D6.1 NEW VALUE CHAINS CONFIGURATION IMPLEMENTED

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Executive Summary

This deliverable, developed within WP6 of the REDOL project, presents the implementation status of the five redesigned value chains: packaging, plastics, construction and demolition waste (CDW), textiles, and waste electrical and electronic equipment (WEEE). The objective of this work was to ensure that the new circular configurations defined in previous work packages (WP3, WP4 and WP5) were effectively deployed in real waste management environments, ready to move forward to the validation and demonstration phase.

Table 1 summarises the current deployment stage of the equipment procured across the different value chain.

Table 1. Status of the deployments

Process	Equipment	Deployment date	Deployment location	Comments
T6.1 - Redesign of new circular packaging value chains: multi-material multilayer plastic (MMPP)				
SORTING	MMPP sorting system	Awaiting delivery (expected M38-M40: January – March 2026)	GRHUSA (Huesca, Spain)	To be defied the final place of deployment within GRHUSA
RECYCLING	Delamination reactors (Pretreatment line already in place at ACTECO prior to the project)	Delivered: March 2025 Commissioning and setup: April to September 2025	ACTECO (Ibi, Spain)	Until the performance of the delamination line is confirmed, the process is carried out in the different ACTECOS's locations
T6.1 - Redesign of new circular packaging value chains: paper and cardboard				
SORTING	Paper and cardboard sorting system	Delivered and installed (M31 - June 2025)	CIRCE's facilities (Zaragoza, Spain)	The trials are being conducted at CIRCE's facilities using real material from the city of Zaragoza's selective paper and cardboard collection, provided by SAICA
T6.2 - Redesign of new circular plastic value chains				
SORTING	Smart bins	Awaiting delivery (expected M40: March 2026)	Zaragoza, Spain	Until its deployment, ICCS is validating the bin's performance through optimisation and validation tests.
RECYCLING	Pressure Reactor	Delivered and installed (M36: November 2025)	MOSES (Zaragoza, Spain)	Temporary placement to begin with the activities the initial tests.

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T6.3 - Redesign of new circular CDW value chains				
COLLECTION	Type of GPS sensor	Awaiting delivery (expected M41-M46: April – September 2026)	CASALE (Zaragoza, Spain)	The optimization algorithm for CDW waste collection has been developed and is functioning as intended. The procurement of the necessary sensors is in progress, with system deployment expected in 2026.
SORTING	CDW sorting system	Awaiting delivery (expected M40: March 2026)	CASALE (Zaragoza, Spain)	Unforeseen bureaucratic reasons have caused delay on the procurement of the container
RECYCLING	New clinker production, new cement and concrete development and new cast polymer	No new equipment was deployed for this value chain, as the existing installations were already suitable	CEMEX (Morata de Jalon, Spain) CASALE (Zaragoza, Spain) ACCIONA (Madrid, Spain)	First tests already started
T6.4 - Redesign of new circular textiles value chains				
SORTING	Textile sorting system	Already installed at pilot scale prior to the project (M1)	NTT (Prato, Italy)	The textile hub (ALIA) will be operational from the end of 2026.
RECYCLING	Elastane removal pilot plant	Already installed at pilot scale prior to the project (M1)	NTT (Prato, Italy)	The textile hub (ALIA) will be operational from the end of 2026.
RECYCLING	50L glycolysis reactor	Already installed (M18)	AITEX (Alcoy, Spain)	Samples obtained are then sent to BRILEN
RECYCLING	No additional equipment is required -	Already installed prior to the project (M1)	BRILEN (Barbastro, Spain)	Fabric production is scheduled for Q1 2026
T6.5 - Redesign of new circular WEEE value chains				
SORTING	Electrocomponents automatic sorting	Awaiting delivery (expected M40: January 2026)	TATUINE (Zaragoza, Spain)	Equipment has been assembled and tested at AMB facilities up to October 2025. Then moved to CIRCE for additional tests before deployment in TATUINE

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RECYCLING	Hazardous liquid waste treatment	To be evaluated	TATUINE (Zaragoza, Spain)	The proposed solution will be assessed from both technical and economic perspectives before a final deployment decision is made.

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List of Acronyms

Acronym	Meaning
AI	Artificial Intelligence
API	Application Programming Interface
BHET	Bis(2-Hydroxyethyl) terephthalate (monomer)
CDW	Construction and demolition waste
CTRUZ	Centro de Tratamiento de Residuos Urbanos de Zaragoza (in English: Zaragoza Urban Waste Treatment Centre)
D	Deliverable
DES	Deep Eutectic Solvents
DSC	Differential Scanning Calorimetry
EC PCB	Electrocomponent PCBs
EL	Elastane
FT-IR	Fourier Transform – Infrared spectroscopy
GIS	Geographic Information System
GP PCB	Gold Plated PCBs
GPS	Global Positioning System
HMI	Human-Machine Interface
HSI	Hyperspectral Imaging
I-US	Industrial Urban Symbiosis
LDPE	Low Density Polyethylene
MFI	Melt Flow Index
ML	Machine Learning
MMPP	Multi-material Multilayer Plastics
MRF	Material Recovery Facilities
NIR	Near-Infrared
PA	Polyamide
PC	Personal Computer
PCB	Printed Circuit Boards
PE	Polyethylene
PES	Polyester
PET	Polyethylene Terephthalate
PLC	Programmable Logic Controller
PP	Polypropylene

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PVC	Polyvinyl chloride
PVDF	Polyvinylidene Fluoride
RDF	Refuse-Derived Fuel
REDOL	Aragon's REgional Hub for circularity: Demonstration Of Local industrial-urban symbiosis initiatives
RGB	Red Green Blue
RO	Reverse Osmosis
rPET	Recycled Polyethylene Terephthalate
SUW	Solid urban waste
SWIR	Short-Wave Infrared
TRL	Technology Readiness Level
UF	Ultrafiltration
WEEE	Waste electrical and electronic equipment
WP	Work Package

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1 Introduction

The REDOL project aims to demonstrate innovative and sustainable routes for the valorisation of Solid Urban Waste (SUW) through Industrial-Urban Symbiosis (I-US) approaches. To this end, five different value chains such as packaging, plastics, construction and demolition waste (CDW), textiles, and waste electrical and electronic equipment (WEEE) are being redesigned and implemented in real waste management facilities, producing secondary raw materials to manufacture at the end high added-value circular products.

Within the project, WP6 focuses on the implementation and optimization of these circular value chains. The main objective is to demonstrate REDOL's technical, organizational, and financial innovations at TRL 6-7 by transforming these value chains into circular, symbiotic, and interconnected material flows. Considering the deployment of the technologies developed under WP3 and WP4, this deliverable presents the latest update on the installation status of the new technologies and equipment across the value chains, confirming their readiness to enter the validation phase with the respective end users. In cases where delays are anticipated, these are also documented, together with the necessary explanations to ensure a proper and effective subsequent validation phase.

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2 Methodology

This deliverable is classified as a demonstrator. Therefore, the activities conducted are focused on the coordination and support provided for the task leaders to ensure the proper deployment of the new configurations of each value chain. This work was closely aligned with the development and progress of WP3, WP4 and WP5, ensuring technical consistency across the project.

To ensure the smooth progress of this activity, coordination and monitoring tools were used to track progress and ensure that all required tasks were carried out efficiently. A structured Excel-based document was developed to record the deployment of each value chain, including:

- A detailed description of each process step
- Characterization of input materials and expected outputs
- A comparative analysis between the baseline and the REDOL solution
- Deployment timelines for the main equipment
- Identification of potential bottlenecks and countermeasures

Figure 1 shows an extract from the coordination and monitoring document used to track the different actions carried out. This document records the dates of the meetings, the participants, the planned actions with their assigned responsible person, deadlines, and additional comments. In this way, a clear follow-up of completed and pending activities was maintained.

Date	Attendees	Action	Responsible	Deadline	State	Comment
15/01/2025	M BLECUA (CIRCE), L VENTURA (CIRCE), J ARROJO (CIRCE), F SÁNCHEZ (ITENE)	Preguntar a HUSA CÓMO SE SEPARAN los residues de los contenedores amarillos	F SÁNCHEZ	30/01/2025	done	13.02.2025: ya ha contactado a los partners para pedirles información. Deadline 3/3/2025.
		Preguntar al CETRUZ CÓMO SE SEPARAN los residues de los contenedores amarillos	F SÁNCHEZ	30/01/2025	done	13.02.2025: ya ha contactado a los partners para pedirles información. Deadline 3/3/2025.
		Preguntar a ACTECO que PROCESO DE RECICLAJE hacen con los MMPP fuera del REDOL	F SÁNCHEZ	30/01/2025	done	13.02.2025: ya ha contactado a los partners para pedirles información. Deadline 3/3/2025.
		Rellenar la baseline de la sepración del papel de la T6.1	F SÁNCHEZ	30/01/2025	done	13.02.2025: ya ha contactado a los partners para pedirles información. Deadline 3/3/2025.
		Organizar KoM	M BLECUA	30/01/2025	Done	
		Organizar T6.1 monthly meeting	F SÁNCHEZ	30/01/2025	Done	
		Mandar tareas a F SÁNCHEZ	M BLECUA	30/01/2025	Done	
		Definir los contenidos de la tabla para que la rellenen los task leaders	L VENTURA	30/01/2025	Done	
15/01/2025	M BLECUA (CIRCE), C CHAINE (CIRCE), J ARROJO (CIRCE)	Pedir a TATUINE costes de las vias de sorting y reciclaje	C CHAINE	30/01/2025	done	13.02.2025: pedida información pero sin trasladar al
		Pedir a TATUINE propiedades de las inputs y outputs	C CHAINE	30/01/2025	done	13.02.2025: pedida información pero sin trasladar al
		Pedir a TATUINE end users de cada producto	C CHAINE	30/01/2025	done	13.02.2025: pedida información pero sin trasladar al
		Pedir a RINA el coste de su via de reciclaje en función del Au recuperdo	C CHAINE	30/01/2025	done	13.02.2025: pedida información pero sin trasladar al
		Preguntar a PRATO	C CHAINE	30/01/2025	done	13.02.2025: no sabemos si ha preguntado.
		DIGITALIZATION members meeting - know the roles	L VENTURA	30/01/2025	done	OK
15/01/2025	M BLECUA (CIRCE), L VENTURA (CIRCE), J ARROJO (CIRCE), D REDONDO (CIRCE), A LERMA (AITEX), R GADEA (AITEX)	Preguntar a ALIA por la clasifiación baseline	A LERMA, R GADEA	30/01/2025	done	13.02.2025: Sin información en el excel ni en la
		Preguntar a NTT o ALIA por el proceso de elastan removal - BASELINE	A LERMA, R GADEA	30/01/2025	done	13.02.2025: Sin información en el excel ni en la
		Preguntar a ALIA por el recilaje del PET - Baseline - usar datos de AITEX si no	A LERMA, R GADEA	30/01/2025	done	13.02.2025: Sin información en el excel ni en la
		Buscar propiedades PET claves en la producción de fibras para definir	A LERMA, R GADEA	30/01/2025	done	13.02.2025: Sin información en el excel ni en la
		Task 5.2.4 textile value chain in ZARAGOZA	A LERMA, R GADEA	30/01/2025	done	13.02.2025: pendiente preguntar a Elena.
			M BLECUA	30/01/2025	Done	13.02.2025: Pendiente aclarar con Araceli.
15/01/2025	M BLECUA (CIRCE), L VENTURA (CIRCE)	Reunión con CARLOS	M BLECUA	22/01/2025	Done	
16/01/2025	M BLECUA (CIRCE), L VENTURA (CIRCE), J ARROJO (CIRCE), D REDONDO (CIRCE), L VILLACIÁN (TEC), L HERNÁNDEZ (AITIIP)	Coste gestionar residuo papeleras (€/kg de residuo)	L HERNÁNDEZ (AITIIP)	30/01/2025		13.02.2025: sin actualización en la tabla.
		Rellenar lo que está en pendiente en la tabla	L HERNÁNDEZ (AITIIP)	30/01/2025		13.02.2025: sin actualización en la tabla.
		Hablar con ACC de los productos que quieren hacer con fibras	M BLECUA	30/01/2025	done	13.02.2025: Pendiente aclarar con Araceli.

Figure 1. Extract from the coordination and monitoring file used in WP6

Figure 2, on the other hand, shows the document that summarised the progress made in each value chain, including different characteristics of the process for both the baseline and the REDOL solution

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Value chain	Process	INPUT		Baseline							
		Type of waste	Properties	Process	OUTPUT	Properties	End-user	New product	Recyling or sorting rate (%)	Approximate cost (€/ton)	Process
CDW	Sorting system (T3.3)	CDW 1 1) VOLUMINOSOS: metal, plastic, wood, paper 3) FRACCIÓN MIXTA (no pétreo, mayor tamaño) - Smaller materials of metal, plastic, wood, paper 4) PLÁSTICOS LÍGEROS: PE, LDPE...	Wood 15% Mineral fraction (stone, cement, concrete) 10% Plastic fraction 71% Metals 1% Other 3%	Direct utilization of the wastes.			1) VOLUMINOSOS: another waste manager. 3) FRACCIÓN MIXTA (no pétreo, mayor tamaño): another waste managers. 4) PLÁSTICOS LÍGEROS: another waste managers.	1) VOLUMINOSOS: Valorization. 3) FRACCIÓN MIXTA (no pétreo, mayor tamaño): Valorization. 4) PLÁSTICOS LÍGEROS: Valorization - Energy valorization.	2024: 75% go to another waste manager (they recycle 70%) 25% go to landfill.	**1) VOLUMINOSOS: 3) FRACCIÓN MIXTA (no pétreo, mayor tamaño): 4) PLÁSTICOS LÍGEROS:**	Robotic arm that picks up the plastic material. More efficient for PVC separation.
	Formulation of recycled components (T4.3)	CDW 1 - 2) FRACIÓN FINA PÉTREA	Mineral = 40% SiO2, 27% CaO, Alumina, FeO, SO4. REQUIREMENTS FOR CLINKER: high content in CaO, low content in heavy metals, the mineral phase (CEMENT: EN 197).	Fabrication of Clinker with recycled minerals at 14%.	Clinker made with recycled raw materials	Similar than natural raw materials EN 197	CEMEX	N/A	14%	**Extra production cost of 8.6€/ton of clinker when added the 14.31% of wastes.**	Fabrication of Clinker with 21% recycled raw materials from CDW
		CDW 1 - 2) FRACIÓN FINA PÉTREA	Mineral = 40% SiO2, 27% CaO, Alumina, FeO, SO4. REQUIREMENTS FOR CLINKER: high content in CaO, low content in heavy metals, the mineral phase (CEMENT: EN 197).	Commercial fabrication of concrete	Concrete	Casalé concrete properties	CASALÉ		0	Commercial cost 120€/m3	Concrete recipe made with CDW improved by VDZ
		CDW 1 - 2) FRACIÓN FINA PÉTREA	Mineral = 40% SiO2, 27% CaO, Alumina, FeO, SO4. REQUIREMENTS FOR CLINKER: high content in CaO, low content in heavy metals, the mineral phase (CEMENT: EN 197).	Commercial fabrication of cement	Cement	Cement standards EN 197	CEMEX / CASALÉ		0	Commercial cost 110 €/ton	CEMENT recipe made with CDW improved by VDZ
		CDW3 Recycled sand and Recycled gravel (CDW2) Slag (INDUSTRIAL)	CDW2: 0/22 mm (ARH022 - CASALE) Slag (indrustrial): Al, Fe, STANDARDS: Controlled size distribution, high silica	Fabrication of cast polymer with VIRGIN materials (Resin + aggregates)	CAST POLYMER without recycled materials	ASTM C395: Standard specifications for Chemical-Resisitant resin mortars	ACCIONA	Cubeto de retención - ALTA RESISTENCIA QUÍMICA	0	608.5€/ton 85% virgin aggregates + 15% resin	Fabrication of cast polymer with recycled materials

Figure 2. Extract from the document showing the characteristics of each value chain

This document was updated monthly by the task leaders, providing a centralized and up-to-date overview of the implementation status across WP6. Additionally, monthly coordination meetings were held with all task leaders to monitor progress, share key achievements, and identify or address potential delays.

The new value chain configurations are presented below for the five value chains analysed in the project (one per chapter). Each case begins with a process description, across all relevant phases: collection, sorting, recycling, and end-user validation. For the first three phases — collection, sorting, and recycling — the baseline scenario is compared with the REDOL solution.

- **Collection** refers to the gathering and aggregation of waste materials from various sources to ensure an adequate supply of input for subsequent processing stages.
- **Sorting** involves the separation of collected materials into distinct fractions based on their composition, quality, or potential for recovery, typically using mechanical or manual methods.
- **Recycling** encompasses the processing of sorted materials into secondary raw materials.
- **End-user validation** represents the final phase, in which the secondary raw materials are used to formulate new circular products, enabling the closure of the loop within the REDOL value chains. A selected group of end users will participate in the production and validation of these new circular products.

In some cases, not all phases are represented within a specific value chain. Therefore, only the phases applicable to each value chain are described in detail.

Next, a process diagram is provided, illustrating the full implementation of each redesigned value chain. These diagrams depict the workflow of each material, highlighting the technologies, streams, and interconnections among the partners involved in the circular configuration of packaging materials. This section describes the collection, sorting, and recycling phases when relevant.

Then, a layout section showcases the equipment already installed and ready to begin the validation phase. This section includes either layout schematics or images of the equipment, along with key technical details. This section describes the collection, sorting, and recycling phases when relevant.

Finally, a closing section is included, detailing the future work plan for the final year of the project. This section describes the collection, sorting, recycling, and end-user validation phases, when relevant.

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3 Task 6.1. Redesign of new circular packaging value chains: multi-material multilayer plastic packaging (MMPP)

3.1 Processes description

The packaging value chain focused on MMPP comprises several key stages, including collection, sorting, recycling, and the validation of products manufactured using secondary raw materials. For each of these activities, a specific solution has been developed within the REDOL project.

- The collection stage aimed to enhance the efficiency of collection operations by reducing travel distances, collection time, and the associated environmental impacts. This innovative approach was applied to the optimisation of collection routes for lightweight packaging waste in the city of Zaragoza.
- During the sorting stage, efforts focused on improving the separation of MMPP at the Huesca waste treatment plant (GRHUSA).
- The recycling stage was carried out in collaboration with ITENE and ACTECO, where the recovered materials were processed into new secondary raw materials with the quality and performance required for further industrial applications.
- Finally, in the valorisation stage, the obtained secondary raw materials were utilised by end-users, such as TECNOPACKAGING, to demonstrate their potential in the production of new circular products, closing the loop of the circular value chain.

Each stage has been redesigned to enhance material recovery, traceability, and circularity, as shown in Figure 3.

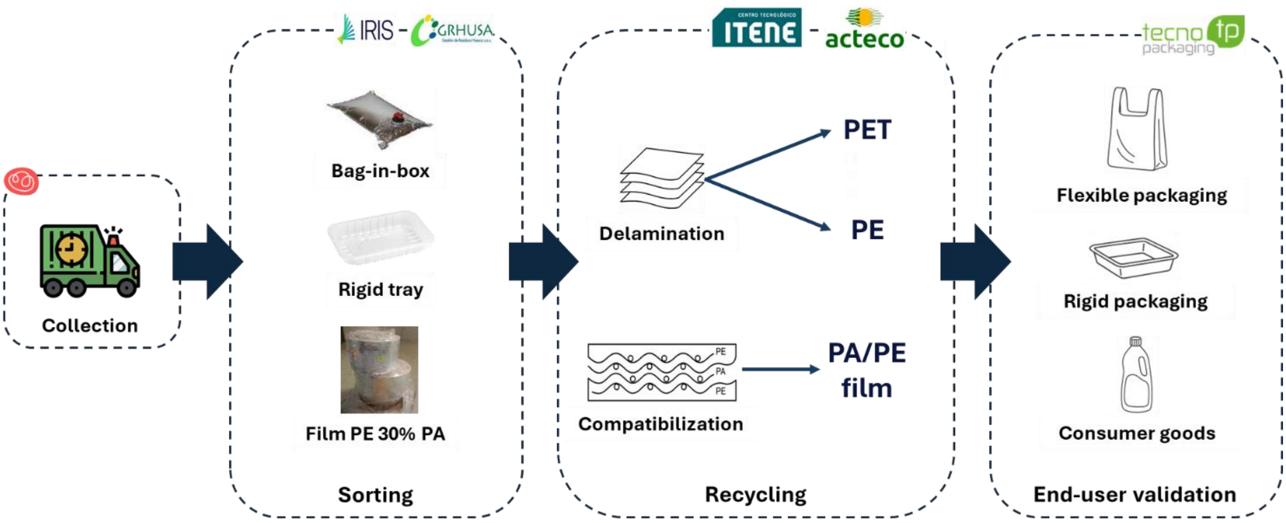

Figure 3. REDOL Packaging (MMPP material) redesigned value chain

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3.1.1. Collection

3.1.1.1. Baseline

The collection of lightweight packaging waste in Zaragoza is managed by the municipal contractor FCC. The city is divided into areas covered in morning, afternoon, or night shifts. Routes are organized directly by FCC and not strictly linked to municipal districts.

Collection starts and ends at FCC facilities (Carretera de Castellón s/n, Zaragoza, Spain), with unloading mainly at CTRUZ (for packaging). Vehicles of different capacities (10–28 m^3) are used, including narrow-width trucks for urban areas.

Although fill-level sensors are installed on some containers, they are only partially operational, and route adjustments are based on operational experience and periodic data updates.

3.1.1.2. REDOL innovation

As part of Task 5.4, an improvement in the collection stage of the packaging (yellow bin) waste streams in the city of Zaragoza was implemented. This initiative focused on designing and evaluating routing optimization algorithms for municipal solid waste collection using data from tracking technologies such as GIS and partial fill-level sensors data. The main objective was to enhance the efficiency of collection operations by reducing travel distances, collection time, and associated environmental impacts within the REDOL value chain. In the future, the resulting dynamic collection routes will be visualized through the I-US platform, enabling improved monitoring and management of the optimized collection process.

3.1.2. Sorting

3.1.2.1. Baseline

GRHUSA operates a lightweight packaging sorting facility that combines manual processes with automated classification technologies. The process begins with the reception of the incoming waste and its dosing onto a variable-speed conveyor belt using a telescopic handler. The material then passes through a visual inspection cabin where operators remove oversized items and undesired materials. Afterward, it goes through a bag-opener and reaches the ballistic separator, which divides the material into three fractions: rolling, planar, and fine (the fine fraction is treated as reject material and sent to landfill). The planar fraction is directed onto a dedicated conveyor from which it is pneumatically extracted by suction, passing through a post-sorting cabin where paper and cardboard are manually separated before being stored in a silo. The rolling fraction continues along its conveyor and is first subjected to a magnetic separator, followed by optical and Foucault separators, enabling the discrimination of conductive, metallic, and non-conductive materials.

3.1.2.2. REDOL innovation

Within the REDOL project, an AI tool is a real-time, monitoring and classification prototype based on advanced Hyperspectral Imaging (HSI) technology, has been developed for sorting MMPP. It operates in the short-wave infrared (SWIR) spectrum, which allows the system to capture detailed spectral fingerprints of plastic materials for chemical-based discrimination. This enables the system to identify and separate various types of MMPP found in municipal solid waste streams. The system prototype is designed to simulate industrial sorting conditions on a conveyor belt and focuses on three specific categories of plastic packaging defined by the industrial partner HUSA: rigid multilayer packaging such as PET trays, flexible multilayers like polyethylene/polyamide films, and metallized plastic packaging such as snack wrappers and coffee bags. The comprehensive setup includes an HSI camera unit, a custom conveyor with adjustable speed, halogen lighting

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for uniform illumination, a metallic frame for precise camera positioning, an industrial PC for real-time data processing, and a touchscreen interface for user interaction.

The innovation developed lies in its development of an HSI system combined with advanced AI-driven hybrid classification models specifically tailored for sorting MMPP waste. AI is central to the system, using chemometric and supervised learning models. The AI models are trained on real-world, food-contaminated waste samples representative of municipal streams, and include specialized classes to reduce misclassification tags such as labels or paper contaminants.

This system reduces manual labour and overcomes key limitations of existing waste sorting technologies by enabling pixel-level, chemical composition-based identification and classification of complex plastic packaging streams in a conveyor-based industrial environment. It uniquely targets the accurate discrimination among three challenging MMPP categories; rigid multilayer packaging (like PET trays), flexible multilayers (such as PE/PA films), and metallized plastic packaging (like snack wrappers). The system is designed for operation at industrial sorting lines, offering enhanced speed, accuracy, and robustness compared to manual or simpler automated methods. It integrates spectral sensing, chemometrics, and supervised machine learning in a modular hardware-software prototype ready for demonstration and eventual industrial deployment at TRL7.

By delivering this innovative AI-based sorting capability, Task 3.2 directly contributes to REDOL's goals of upgrading municipal solid waste sorting technologies, improving recycling quality and yields, supporting circular economy models, and enabling the efficient valorisation of multilayer plastic packaging waste streams. This advancement represents a breakthrough in automated urban waste monitoring that is well aligned with REDOL's industrial-urban symbiosis and zero-waste city ambitions.

3.1.3. Recycling

3.1.3.1. Baseline

Multi-material multilayer plastic packaging (MMPP) represents one of the most problematic waste streams in the current urban waste management system. These materials are designed to combine different polymers (such as polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET)…) to provide enhanced barrier performance, mechanical resistance and product preservation. It simultaneously makes these materials extremely challenging to recycle. Conventional mechanical recycling systems are unable to efficiently separate the different layers, since these structures are permanently laminated and the polymers involved are typically immiscible. As a result, MMPP entering sorting plants is usually classified as mixed plastic waste and directed either to low-grade downcycling routes or to waste-to-energy recovery due to their pellets with poor mechanical, optical, and thermal properties.

In standard municipal waste treatment facilities, multilayer films and trays are of the rejected by optical sorters due to their heterogeneous composition and the presence of coatings or multilayer interfaces that distort near-infrared (NIR) identification. The heterogeneity of these packages also obstructs density-based or air-based separation techniques. Furthermore, MMPP frequently contain adhesives, inks and coatings that further hinder their recyclability and increase the cost of any potential treatment. Current industrial facilities offer no efficient routes for delamination or selective dissolution. Consequently, under the conventional baseline scenario, MMPP is considered a low-value, non-recyclable stream.

3.1.3.2. REDOL innovation

Under REDOL, the recycling stage integrates innovative delamination with green solvents and washing processes developed in WP4. These processes employ green solvents and surfactant-assisted separation,

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enabling the recovery of mono-material layers from multilayer packaging. These technological advances increase the yield of recycled polymers and generate materials suitable for high-quality reprocessing.

Building on this approach, REDOL introduces a set of targeted innovations that directly address the limitations identified in the baseline scenario. Instead of relying on traditional recycling, WP4 develops strategies for each MMPP flow. These innovations establish controlled, energy-efficient, and scalable recycling pathways that were previously unavailable for multilayer packaging, enabling selective recovery, improved material quality, and higher circularity potential. The lines studied are:

- **Metallized films**: A new delamination strategy based on green solvents and surfactant-assisted systems enables the selective removal of aluminium layers. This directly overcomes the baseline barrier where metallized structures cannot be separated by NIR-sorting or by mechanical means and are therefore routed to incineration.
- **Rigid trays**: REDOL introduces a selective-dissolution methodology capable of separating PET from bonded PE layers, something not achievable with conventional recycling. This controlled solvent-based process creates a new valorisation pathway for rigid trays that were previously considered unrecyclable due to adhesive strength and polymer immiscibility.
- **PA/PE compatibilization**: Instead of attempting physical separation, REDOL develops a compatibilization framework based on tailored functional additives that enhance interfacial adhesion between PA and PE. This turns an inherently incompatible multilayer into a processable and higher-quality recycled blend, offering a completely new end-of-life strategy for materials that otherwise would be downcycled or rejected.

3.1.4. End user validation

As part of the validation phase in REDOL, three distinct products are being developed using the recovered plastic fractions, demonstrating its versatility and potential for upcycling

- **Flexible packaging**: The fraction coming from PE layer of rigid trays and the LDPE layer recovered from metallized film are compounded with virgin material to create a blend suitable for extrusion film blowing, for developing flexible bags.
- **Rigid packaging**: The PET fraction recovered from rigid trays and PET film from metallized structures will be compounded with virgin material to create a blend suitable for extrusion blow moulding, for developing bottles for household products.
- **Consumer goods**: This category uses the PET fraction that is not allocated to rigid packaging, and/or PA-PE recovered fraction to be compounded with virgin material to create a blend suitable for injection moulding, for developing consumer goods (i.e. injected jars).

3.2 Diagrams

This section presents and briefly describes the process diagrams corresponding to each stage of the packaging value chain implemented within the REDOL project. These diagrams illustrate the workflow of each material, highlighting the technologies, streams, and interconnections among the partners involved in the circular configuration of packaging materials.

For this section, diagrams are provided for the sorting and recycling phases.

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3.2.1. Collection

The tool, trough optimization algorithms, allows to design and evaluate routes for the collection of municipal solid waste using data from tracking technologies such as GIS and bin fill sensors. The optimization aims to reduce travel distances, time, and environmental impact in the REDOL value chain.

3.2.2. Sorting

Firstly, the MMPP sorting diagram is shown in Figure 4, detailing the sequential operations carried out from waste input to the extraction of specific plastic fractions.

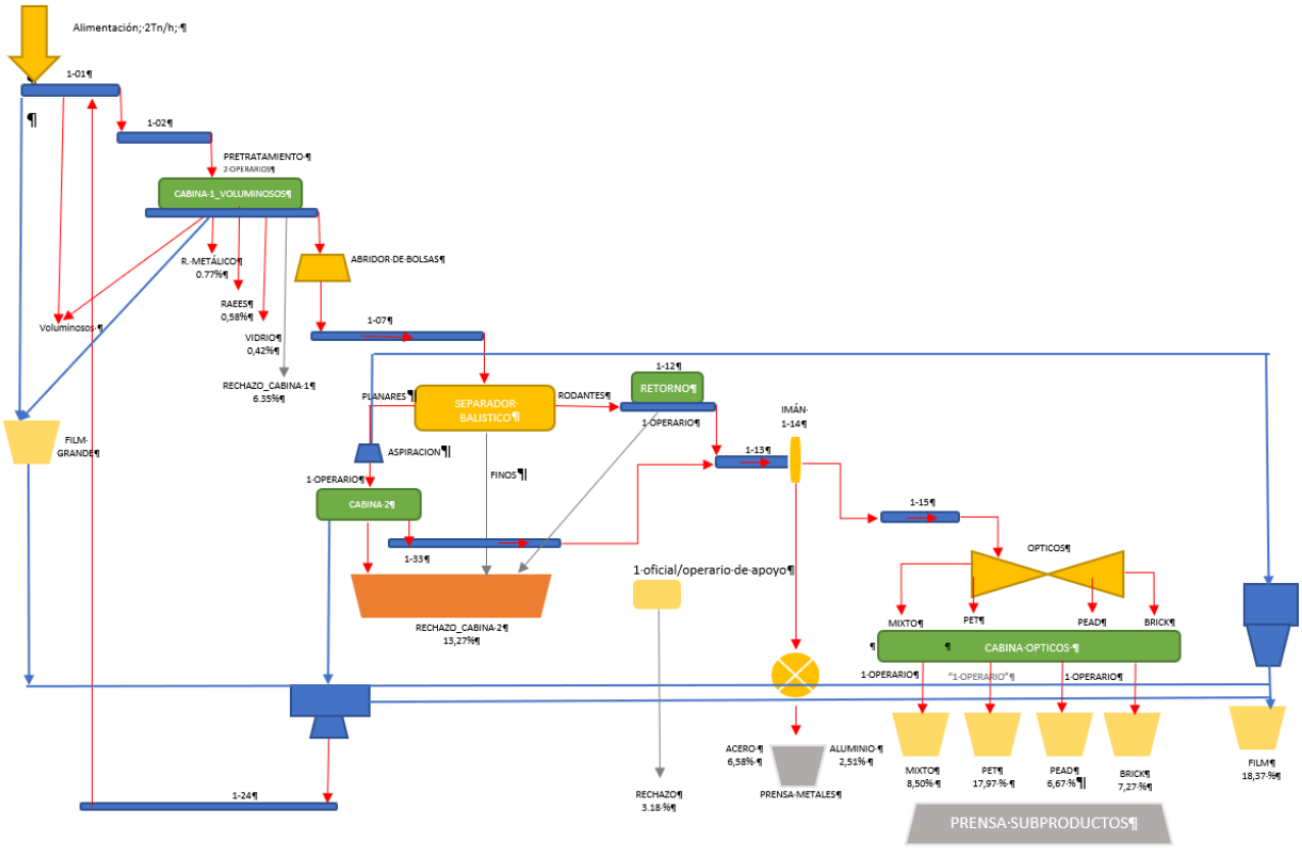

Figure 4. MMPP Sorting diagram.

In this case, the process integrates conventional mechanical separation units (ballistic separators, optical sorters, and manual cabins) with the IRIS optical sorting system, which enables the identification and separation of MMPP such as rigid multilayers (e.g., PET-based trays), flexible multilayers (e.g., PE and PA films) and metallized multilayers (e.g., aluminium-coated bags). This configuration improves the recovery of high-value polymers and enhances the purity of the resulting fractions, which are subsequently directed to the appropriate recycling and valorisation routes.

3.2.3. Recycling

Subsequently, Figure 5 summarizes the recycling processes developed for plastic packaging within the REDOL project.

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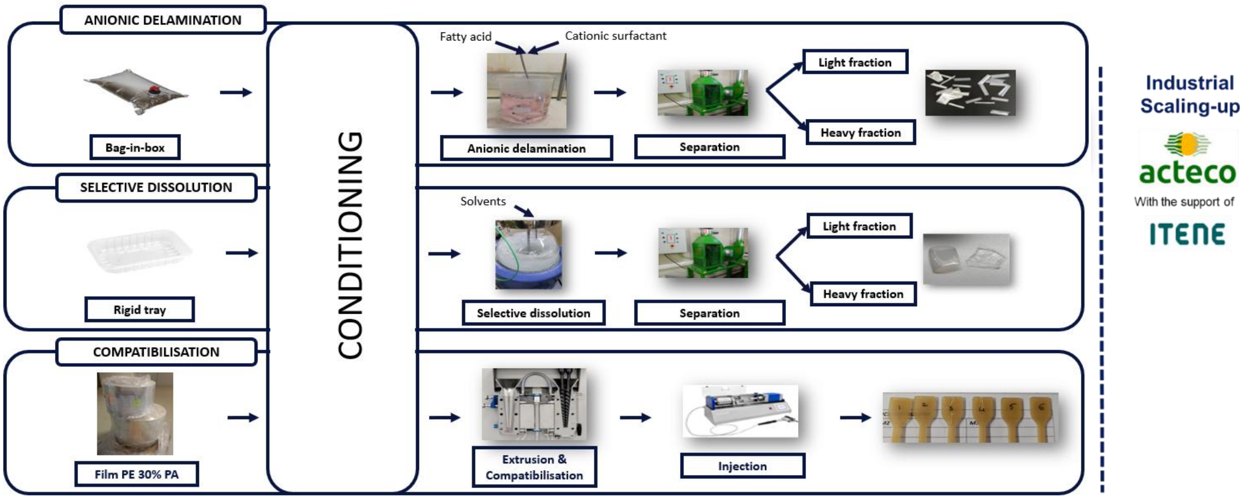

Figure 5. MMPP Recycling diagram.

Three complementary routes have been developed to recover materials from complex multilayer plastic packaging. The anionic delamination line focuses on bag-in-box films, enabling the selective separation of polymer and metallic layers to obtain clean plastic fractions for further recycling. The selective dissolution line targets rigid packaging structures, such as PET/PE trays, where environmentally compatible solvents are used to act on adhesive interfaces and facilitate the separation of polymer layers without altering their integrity. Finally, the compatibilization line addresses films composed of polymers with low mutual compatibility, such as PA and PE, by incorporating functional additives that improve the adhesion and mechanical behaviour of the recycled material. Together, these three processes represent a comprehensive approach to the recovery and valorisation of complex packaging waste, currently being scaled up in ACTECO's facilities.

3.3 Layouts

This section presents the equipment that has been installed or is still pending installation, and which will be used in the upcoming validation phase. It includes layout schematics or photographs of the equipment, together with key technical specifications.

This section describes the collection, sorting and recycling phases.

3.3.1. Collection

The platform developed for collection has two main components (Figure 6):

1. **Map-based Visualization:** A dynamic map now displays the bin fill level across the city. Fill levels are simulated with weighted randomness, increasing in high-density areas. The user can explore different days of the simulation, moving forward or backward through time.

2. **User Parameters and Controls:** A comprehensive set of parameters is now configurable by the user. This includes algorithm selection, number of vehicles, optimization goals (CO_2, time, distance), clustering behaviour, and more.

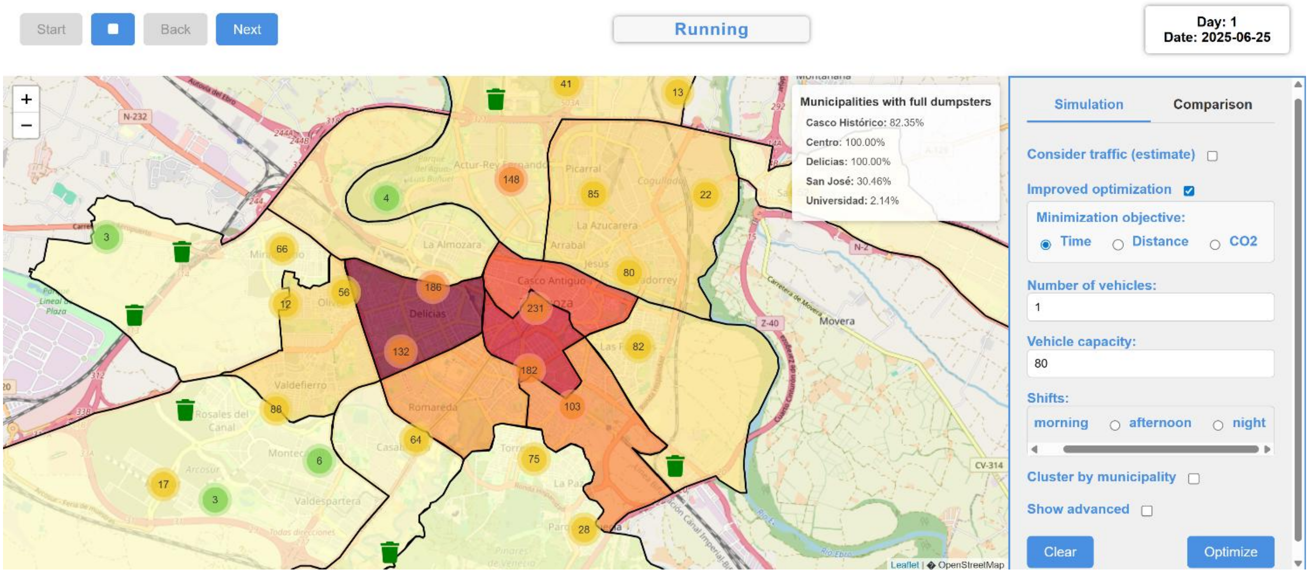

Figure 6. Main user interface (Simulation)

A comparison module was also implemented to evaluate the performance of the optimization strategies against real-world municipal data. This allows comparing and validation of the simulation outputs (Figure 7).

The user can upload a .xlsx or .csv file, select sector and date, and, finally, the optimization algorithm. At this point, the optimization will be performed and then the comparison.

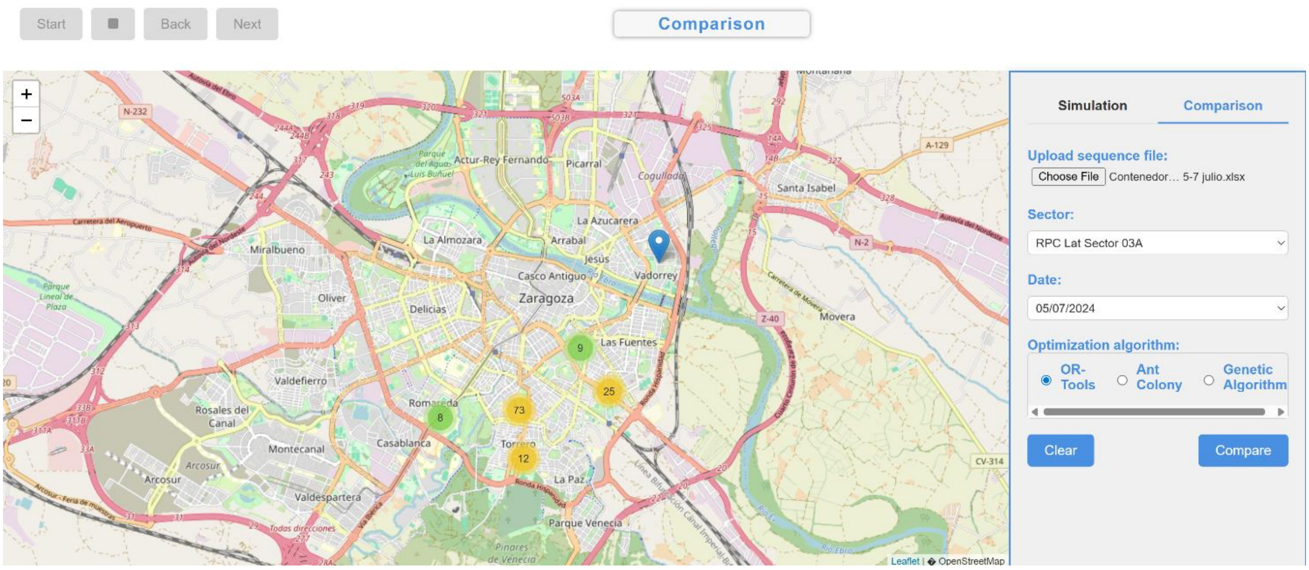

Figure 7. Main user interface (Comparison)

3.3.2. Sorting

The core sensing component of the system is the Specim FX17 HSI camera, operating in the SWIR range from 900 to 1700 nm. This camera is designed to capture detailed spectral information of plastic packaging materials as they pass through the acquisition area.

For the demonstration phase, the camera and associated hardware, including the processing computer running the AI classification models and a user-friendly touchscreen interface, are integrated directly onto the preexisting conveyor belt at HUSA's waste monitoring and sorting facility. This strategy leverages the existing infrastructure, facilitating straightforward installation and operational integration without the need to build a new conveyor system from scratch. The user interface is designed to provide real-time feedback and can be customized according to the end-user's operational needs.

The location within the GRHUSA process where the deployment and validation of the equipment will take place is still under evaluation. Different zones have been identified as potential candidates (Figure 8).

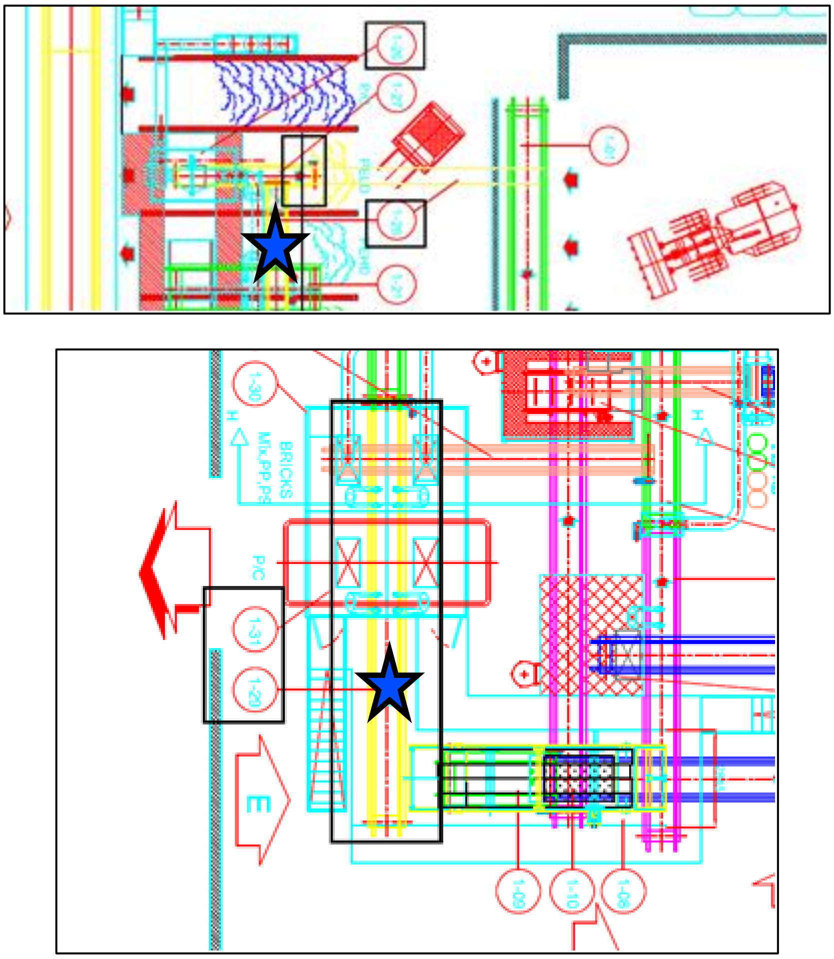

Figure 8. Points being evaluated to install the new equipment (marked with a star)

During the first months of 2026, logistical changes are planned at the GRHUSA plant, involving a reconsideration of the validation date and the specific area within the plant's process where the sorting technology will be deployed and tested. Discussions are ongoing, and a rescheduled plan is expected to be agreed upon soon.

A summary of the equipment to be installed is provided in Table 2.

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Table 2. Equipment to be deployed in the packaging value chain (sorting)

Equipment	Process	Function	Deployment date and location	Comment
MMPP sorting system	SORTING	HSI-based sorting system using a SWIR camera integrated into the existing conveyor to classify plastics in real time.	Q1 2026 GRHUSA (Huesca, Spain)	Changes at the GRHUSA plant will require rescheduling the deployment of the sorting technology.

3.3.3. Recycling

At ACTECO, the scaling up of the recycling process at industrial scale is being carried out. The delamination reactor was acquired during the project, as shown in Figure 9. The process begins with the shredder, where the material is reduced into small flakes (Figure 10). If post-consumer waste is being treated, a washing stage is required before delamination; otherwise, the material is fed directly into the reactors, where the trays are separated into two fractions. These fractions are then separated by density. The film fraction is extruded to produce pellets for re-use, while the rPET fraction can be reused in flake form.

For this scale-up, the main equipment required to perform the process includes conveyor belts, a shredder, a milling machine, a washing line (for post-consumer waste), delamination reactors, a density-separation bath, a centrifuge, a mixing silo, an extruder, a cooling system, a big-bag loader, and a filtration system (Figure 11).

ACTECO has several facilities distributed across Spain; however, until the performance of the delamination lines is fully validated, the process cannot be implemented at the different ACTECO sites, as each location has specific operational characteristics (Table 3).

Table 3. Equipment deployed in the packaging – MMPP value chain (recycling)

Equipment	Process	Function	Deployment date and location	Comment
Delamination reactors (Pretreatment line already in place at ACTECO prior to the project)	RECYCLING	Delamination of MMPP to get pellets to be used again and the rPET can be used in flakes.	• Transport: March 2025 • Commissioning and setup: April to September 2025 • Location: Ibi (Alicante)	Until the performance of the delamination line is confirmed, the process is carried out in the different ACTECO's locations

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Figure 9. Dosification system (left), drying centrifuge (centre) and delamination reactors (right) ready for industrial test

Figure 10. Pretreatment line: washing bath (top), plastic shredder (middle) and washing bath (bottom) ready for industrial test

Figure 11. Filter system (left), dosification hopper (right) and extruder (below) ready for industrial test

3.4 Future work plan

The final project period will focus on completing the industrial validation of the packaging value chain, ensuring that the recycled fractions and developed technologies perform under real operational conditions. The value chain configuration was originally developed within WP3 and WP4, where the processes were demonstrated at laboratory and pilot scale. In WP6, these results will be scaled up and validated at industrial level, confirming the technical feasibility and quality of the recovered materials. In parallel, optimisation activities will target improvements in consolidating the transition from laboratory testing to full-scale implementation.

3.4.1. Collection

In the upcoming months, the resulting dynamic collection routes will be visualized through the I-US platform, enabling improved monitoring and management of the optimized collection process.

3.4.2. Sorting

The future plan associated with the validation and optimization of the AI-based system for the identification and classification of MMPP in the REDOL project focuses on deploying and demonstrating the developed monitoring system in a real industrial environment at GRHUSA facilities, targeting TRL7.

This phase includes calibrating and fine-tuning the HSI system in situ to adapt to operational variables such as lighting conditions and conveyor speed variations. Continuous acquisition and real-time processing of

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hyperspectral data will assess the system's throughput capability and classification accuracy in identifying multilayer plastic packaging types within fast-moving municipal waste streams.

The validation activities will benchmark performance against current monitoring technologies at GRHUSA, measuring improvements in speed, sorting precision, and reduction of misclassification, especially for challenging materials like metallized plastics and plastics contaminated with labels or food residues. Feedback from these operational trials will be used to refine AI classification models, expanding spectral libraries and improving hybrid AI algorithms for more robust material discrimination.

Furthermore, data gathered during this phase will be analysed to optimize classification thresholds and enhance integration potential with downstream mechanical sorting systems, such as pneumatic ejectors, to enable automated separation of plastics. Operator training and system usability assessment will ensure seamless adoption of the technology in industrial workflows.

In any case, the place where the equipment will be installed is still unknown due to possible modifications of the GRHUSA plant.

3.4.3. Recycling

In this case, the delamination of processes for plastic recycling previously optimised in WP4 for both rigid trays and bag-in-box multilayer packaging are being conducted in a 20 L glass reactor, adapting the sample mass and process parameters to larger volumes (Figure 12). This scale-up is revealing specific operational challenges. For example, for the bag-in-box materials, the washing stage required adjustment to achieve neutral conditions efficiently, due to the higher sample mass and the interaction between the polymer and metallic layers. These findings highlight the importance of process tuning during the transition from laboratory to pilot environments.

Figure 12. Bag-in-box delamination process

For the rigid trays (Figure 13), a clear separation between the upper and lower fractions was observed in the upscaling, corresponding to the PE in the floating fraction as well as the PET in the sinking fraction. However, some residual adhesion between layers was still detected, indicating the need for further optimisation of temperature and washing parameters to improve full delamination.

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Figure 13. Rigid trays delamination process.

In addition to the validation processes, future work will also focus on improving the separation of PET and PE layers obtained after delamination in both cases. Although the initial separation achieved during pilot trials was effective, partial overlaps between the polymer layers were still observed. To enhance de quality and purity of the recovered fractions, different physical separation techniques will be evaluated, such as elutriation and electrostatic separation. These approaches will help to obtain cleaner PET and PE streams, facilitating their subsequent recycling and processing into new products. Figure 14 shows an electrostatic separation essay done for the 20 L rigid tray samples delaminated.

Figure 14. Separation of delaminated fractions.

Furthermore, as part of the transition from pilot to industrial scale, the most promising conditions identified in the 20 L reactor will be scaled up to an industrial reactor of approximately 100 L. The ultimate goal is to validate the industrial feasibility of the delamination and separation stages, ensuring that the REDOL packaging value chain can be replicated and implemented beyond the project's demonstration phase. As a preliminary phase to delamination, a pretreatment plant with a capacity of 900 kg/h will be used to prepare the waste so it can later be delaminated. The pretreatment plant includes a shredder that reduces the material size, followed by a mill that further reduces it to a diameter of 12 mm. After this, the process includes washing to remove potential contaminants and drying with dust extraction to eliminate light materials that could reduce the efficiency of the delamination process.

Once pretreatment is complete, the delamination process begins. This involves a system of reactors operating in a staggered manner—while one reactor handles loading and unloading; the other continues processing to avoid downtime. Each reactor has a capacity of 1500 litres. A dosing system is used to feed plastic into the reactors, and a separate liquid dosing system ensures that the reagents are not lost during discharge. Since the material exits wet, it is dried in a centrifuge and stored in a big bag. At this stage, the two product phases are

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also separated, yielding rPET on one side and rLDPE on the other. In this stage of the project the goal in to validate about 800 kg of multilayer trays and 800 kg of bag in box waste stream.

In the case of the multilayer PA/PE film waste stream, consisting of approximately 30% polyamide and 70% polyethylene, the material was first shredded to obtain a uniform particle size suitable for subsequent processing steps. Following this, agglomeration trials were carried out to increase the bulk density of the material, thereby improving feeding stability and minimizing dosing fluctuations during extrusion.

After agglomeration, the material was compounded using a co-rotating twin-screw extruder, where it was blended with the preselected additive formulations under carefully controlled temperature and screw-speed conditions to ensure optimal dispersion and strong interfacial adhesion between the two polymer phases (Figure 15). The resulting melt was then filtered and pelletized, obtaining the corresponding regranulate suitable for subsequent film production trials.

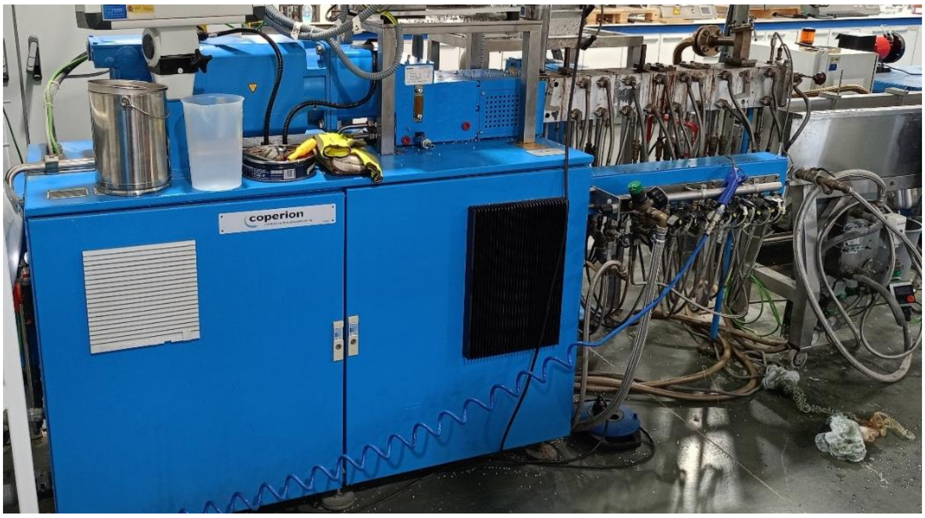

Figure 15. Extrusion equipment for the manufacture of compatibilized pellets

To evaluate the performance of the different additive configurations, film samples were produced from the resulting pellets (Figure 16). These films were tested for mechanical properties, including tensile strength and tear resistance, to assess how the compatibilization strategy influenced the final material behaviour.

Figure 16. Film made after pellet extrusion

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Particular attention was given to the film extrusion conditions, which must operate at sufficiently high temperatures to ensure complete melting of the polyamide without causing thermal degradation of the polyethylene. The optimized use of compatibilizing additives made it possible to lower the processing temperature, improving polyamide flow and preventing degradation. As a result, the final film exhibited excellent optical and mechanical quality, with no visible black spots or unmelted PA inclusions, and a translucent, homogeneous appearance free of weak points or degradation marks—clear evidence of effective compatibilization and a stable processing window

Based on these results, the most promising formulation was selected for scaling up to industrial scale, targeting a total of 700 kg of processed material. This industrial-scale process will be carried out in a real manufacturing environment, using the same pretreatment line as in the pilot stage. All incoming waste will first undergo shredding and agglomeration before being fed into the extruder. The agglomeration step ensures that the material maintains sufficient bulk density, avoiding excessive voids in the screw during melting. The extrusion will then be conducted on a compounding extruder, following the optimized parameters established during pilot testing.

3.4.4. End user validation

For flexible packaging, rigid packaging and consumer goods, TECNOPACKING will develop different blends using recovered fractions and virgin materials. These compounds will be evaluated in terms of their thermal properties (DSC, MFI) in order to ensure greater processability for the manufacture of the desired products. Additives will be included if necessary to improve processability, maximising the incorporation of recycled content. The mixtures developed will then be used for mechanical characterisation by injecting test samples and, once the most suitable formulation has been developed, pre-industrial trials will be carried out to develop the products mentioned above.

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4 Task 6.1. Redesign of new circular packaging value chains: Paper & Cardboard

4.1 Processes description

Regarding the paper and cardboard value chain, during REDOL the collection and sorting phases were improved (Figure 17). In this value chain, no innovations were introduced in the recycling and end user validation stages.

- The collection stage aimed to enhance the efficiency of collection operations by reducing travel distances, collection time, and the associated environmental impacts. This innovative approach was applied to the optimisation of collection routes for lightweight packaging waste in the city of Zaragoza.
- During the sorting stage, efforts focused on developing a transportable sorting system. The system uses hyperspectral imaging and robotics to classify and separate mixed paper and cardboard.

Figure 17. REDOL Packaging (Paper and Cardboard) redesigned value chain.

4.1.1. Collection

4.1.1.1. Baseline

The collection of paper/cardboard waste in Zaragoza is managed by the municipal contractor FCC. The city is divided into areas covered in morning, afternoon, or night shifts. Routes are organized directly by FCC and not strictly linked to municipal districts.

Collection starts and ends at FCC facilities (Carretera de Castellón), with unloading mainly at SAICA (for paper/cardboard). Vehicles of different capacities (10–28 m^3) are used, including narrow-width trucks for urban areas.

Although fill-level sensors are installed on some containers, they are only partially operational, and route adjustments are based on operational experience and periodic data updates.

4.1.1.2. REDOL innovation

As part of Task 5.4, an improvement in the collection stage of the paper and cardboard (blue bin) waste streams in the city of Zaragoza was implemented. This initiative focused on designing and evaluating routing optimization algorithms for municipal solid waste collection using data from tracking technologies such as GIS and partial fill-level sensors data. The main objective was to enhance the efficiency of collection operations by reducing travel distances, collection time, and associated environmental impacts within the REDOL value chain.

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In the future, the resulting dynamic collection routes will be visualized through the I-US platform, enabling improved monitoring and management of the optimized collection process.

4.1.2. Sorting

4.1.2.1. Baseline

In Zaragoza's paper and cardboard sector, the waste management company SAICA plays a central role in treating material from the city's selective collection system, along with additional industrial streams. At its facilities, mixed paper and board undergo mechanical separation followed by advanced, sensor-based NIR sorting. This multi-stage setup enables efficient identification and classification of the different fractions present in the feed.

4.1.2.2. REDOL innovation

The prototype designed within the REDOL project is a transportable sorting system designed for flexible, site-to-site deployment without disrupting existing operations. The aim is to enhance sorting performance not only at fixed plants but also in temporary or remote settings, increasing overall efficiency and adaptability. The prototype is engineered to fit within a standard shipping container, enabling rapid, effective deployment across diverse operating environments.

The system uses hyperspectral imaging and robotics to classify and separate mixed paper and cardboard. After materials arrive and are temporarily stored, they are fed onto a conveyor and evenly distributed to prevent blockages and occlusions. A Specim FX17 NIR hyperspectral camera then performs real-time inspection, using machine learning and computer vision to identify each item by its spectral properties. The classification data is sent to the robot controller, and at the picking station a Delta robot selects the items and places them into the appropriate containers.

4.2 Diagrams

This section presents and briefly describes the process diagrams corresponding to each stage of the packaging value chain (paper and cardboard flow) implemented within the REDOL project. These diagrams illustrate the workflow of each material, highlighting the technologies, streams, and interconnections among the partners involved in the circular configuration of packaging materials.

For this section, diagrams are provided only for the sorting phase because for the collection the information is the same described in section 3.

4.2.1. Sorting

Figure 18 shows the diagram of the REDOL concept, which represents an optimized process for recovering high-quality cardboard from mixed waste streams while improving the efficiency of pre-RDF (Refuse-Derived Fuel) preparation. The process begins with the input of mixed materials, which pass through an oversize screening stage where large, clean cardboard pieces are separated and sent directly for baling as best-quality cardboard. The remaining material undergoes fine screening to isolate smaller or more degraded fractions, which are classified as low-quality cardboard. The intermediate fraction is then processed through optical classification, where sensors distinguish cardboard by quality, directing medium-grade material to baling and sending the rest toward the pre-RDF flow. Before final RDF preparation, a robotic sorting unit identifies and retrieves any remaining high-quality cardboard from the pre-RDF stream, ensuring that recyclable material is not lost. As a result, the process produces four distinct output streams: best, medium, and low-quality cardboard, along with the pre-RDF fraction.

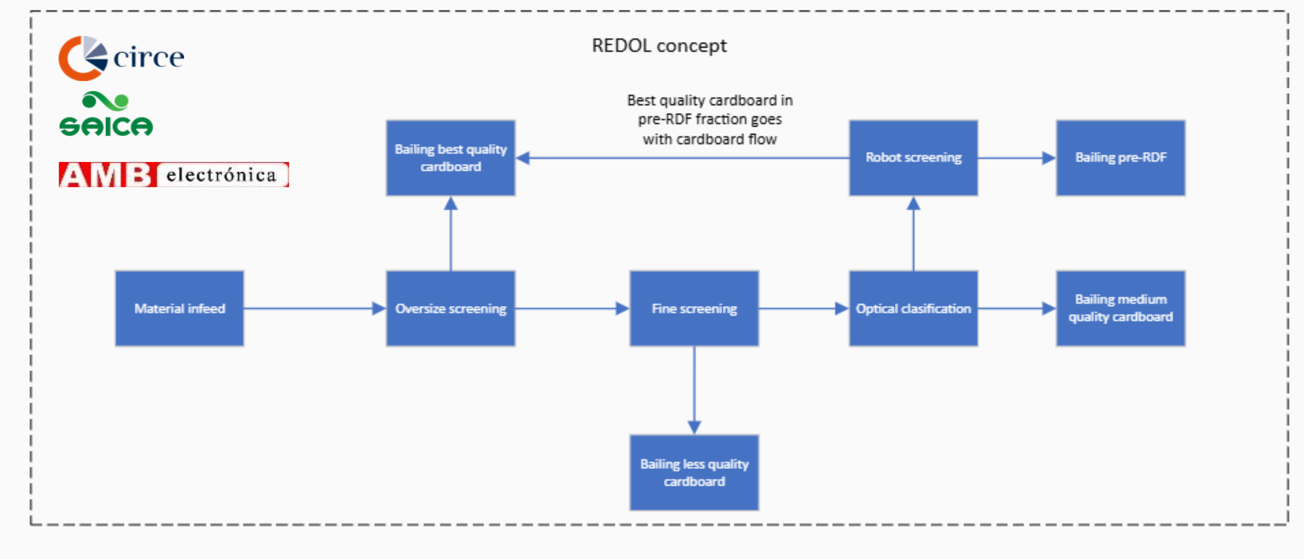

Figure 18. Paper Sorting diagram

Overall, the REDOL concept integrates mechanical, optical, and robotic sorting technologies to maximize cardboard recovery, enhance material purity, and minimize the amount of recyclable material diverted to energy recovery, thus contributing to a more efficient and circular waste management system. The diagram of such sorting system is presented in Figure 19.

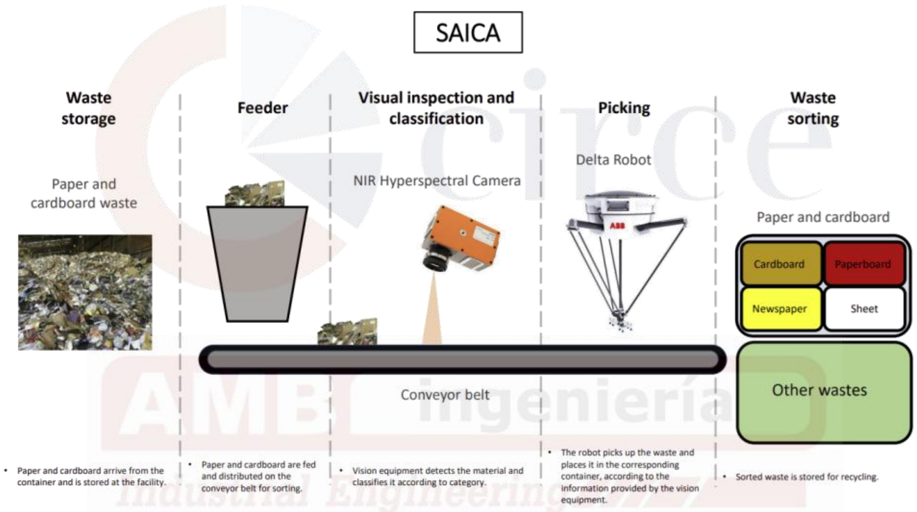

Figure 19. Diagram of the mobile sorting system

4.3 Layouts

This section showcases the equipment already installed and ready to begin the validation phase. This section includes either layout schematics or images of the equipment, along with key technical details.

4.3.1. Sorting

CIRCE and AMB have developed a mobile sorting line for paper & cardboard sorting which can be deployed at different location within the waste collection plants (Table 4). The system does not need to be connected to the current SAICA lines since waste streams can be feed with an auxiliary conveyor belt. CIRCE developed the machine learning and deep learning algorithms applied to spectral images for material identification, while AMB integrated the picking system controlled by these algorithms.

The paper and cardboard sorting system comprises several pieces of equipment, including conveyor belts, hyperspectral cameras, halogen lighting, a Delta robotic arm, component collection bins, linear rails, servo motors, a PLC, an HMI, and safety sensors. Its main function is to classify paper and cardboard by evenly feeding material onto a conveyor and scanning it with a Specim FX17 NIR hyperspectral camera that uses ML/computer vision for real-time identification. The classifications then guide a Delta robot at the picking station to pick items and place them into the appropriate containers, enabling efficient and flexible recycling.

Table 4. Equipment deployed in the packaging value chain (paper &cardboard sorting system)

Equipment	Process	Function	Deployment date and location	Comment
Paper and cardboard sorting system	SORTING	The system classifies paper and cardboard by evenly feeding material	• Transport: January 2025 • Commissioning and setup: February to June 2025 • CIRCE industrial laboratory	In order to improve operations and avoid unexpected costs and risks during testing, the trials are being conducted at CIRCE's facilities using real material from the city of Zaragoza's selective paper and cardboard collection, provided by SAICA.

In Figure 20 images can be seen showing the transport of the prototype from AMB facilities to CIRCE, its commissioning, and its final position within CIRCE's premises. In addition, Figure 21 shows an image of the final prototype ready for testing.

Figure 20. Images of the transport, commissioning and final location of the mobile sorting system.

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Figure 21. Paper and carboard mobile sorting system ready for testing.

4.4 Future work plan

The final project period will focus on completing the industrial validation of the packaging value chain, ensuring that the recycled fractions and developed technologies perform under real operational conditions. The value chain configuration was originally developed within WP3. In WP6, these results will be scaled up and validated at industrial level, confirming the technical feasibility and quality of the recovered materials.

4.4.1. Collection

In the future, the resulting dynamic collection routes will be visualized through the I-US platform, enabling improved monitoring and management of the optimized collection process.

4.4.2. Sorting

To achieve that, for the initial testing of the paper & cardboard sorting prototype, SAICA has provided two boxes measuring 1.2 × 1.2 × 1 m containing waste collected from the selective collection system of the city of Zaragoza. Using this waste, material identification and picking tests have been carried out (with SAICA, AMB and CIRCE involved), which have led to improvements in the performance of the prototype. During WP6, tests will be conducted to verify its operation and identify design modifications that enhance performance, robustness, and reliability.

After characterizing the samples and subjecting the system to stress tests—by varying input volumes and compositions—it will be possible to detect deviations, anticipate failures, and eliminate bottlenecks. In parallel, it is planned to verify that the design meets usability, ergonomics, and accessibility criteria for operation and maintenance, anticipating real industrial conditions.

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5 Task 6.2 Redesign of new circular plastic value chain

5.1 Process description

The plastic value chain addressed in REDOL is structured into three main stages (Figure 24). The first stage involves the initial sorting of waste in street bins, which plays a critical role in subsequent recycling steps for various value chains. In this stage, SUW is sorted using smart bins.

The second stage focuses on the recyclability of composite materials. This activity is not connected to the previous sorting stage, as the composite waste does not originate from the smart-bin sorting system. Instead, these materials are identified and collected within the CDW stream, and their heterogeneous composition and dependence on specific resin–reinforcement combinations present significant recycling challenges.

Finally, the circularity of the value chain is demonstrated through the incorporation of recovered materials—specifically glass fibre—into the manufacturing of new products, showcasing the potential to close the loop and reduce reliance on virgin resources.

In this value chain, three phases are presented: sorting, recycling, and end-user validation.

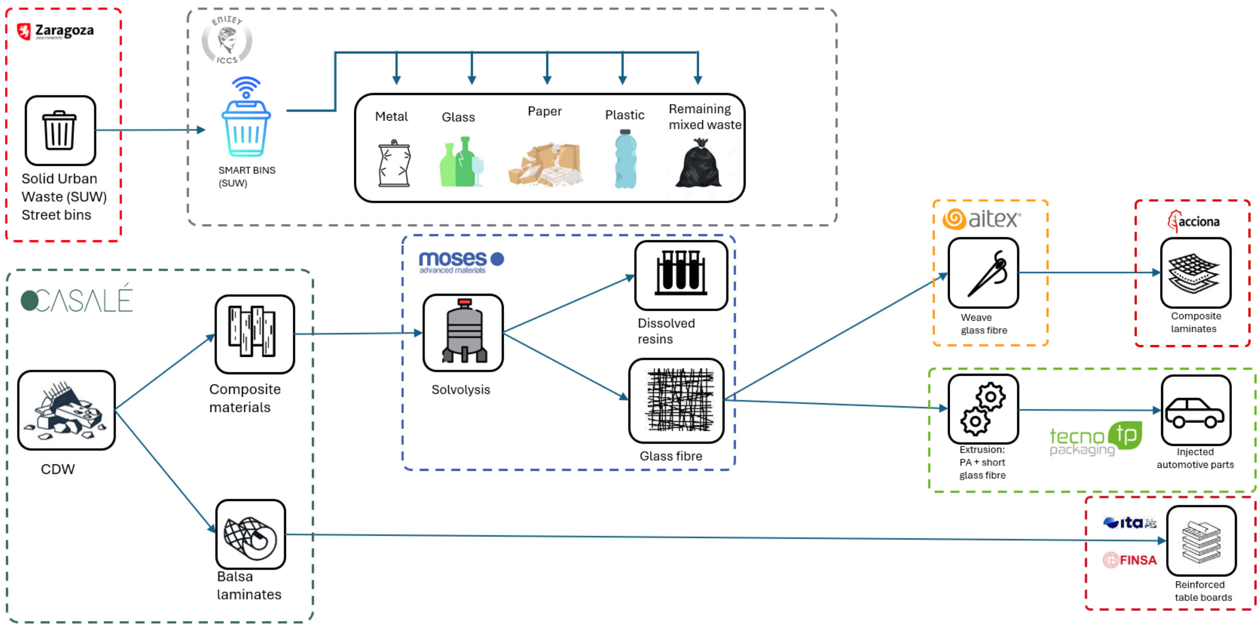

Figure 22. REDOL Plastics redesigned value chain.

5.1.1. Sorting

5.1.1.1. Baseline

Standard street bins offer limited functionality, resulting in mixed waste streams, low quality recyclables, and high contamination rates, which hinder downstream recycling processes. Conventional systems provide no control over what enters the bin, no feedback to the user, and no ability to sort or pre-treat materials at the source. In many cases, users who are unsure about how recycling or manual sorting actually works tend to skip

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the process entirely or dispose of materials incorrectly. This behaviour further increases contamination and reduces the effectiveness of downstream recovery operations.

The result is higher operational costs in Material Recovery Facilities (MRF), where extensive mechanical and manual sorting is required to separate plastics, paper, cardboard, metals, and various types of packaging materials. High contamination levels reduce the efficiency of optical and robotic sorting systems, increase residue rates, and force facilities to allocate additional labour, energy, and processing time. Consequently, recovered fractions exhibit lower purity and reduced market value, while large quantities of potentially reusable materials fail to be properly recirculated or repurposed. This baseline reflects the current state of urban waste collection, where the absence of intelligent, source-focused infrastructure, combined with user uncertainty, directly undermines material recovery performance and circular economy objectives.

5.1.1.2. REDOL innovation

REDOL introduces smart sorting bins equipped with sensor-based recognition and automated separation capabilities. These systems can identify and categorize waste into predefined fractions, such as plastics, glass, paper, metals, and residuals, directly at the point of disposal, which significantly enhances source separation quality.

The smart bin supports multiple sensing modalities and integrated actuation units that sort materials automatically to their respective categories, reducing user error and limiting the contamination commonly observed in conventional street bins. By offering guided disposal and automated verification, it targets to significantly reduce and eventually eliminate the uncertainty many users face regarding what belongs in each stream. In parallel, the system enables real time data collection on material quantities, container occupancy, and disposal patterns, while it also transmits information on potential contamination risks by monitoring air quality in the interior. This data layer supports dynamic routing, optimized collection schedules, and adaptive waste management strategies at municipal level. It also improves traceability and transparency across the recycling value chain, facilitating better planning for downstream processing and increasing the likelihood that materials are properly recirculated or repurposed.

Overall, the REDOL Smart Bin enhances the efficiency of urban waste management, reduces the burden on recovery facilities, and strengthens the transition toward a data driven, circular system.

5.1.2. Recycling

5.1.2.1. Baseline

Composite materials are increasingly used in the construction sector due to their high strength-to-weight ratio, durability and design flexibility. They are commonly found in structural panels, insulation systems, façade elements and reinforcement components, often combining thermoset resins with glass or carbon fibres. However, as relatively new and complex materials, composites pose significant challenges at end-of-life, particularly in terms of recycling and recovery. One of the key challenges associated with composite materials is the lack of separate collection systems, which significantly hinders their recovery and recycling. Moreover, the recycling process itself is complex and highly dependent on the type of resin used in the composite, as different matrices require distinct treatment methods. This variability complicates the development of standardised recycling protocols and limits the scalability of current solutions. Currently, the baseline scenario involved landfilling these materials, leading to resource loss and environmental impact. Unlike more established waste streams, there is no mature strategy for the valorisation of construction composites, and their heterogeneous nature makes mechanical recycling ineffective. As a consequence, composite materials are usually landfilled at the end of their life.

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5.1.2.2. REDOL innovation

The project focuses on CDW composites sourced from CASALE. The key innovation lies in the application of pressurized solvolysis with green solvents to recover fibres from composite materials. This advanced chemical recycling technique enables the selective depolymerisation of the resin matrix under controlled conditions, allowing the embedded fibres- such as glass fibre- to be separated and recovered with minimal degradation. By employing environmentally friendly solvents, the process aligns with the commitment to sustainability and demonstrates a viable pathway for improving the recyclability of composites while reducing the environmental impact of chemical treatments.

5.1.3. End user validation

As part of the validation phase in REDOL, three distinct products are being developed using the recovered glass fibre, demonstrating its versatility and potential for reintegration into high-value applications.

- **Automotive parts (TECNOPACKAGING**). Short glass fibres are compounded with thermoplastic polymers to create a reinforced material suitable for injection moulding. This compound will be designed to meet the mechanical and thermal requirements of automotive components, offering a sustainable alternative to fibre-reinforced plastics.

- **Composite laminates (ACCIONA)** will be manufactured through resin infusion using woven glass fibres. This process enables the production of structural panels with tailored properties, suitable for use in construction or industrial applications.

- **Reinforced table boards (ITA and FINSA).** This validation is performed by ITA as technology centre to do the initial tests and FINSA as industrial partner, to do the scaled-up tests. The initial plan was to incorporate glass fibre directly into the board matrix, with the aim of improving their mechanical properties. Since initial tests resulted in bad results, new synergies are being exploited with other value chains to incorporate further waste in the table boards.

5.2 Diagrams

This section presents and briefly describes the process diagrams corresponding to each stage of the plastic value chain implemented within the REDOL project (both baseline and REDOL innovation). These diagrams illustrate the workflow of each material, highlighting the technologies, streams, and interconnections among the partners involved in the circular configuration of plastics materials. For this section, diagrams are provided for the sorting and recycling phases.

5.2.1. Sorting

As illustrated in the schematic and further elaborated in the previous paragraphs, the baseline and Smart Bin constitute two contrasting workflows for urban waste handling (Figure 23).

In the conventional system, mixed recyclable wastes are deposited into a standard street bin with no control or pre-sorting at the source. The collection vehicle retrieves the bin contents as a single mixed stream, which typically undergoes minimal separation and often ends up in landfill due to high contamination and low material purity. This linear flow demonstrates the limitations of conventional bins, where valuable materials are lost and the recycling potential is significantly reduced.

In the second part of the diagram the smart bin workflow is presented. In this section, recyclable wastes are deposited into the bin, automatically identified through sensor-based recognition, and sorted into predefined

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fractions. Each material stream is separated at the point of disposal, preserving quality and minimizing cross contamination. The collected streams are then directed to dedicated recycling routes, enabling more efficient downstream processing and increasing the likelihood that materials are properly recovered, recirculated, or repurposed. This workflow reflects a shift from a linear disposal model toward a source-separated, circular approach supported by intelligent infrastructure.

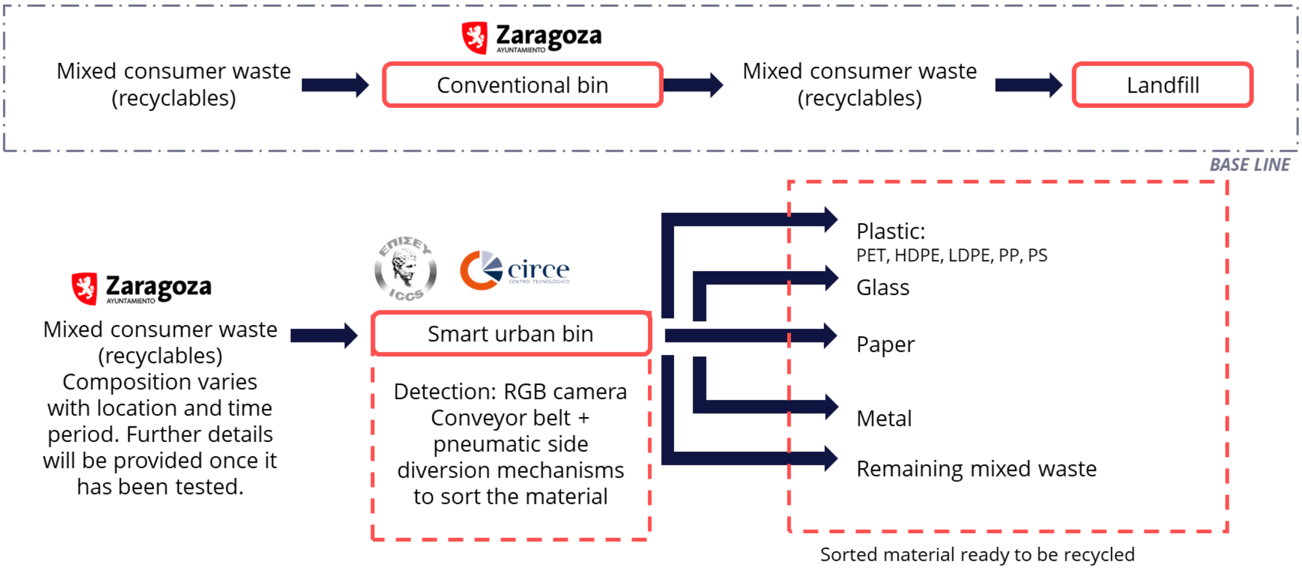

Figure 23. Plastics value chain – sorting diagram (baseline and REDOL scenario)

5.2.2. Recycling

Figure 24 illustrates two different approaches for managing construction waste composites made of polyester resin and glass fibre:

- Baseline Scenario (Top Section): Currently, composites from CASALE are sent directly to landfill, representing a linear disposal model with no material recovery.
- Proposed Circular Process (Bottom Section): Instead of landfilling, the composites undergo green solvolysis (a process using high temperature, high pressure, and environmentally friendly solvents) by MOSES. This treatment separates the material into:
    - **Glass fibres**, which are repurposed into:
        - Wood-based panels (by ITA and FINSA)
        - Automotive parts (by TECNOPACKAGING)
        - Laminated composites (by ACCIONA)
    - **Dissolved resins**, which could be recovered for further applications.

Overall, the diagram contrasts the traditional waste disposal route with a sustainable, circular economy approach that enables material recovery and reuse across multiple industries.

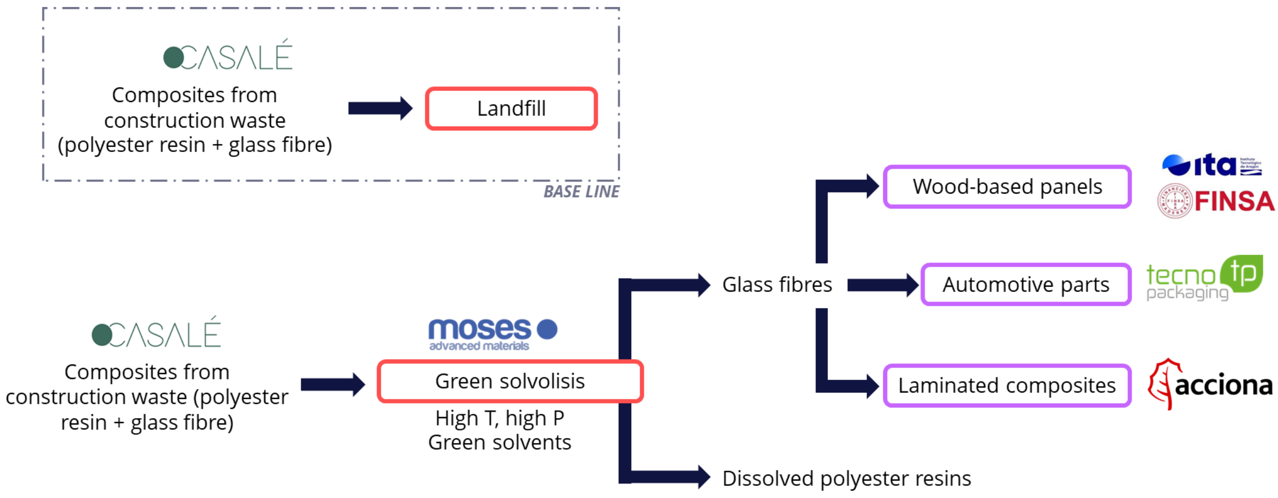

Figure 24. Plastic value chain, recycling diagram (baseline and REDOL scenario)

5.3 Layouts

This section showcases the equipment already installed and ready to begin the validation phase. This section includes either layout schematics or images of the equipment, along with key technical details. This section describes the sorting and recycling phases.

5.3.1. Sorting

The prototype Smart Bin has been developed and demonstrated at ICCS facilities by M32 (July 2025). More details about the development of the Bin, the layout, the operation and the validation tests can be found in the submitted Deliverable 3.2: "REDOL Prototypes for automated sorting and classification".

The following figures (Figure 25, Figure 26,**¡Error! No se encuentra el origen de la referencia.** and Figure 27) show detailed layouts of the equipment, as well as its operating mode, illustrated through pictures of the developed prototype.

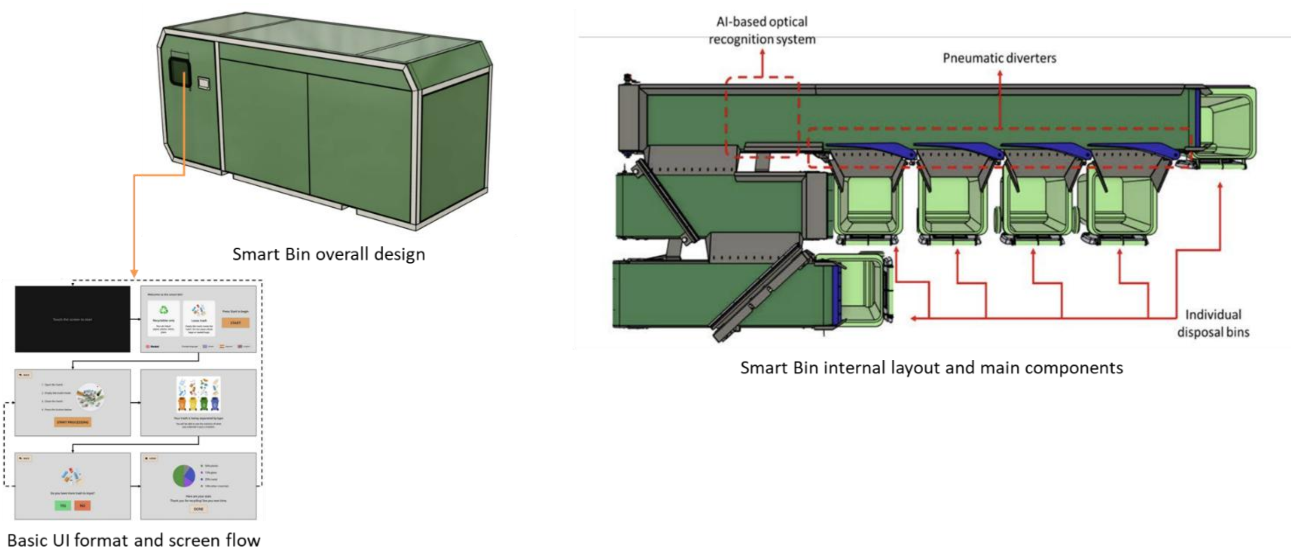

Figure 25. Smart bin, overview of the external and internal design

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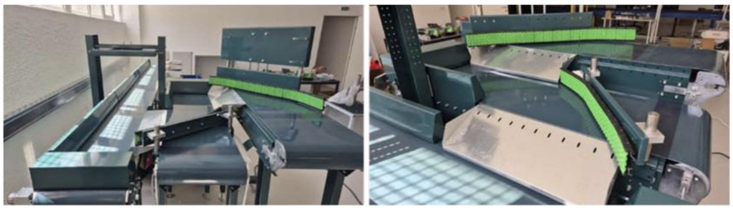
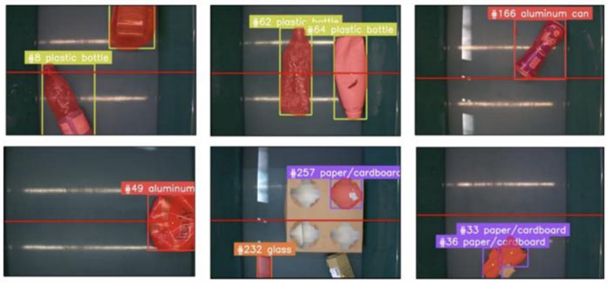
Smart Bin interior waste circulation configuration

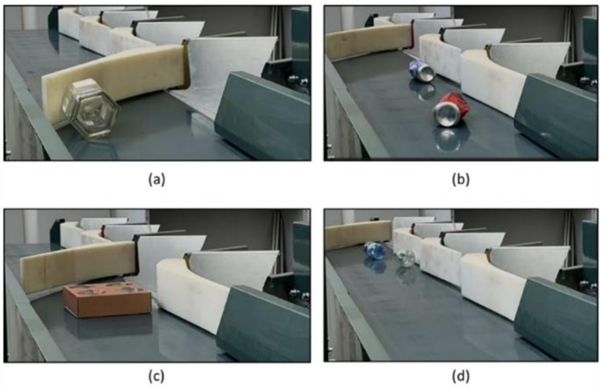


Multistage accelerator for waste decluttering and stream linearization

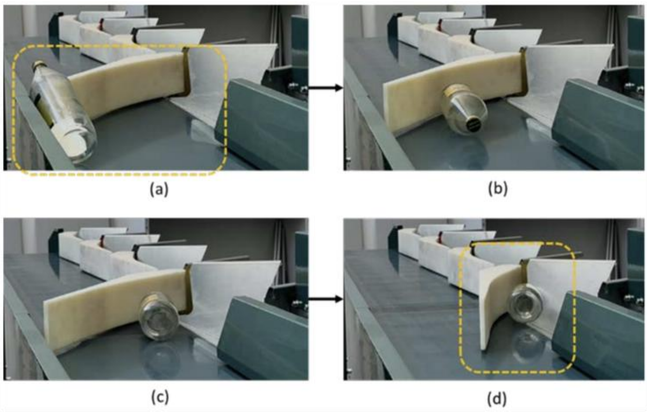


Optical classification of the waste

Figure 26. Smart bin, internal layout



Indicative sorting operation of various items. (a) glass bottle, (b) metal cans, (c) cardboard coffee holder, (d) plastic bottles.



Indicative sorting of a large glass bottle.
(a) to (b): the diverter successfully routes the bottle towards the opening.
(c) to (d): the bottle results between the flap and the disposal chute, ending to the proper disposal bin.

Figure 27. Smart bin, sorting operation

Table 5 summarises the main information on the equipment to be installed for the sorting phase of this value chain.

Table 5. Equipment to be deployed in the plastic value chain (sorting)

Equipment	Process	Function	Deployment date and location	Comment
Smart bins	SORTING	Automates waste segregation and enables data-driven collection.	• Awaiting delivery (expected M40) • Zaragoza city	Until its deployment, ICCS is validating the bin's performance through optimisation and validation tests.

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5.3.2. Recycling

The Pressure Reactor is currently being prepared for initial testing and reaction trials by the team at MOSES (starting by the end of Q4 - 2025). The reactor has been designed to support controlled chemical reactions under elevated pressure and temperature conditions, suitable for small- to medium-scale processes (Figure 28 and Figure 29).

It is important to note that actual placement is temporary, while the appropriate site for permanent deployment is being prepared at MOSES. The final installation at MOSES is expected to take place during the first half of 2026.

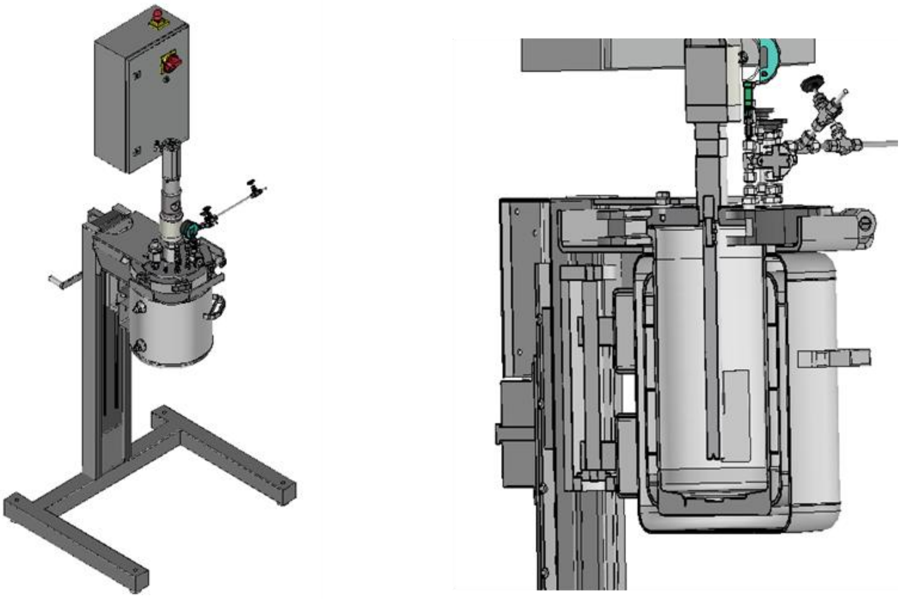

Figure 28. Pressure Reactor Layout

Figure 29. Pressure Reactor Deployment

Table 6 Table 6presents the list of equipment already deployed within the plastics value chain.

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Table 6. Equipment deployed / to be deployed in the plastics value chain.

Equipment	Process	Function	Deployment date and location	Comment
Pressure Reactor	RECYCLING	Solvolysis of composites waste materials	• Delivered and installed (M36) • MOSES's facilities	Temporary placement to begin with the activities & the initial tests.

5.4 Future work plan

The final project period will focus on completing the industrial validation of the plastic value chain, ensuring that the recycled materials and developed technologies perform under real operational conditions. The value chain configuration was originally developed within WP3 and WP4, where the processes were demonstrated at laboratory and pilot scale. In WP6, these results will be scaled up and validated at industrial level, confirming the technical feasibility and quality of the recovered materials. In parallel, optimisation activities will target improvements in consolidating the transition from laboratory testing to full-scale implementation.

5.4.1. Sorting

The Smart Bin will be deployed to Zaragoza City. Due to bureaucratic reasons, delays have been raised on the procurement process of the exterior part of the bin. Therefore, the Smart Bin is expected to be transferred and implemented at Zaragoza City Council building during Q1 of 2026 (around M40 of the project).

During this period (M32 to M40), ICCS is validating the operation of the Bin, continuously performing validation and optimisation tests and activities.

Following their definitive deployment, the Smart Bin prototypes will operate continuously in Zaragoza City until the end of the project. During this operational phase, a structured data collection campaign will be carried out, focusing on metrics related to:

- Sorting accuracy
- Waste recognition model long-term performance
- Device throughput
- Stability of operation
- User interaction patterns
- Maintenance requirements

These data-driven insights will enable the evaluation of the added value of the Smart Bin within the overall waste handling pipeline and assess its contribution to improved material recovery. The collected evidence will also support the identification of potential design refinements, guiding the development of subsequent system iterations and providing input for future scaling and deployment scenarios.

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5.4.2. Recycling

The first series of reactions is scheduled to begin by the end of the year, marking the start of the validation phase. During this period (M35 to M42), the team will focus on:

- **Operational validation** of the reactor under various pressure and temperature conditions.
- **Optimization activities**, including reaction yield assessments and process reproducibility.
- **Safety and reliability testing**, ensuring compliance with internal and external standards.

Pending successful validation, the reactor will be integrated into broader experimental workflows for collaborative research activities in 2026.

Future activities will also include:

- **Grinding and processing of polyester composite roofs recovered from CASALE's landfill** to enable material reuse and recycling.
- **Processing of composite profiles from ACCIONA**, supporting circular economy initiatives and material recovery for subsequent experimental applications.

5.4.3. End user validation

During the following months, the work will focus on the validations:

- **Automotive parts**: TECNOPACKAGING will develop up to 8 different formulations with different recycled fibre percentages and additives by extrusion compounding. The thermal properties such as melt flow index will be assessed to ensure further processability during injection moulding process. Mechanical properties will be also evaluated following ISO-527, ISO-179 & ISO-178. The 2 best performing formulations will be then scaled up and validated for automotive parts manufactured at pre-industrial scale.

- **Composite laminates**: the clean fibres obtained after the solvolysis process from Moses will be introduced in the composite chain again using new fabrics made with recycled glass fibre. AITEX will produce recycled mats and ACCIONA will include these mats in the configuration of composite laminates. Infusion thermoset resin laminate will be produced to test the wettability of the fibres and the mechanical strength compared with conventional laminates.

- **Reinforced table boards** (ITA and FINSA): The next steps involve completing the characterization of the new synergies that have emerged within the project, such as the use of PVC from electronic waste, balsa wood from wind turbine blades, or plasterboard and polyethylene from construction waste. Initial tests have shown promising results with the incorporation of balsa wood and polyethylene into particleboard. The project will now focus on assessing the feasibility of conducting an industrial-scale trial to validate these findings and evaluate their practical application in production processes.

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6. Task 6.3. Redesign of new circular CDW value chains

6.1 Processes description

The CDW value chain addressed in REDOL is structured into four steps: collection, sorting, recycling and validation by end-users. The collection focuses stage involves logistic improvement in the container movements The second stage focuses on the sorting of the different plastics in the lighter fraction. In the recycling phase, different plastic fractions and mineral materials from CDW are separated and processed to recover value, through mechanical, chemical, or energy valorisation, and used as secondary raw materials in the production of cement, clinker, and cast polymer composites. In the end-user validation phase, industrial partners such as CEMEX, CASALE, and ACCIONA test and demonstrate the practical application of these recycled materials in real products, including clinker and cement production, concrete formulations, and cast polymer coating.

Figure 30 provides a general overview of the redesigned value chain.

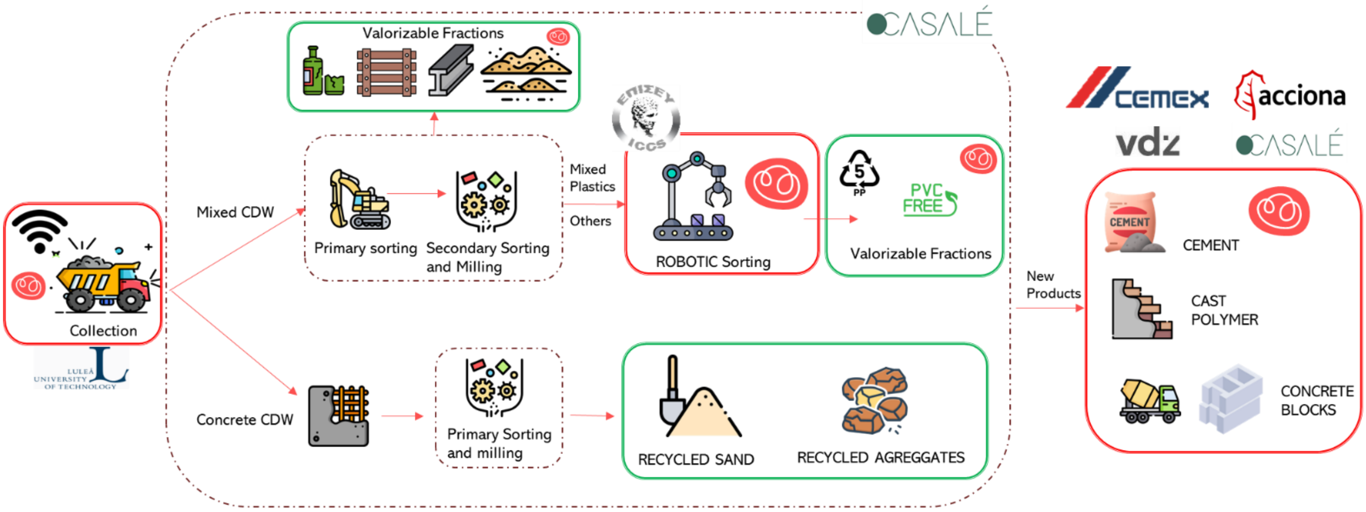

Figure 30. Redesigned value chain - CDW

6.1.1. Collection

6.1.1.1. Baseline

Construction companies call CASALE in order to ask for a container for a specific construction site and waste. After a data collection phase and creating a waste treatment contract, the container can be served on the construction site. Once the container is full, the manager of the construction site calls CASALE's office to ask for a change of the container or a retrieval. During the day, the truck driver receives multiple orders from the office about container movements. It is the driver who managed and calculated the best route.

6.1.1.2. REDOL Innovation

Logistic improvement in the container movements will be analysed with the development of algorithms and new sensors. Technologies developed in REDOL by LTU for the trash truck routes can be implemented in the CDW collection to optimize this step.

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Towards digitalization of the construction and demolition waste industrial partner CASALE, under Task 5.4, LTU contributes towards development of the optimization algorithm, which is continuation and relevant with Task 6.3. This optimization algorithm considers all the required parameters for logistic operations including static and dynamic data, such as the positions of waste bins, road network and the related traffic. In addition, waste collection schedules, trucks and containers capacities and their characteristics are taken into consideration.

6.1.2. Sorting

6.1.2.1. Baseline

Waste from construction and demolition sites are transported to waste management facilities, where it is weighted and processed. The nature of this waste is a mixture of heavy (concrete, bricks, and other stone materials) and light fractions (plastics, gypsum, wood) that in most of cases arrives in the same container without sorting on site. For Aragon, although variations are expected from delivery to delivery, more than 75% of the waste (by weight) is composed of concrete, brick and other inert materials. Some fractions go directly to mechanical treatment for recycling and transformation into aggregates. Finally, the manager has well-established processes to use this heavy fraction and recycle it near to 100%.

Lighter fractions represent around 25% of the CDW and it presents higher variability in material composition: metal, wood, glass, plastics. This mix needs to be classified and pre-treated prior to their recycling treatment or their release to other managers. Although operator-guided machinery, e.g. excavators, wheel loaders, and automated separation equipment, e.g. trommels, jaw crushers, are widely utilized for processing CDW, manual sorting via moving conveyor belts remains common. Even so, the operators only classify the stone and non-stone fractions, differentiating between plastic, wood, cardboard and metal. Metal waste objects can be easily separated from the stream with mechanical or magnetic separators; wood waste, though typically a small component, can also be separated, but it is often contaminated; plastics and cardboard, on the other hand, are difficult to extract with existing processes due to their low weight, small size and other physical properties. The plastic fraction is a mixture of thermoplastics of different nature, that only could be recovered through energy valorisation if it does not contain PVC.

6.1.2.2. REDOL Innovation

The sorting of the different plastics in the last fraction referred to baseline scenario could improve the valorisation of this stream. The REDOL Innovation in CDW value chain consists of the use of robotic- and AI-based sorting to achieve an efficient, consistent and high purity separation.

The sorting system developed takes the advantage of recent advancements of artificial intelligence and sensor technologies, as well as the efficiency of industrial robotics in order to separate the highly mixed plastics stream. The system is designed to be installed and integrated to existing CDW management facilities and enable the valorisation of precious materials that would otherwise be landfilled. Based on the interests and feedback of the waste manager the system focused on sorting plastic material.

With REDOL sorting system, the light waste fraction is sorted in all these streams:

- Mixed fraction without plastics: Wood [52%], Mineral (inorganic fraction: Stone, Concrete) [34%], Metals [3.5%], Other [10.5%]
- PP
- PVC

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- Plastic materials without PVC and PP.

With this sorting process, high-purity polymeric streams are achieved. This progress goes to the upcycled of this polymeric mixture avoiding its landfill.

6.1.3. Recycling

6.1.3.1. Baseline

The management of the different fractions sorted from the CDW depends on the nature of the material. The CDW manager, CASALE, after the sorting process, recovers from the heavy concrete fractions the sand and aggregates and recycles them as new commercial products for construction sector. Regarding the other sorted fractions, the CDW manager contacts with other wastes managers from the plastic, metal, glass or paper and wood sectors that pick up those materials and include them in their recycling processes. Furthermore, CASALE produces and commercialize its own concrete blocks with the recycled aggregates, adding value to their recycled fractions.

With all these recycling streams, CASALE recycles from the heavy and the light fractions the amount showed in Table 7.

Table 7. Fractions recycled by CASALE

Heavy fraction (75% of wastes)	Light Fraction (25% of wastes)
• 96% aggregates. • 2-3% go to another waste manager (recycling rate 70%) • 1% go to landfill	• 75% go to another waste manager (recycling rate 70%) • 25% go to landfill.

6.1.3.2. REDOL Innovation

<u>Recycling by waste managers</u>

The use of the sorting system developed in REDOL aims the separation of the different plastics from the CDW and mainly the remove of PVC from that stream. This extra process increases the material value of the new plastics streams and the recycling possibilities and avoids moving to landfilling part of the plastics. The new clean streams have the potential to be recycled by:

- Mixed fraction without plastics: energetic valorisation after grinding (organic: heating; inorganic: clinker)
- PVC: landfill or chemical recycling
- PP: chemical or mechanical recycling
- Plastics without PVC and PP: energy valorisation.

<u>Recycling by development of new construction materials</u>

CEMEX, as a big company in cement manufacturing, with its only cement plant in Aragon, is concerned with carrying out processes that are as sustainable as possible. The use of alternative raw materials for the production of cement clinker is one of them. Currently, the substitution with recycled raw materials at the Morata de Jalón plant (Zaragoza, Spain) is 14.3% and to this is added an energy recovery of 60.55%. Up to date, this material

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valorisation is made with slag, ash from different industrial processes, sand, etc., but the potential use of mineral fraction from CDW has been satisfactory tested by VDZ. (D4.1) An increase up to 20% of material substitution is the objective of the cement factory, especially of decarbonated raw materials.

In the production of cement, additives and other inorganic materials are added to the fine milled clinker to develop the different cement classes. The use of wastes as slags and fly ash is common but the use of some of the fractions of CDW is other way of recycling and increase the sustainability of cement. Satisfactory tests confirm this possibility producing cements with similar properties to general formula and with improved ones.

The last process for recycling CDW is the use as inorganic fraction in the development of cast polymer. Cast polymer is a polymeric concrete but with all the binder substituted by a thermoset polymer and it is used in specific applications where cement is unable to use due to corrosive environment (contact with chemical products, saline environment, etc.) Generally, it is used for coatings and repair surfaces. The totally replacement of the conventional aggregates with CDW aggregates and fillers has been satisfactory tested by ACCIONA and has developed a novel formula with all the required properties.

6.1.4. End user validation

The last step in the value chain demonstration is the validation of the pathway by different end users.

- **New Clinker production**: CEMEX will use a fraction of CDW as alternative raw material in the industrial clinker kiln of the cement production plant in Morata de Jalón. After pollutant analysis of the selected fraction, CEMEX will calculate the amount of material allowed to introduce in their industrial process and CASALE will provide it to them.
- **New cement and concrete development**: The development of new cement formulas will be validated with the production of 500 kg of cement and the use of it in the development of a concrete formula. Previously validated through laboratory testing at Cemex. This concrete will have the specification for the production of CASALE's blocks (Megalito; Figure 31) and CEMEX and VDZ will develop the final formula.

Figure 31. Megalito (CASALE)

- **New Cast Polymer**: The last activity in validation of the recycling processes is the production of around 400 L of the formulated cast polymer for the use in covering a concrete slab where chemical products will be stored. The cast polymer will prove the concrete of possible leaks.

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6.2 Diagrams

This section presents and briefly describes the process diagrams corresponding to each stage of the CDW value chain implemented within the REDOL project (both baseline and REDOL innovation). These diagrams illustrate the workflow of each material, highlighting the technologies, streams, and interconnections among the partners involved in the circular configuration of the materials. For this section, diagrams are provided for the collection, sorting and recycling phases.

6.2.1. Collection

Figure 32 presents the diagram corresponding to the collection phase, in which, in the REDOL scenario, the optimization of truck routes and the tracking of waste containers will be implemented.

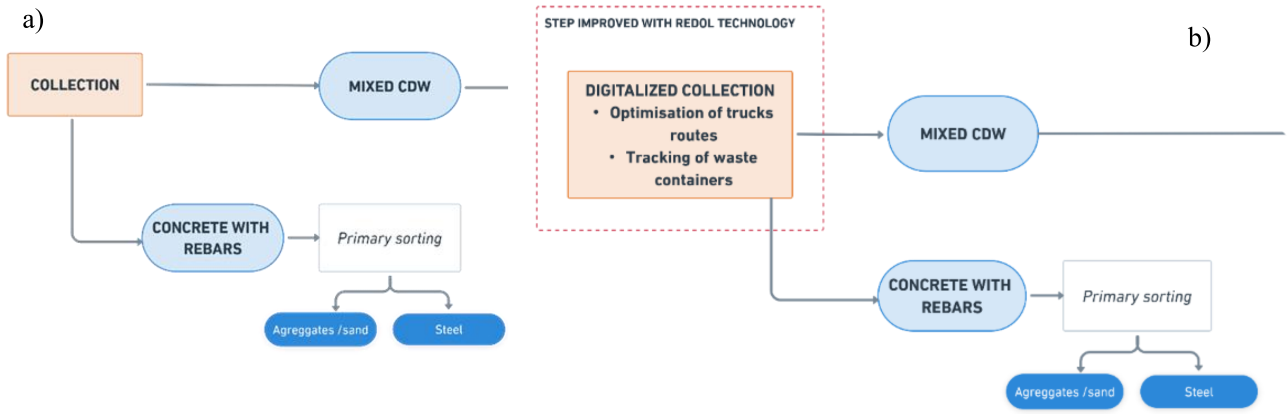

Figure 32. Diagram of the collection stage of the CDW value chain. a) Baseline scenario b) REDOL scenario

6.2.2. Sorting

The sorting stage is redesigned in this value chain. Figure 33 shows the diagram of the baseline scenario corresponding to the secondary sorting, while Figure 34 focuses on the REDOL solution in the sorting stage.

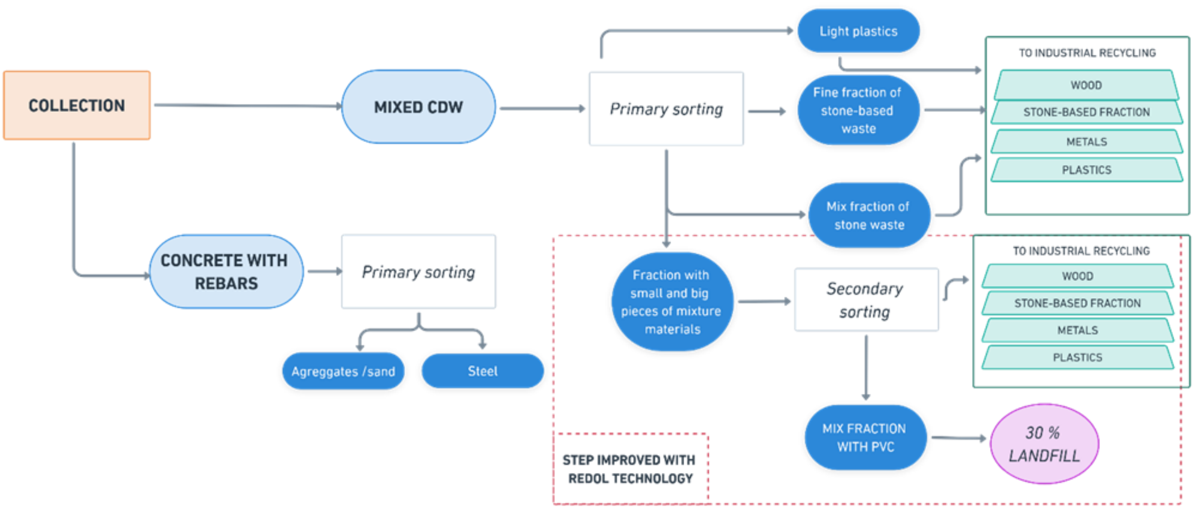

Figure 33. Diagram of the sorting stage of the CDW value chain. Baseline scenario b) REDOL scenario

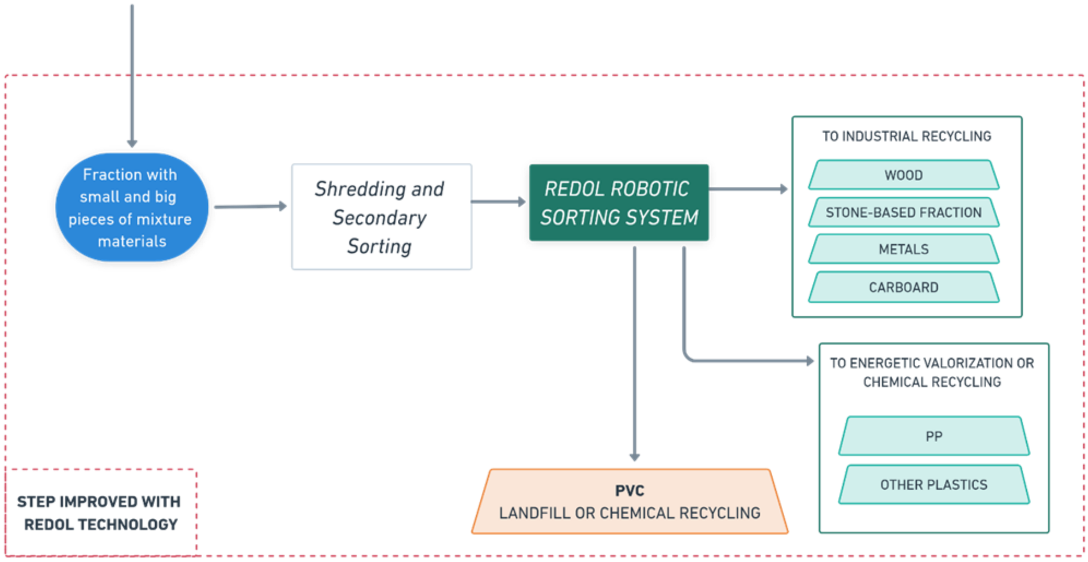

Figure 34. Diagram of the sorting stage of the CDW value chain. REDOL scenario

6.2.3. Recycling

Regarding the recycling stage, Figure 35 presents a diagram showing all the fractions that undergo a recycling step in the baseline scenario, while Figure 36 describes the treatment of the different fractions in the recycling stage of the REDOL scenario.

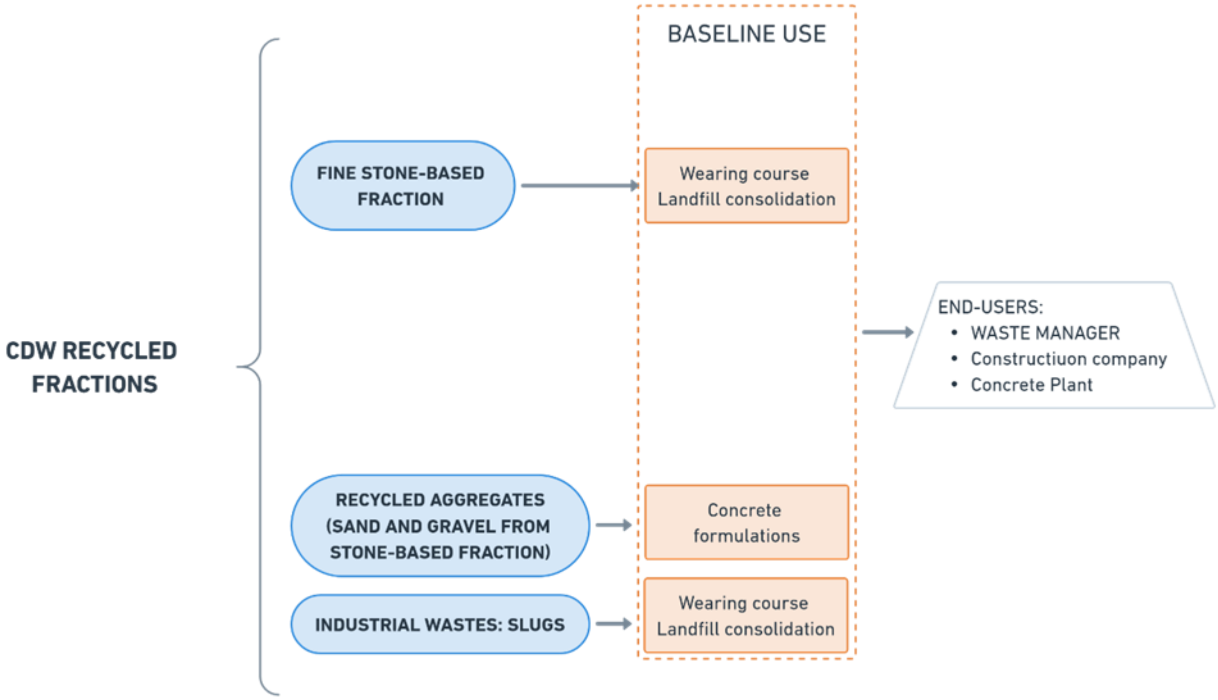

Figure 35. Recycling stage in the CDW value chain – Baseline scenario.

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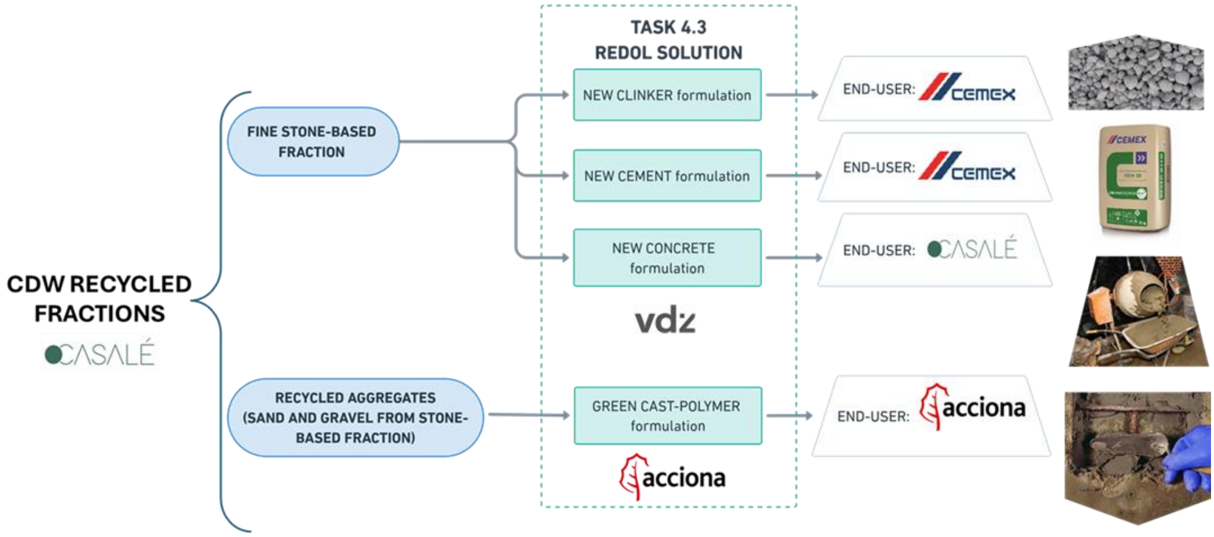

Figure 36. Recycling stage in the CDW value chain – REDOL scenario.

6.3 Layouts

This section showcases the equipment needed to start the validation phase. This section includes either layout schematics or images of the equipment, along with key technical details. This section describes the collection and sorting phases, as no new equipment is needed for the recycling process.

6.3.1 Collection

In the conceptual scenario illustrated in Figure 37, the pick-up and drop-off problem is framed around a set of trucks circulating between construction or demolition sites and the central depot or processing station. Each truck is uniquely identified by its truck ID and its location is known to the central system via GPS. At any given moment, a truck can be in one of two operational states: either travelling with a container on board or moving empty. When it is carrying a load, the system also records the quantity of container units so that the planning process always knows the truck's current capacity and availability for additional tasks.

The sites themselves represent dynamic points of demand within the system. Each site has several attributes that influence how and when it can be serviced. These include the amount of debris currently stored in containers, the time the containers have been waiting on-site, and whether the debris is already prepared and ready for pick-up. If a container is still being filled, the system stores an estimated time when it will become available. All of these elements define the service window within which the truck must arrive. Sites may also require the delivery of empty containers to ensure continuous operation, adding another layer of complexity to the planning task.

The central dispatching unit orchestrates the full process by integrating data from trucks and sites. Knowing the number of trucks available, their GPS-tracked positions, their load status, and the demands from each site, the system must decide which truck should perform which task. This assignment is not arbitrary. It considers the immediate need for empty containers at certain sites, the urgency of picking up full containers waiting to be processed, the expected waiting times, and the overall cost associated with transport, typically expressed as travel distance, travel time, or a combination of both. The goal is to generate a plan in which each container movement is covered by an appropriate truck in a timely and cost-efficient manner. In this way, the pick-up and drop-off problem becomes a coordinated optimization challenge, ensuring that debris is collected promptly, sites remain operational, and trucks operate along efficient and well-structured routes.

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6.3.1.1 Problem definition

The conceptual illustration in Figure 37 presents a representative scenario involving two trucks, T1 and T2, operating across nine active sites, A, B, C, D, E, F, G, H, I, that are distributed throughout the city. Each site generates a specific number of container units that must be transported, and these movements are associated with approximate service times. For instance, site A may require the transport of nA units around a preferred time window tA. The planning process uses this information to produce optimized routes for each truck, ensuring that all site demands are met within their operational constraints.

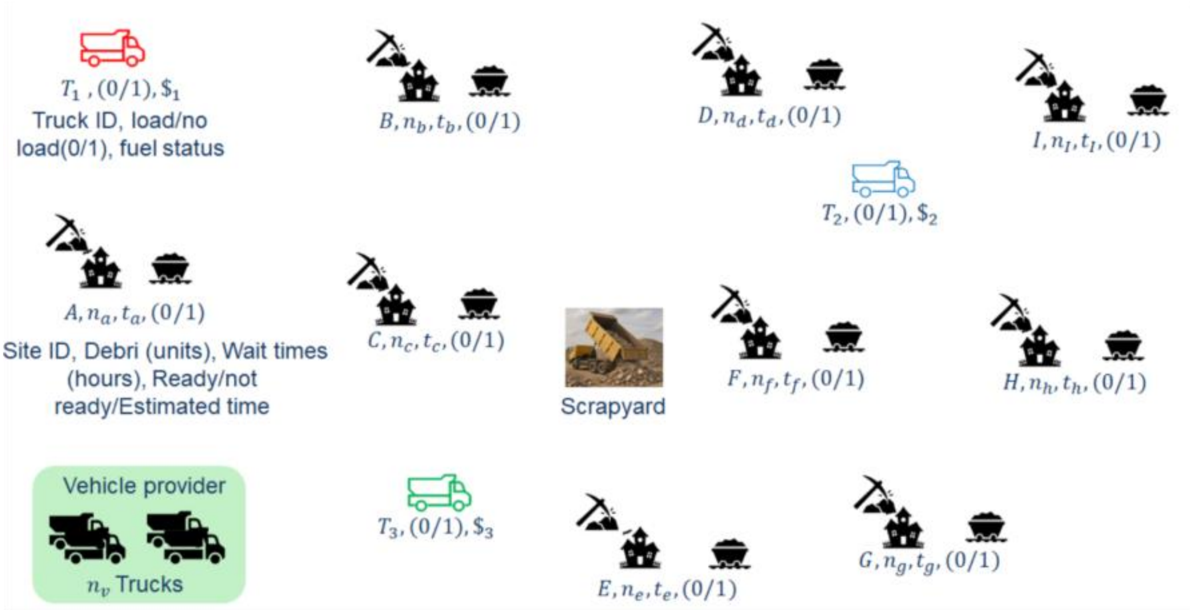

Figure 37.Conceptual figure for optimization algorithm

For example, truck T1 begins its route at the central depot, where it is loaded with empty containers destined for delivery. Its first stop is site A, where it drops off the required containers. After completing the delivery, T1 proceeds to site B, where a container filled with debris is waiting for collection. The truck loads the full container and transports it to the designated scrap or processing station. Once at the station, the truck unloads the debris and is again supplied with empty containers. It then continues its route to sites D and F, delivering the empty units according to the planned sequence and timing. In parallel, truck T2 follows its own optimized route, collectively ensuring that all sites receive the appropriate pick-up and drop-off services.

To support this planning and execution process, a well-structured database framework is required. This structure defines how information about trucks, sites, containers, and tasks is stored, updated, and shared across the system. The database enables seamless interaction between the optimization system, the central dispatching unit, and the real-time operational data coming from the field. It ensures that all stakeholders and system components operate on consistent, updated information, allowing the routing algorithm to generate feasible and efficient plans and enabling the continuous monitoring and adjustment of operations as conditions evolve.

6.3.1.2 Framework

A framework for the debris transportation is shown in Figure 38. The database contains information about vehicles, trucks' position, and the load with truck. It also stores the information about the sites; site location, the containers at sites, request for empty containers, and the request for removing the debris-filled containers. The ground situational awareness unit keeps track of the vehicle location, load in vehicles, and completion of tasks. The input to ground situational awareness information comes from the truck drivers.

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Action task manager is the requests coming from the sites, these requests define the tasks to be done. they are shared with the database and the planning unit.

The planning unit consists of two stages. One is Google Maps API, which obtains the travelling path from one location to another. It checks the route, the distance to be travelled, and the time required for travel. Then this information is shared with the optimized vehicle routing unit. This optimizer computes the best route that the vehicle should follow so that maximum tasks can be completed at a lower cost.

The computed routes will then be shared with the truck drivers. Trucks will follow the routes, which will update the information on ground situation. Customers can scan the QR codes on the containers to send in requests. Such requests are then updated in the database digitally.

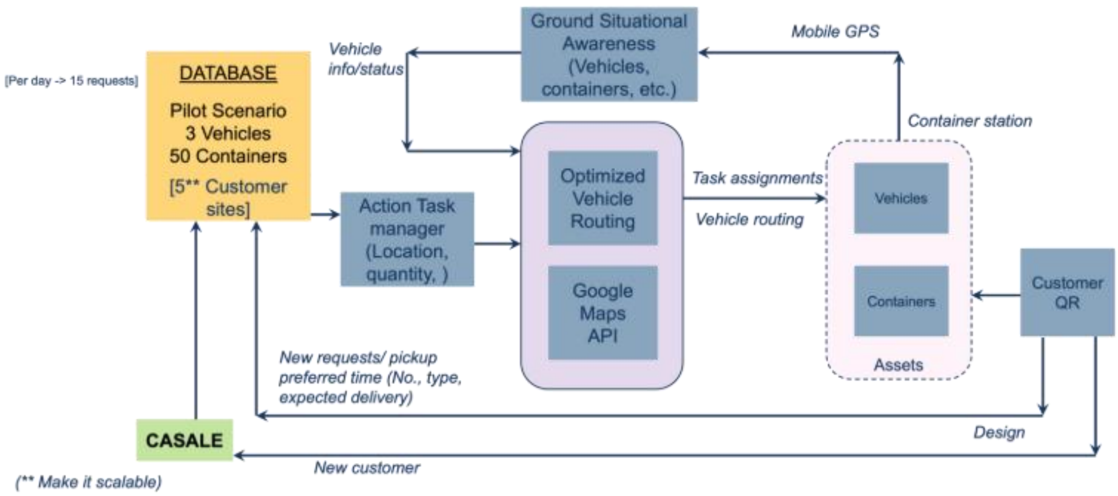

Figure 38. Framework for the debris transportation

6.3.1.3 Optimization

Optimization problem plan routes for a group of vehicles that must pick up items from certain locations and deliver them to other locations. To describe the system parameters are defined such us a set of nodes: V = {1, 2, …, n}.

The nodes are **locations** on a map:

- Some locations are **pickup points** (where items must be collected).
- Some locations are **delivery points** (where items must be dropped off).
- One location is the **depot**, where all vehicles start and end their routes.

a) Depot (Node 1): The depot is the base station for all vehicles. Every vehicle must start from the depot, go out to perform pickups and deliveries, and return to the depot.

b) Pickup Nodes: P = {2, 3, …, m + 1} These are the locations where vehicles pick up the container (empty or filled). Every pickup node has a positive demand (because items are being added to the vehicle). Examples: depot is pickup for empty containers. The scrap collection site is pickup location for filled container.

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c) Delivery Nodes: D = {m + 2, …, 2m + 1} These are the locations where vehicles deliver items. Each delivery node has a negative demand (because items are being removed from the vehicle). Example: dropping off scarp at the depot. Dropping off the empty container at job site.

d) Set of Vehicles: K = {1, 2, …, k}. This is the fleet of vehicles available for the job. Each vehicle has its own route, load limit, and must visit both pickup and delivery nodes assigned to it.

e) Cost: c_{ij}: This is the cost of traveling from location *i* to location *j*. This cost is the distance between the location *i* to location *j*.

f) Vehicle Capacity (Q): Each vehicle can only carry a certain amount of load. The vehicle cannot exceed this capacity during pickups.

g) Demand at Each Node (q_i). This tells us how the vehicle load changes at each location.

- $q_i > 0$ Pickup node (vehicle takes items)
- $q_i < 0$ Delivery node (vehicle drops off items)

6.3.1.4 Decision variables

These variables represent the **choices** the model must make to build the optimal set of routes.

a) Route Selection Variable: $x_{ijk} \in \{0,1\} \rightarrow$ 1 if vehicle *k* travels from *i* to j, 0 otherwise.

   Does vehicle k travel directly from location i to location j

b) Load Variable: $u_{ik} \in \mathbb{Z}^+ \rightarrow$ Load of vehicle *k* after leaving node *i*.

   It denotes the capacity of the vehicle after leaving location i.

c) Position Variable: $\mu_{ik} \in \mathbb{Z}^+ \rightarrow$ Load of vehicle *k* after leaving node *i*

   It denotes the order in which a vehicle visits each location.

Objective function

The goal is to make all the pickups and deliveries while minimizing the total travel cost. Mathematically we express this as:

$$\min \sum_{k=1}^{K} \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} \cdot x_{ijk} \tag{1}$$

Flow conservation constraints

For each vehicle *k* and each node *h*:

$$\sum_{i=1}^{n} x_{ihk} = \sum_{j=1}^{n} x_{hjk} \quad \forall h \in V, \forall k \in K \tag{2}$$

The flow conservation rule implies that for every vehicle and for every location, the number of times the vehicle arrives at that location must equal the number of times it leaves.

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Depot constraints

Each vehicle must start and end at the depot:

$$\sum_{j=1}^{n} x_{1jk} = 1 \quad \forall k \in K \tag{3a}$$

$$\sum_{i=1}^{n} x_{i1k} = 1 \quad \forall k \in K \tag{3b}$$

These constraints force every vehicle to start from the depot and return to the depot exactly once. Concretely, each vehicle must have one arc leaving the depot at the start and one arc entering the depot at the end.

Task completion constraints

Each pickup and delivery node must be visited exactly once:

$$\sum_{k=1}^{K}\sum_{i=1}^{n} x_{ipk} = 1 \quad \forall p \in P \tag{4a}$$

$$\sum_{k=1}^{K}\sum_{i=1}^{n} x_{idk} = 1 \quad \forall d \in D \tag{4b}$$

These constraints ensure every pickup location and every delivery location is visited exactly once by the whole fleet. In plain terms: no pickup or delivery should be missed, and none should be visited twice.

Remark: for a multiple pickup from a site, every pickup has different id so, vehicle may visit same location but that will happen only for the different tasks.

Capacity constraints

Node capacity limits,

$$u_{ik} \leq Q \cdot \sum_{j=1}^{n} x_{jik} \quad \forall i \in V, \forall k \in K \tag{5}$$

if vehicle does visit a location, the load at that point must be at most the vehicle's capacity.

Load propagation constraints

$$u_{jk} \geq u_{ik} + q_j - M_c \cdot \left(1 - x_{ijk}\right) \quad \forall i, j \in V, i \neq j, \forall k \in K \tag{6}$$

where, $M_c = Q + max(|q_i|)$

When a vehicle goes from node *i* to node *j*, the load after *j* must be at least the load after *i* plus the change at node *j* (pickups increase load, deliveries decrease it).

Subtour elimination constraints (MTZ formulation)

$$\mu_{jk} \geq \mu_{ik} + 1 - M_s \cdot \left(1 - x_{ijk}\right) \quad \forall i, j \in V \setminus \{1\}, i \neq j, \forall k \in K \tag{7}$$

where, $M_s = n - 1$

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Subtour elimination prevents the solver from producing disconnected cycles that excludes depot.

Self-loop prevention

$$x_{iik} = 0 \quad \forall i \in V, \forall k \in K \tag{8}$$

Route reconstruction

For each vehicle k, construct route $\pi = (v_1, v_2, \ldots, v_m)$ such that:

$$x_{v_i v_{i+1} k} = 1 \text{ and } v_1 = v_m = 1$$

Load calculation

For each node in the route:

$$u_{v_{i+1}k} = u_{v_i k} + q_{v_{i+1}}$$

Recommendations for implementation

1. Add same-vehicle constraints for pickup-delivery pairs
2. Revise precedence constraints to enforce pickup before delivery
3. Adjust Big-M parameters for stability

Optional improvements

1. Sparse constraint generation: Only create constraints for feasible edges $\left(c_{ij} < \infty\right)$
2. Warm starts: Use constructive heuristics for initial solution
3. Symmetry breaking: Add constraints to eliminate equivalent vehicle assignments

Complete mathematical formulation

The complete corrected formulation becomes:

$$\min \sum_{k=1}^{K} \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} \cdot x_{ijk} \tag{O_1}$$

Subject to:

$$\sum_{i=1}^{n} x_{ihk} = \sum_{j=1}^{n} x_{hjk} \qquad \forall h \in V, \forall k \in K$$

$$\sum_{j=1}^{n} x_{1jk} = 1 \qquad \forall k \in K$$

$$\sum_{i=1}^{n} x_{i1k} = 1 \qquad \forall k \in K$$

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$$\sum_{k=1}^{K}\sum_{i=1}^{n} x_{ipk} = 1 \qquad \forall p \in P$$

$$\sum_{k=1}^{K}\sum_{i=1}^{n} x_{idk} = 1 \qquad \forall d \in D$$

$$u_{ik} \leq Q \cdot \sum_{j=1}^{n} x_{jik} \qquad \forall i \in V, \forall k \in K$$

$$u_{jk} \geq u_{ik} + q_j - M_c \cdot (1 - x_{ijk}) \qquad \forall i,j \in V, i \neq j, \forall k \in K$$

$$\mu_{jk} \geq \mu_{ik} + 1 - M_s \cdot (1 - x_{ijk}) \qquad \forall i,j \in V \setminus \{1\}, i \neq j, \forall k \in K$$

$$\sum_{i=1}^{n} x_{ip_tk} = \sum_{i=1}^{n} x_{id_tk} \qquad \forall k \in K, \forall t \ \text{(New)}$$

$$\mu_{p_tk} \leq \mu_{d_tk} - 1 + M_s \cdot \left(1 - \sum_{i=1}^{n} x_{ip_tk}\right) \qquad \forall k \in K, \forall t \ \text{(Corrected)}$$

$$x_{iik} = 0 \qquad \forall i \in V, \forall k \in K$$

This formulation ensures feasible, optimal solutions that respect all operational constraints including the critical pickup-delivery coupling requirements.

6.3.1.5 Case study

This case study considers a scenario as shown in the Figure 39 and Figure 40, involving three vehicles, represented by circles containing red, green, and blue markers. A total of eight tasks are included in the problem here. The tasks requiring the transport of empty containers from the depot to a site are represented by circular icons, and the tasks requesting the transport of debris-filled containers from the site back to the depot are shown by squares.

The optimization algorithm generates an efficient assignment and routing solution for all vehicles and tasks in this scenario:

$$Red - T_5, T_7, T_1 \qquad Green - T_2, T_3, T_4 \qquad Blue - T_6, T_8$$

In the beginning, red vehicle with empty container goes to T_5, the green vehicle goes to T_2 for picking the debris filled container, and blue vehicle with empty vehicle travels to T_6 as shown in fig (a).

Green vehicle reaches to T_2 and pick up the filled container and now moves towards central depot as shown in fig (b). Red and blue vehicles then reach to T_5 and T_6, respectively, to deliver empty containers as shown in fig (c). Red vehicle then moves to T_7 for picking the filled container. The blue vehicle moves to T_8 for picking the filled container. Green vehicle drops the filled container at the depot and completes the task T_2.

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Red vehicle drops the filled container at the central depot and completes the task T_5. After this, red vehicles start T_7 of transporting the empty container from depo to the location of T_7, as in fig (c).

Once blue vehicle reaches to the location of T_8, it loads the debris filled container as shown in fig (d) and moves back to the central depot.

Similarly red vehicle picks the debris filled container from T_7 and transports it to the central depot.

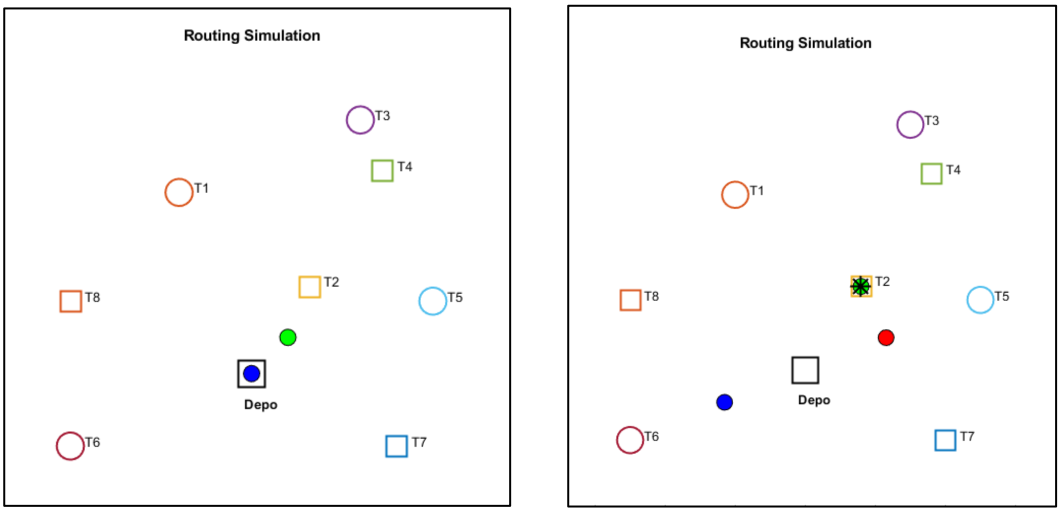

Figure 39. Routing simulation: (a) Initial scenario, with three vehicles and eight tasks. The tasks denoted with squares demand vehicle to transport filled container from site to depot. The tasks denoted in circles demand an empty container at the site, (b) Green vehicle reaches to T_2 and pickup the filled container and now moves towards central depot.

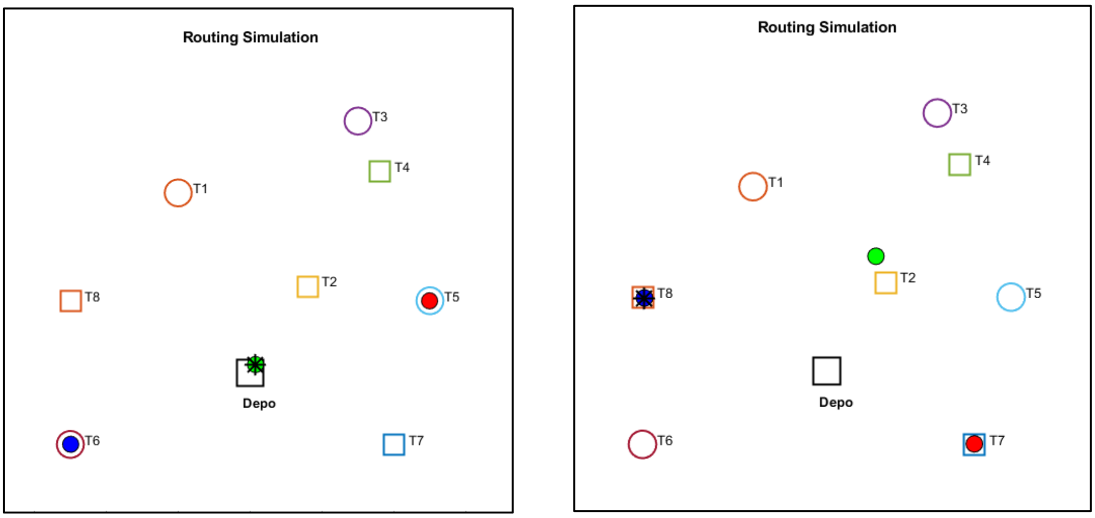

Figure 40. Routing simulation: (c) Green vehicle drops the filled container to the depot. The red vehicle delivers the empty container at T_5. The blue vehicle delivers the empty container at T_6. (d) Blue vehicle picks the debris filled container at T_8. Red container will pick the debris filed container at T_7. Green vehicle is going to drop empty container at T_3.

6.4.1. Sorting

The CDW sorting system has been designed and developed based on end user's (CASALE) needs and requirements and is able to efficiently separate different plastic materials (PVC, PP, other plastics) from

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Construction & Demolition waste. The system, which was tested and demonstrated at ICCS facilities by M32 (July 2025), is also presented at the submitted Deliverable D3.2: “REDOL Prototypes for automated sorting and classification”.

The CDW sorter will be placed into a container in order to be shipped to CASALE premises. Unforeseen bureaucratic reasons have caused delays on the procurement of the container, which is expected to be ready during Q1 of 2026 (around M40 of the project). After that, the CDW will be deployed to CASALE, where operation tests will take place.

During this period, ICCS has been collaborating with CASALE on the details of the installation. At the same time, ICCS is performing validation and optimization activities on sorter’s operation.

CASALE has arranged two possible locations in his company for the sorting system. One of them is the preferred location, which is close to the current separation process when trucks with CDW arrive (Figure 41).

Figure 41. The tentative locations of the sorting equipment in CASALE

In the case of location 1, a layout of the waste streams is drawn in Figure 42.

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Figure 42. Lay out of the waste streams in CASALE

The equipment would be installed in the sorting area after the air separator, where a stream of 3D plastic is finally separated. This stream will be the feedstock of the new REDOL sorting technology, and it will separate the plastics between PVC and PP (Figure 43). The equipment necessary for this extra sorting step is built inside a container with regular dimensions that allows easy transport and change of location (Figure 44Figure 44).

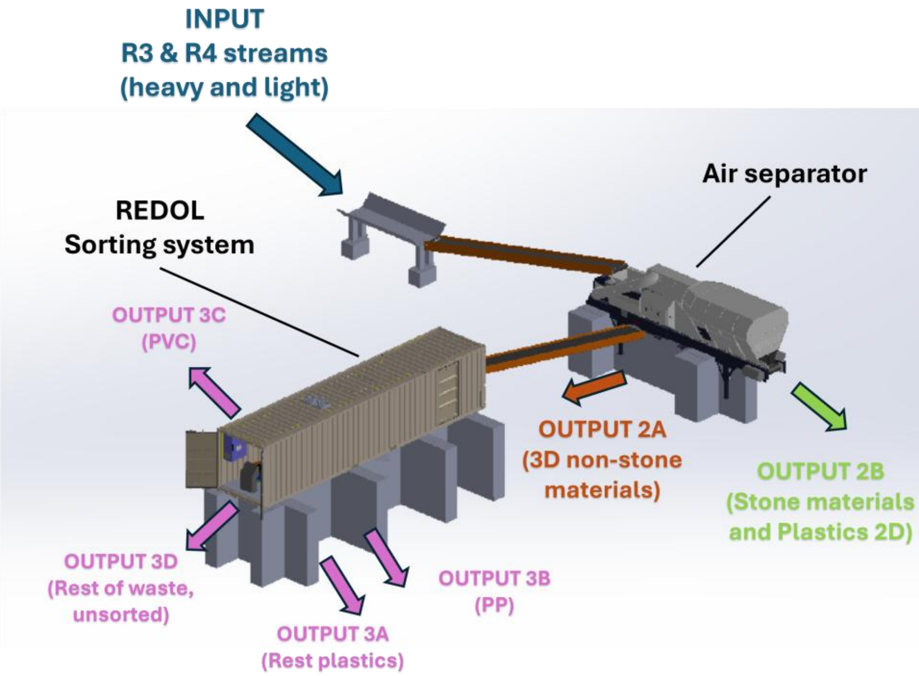

Figure 43. Sorting steps in CASALE and final extra REDOL sorting.

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Figure 44. Sorting container

The surface area that CASALE will have to condition must be 20x20 m^2 and the floor must be reinforced to support a weight of between 11 and 13 tons. In this location there must be access to a three-phase electrical connection of 70 kW, 400 AV. The system does not require any other auxiliary services to start up the equipment.

Figure 45 and Figure 46 show the main components of the sorter with the pneumatic gripper installed in the system and a view of the whole system in the laboratory of ICCS.

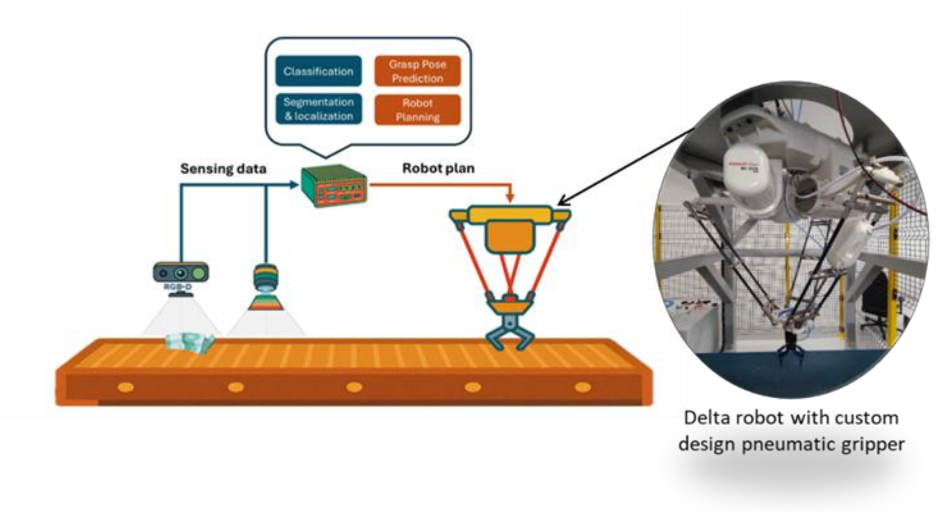

Figure 45. Main components of CDW sorter and detailed of the robotic arm

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Figure 46. Sorting system installed in ICCS laboratory

Table 8 provides a summary of the equipment required for the sorting stage.

Table 8. Equipment to be deployed in the CDW value chain

Equipment	Process	Function	Deployment date and location	Comment
CDW sorting system	SORTING	Sorting of different plastics from the light fraction of CDW streams	• Awaiting delivery (expected M40) • CASALE	Unforeseen bureaucratic reasons have caused delay on the procurement of the container

6.4 Future work plan

The final project period will focus on completing the industrial validation of the CDW value chain, ensuring that the recycled materials and developed technologies perform under real operational conditions. The value chain configuration was originally developed within WP3 and WP4, where the processes were demonstrated at laboratory and pilot scale. In WP6, these results will be scaled up and validated at industrial level, confirming the technical feasibility and quality of the recovered materials. In parallel, optimisation activities will target improvements in consolidating the transition from laboratory testing to full-scale implementation.

6.4.1 Collection

The optimization algorithm developed by LTU for CASALE focuses on enhancing the efficiency of pick-up and drop-off operations for both loaded and empty containers of CDW. The core objective is to streamline the logistics chain by dynamically planning routes and schedules based on real-time operational data. Key parameters include the geographical location of each construction site, scheduled and actual pick-up and drop-off times, waiting times at collection points, the number of available trucks and containers, and their respective capacities. Real-time location tracking will be achieved through GPS-based sensing units ensuring continuous monitoring of fleet movements.

The collected data will feed into the optimization algorithm, to determine the most efficient routing and scheduling strategies. The system will aim to minimize total transportation costs, primarily by reducing travel

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distances, idle times, and fuel consumption. Moreover, the adaptive nature of the algorithm allows it to respond to dynamic conditions such as traffic variations, unexpected delays, or changes in container availability, thereby ensuring robust and cost-effective waste collection operations. LTU is in the process of sensor procurement and then will proceed with the demo case.

6.4.2 Sorting

At this stage, the Smart Bin is being validated at ICCS facilities in Athens. ICCS is disposing unstructured batches of mixed wastes, varying composition, volume, and sequence of items, and running repeated cycles to stress the recognition and sorting subsystems under realistic conditions rather than controlled "clean" test cases.

Once the exterior is received and installed, one smart bin will be shipped immediately to Zaragoza to be tested directly on site.

6.4.3 Recycling

Following the recycling tests conducted within WP4 (by VDZ), work will now proceed with the transfer of these formulations to the end-user validation stage for the newly developed products.

6.4.4 End user validation

- **The production of 500 kg of cement with CDW**

  CEMEX will produce in their low-scale mill the cement using the fine stone based fraction from CDW. The selected formulation includes this waste as partial substitution of the limestone in the original formulation. The cement will include other components to obtain a formula that fits with the regulations.

- **The production of concrete blocks (Megalito) with the new cement by CASALE**
  The concrete formula will be developed by CEMEX and VTZ according to the properties of CASALE. There will be close collaboration for this development to increase the sustainability of the concrete block. CASALE will use their conventional process for the production of Megalito. The dimension of these blocks comes from 30x60x60 (250 kg) to 160x80x80 (2400 kg). Some of the smaller blocks will be produced and sample tests to analyse the mechanical properties.

- **The use of CDW in clinker kiln**
  A test with a small substitution of raw materials will be carried out. The clinker kiln consumes 60.000 t/day of raw materials, but the standards limit the level of substitution because of its chemical composition. The waste to use in this application is the fine stone-based fraction.

- **The production of 400 L of cast polymer** for the use in proofing of a concrete slab and protect it of chemical products leaks. This cast polymer will be produced with the fine stone-based fraction in Acciona facilities and will be applied in a chemical pilot plant concrete slab from Acciona in Spain. The formula used for the cast polymer production will be those analysed in WP4 and other recycled materials from CDW will be included (recycled aggregates).

All the actions are directed to use the same fine stone-based fraction because although other fractions have been evaluated and even better results have been obtained, this fine fraction currently does not have any recycling options.

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7 Task 6.4. Redesign of new circular textile value chains

7.1 Processes description

In the textile value chain, various entities participate with complementary roles (Figure 47). ALIA is responsible for the collection and sorting at industrial level of textile waste, while NTT supports the development on a pilot scale of the textile waste sorting system. In addition, NTT has developed and optimized a thermo-chemical pre-treatment on a pilot scale to selectively remove the elastane from bi-component fabrics, such as PET/EL textiles. Subsequently, AITEX and CIRCE carry out the chemical recycling process of polyester, and finally, BRILEN transforms the regenerated material into high-tenacity yarns. Therefore, the chemical recycling value chain of textiles follows a structured sequence that begins with the collection and sorting of textile waste and ends with the production of high-performance polyester fibres, which are used in technical applications such as geotextiles.

In this value chain, three phases are presented: sorting, recycling, and end-user validation.

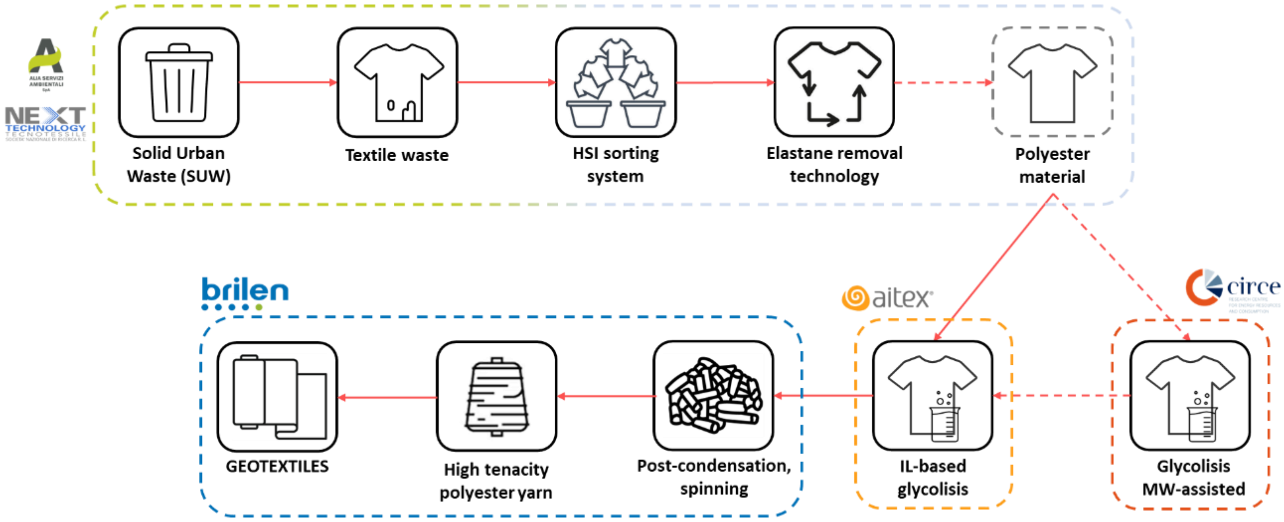

Figure 47. Textile value chain (REDOL solution).

7.1.1 Sorting

7.1.1.1 Baseline

Reusing and recycling textile waste are more sustainable options than incineration or landfilling, as they align with circular economy principles and reduce the need for virgin fibre production. Textile reuse can occur through activities such as trading, swapping, renting, or inheriting items, while recycling involves reprocessing pre- or post-consumer waste into new textile or non-textile products.

Effective recycling processes depend on accurate sorting of textiles by characteristics like composition, colour, and fabric structure. Traditionally, sorting has been done manually, but this method is slow, costly, and difficult to scale, especially since labels are often missing or inaccurate. Existing analytical methods (*e.g.*, ISO 1833-1, FT-IR analysis, microscopy analysis, etc.) provide precise identification, but they are too time-consuming for large-scale automation.

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7.1.1.2 REDOL innovation

Within the REDOL project, NTT developed an advanced textile waste sorting system to enhance reuse and recycling, providing sustainable alternatives to landfilling and incineration. Using Near-Infrared (NIR), Hyperspectral Imaging (HSI), and RGB cameras, the system identifies textiles by colour, composition, and fabric structure to ensure high-quality input for recycling. Sorting systems based on these technologies enable fast, automated material recognition without sample preparation, offering practical solutions for high-volume sorting. The results will contribute to achieving TRL6 validation and support ALIA’s upcoming textile hub in Prato (Italy), scheduled to begin operations in 2026, with a capacity to sort over 30,000 tons of textile waste annually. This model could be replicated across other European cities.

In the REDOL project, bi-component PET/EL items are identified and sorted from other types of textile waste and recycling strategies are evaluated in collaboration with different partners (NTT, CIRCE, AITEX, BRILEN).

7.1.2 Recycling

7.1.2.1 Baseline

The next step – after an appropriate sorting phase – in textile recycling is selecting an appropriate recycling method – mechanical or chemical – with a preference for fibre-to-fibre processes. However, such technologies remain limited and are highly sensitive to contamination, making them suitable mainly for mono-material waste streams. One of the major obstacles to recycling is the presence of elastane (EL), a polyurethane-based elastic fibre commonly blended in small amounts (2–10%) in woven textiles and up to 50% in items like medical stockings. Often hidden as the core of spun yarns, elastane enhances stretch and comfort but complicates fibre separation. Its inclusion reduces both its own recyclability and that of the surrounding fibres (e.g., polyester or polyamide). Therefore, developing efficient methods to separate elastane from blended fabrics would significantly expand the range of textiles that can be effectively recycled.

Regarding textile recycling, under the baseline scenario, the current approach is mainly based on mechanical recycling routes. In this process, post-industrial and post-consumer textiles are collected, sorted according to fibre composition and colour, and mechanically processed through cutting and shredding stages to obtain recycled fibres. These fibres are then cleaned, homogenized, and reintroduced into the textile value chain, either blended with virgin fibres to produce new yarns or used directly in nonwoven applications such as insulation materials, felts or filling products. Although mechanical recycling is an established and widely implemented technology, it presents significant limitations regarding the quality of the recycled material, since the repeated mechanical stress causes fibre shortening and loss of mechanical strength. Consequently, the recycled fibres are generally used in lower-value applications, leading to a progressive downcycling of the material rather than true circularity within the textile sector.

7.1.2.2 REDOL innovation

After sorting, the PET/EL textile waste is directed to the chemical recycling stage. However, as stated before, the presence of EL – also in low quantities – could complicate and prevent efficient recycling of the polyester fibre. Thus, in the REDOL project, NTT optimized a thermo-chemical pre-treatment for selectively remove elastane from blended fabrics using a closed-cycle solvent system. This process effectively separates elastane from both natural and synthetic bi-component textiles (i.e., polyamide, polyester, or wool as the main component), producing clean material streams suitable for fibre-to-fibre recycling.

More in detail, the recovered polyester from PES/EL blends is then depolymerized by AITEX and CIRCE into monomers for new polyester fibres, closing the material loop. In the REDOL project, two complementary

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chemical recycling processes are employed: on one hand, ionic liquid catalysed glycolysis, which enables the selective depolymerization of polyester into its basic building blocks and on the other hand, microwave-assisted glycolysis, which accelerates the reaction, reducing both processing time and energy consumption. Both processes lead to the recovery of monomers such as BHET, which serve as the basis for regenerating new polyester.

Once purified, the monomers undergo a repolymerization process to produce polyester with properties equivalent to those of virgin material. The regenerated polyester is then processed through melt spinning. The molten polymer is extruded through fine spinnerets to form filaments, which are subsequently drawn and thermally stabilized. This drawing step orients the molecular chains, enhancing the strength and durability of the yarn. In this way, high-tenacity polyester fibres are produced by BRILEN, suitable for more demanding technical applications than conventional textiles. Finally, these fibres are converted into geotextiles. Through this integrated process, the textile life cycle is effectively closed, transforming municipal waste into new high value-added products, with a positive impact in terms of both sustainability and circular economy.

7.1.3 End user validation

BRILEN subcontracted its sister company, Novapet, both part of the SAMCA Group, to carry out the post-condensation of the pellets supplied by AITEX using a pilot-scale polymerization unit. This process increased both the molecular weight and viscosity of the polymer, enabling the production of high-tenacity yarn that BRILEN subsequently spun. As a result, the polymer's mechanical properties and processability were significantly improved.

After post-condensation, the material was processed at the BRILEN pilot spinning plant. There, the polymer underwent drying, extrusion, and final spinning, producing yarn bobbins according to the specifications of the final product for geotextile manufacturing. From the approximately 400 kg of material delivered, 180 kg of high-tenacity yarn were produced, of GLE 2200 type, with quality optimized for the spinner to manufacture the geotextile.

The spinning process was satisfactory: no issues occurred during processing, package pressure remained stable, and once stable machine conditions were established, spinning proceeded successfully.

The properties of the yarn obtained are shown in Table 9.

Table 9. Yarn properties obtained

Property	GLE 2200/384
Titer	2249
Elongation (%)	12.9
Force (cN)	169.8
Tenacity (cN/tex)	75.5
EASF	4.8
Shrinkage (GLE)	7.9

The resulting 180 kg of yarn exhibited good tensile properties, particularly in terms of tenacity. With these 18 bobbins of GLE 2200, BRILEN will assemble the strands on the plant cabling machine to obtain a GLE 4400 yarn. The plan is to use this yarn, produced from the chemically recycled pellets supplied by AITEX, only in the weft direction, while the warp yarns will be BRILEN's standard type. This allows the weaver to produce a geotextile with good mechanical and tensile properties.

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7.2 Diagrams

This section presents and briefly describes the process diagrams corresponding to each stage of the Textile value chain implemented within the REDOL project (both baseline and REDOL innovation). These diagrams illustrate the workflow of each material, highlighting the technologies, streams, and interconnections among the partners involved in the circular configuration of the materials. For this section, diagrams are provided for the sorting and recycling phases.

7.2.1 Sorting

In the textile value chain, under the baseline scenario, the management of textile waste begins with the identification and sorting of materials using technologies such as NIR (Near Infrared), HSI (Hyperspectral Imaging), and RFID systems. This approach primarily enables the selection of PET-based textiles, which are subsequently sent to chemical recyclers for depolymerization and monomer recovery. The final outcome consists of sorted textile streams destined mainly for chemical recycling (Figure 48). However, this approach presents certain limitations, as it relies heavily on the initial accuracy of the sorting systems, thereby restricting both the diversity of recovered fractions and the potential valorisation routes.

In contrast, the REDOL solution introduces a significant improvement to this framework. NTT uses a technology – based on NIR and HSI camera and a RGB matrix camera – for the textile waste sorting that allows the selection and separation of items on the basis of colour, composition or fabric structure. According to NTT's expertise, this is the only sorting system capable of using fabric structure as a separation criterion. This feature is particularly advantageous for subsequent mechanical recycling, as fibres recovered from weft-knitted fabrics are typically of higher quality and longer length than those from warp-knitted fabrics.

The wide diversity of textiles in composition, colour, and fabric structure often causes traditional software and sorting machines to underperform. To overcome this, a large and diverse dataset is essential for accurate and reliable sorting systems. NTT trained its sorting system using various types of garments, with the option to expand the data library as needed. This adaptability allows the sorting machine's performance to be customized for specific goals – for example, in the REDOL project, it was trained to detect garments with varying elastane content and different fibre matrices (e.g., polyester, wool, polyamide, and cotton). Once the learning algorithm had accumulated sufficient data, the system could reliably begin the sorting process. The training phase was therefore crucial in building a comprehensive database to enable accurate recognition of unknown textile samples. As a result, differentiated streams of textile waste are generated, suitable for various valorisation pathways, including chemical, mechanical, and alternative recovery routes. In particular, thanks to this technology, PET textile streams with higher purity and traceability are obtained, which are subsequently pre-treated by NTT.

The results of the REDOL project can also provide valuable expertise for ALIA, which is overseeing the development and management of the Prato Textile Hub, scheduled to open at the end of 2026. Designed to process two main waste streams – post-consumer textiles from households (20,000 tons/year) and pre-consumer industrial scraps (13,000 tons/year) – the facility will feature separate sorting lines for each flow. Using advanced NIR spectroscopy, the hub will automatically sort textiles by colour and composition, making it the first facility of its kind in Italy and one of the most innovative in Europe. This technology will enhance sorting efficiency, improve material quality for recycling and reuse, and accelerate processing. Reusable garments will be returned to consortia for redistribution in domestic and international markets, while non-reusable items will be sorted for recycling according to industry demand. Overall, the hub is expected to recover around 77% of incoming textiles – 68% for recycling and 32% for reuse.

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From a comparative perspective, while the baseline scenario provides a functional classification system that mainly supplies material for chemical recyclers, the REDOL solution delivers a more accurate, versatile, and traceable approach. This enables the maximization of material recovery and diversification of output streams, representing a step forward in textile circularity by increasing system efficiency, reducing resource losses, and expanding the possibilities for waste valorisation.

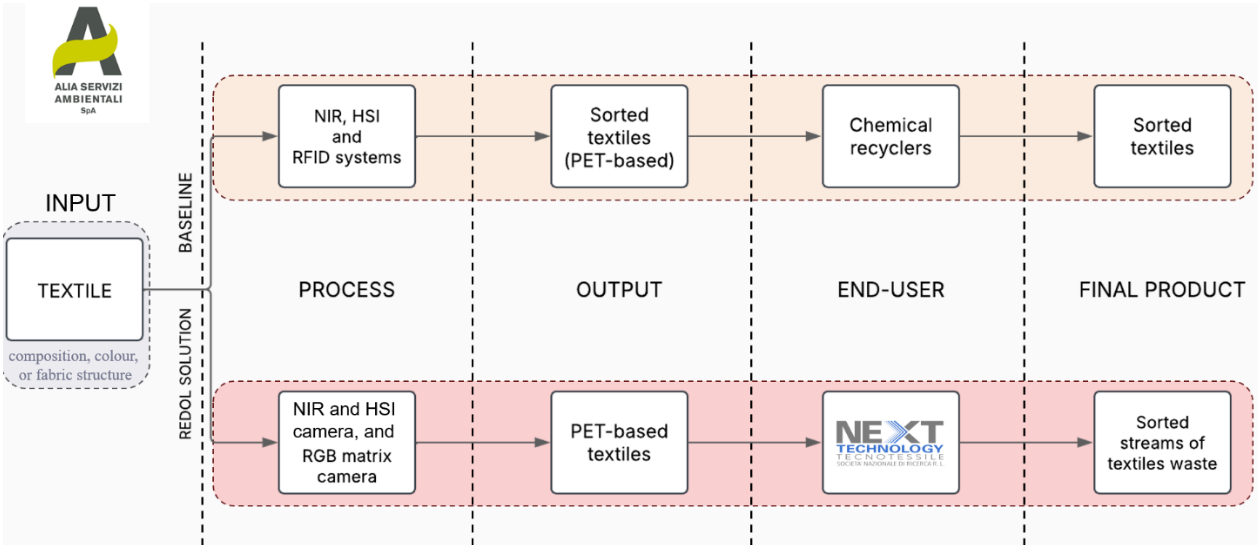

Figure 48. Baseline vs. REDOL solution: textile sorting

7.2.2 Recycling

Under the baseline scenario, bi-component PET/EL textiles are directly processed through chemical recycling, since mechanical recycling can be complicated even in the presence of low percentages of elastane. This treatment generates a mixture of PET and elastane, which is subsequently sent to chemical recyclers, who act as the end-users of the recovered material. The process yields streams of recycled elastane and rPET (Figure 49). However, this pathway presents significant limitations, as the joint treatment of materials of different nature reduces the overall process efficiency and may compromise both the quality of the final product and the recovery yield.

In contrast, the REDOL solution proposes an alternative approach that optimizes the management of this type of waste. In this case, bi-component post-consumer PET/EL textiles with varying elastane contents (2–15 wt.%) are processed by NTT through a thermo-mechanical pre-treatment, specifically designed to selectively remove elastane. The developed process achieved excellent elastane extraction, enabling the recovery of polyester free from impurities (i.e., elastane). This enables the production of purer and more traceable PET, directly suitable for subsequent valorisation processes. At this stage, AITEX acts as the end-user of the recovered material.

Therefore, while the baseline addresses the joint chemical recycling of PET and elastane, resulting in more complex processes and reduced control over material purity, the REDOL solution introduces a preliminary separation step that allows for the selective and efficient recovery of PET. This approach facilitates the production of higher quality, traceable material, increases the valorisation potential of PET, and reduces the interferences associated with the presence of elastane.

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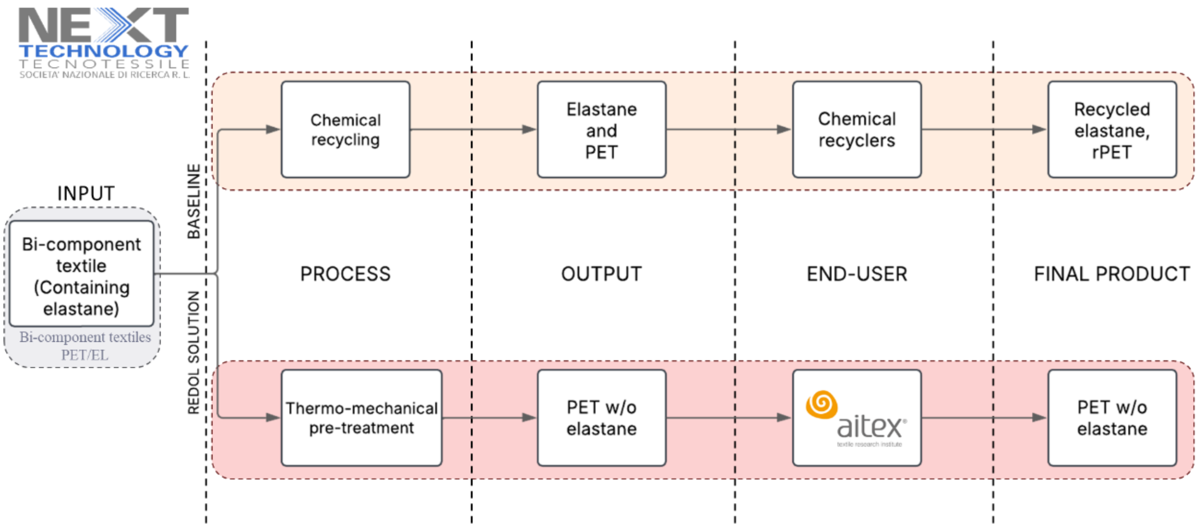

Figure 49. Baseline vs. REDOL solution: elastane removal

Regarding PET recycling, under the baseline scenario, the starting material is elastane-free PET with a purity higher than 98%. This stream is processed through thermo-mechanical recycling, allowing the production of rPET, which is subsequently transformed by the industry into recycled PET yarns (Figure 50). Although this approach is efficient and widely applied, it presents limitations in terms of material quality, since thermo-mechanical processes may lead to partial degradation of the polymer properties, thereby reducing its performance in more demanding technical applications.

In contrast, the REDOL solution introduces a chemical recycling scheme aimed at improving both the quality and circularity of the recovered material. Elastane-free PET is subjected to a glycolysis process, carried out by AITEX and assisted with ionic liquids, followed by the isolation of the monomer (BHET) and its subsequent repolymerization. The resulting material – a repolymerized PET with properties equivalent to virgin polymer – is then used by BRILEN to manufacture yarns, thus ensuring a final product with higher added value and an extended lifecycle.

It is worth highlighting that, while the baseline yields recycled yarns from rPET with properties limited by thermo-mechanical recycling, the REDOL solution delivers a higher-quality, more traceable material, fully equivalent to virgin polymer. This enables the production of PET yarns with optimal technical characteristics.

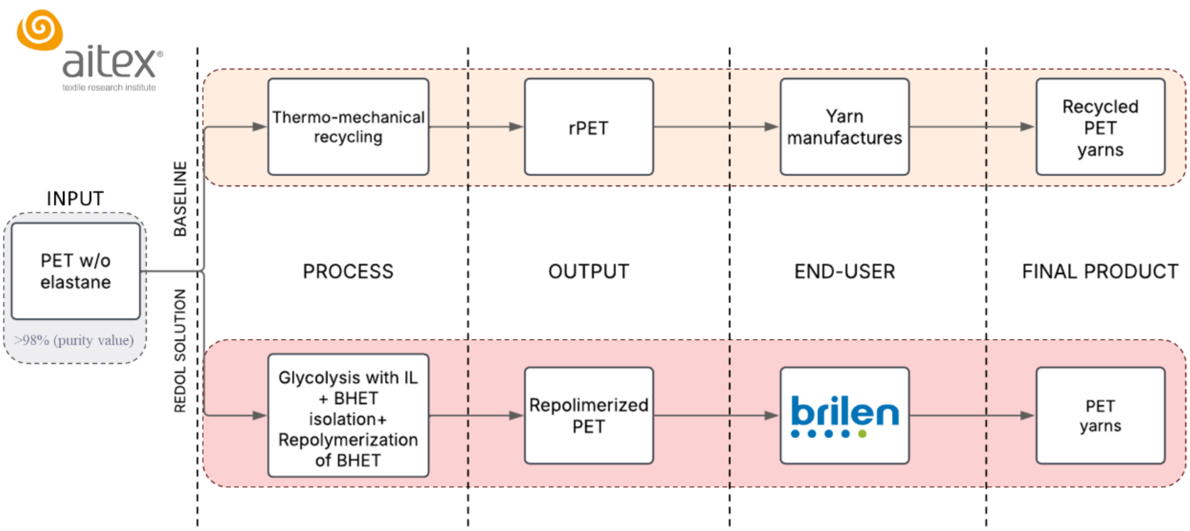

Figure 50. Baseline vs. REDOL solution: PET chemical recycling

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7.3 Layouts

This section showcases the equipment already installed and ready to begin the validation phase. This section includes either layout schematics or images of the equipment, along with key technical details. This section describes the sorting and recycling phases.

7.3.1 Sorting

NTT has implemented a textile sorting system equipped with NIR and HSI camera and RGB matrix camera capable of classifying garments based on composition, colour and fabric structure. The main advantages of NTT's improved sorting system are a more rapid and precise response, a modular structure (and cost) and an improved software. In addition, another innovation relies in its ability to recognize and differentiate textiles according to their structural features, enabling a more accurate material separation for recycling purposes. This pilot-scale system is currently operational at NTT's facilities and serves as a validation platform for future large-scale applications. Furthermore, the Prato Textile Hub, which will incorporate this technology, is expected to be fully operational by the end of 2026 and it is managed by ALIA. Figure 51shows NTT's demonstration prototype and the main steps of the classification process.

Figure 51. Demo prototype of the textile sorting system. A1: loading area of garments; A2: identification area (based on composition, colour and fabric structure); A3: sorting area; A4: control cabinet

7.3.2 Recycling

NTT has developed and optimized a dedicated system for the efficient removal of elastane from PET/EL textile samples, representing a crucial step toward obtaining higher polymer purity prior to chemical recycling. To achieve this, new heating elements have been integrated into the pilot plant to ensure a uniform temperature distribution across the system, thereby improving process control, reducing thermal gradients, and enhancing overall energy efficiency. In parallel, the filtration unit has been upgraded to increase the recovery and recycling rate of the organic solvent while minimizing the presence of contaminants in the recovered stream. These combined improvements contribute to a more stable, sustainable, and cost-effective operation, enabling the treatment of larger sample volumes under controlled conditions. The pilot plant, which is fully operational at

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NTT's facilities, serves as the final site for system validation and demonstration at pilot scale. Figure 52 provides an overview of the installation.

Figure 52. Elastane removal pilot plant

After elastane removal, the process continues with the chemical recycling of polyester. AITEX has successfully scaled up the chemical recycling of PET by implementing a 50 L reactor operated in semicontinuous mode, coupled to a 30 L filtration reactor. This setup enables the processing of larger material volumes, optimizing production time and enhancing recycling efficiency. The semicontinuous configuration also allows for more precise control over reaction conditions, including temperature, agitation, and residence time, contributing to a more uniform recovery of both PET and solvent. Both reactors are installed at AITEX's facilities, which serve as the final site for these pilot-scale operations. Figure 53 depicts the reactors and their main components

Figure 53. Glycolysis reactor coupled to a filtration reactor

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The final step of the process, related to end-user validation, involves producing geotextiles using the recycled material.

The process involved a pilot-scale polymerization unit at Novapet for the post-condensation of the pellets. In BRILEN's semi-pilot technical spinning plant, the main equipment used included the polymer dryer, the extruder, and the winder. The plant cabling machine is planned to be used in the next stage to assemble the GLE 2200 bobbins into GLE 4400 yarn. Figure 54 shows the final stage of the production process, corresponding to yarn winding, where surface quality and product uniformity are inspected prior to storage and subsequent shipment.

Figure 54. Image of the pilot plant technical spinning winder

In summary, the equipment to be deployed in the textile value chain are presented in Table 10.

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Table 10. Equipment to be deployed in the textile value chain.

Equipment	Process	Function	Deployment date and location	Comment
Textile sorting system	SORTING	Textile classification	• Already install on a pilot scale • NTT's facilities	The textile hub will be operational from the end of 2026 (ALIA).
Elastane removal pilot plant	RECYCLING	Elastane removal	• Already install on a pilot scale • NTT's facilities	-
50L glycolysis reactor	RECYCLING	Textile glycolysis	• Already install • AITEX's facilities	-
Pilot plant spinning line	RECYCLING	Spinning	• Already install before the project • BRILEN's facilities	Fabric production planned for Q1 2026

7.4 Future work plan

The final project period will focus on completing the industrial validation of the Textile value chain, ensuring that the recycled materials and developed technologies perform under real operational conditions. The value chain configuration was originally developed within WP3 and WP4, where the processes were demonstrated at laboratory and pilot scale. In WP6, these results will be scaled up and validated at industrial level, confirming the technical feasibility and quality of the recovered materials. In parallel, optimisation activities will target improvements in consolidating the transition from laboratory testing to full-scale implementation.

7.4.1 Sorting

Within the REDOL project, NTT optimized a textile waste sorting system to enhance textile reuse and recycling, reducing dependence on landfilling and incineration while viewing textile waste as a valuable resource with economic potential.

- The sorting system integrates advanced imaging technologies:
  - NIR and HIS for the recognition based on composition.
  - RGB matrix camera for colour and fabric structure identification.
- The system's results will:
  - Contribute to reaching TRL6 validation.
  - Support ALIA's Prato Textile Hub, expected to be operational in late 2026. The Textile Hub is expected to process over 30,000 tons of textile waste per year.
- The Prato model aims to be replicable in other European cities as a scalable circular solution.

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7.4.2 Recycling

With the aim to introduce innovative and sustainable solutions into the textile value chain, NTT has developed and optimised a thermo-chemical pre-treatment for EL-based textiles. The elastane removal technology, based on a closed-cycle solvent process, selectively dissolves elastane fibres from bi-component textiles using a non-toxic organic solvent. Future work will focus on:

- Extending the method to tri-component elastane-based fabrics.
- Further evaluating its selectivity and efficiency.

Upcoming activities of AITEX:

- Preparation of a scientific paper in collaboration with CIRCE, comparing chemical recycling using conventional heating versus microwave heating.
- Redesign of the new value chain, identifying potential companies in Zaragoza for their integration into the model.

7.4.3 End user validation

Once the high-tenacity technical yarn had been produced and its properties were thoroughly evaluated, the material was deemed suitable for advancing the next phase of the project. With this confirmation, work can now begin on the geotextile to be manufactured for validation within the textiles section of the project. Future work will focus on:

- **Strand assembly to obtain GLE 4400 yarn**
  The next step will consist of assembling the strands from the 18 available GLE 2200 bobbins to produce a GLE 4400 yarn. This yarn, obtained from the chemically recycled pellets supplied by AITEX, is intended to be used exclusively in the weft direction, while the warp will consist of BRILEN's standard yarn types. This configuration will enable the weaver to produce a geotextile with solid mechanical and tensile performance.

- **Redefinition of the final product**
  Based on the amount of high-quality ("A-grade") yarn obtained, the final geotextile product to be manufactured will be redefined in terms of specifications, structure, and expected performance.

- **Shipment of yarn samples to Solmax (TenCate Geolon)**
  Samples of the produced yarn will be sent to Solmax for the weaving of prototype geotextiles.

- **Textile analysis**
  The woven material will undergo a series of textile evaluations to verify fabric structure, uniformity, and overall processing behaviour.

- **Mechanical performance testing**
  The resulting geotextile will be subjected to tensile and mechanical strength test to confirm that the product's performance targets are met and that it is comparable to a geotextile manufactured with standard yarn. By achieving this, the circularity goal of the project will be validated.

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8 Task 6.5. Redesign of new circular WEEEs value chains

8.1 Processes description

The WEEE value chain in the TATUINE-WIREC system follows a clear and structured sequence that begins with the collection of electronic waste and ends with the recovery of valuable materials, particularly gold, from selected components.

The process starts with the collection of WEEE, which is carried out by WIREC. This company receives electronic waste directly at its facilities. There is no formal storage area at WIREC, and the logistics are managed by a small team of two people. Once received, the WEEE is dismantled on-site. During dismantling, printed circuit boards (PCBs) are recovered. These include both GOLD PLATED PCBs (GP PCB) and ELECTROCOMPONENT PCBs (EC PCB). WIREC recovers more than fifteen different types of PCBs, which are sorted according to several classification criteria. These include the typology of the electronic components present, the type of electrical connections, and the origin of the equipment, such as whether it came from IT devices.

After sorting, the PCBs are sent to TATUINE for processing. At this facility, the boards are stored either on dedicated shelving or in a designated zone within the working area of the plant. All PCBs pass through WIREC before reaching TATUINE, where WIREC operators are also responsible for pre-selecting which boards are forwarded. TATUINE only processes PCBs that contain visible or exposed gold. Boards without exposed gold are not treated at TATUINE; instead, they are exported, typically to a Japanese company, for the recovery of other valuable metals such as silver, palladium, and other platinum group metals.

In this value chain, two phases are presented: sorting and recycling.

8.1.1 Sorting of EC PCB

8.1.1.1 Baseline

Electrolytic capacitors containing tantalum and some aluminium capacitors are manually removed from the PCBs. Once extracted, both types of capacitors and the remaining depopulated PCBs are sold to other waste management companies. The outputs of the current sorting stage are therefore electrolytic capacitors (with about 700 g Ta per kg of capacitors), aluminium capacitors (around 500 g Al per kg of capacitors) and a depopulated PCB whose precious metal content (Au, Ag, Pd) varies with PCB type. The final applications and end-users of these recovered materials are not disclosed by TATUINE. In terms of performance, they report 100% extraction of metals from the capacitors and an overall metal content in PCBs of 15–20 wt%, although this depends on the PCB source. Costs for the manual sorting step and the prices paid/received for PCBs are not disclosed.

8.1.1.2 REDOL innovation

The novel development in the REDOL project consists of an automatic sorting machine that integrates computer vision together with a robot, allowing components to be extracted from PCBs automatically. A real-time data acquisition system was developed to interface with both a camera and a profilometer, enabling synchronized data collection from the sensing components. Efforts were dedicated to improving the performance of the sorting algorithm through enhanced vision-based processing. In parallel, an algorithm was developed to determine the exact coordinates where the robotic arm should grasp components for extraction, ensuring precise and efficient

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handling. This robot is equipped with a special gripper, designed and manufactured specifically for the project, which, together with a force controller applied to the robotic arm, enables precise approach and extraction of components. To support the mechanical aspects of the system, a vacuum dust collection system was designed to maintain cleanliness and functionality. The heating system required for certain operations was successfully integrated into the prototype. Practical picking trials were conducted to validate the system's performance in real-world conditions. Finally, the communication architecture was refined by defining the necessary communication nodes within the PLC to ensure seamless control and data flow across all system components.

8.1.2 Recycling of GP PCB

8.1.2.1 Baseline

Gold is recovered from PCBs through a hydrometallurgical route. The process involves chemical recycling via leaching to dissolve the gold, followed by electrodeposition to recover metallic Au. The resulting de-goldened PCBs are then sold to another company, which applies thermal and electrochemical treatments to recover copper and other metals. The main outputs are high-purity gold (500–600 g Au per tonne of PCB at 99.96% purity), treated PCBs that still contain metals such as Cu, Ag, Pt and Pd, and a hazardous liquid treatment medium whose exact composition is confidential, but it is known to be hazardous. The recovered gold is mainly used in the jewellery sector, and the hazardous media is managed as waste by a waste manager. The reported recycling performance is 100% recovery of the gold from the PCBs and 100% recovery of the remaining metals in the treated PCBs by the third-party company, while the hazardous medium is not recovered (0%).

8.1.2.2 REDOL innovation

Once at TATUINE, the selected GP PCBs undergo a gold recovery process. This process consists of chemically extracting the gold using hydrometallurgical techniques and finally using electrolysis to recover gold in its metallic form. The facility operates with a maximum batch capacity of three tons. Because the selection and processing depend on the internal capacity of the facility and not on external supply fluctuations, TATUINE does not experience seasonal variation in activity. On the other hand, WIREC observes clear seasonal variation in the volume of WEEE received, particularly during the months of June, July, and December.

The REDOL project initially aimed to replace the conventional hydrometallurgical gold stripping process with a more sustainable solvometallurgical approach based on Deep Eutectic Solvents (DES). RINA was responsible for developing this alternative treatment system under Task 4.5. However, the process failed to deliver the necessary performance levels to justify further development or scale-up. Consequently, the decision was made to discontinue work on the system proposed by RINA.

As an alternative, TATUINE proposed shifting the focus to the treatment of chemical effluents generated by the existing gold recovery process. This process currently produces around 12 tonnes per year of wastewater contaminated with substances such as cyanide and heavy metals. The objective is to regenerate this water for reuse within the process, thereby reducing the volume of hazardous waste produced.

To achieve this, TATUINE plans to implement a treatment system combining chemical precipitation and membrane filtration, aiming to recover water of sufficient quality to be reintegrated into the gold recovery cycle.

8.2 Diagrams

This section presents and briefly describes the process diagrams corresponding to each stage of the WEEE value chain implemented within the REDOL project (both baseline and REDOL innovation). These diagrams illustrate the workflow of each material, highlighting the technologies, streams, and interconnections among the partners

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involved in the circular configuration of the materials. For this section, diagrams are provided for the sorting and recycling phases.

8.2.1 Sorting of EC PCB

Figure 55 shows the difference in the sorting process between the baseline scenario and the REDOL solution: in the baseline, tantalum and aluminium capacitors are manually removed from PCBs and sold, along with the depopulated boards, to external waste managers; in contrast, the REDOL solution introduces an automated sorting system combining computer vision, coordinated sensing, and a robotic arm with a specialized gripper, enabling precise, efficient, and autonomous extraction of components.

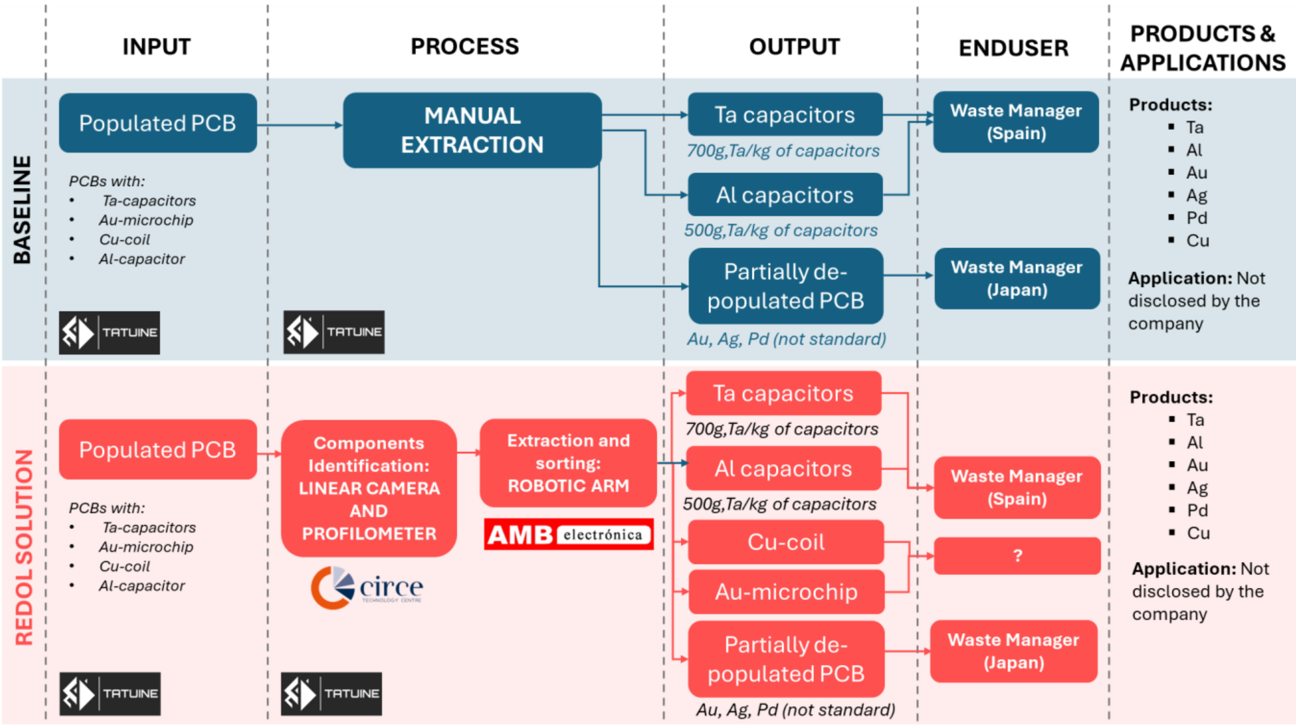

Figure 55. Electrocomponent PCBs sorting. Baselines vs REDOL solution

8.2.2 Recycling of GP PCB

In the recycling phase (Figure 56), the baseline relies on conventional hydrometallurgy to extract gold from selected PCBs—typically those with visible exposed Au—achieving 500–600 g of high-purity gold per tonne of PCB, while the remaining metals are recovered by an external company and the hazardous liquid residues are discarded. In contrast, the REDOL solution retains the hydrometallurgical gold recovery process but shifts innovation toward treating the hazardous effluents generated, after the alternative DES-based method proved insufficient. The initial solution was based in changing the treatment of the PCB by using DES. The yield extraction was very low in comparison to the actual process, so TATUINE proposed to do a treatment of the hazardous liquid to reuse the water and reduce significantly the volume of hazardous waste. The proposed system combines chemical precipitation and membrane filtration to regenerate water for reuse, significantly reducing hazardous waste and improving overall process sustainability.

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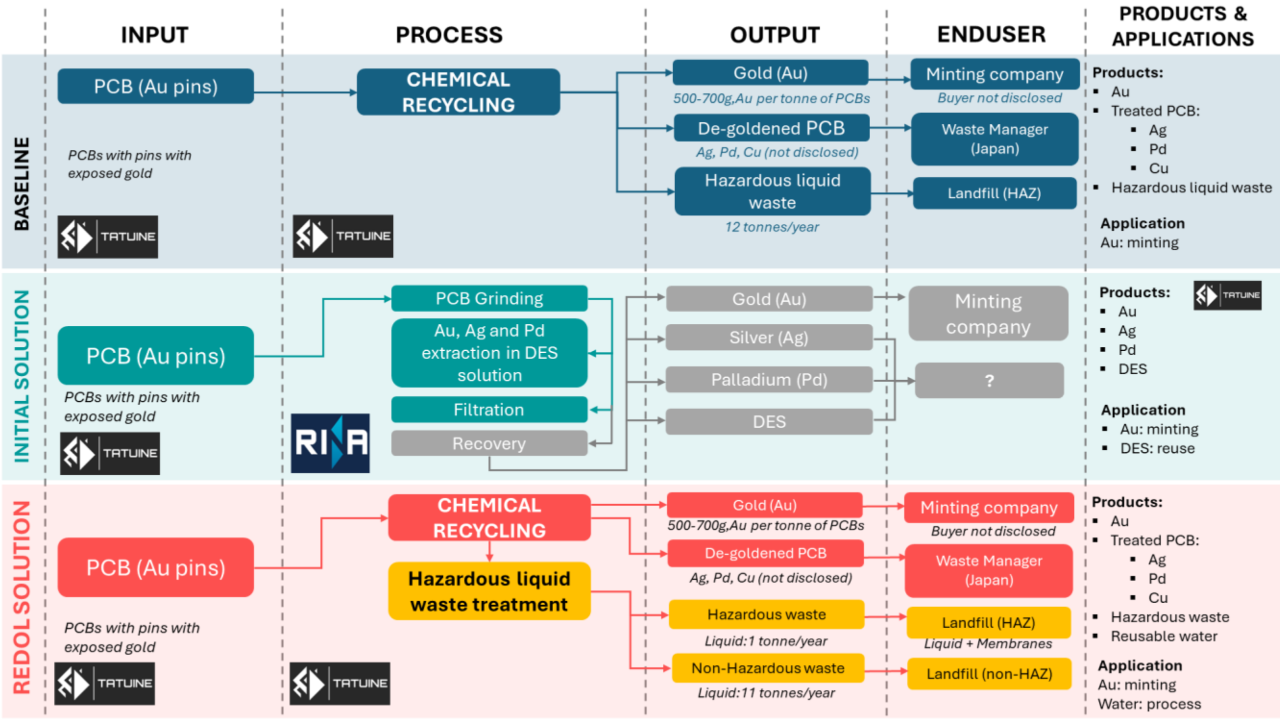

Figure 56. GP PCBs Recycling. Baseline vs REDOL solution

8.3 Layouts

8.3.1. Sorting of GP PCB

CIRCE and AMB have developed an automated mobile sorting line for electronic components from PCBs (Figure 57). The system is fully autonomous from existing process lines, allowing it to be deployed at different locations within the plants according to TAT's requirements. CIRCE developed the machine learning and deep learning algorithms applied to spectral images for material identification, while AMB integrated the picking system controlled by these algorithms.

The automated extraction system will be deployed at TATUINE in Q1 2026. The installation includes a profilometer, a line-scan camera, linear illumination modules, a robotic arm, a hot-air desoldering tool, a grinding tool, a dedicated component collection bin, linear rails, servo motors, a PLC, an HMI, and the necessary safety sensors.

The process begins with the operator loading and securing the PCB in the system. The board is then transported to the inspection station, where the vision subsystem detects, identifies, and determines the precise position of the valuable components. This information is transmitted to the robot controller, enabling accurate manipulation. At the extraction station, the solder is melted using the desoldering tool, allowing the robot to remove each identified component. After extraction, the component leads are ground to eliminate any remaining tin, ensuring clean and uniform outputs. Finally, the components are sorted and deposited into their corresponding collection bin.

The system is designed to extract four specific types of components: gold-bearing microprocessors, aluminium capacitors, tantalum capacitors, and copper inductors (coils).

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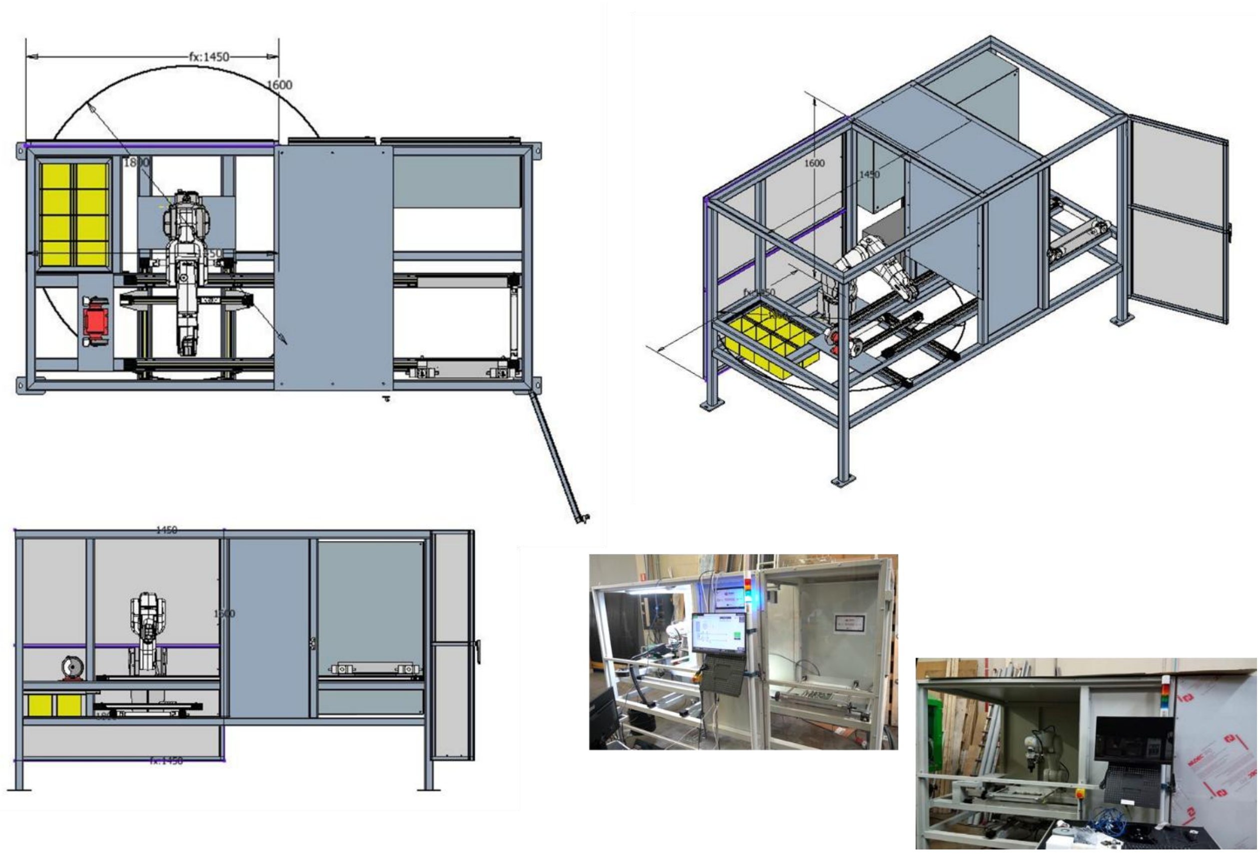

Figure 57. Sorting line for electronic components from PCBs, layouts

8.3.2. Recycling of GP PCB

An ad hoc designed process is proposed, and will be duly assessed, for treating the liquid effluent from the PCB gold recovery process as it is considered as hazardous liquid. This is described in Section 7.4 Future work plan. No pictures are included here due to confidential issues.

8.4 Future work plan

The proposed systems at TATUINE represent a significant step toward sustainable and automated resource recovery from electronic waste.

8.4.1. Sorting of EC PCB

After carrying out the initial commissioning tests during WP3 at AMB's facilities, the prototype was transferred to CIRCE's facilities for the first validation tests with PCB samples provided by TATUINE. Figure 58 shows images of the validation phase at AMB and the unloading of the prototype at CIRCE's facilities during November of 2025.

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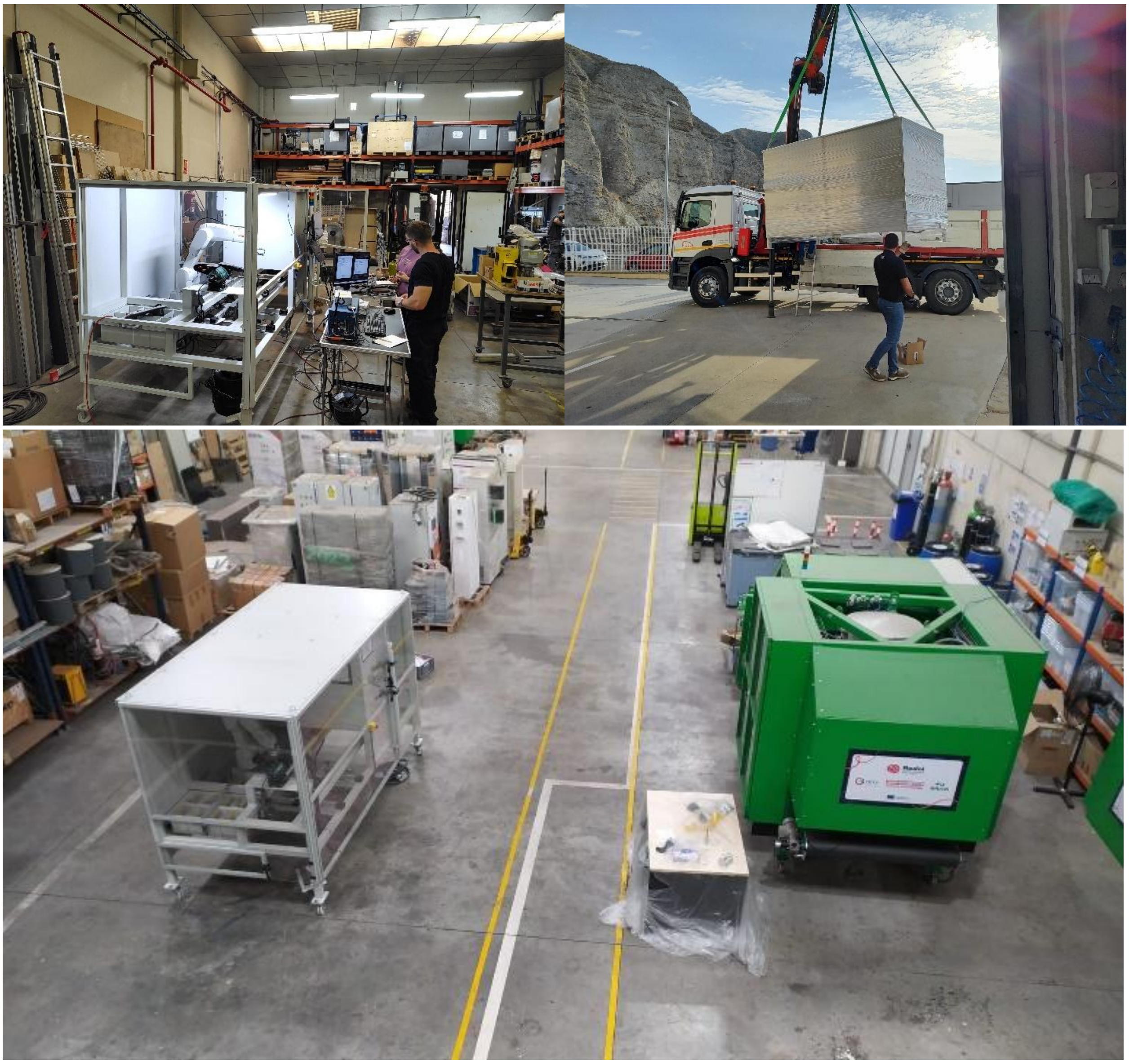

Figure 58. Pictures of the validation in AMB and transport of the PCB sorting prototype to CIRCE's facilities

During the months from November 2025 to January 2026, the prototype will be tested and fine-tuned at CIRCE's facilities using PCB boards provided by TATUINE. Subsequently, during Q1 2026, the prototype will be transferred to TATUINE for its final validation at TRL7.

8.4.2. Recycling of GP PCB

Given the initial plan to develop a greener recycling process for GP PCBs failed to deliver the necessary performance levels to justify further development or scale-up, an ad hoc designed process is proposed. In this case, the target is to treat the liquid effluent from the PCB gold recovery process as it is a hazardous liquid.

The process will start in a 400 L HDPE tank that will act as a covered reactor, with its vent connected to a caustic scrubber. In this tank, the pH will first be raised above 11 to avoid volatilization of sulphide carbon species. If desired, a cementation step will then be carried out to selectively recover precious metals, which will be optional from a process point of view but economically attractive. After cementation, the pH will be adjusted to around 9–10 to precipitate base and heavy metals from the solution. Once these metals have been removed, a source of SO_2 will be added to destroy residual cyanide or carbon-containing species via the INCO process.

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The clarified solution will then be sent to a polishing stage based on membrane filtration. It will first pass through a 5 µm cartridge filter and then through an ultrafiltration (UF) module with PVDF hollow fibres and a molecular weight cut-off of 100–150 kDa. This step will remove remaining suspended solids and colloids, thereby protecting the downstream reverse osmosis unit. The only solid residue generated at this point will be the spent UF cartridges, which will not be hazardous provided that cyanide or carbon species have been destroyed in the previous step.

Finally, the pretreated stream will be fed to a reverse osmosis (RO) unit equipped with thin-film polyamide 2.5" elements, designed to recover about 70–75% of the dissolved solids and remove residual organics. The permeate from RO will be a clean water stream that can be reused in the gold recovery process, effectively closing the water loop. The remaining waste from this stage will consist of spent RO cartridges, which will also be non-hazardous if the destruction of cyanide or carbon species has been properly completed beforehand.

The next steps will be to conduct laboratory tests to validate some or all of the proposed stages, as well as a techno-economic analysis of each of the options. The aim will be to enable TATUINE to evaluate the proposed option from both a technical and economic point of view, the latter being the criterion that will determine whether or not to proceed with the installation of a hazardous effluent treatment plant.

- Laboratory tests to evaluate proposed technologies (Responsible: TATUINE)
- Technoeconomic analysis of the proposed technologies (Responsible: TATUINE)

Figure 59 shows the site location of the REDOL solutions for WEEE management.

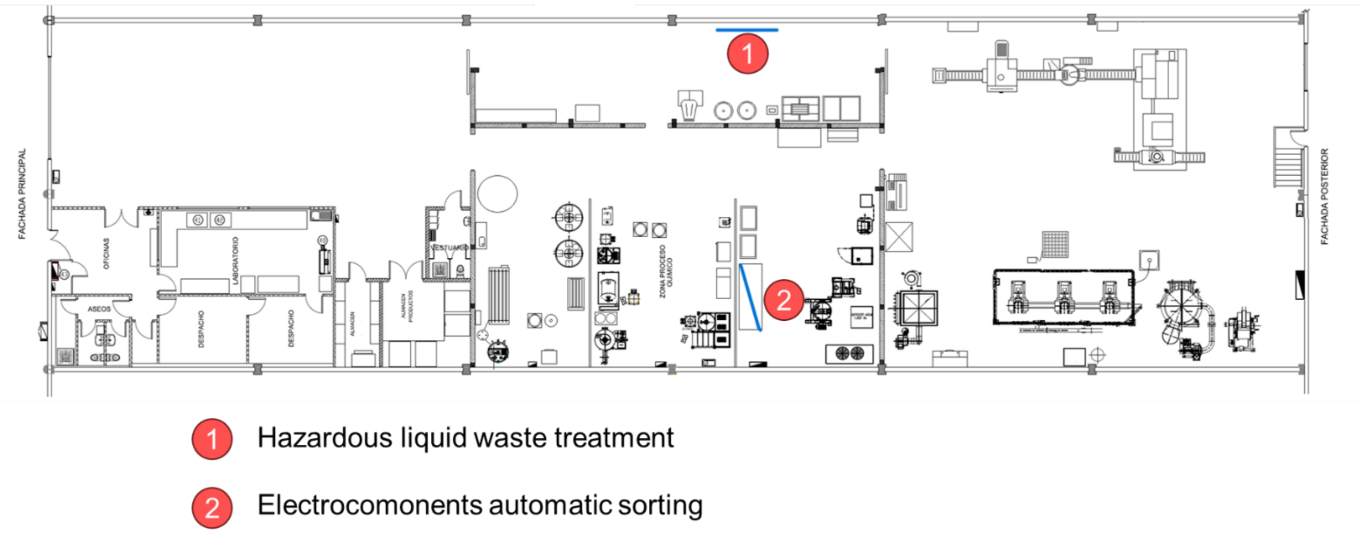

Figure 59. Site location of REDOL solutions in TATUINE

In summary, the main equipment to be deployed in the WEEE value chain is presented in Table 11.

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Table 11. Systems to be deployed in the WEEE value chain.

System/equipment	Process	Function	Deployment date and location	Comment
Electrocomponents automatic sorting	SORTING	Sorting line for electronic components from PCBs	• AMB facilities (up to October '25) • CIRCE´s facilities (November/December '25) • TATUINE's facilities (Q1)	Equipment will be deployed in CIRCE for a couple of weeks for trials, before moving it to TATUINE
Hazardous liquid waste treatment	TREATMENT OF EFFLUENTS	Process for treating the liquid effluent from the PCB gold recovery process	• To be evaluated • TATUINE's facilities	The proposed solution will be assessed from both technical and economic perspectives before a final deployment decision is made.

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9 Conclusions

The activities carried out within this deliverable confirm that the redesigned value chains for packaging, plastics, CDW, textiles, and WEEE have been successfully implemented or are in the final stages of deployment. The coordination and monitoring framework established in WP6 ensured a consistent and harmonized implementation process across all partners, enabling early identification of potential bottlenecks and the adoption of corrective measures.

The results demonstrate that the technologies and processes developed under WP3, WP4 and WP5 have been effectively integrated into real waste management environments or are in the final stages, paving the way for the upcoming validation phase with the respective end users. Moreover, the collaboration among partners has proven essential for ensuring technical coherence, optimizing operational efficiency, and reinforcing the overall circularity objectives of the REDOL project.

The following sections detail the deployment status of the main equipment and technologies for each value chain:

- PACKAGING VALUE CHAIN
    - **Collection**: already finished, just waiting for integrating in the REDOL platform
    - **Sorting 1:** MMPP sorting system, awaiting delivery (expected M38-M40: January – March 2026) at GRHUSA (Huesca).
    - **Sorting 2:** Paper and cardboard sorting system, delivered and installed (M31 - June 2025) at CIRCE's facilities (Zaragoza, Spain) this is the final location.
    - **Recycling:** Delamination reactors at industrial scale, delivered: March 2025, commissioning and setup: April to September 2025 at ACTECO (Spain).
- PLASTIC VALUE CHAIN
    - **Sorting:** Smart bins, awaiting delivery (expected M40: March 2026) at Zaragoza (Spain).
    - **Recycling:** Pressure reactor, delivered and installed (M36: November 2025) at MOSES (Spain)
- CDW VALUE CHAIN
    - **Collection:** Type of GPS sensor, awaiting delivery (expected M41-M46: April – September 2026) at CASALE (Spain)
    - **Sorting:** CDW sorting system, awaiting delivery (expected M40: March 2026) at CASALE (Spain)
    - **Recycling:** New clinker production, new cement and concrete development and new cast polymer. No new equipment was deployed for this value chain, as the existing installations were already suitable. First tests have already started.
- TEXTIL VALUE CHAIN
    - **Sorting:** Textile sorting system, already installed at pilot scale prior to the project (M1) at NTT (Italy).

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  - **Recycling**:
    - Elastane removal pilot plant, already installed at pilot scale prior to the project (M1) at NTT (Italy).
    - 50L glycolysis reactor, already installed (M18) at AITEX (Spain).
    - Pilot plant spinning line, already installed prior to the project (M1) at BRILEN (Spain).
- WEEE VALUE CHAIN
  - **Sorting:** Electrocomponents automatic sorting, awaiting delivery (expected M40: January 2026) at TATUINE (Spain).
  - **Recycling:** Hazardous liquid waste treatment, to be evaluated from both technical and economic perspectives before a final deployment decision is made at TATUINE (Spain):

This deliverable also relates to the verification of **Milestone 5: "REDOL solutions mature enough to start the demonstration activities in WP6".** While the milestone has been partially achieved, supported by the presentation and approval of the layouts for both waste managers and end users by the Project Coordinator, some developments still need to be fully implemented and installed at their final sites before the validation stage can begin. Work will continue over the upcoming months to ensure their completion and full readiness for the demonstration phase.

In the next phase, efforts will focus on validating the technical performance and economic feasibility of the implemented solutions. The outcomes of this validation will provide crucial insights into the replicability and scalability of the REDOL circular value chains, supporting the transition towards a more sustainable and resource-efficient waste management model.

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