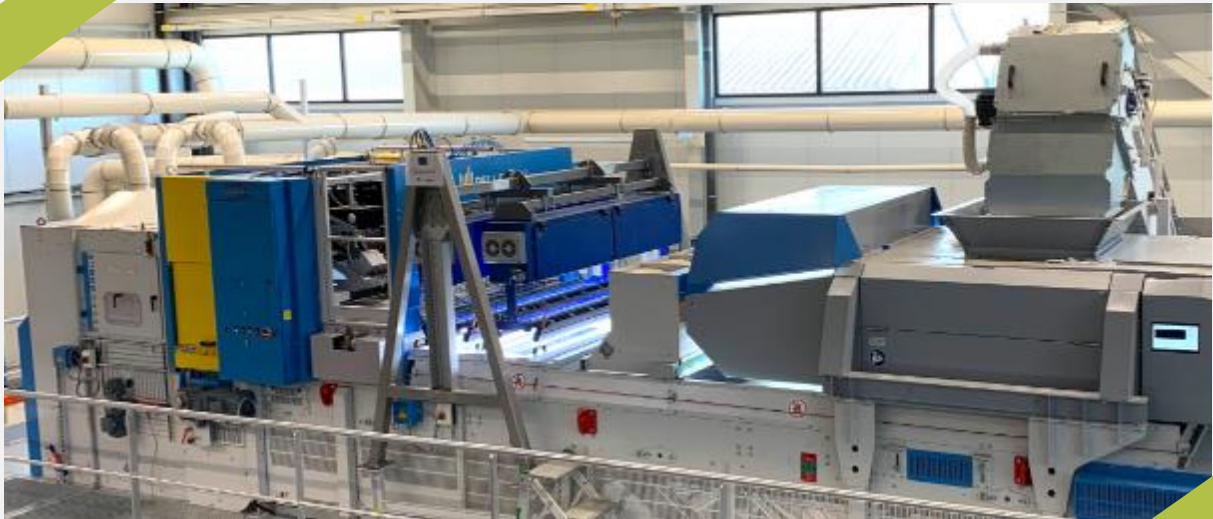


# Two automated sorting solutions for multilayer flexible packaging

CIMPA White Paper



**Authors :** Raphael Josselin, Marien De lint, Johan Kerver, Antoine Bourelly, Celine Chevalier, Maria Vera Duran

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## Introduction

Multilayer films (MLs) are widely used for packaging due to their low weight and high barrier properties. Their structure differs in terms of thickness, number of layers, and number of different materials to perfectly fit the desired applications.



Figure 1: Examples of existing MLs and their applications.

Recycling is more and more encouraged by national and European regulations. The upcoming Packaging and Packaging Waste Regulation (PPWR) will require that all packaging comply with design for recycling criteria by 2030, and all packaging should be recycled at scale by 2035.

However, due to the lack of sorting and recycling technologies, today, most of these MLs end up into the refuse outlet, being incinerated or dumped in landfills. Moreover, depending on their structure, MLs sometimes contaminate the current output made of Mono-material films only (Mainly Mono-PE and Mono-PP flexibles for mechanical recycling) due to incorrect sorting. In the future, MLs might be considered as recyclable thanks to innovative processes, such as physical and chemical recycling.

CIMPA is an EU funded H2020 project aiming to address the circularity challenges of MLs by developing a recycling value chain for post-industrial and post-consumer multilayer films from food and agricultural applications. CIMPA proposes innovative solutions including the development of new technologies for sorting different films, together with mechanical and physical (dissolution) recycling processes. Furthermore, decontamination and upgrading processes are applied to produce quality material from waste which will be suitable to close the loop.

Thus, accurate sorting of MLs is the first step to increase the circularity of packaging and has two main advantages:

- It prevents contamination of existing recycling processes and upgrades the quality of existing sorted streams.
- It allows the creation of MLs waste fractions fit for specific recycling processes.

Most MLs flexible packaging pass through Material Recovery Facilities (MRFs) where NIR optical sorters are widely used. Therefore, the best way to quickly enhance MLs recycling is to provide solutions on existing machinery in MRFs. This white paper describes two solutions:

## 1 – Advanced NIR-based detection with Mistral + Connect – TRL9

This solution is based on the compositional analysis and sorting trials done by Pellenc ST on flexible samples, with the support from all plastic film manufacturing partners and Paprec. It uses Pellenc ST's NIR optical sorter, the Mistral + Connect. Advanced Chemometric algorithms used give accurate detection results for PE/PET and PE/PA structures.

## 2 – Combined NIR + DW prototype – TRL7-8

Digital watermarking is a promising technology for effective sorting of multilayer materials. The technology of FiliGrade has the potential to deliver sorted fractions that meet specific quality standards. Moreover, digital watermarks enable sorting to be triggered by characteristics unrelated to package composition like 'membership' and 'usage' (food versus non-food). The combination of digital watermarking and NIR technologies surpasses the intrinsic limits of NIR detection and permits closed-loop recycling for food grade materials.

# Optical sorter Mistral + Connect using NIR Spectroscopy

### Basics of Near-Infrared (NIR) Spectroscopy

Once illuminated by a continuous light that covers the NIR domain (1000nm – 2500nm), each molecule absorbs some very specific wavelengths (See Table 1) of the light through vibration, rotation, or bending of the atomic bond. The energy of each atomic bond (e.g. the C-H bond) is slightly modified by the structure of the rest of the molecule, providing a fingerprint information for each polymer or product. The analysis of these absorption peaks makes the identification of organic material and polymer possible.

Material	Main Absorption peak associated (nm)
PET	1660
PP	1705, 1720
PE	1730
PA	2050
Biofilm - starch	1940
PVC	1720

Table 1: Main absorption peaks of common polymers in the NIR domain

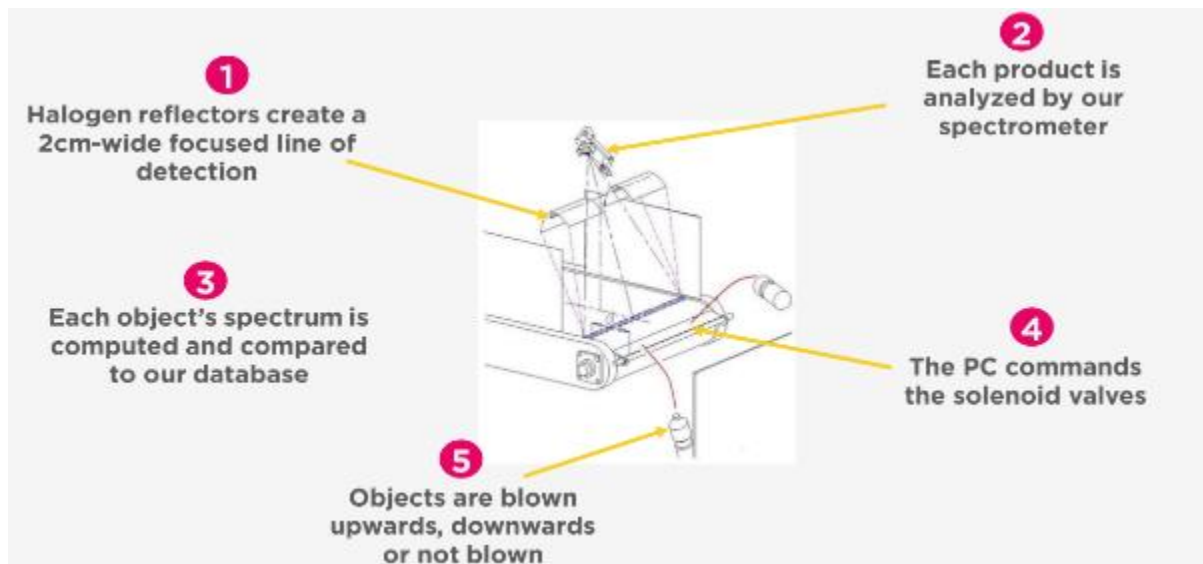


Figure 2: Basics of NIR sorting

The optical sorter Mistral + Connect analyses these peaks within milliseconds and decides to blow on the objects or not. The different sorting steps are explained below in Figure 2. On a Mistral+ Connect from Pellenc ST, the signal is backscattered: illumination and detection are from the top.

### Pre-consumer MLs lab analysis

Barbier, Leygatech and Eversia supplied Pellenc ST with a total of 54 different samples differing in terms of:

- Thickness: from 15µm to 200µm
- Opacity
- Prints/no prints: from transparent to black opaque films
- ML Structure
- Material

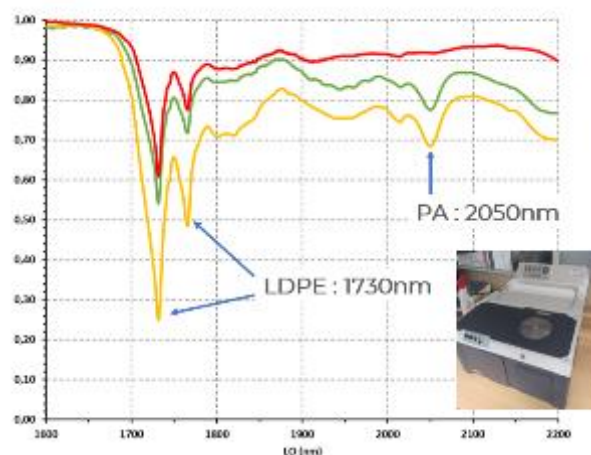


Figure 3: Example of sample spectra from wavelength 1600nm to 2200 and their specific absorption peaks. Red curve: classic plastic bag, Green curve: known PE/PA sample from Leygatech, Yellow curve: Assumed PE/PA characterized sample from post-consumer films.

The 54 films were first analyzed by our lab spectrometer, the Thermo-Scientific Antaris II DR. This spectrometer gives the useful spectra of a sample with wavelengths that go from 1000 nm to 2500 nm.

### NIR Spectroscopy Limits

This lab analysis teaches us about the intrinsic limits of NIR Spectroscopy. Those limits are in agreement with those from Ceflex's literature [1]

- No EVOH peaks could be spotted, probably because EVOH molecule looks like PE molecule It makes it impossible to detect. It is also present at a very low content in MLs.
- No Carbon black containing films could be analyzed.
- No AlOx/SiOx peaks could be spotted. They are impossible to detect.
- If a metallic layer is present, it prevents us from detecting the inner polymer layer of the film. It acts as an impassable barrier for NIR Detection.
- Metallic layer also makes the detection of the outside polymer layer of the film less stable due to a "mirror effect", so it might deteriorate sorting results.
- The films with low thicknesses (<30µm) could cause optical interferences that make the analysis difficult / impossible. However, and unlike the CEFLEX report, films with only 20 µm thickness are detectable on our Mistral+ machine.

### Post consumer ML sorting on Mistral + Connect.

Paprec provided flexible packaging from post-consumer waste from their MRF. The first step was to find at least 50 samples from each category of material: Mono-PE, Mono-PP, PE/PA, PE/PET and Metallized films. The volume of the remaining detectable categories such as PP/PA, PP/PET...etc. was not sufficient in the stream to be considered. Every single object composition was verified using the lab spectrometer. Each batch was then split into two sub-batches: one training set and one test set.

Below is the detection result that confirms the good detection of these ML kinds on the test set. The compositional detection is represented by a color code chosen by Pellenc ST.

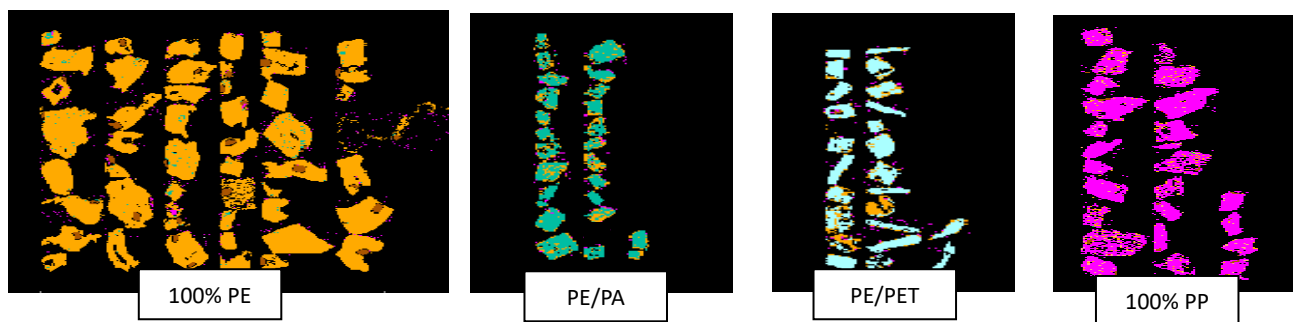


Figure 4: Classification results obtained with test set.

### Legend:

- Orange stands for 100% PE.
- Pink stands for 100% PP.
- Green stands for PE/PA.
- Blue stands for PE/PET.

Two classes PE/PA and PE/PET have been created and are now sortable independently for a future recycling process.

- ➔ All PE/PA structures were detected as such. It will avoid pollution on the Mono-PE stream in MRFs.
- ➔ All PE/PET structures were detected as such. It will avoid contamination on Mono-PE and PET streams in MRF.
- ➔ No Mono structures were detected as ML. It means it will maximize the recovery of Mono-material structures in MRFs but also at recycler’s sites.
- ➔ No distinction could be made between two layers and more than two-layer structures: PE/PET/PE and PE/PET were not distinguished.

Advanced algorithms to treat the signal received were used. This advanced classification is implementable on every Mistral + Connect already in operational use throughout Europe. Unfortunately, it was not possible to sort PE/EVOH, Carbon-black or SiOx/AlOx containing structures and other very complex MLs due to NIR intrinsic limits. Objects also can’t be sorted as food grade with this solution. Regarding these limits, the second solution described later might be the silver bullet solution.

**Mistral + Connect Sorting results.**

This table summarizes sorting performance obtained in one sorting step with a throughput of 1t/h on post-consumer waste provided by Paprec. PE/PA and PE/PET were sorted positively on a Mistral+ Connect with a width of 2000mm and a conveyor speed of 3m/s.

The sorting of metallized structures has been tackled using Mistral+ Connect’s metal sensor only.

Category	PE/PA	PE/PET
Sorting efficiency	90%	90%
Mono-PE Losses	5%	5%
Purity	>80%	>90%

*Table 2: Sorting KPIs for PE/PA and PE/PET Structures*



*Figure 5: 3D Picture of Mistral+ Connect.*



## Combined NIR+DW sorting prototype.

### Basics of Digital Watermarking technology by FiliGrade

FiliGrade Sustainable Watermarks BV (based in Eindhoven, The Netherlands) has developed an intelligent sorting solution named 'CurvCode'. CurvCode consists of a number of visible or (nearly) invisible dots placed in a mathematically generated curve-shaped pattern. See example below:



This patented code is used for applying a 'digital watermark' to plastic, fiber-based and multi-layer packaging. In its current stage of development, CurvCode is used specifically for waste sorting and recycling purposes. It does not aim to replace existing barcoding or other point-of-sale or consumer engagement techniques. This technology allows plastic, fiber-based and multi-layer packaging to be sorted according to packaging and usage characteristics:

- Application: Food, non-food and hazardous
- Type of material: PET, PP, paper laminate, multilayer, cardboard, etc.
- Colour: transparent, white, black, carbon black, other colours
- Layers: single, multilayer composition

With this technology, more than 1.000 different codes are available. Common codes are pre-assigned for sorting different package-types. Examples are:

- PET, transparent, single layer, food
- PP, other colours, single layer, food
- Cardboard+Met, multilayer, food
- PE/Met/PET, multilayer, non-food

To enable CurvCode-triggered detection in waste-sorting facilities, FiliGrade has developed a CurvCode Reading System (CRS) consisting of LED lights, standard colour USB cameras and common PCs. Thanks to the efficient design of CurvCode and FiliGrade's custom-built detection software, the CRS uses a simple and fault-tolerant ICT architecture. When the CRS detects packaging carrying a CurvCode, it sends a trigger-signal to the optical sorter of the waste sorting line. This allows the system to operate in any sorting and/or recycling installation.

Also, a CRS can detect different types of multilayers as well as black plastic packaging.

For rigid plastic packaging nearly invisible 3D CurvCodes are 'embossed' through modifying the moulds. This method is suitable for thermoforming, injection moulding and extrusion blow moulding.

For printed packaging, including multilayer structures, visible and/or nearly invisible 2D CurvCodes are inserted into the artwork, which can be incorporated in all printing techniques.



Depending on the type of packaging, multiple 3D and/or 2D codes are applied redundantly (in different orientations and spread evenly across the surface) so that codes can easily be detected even when packaging is contaminated and crunched.



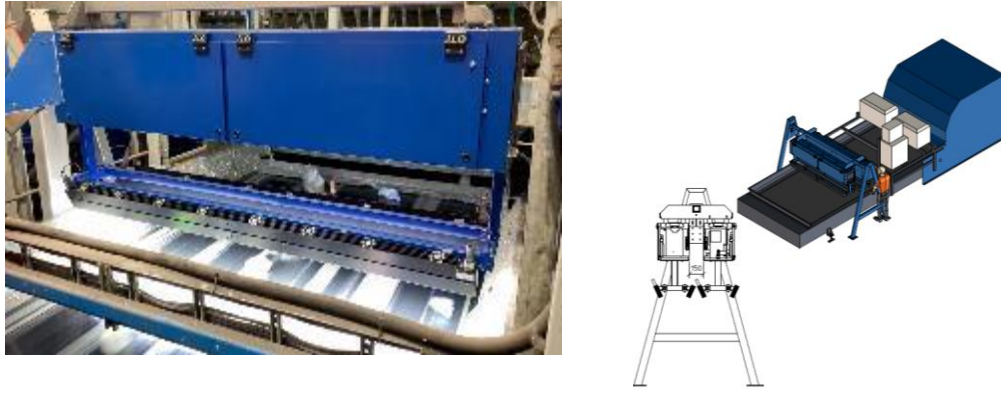
Figure X: Example of printed CurvCodes

### FiliGrade business model

FiliGrade is a technology company. Its primary business model is based on licensing fees charged to brand-owners for the use of the software. Packaging producers and sorters also need to sign a licensing agreement, but they can use the software for free. FiliGrade does not sell sorting equipment. FiliGrade supports manufacturers of industrial sorting equipment who want to add CurvCode detection technology to their products. Depending on specific supply-chain demands, FiliGrade is able to deploy alternative business models.

### FiliGrade mobile CurvCode Reading System (CRS)

To enable semi-industrial testing and demonstrations at different locations, FiliGrade has developed a mobile CurvCode Reading System (CRS) which can be fitted over any existing sorting belt up to 2 meters wide. FiliGrade can either integrate the mobile CRS with an existing blow-out unit or use software to count the number of objects carrying a CurvCode that are detected. In the latter case, interference with operational processes is minimal.



*Figure 6: CRS System by FiliGrade*

The CRS system uses detection software that is developed in-house by FiliGrade. This detection software uses input received from the USB-cameras to detect whether objects on the conveyor belt carry CurvCode markers that match the detection commands provided by the operator of the CRS. The software contains a set of parameters to fine-tune detection performance.

### **Adjustments and pre-study**

Some adjustments were needed to make the prototype work.

The transparent tunnel plaques shown below allowed the cameras of the CRS system to detect the objects and read the Curvodes without deteriorating the airflow created by the turbosorter.



*Figure 7: Tunnel glass window.*

The mounting frame was designed, and custom made in such a way that the CRS could be positioned at exactly the right position over the PEL sorting unit. To allow for exact positioning and calibration, the mounting frame has adjustable feet. Rubber pieces were used to prevent CRS system from slipping.

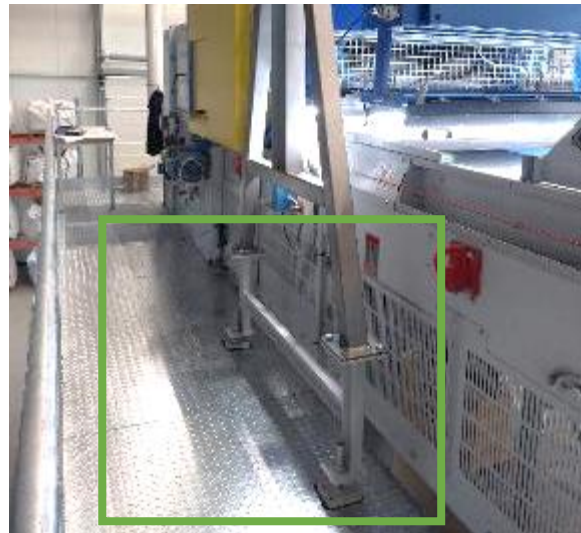


Figure 8: Adjustable Mounting frame.

### Combining CRS system and NIR optical sorting

The prototype was implemented on the “Emerging Technologies” sorting line located in Pertuis, at Pellenc ST Headquarters. To build the combined sorting prototype, FiliGrade used its latest Curvcode detection unit built in 2022. This mobile unit is referred to as the ‘CurvCode Detection System’ (CRS).



Figure 9: Picture of the combined prototype.

The NIR+DW sorting prototype is composed of various elements:

- 1 • A **“Disc spreader”** to evenly spread the products across the belt. Thus, this equipment reduces film overlapping which is crucial for sorting performance.
- 2 • A **“Turbosorter”** that creates an air flow at the same speed as the belt: it avoids sliding of the products between detection and ejection. It therefore helps objects to be blown at

the right time to improve sorting efficiency. This equipment is a must-have when it comes to flexible sorting, especially when the detection is far from the nozzle bar.

- 3 • **A CRS system** that crosses the conveyor belt. This is the Watermarking detection unit.
- 4 • **A sorting belt** with 2000mm width and a standard speed of 3m/s. This width is standard, even if classic width tends to be 2800mm at a speed of 4.5m/s.
- 5 • **A Mistral + Connect V2.1** NIR/VIS detection and sorting head.
- 6 • **A valve block unit** with a standard resolution valve spacing (25mm between nozzles).

This operation scheme summarizes all steps from detection to ejection of each object on the conveyor.

A sorting PC was connected to 3 devices by Ethernet connections by means of a switch:

- The NIR/VIS Mistral+ Sorter (M+).
- The CRS system.
- The valve block of M+.

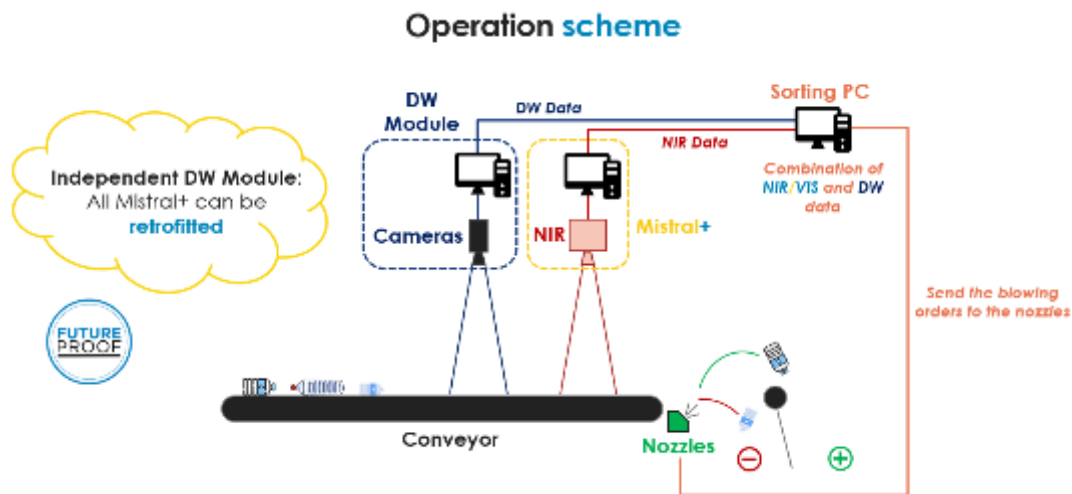


Figure 10: NIR+DW Operation Scheme.

## Software architecture

Instead of the normal operating mode, where detection results from M+ are directly used to drive the valve block, these results are sent to the sorting PC, where they are combined with the information coming from the CRS. Final orders are then issued to the valve block. This architecture enables 3 operating modes:

- DW only.
- NIR only.
- Combined mode NIR + DW.

Both sources of information are combined into a detection table.

For each test, the PC is capable of recording and visualizing the quantity of objects detected by each technology alone and by the combination of both.

**Marked Materials:**

The following pictures show four kinds of flexible packaging produced by Eversia and Leygatech. They are all marked with CurvCodes in their printing design.



Figure 11: Images of watermarked packaging.

	Sample name	Material Structure	Producer
#1	Porsi	PP/Met/PP	EVERSIA
#2	Boqueron	PET/Al/PE	EVERSIA
#3	Cauliflower	PET/PE	EVERSIA
#4	Doypack	PE/EVOH	LEYGATECH

Table 3: Watermarked packaging details

**Prototype sorting results**

This table summarizes sorting performance obtained with the prototype with a throughput of 500kg/h. 100 units of each marked reference (#1, #2, #3, #4) were mixed with post-consumer waste provided by Paprec. The ejection order is to eject only marked materials. The conveyor speed was 3m/s.

The table below summarises the sorting performance:



Detection rate	100%	100%	100%	93%
Efficiency	91%	97%	93%	Not tested
Purity	>80%			

*Table 4: Sorting KPIs of watermarked packaging*

After dozens of trials under different sorting configurations, this is what we can state about sorting performance:

- The detection rate is almost perfect for all samples.
- Sorting efficiency reaches an average value of 92% at 500kg/h in one sorting step which is very good.
- Good level of purity under industrial conditions. NB. Purity was limited in our sorting line by a less than perfect product distribution.
- Combining DW and NIR technologies increases the level of efficiency for all samples compared to DW alone.
- Sorting efficiency decreases when marked samples are heavily soiled.



# Conclusions

**Solution 1:** Advanced NIR-based detection with Mistral + Connect.

PE/PA and PE/PET, two main ML structures widely used, are now detected as a separate category in Mistral + Connect thanks to advanced chemometric algorithms. Those categories can be sorted out from the Mono-PE stream or sorted independently for recycling. Sorting efficiencies on these categories are above 90% for less than 5% of Mono-PE losses in one sorting step.

**Solution 2:** Combined NIR + DW prototype.

The CurvCode Digital Watermark provided by FiliGrade surpasses intrinsic NIR limits by incorporating key information about packaging objects. The CurvCode ‘payload’ enables sorting commands based on:

- Material composition including the material structure used by MLs.
- Food-grade packaging to enable material-recycling within the food-packaging supply-chain.

Overall, the joint prototype harnesses the strengths of Near Infra-Red (NIR) and Digital Watermarking (DW). **Combining the two technologies is key for performance.**

Solution	1 - NIR optical sorter Mistral + Connect	2 - Combined sorting prototype NIR + DW
TRL	9	7-8
Sorting performance on Mono-material flexibles	Excellent	Not tested within CIMPA. NB. Sorting performance for mono-Materials is expected to match or exceed the results for MLs.
Sorting performance on simple MLs like PE/PA/ and PE/PET	Very Good	Very Good
Sorting performances on other complex MLs	Poor results	Very Good
Sorting food grade MLs for closed-loop recycling	Impossible	Possible

*Table 4: Comparison of the two solutions proposed for ML sorting.*



## Outlook of NIR+DW joint prototype

### In the near future:

Encouraged by promising results and continuous improvements through all sessions within CIMPA project, FiliGrade and Pellenc ST are planning to continue working on the joint prototype in 2024. Several test sessions in 2024 are already booked with other materials like rigid plastic packaging.

### In a more distant future:

- Build compact hardware design (all cameras in one line) of the CRS.
- Bring the DW and NIR detection lines closer together.

## Bibliography

[1] <https://www.packaginglaw.com/special-focus/eu-proposal-regulation-packaging-and-packaging-waste-highlights>

[2] CEFLEX - Near-infrared classification and sorting test program. December 2023

## Abbreviations

<b>NIR</b>	Near InfraRed spectroscopy
<b>DW</b>	Digital Watermarking
<b>PP</b>	Polypropylene
<b>PA</b>	Polyamide
<b>PET</b>	Polyethylene terephthalate
<b>EVOH</b>	Ethylene Vinyl Alcohol
<b>Met</b>	Metallized
<b>MRF</b>	Material Recovery Facility
<b>MLs</b>	Multilayer films
<b>CRS</b>	Currcode Reading System
<b>VIS</b>	Visible spectroscopy
<b>KPI</b>	Key Performance Indicators

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This document reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Project's website: <https://cimpa-h2020.eu/>

## List of CIMPA partners

**Barbier (FR):** Barbier Group, with 155 000 tons processed each year, is a leader in the production of polyethylene films for agriculture, industry, and trade. It incorporates 30,000 tons of recycled plastic each year in its production.

**Eversia (ES):** EVERSIA is a large company specialized in integral solutions in flexible packaging with a production of 40,000 tons of plastics and 5,000 tons of paper.

**FiliGrade (NT):** a technology company that provides digital watermarking solutions for counterfeit detection purposes as well as advanced sorting of waste-streams. Its CurvCode digital watermark is a key enabler for circular deployment of plastic (food) packaging.

**Leygatech (FR):** Leygatech is a French blown film manufacturer company employing 175 people with annual turnover of 68M€ and a production capacity of 30 000 tons of plastic films.

**PAPREC (FR):** Paprec Group is a French waste management and recycling company with about 10 000 people and a turnover of €2 billion.

**Pellenc ST (FR):** Optical sorter manufacturer employing around 250 people; it has been designing and manufacturing intelligent sorting equipment for waste and recycling since 2001.

**VTT (FI):** VTT is one of Europe's leading research institutions, owned by the Finnish state.

**TNO (NL):** TNO is a Dutch independent contract research organization with a staff of about 3,000 and a total annual turnover of more than 500 million Euros.

**IPC (FR):** IPC is the Industrial Technical Centre of the French plastics and composites industry, with more than 2500 SMEs directly connected to IPC.

**AIMPLAS (ES):** AIMPLAS, located in Valencia, is a private, non-profit Association with more than 600 associated companies created in 1990.

**EURIC (BE):** EuRIC is the Confederation representing the interests of the European recycling industries at the EU level.

**BENKEI (FR):** Benkei assists its clients in defining and implementing innovation strategies.

**PROSPEX INSTITUTE (BE):** PI promotes participation of citizens and stakeholders in societally relevant decision-making and development.

