Technical performance of smart port-based solutions for EOL fishing gear

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Abstract

The growing accumulation of marine litter and end-of-life (EOL) fishing gear poses a critical threat to global marine ecosystems, biodiversity, and coastal economies. In response to these pressing environmental challenges. This report presents a comprehensive, circular-economy framework designed to transform port-based waste management as a way to prevent the formation of marine litter. By establishing specialized protocols and infrastructure, this initiative aims to intercept EOL fishing gear at source (i.e. their disposal in port) and transition from traditional disposal methods toward sustainable, high-value material recovery.

To ground this strategic model in real-world conditions, Chapter 2 provides a detailed Case Study of the Basque Country Region. This section analyses the operational reality of local port reception facilities in Basque ports, through frequent site visits and assessment of their current status (2.1) It also establishes a baseline of the current environmental challenge by defining the main waste streams present in these ports (2.2), focusing on the volumes and characteristics of discarded materials.

Building upon these regional insights, Chapter 3 introduces the core innovative concept of this study: the deployment of “Blue Point” at port. This section outlines the practical potential implementation of this specialised waste facility through several strategic steps:

- Definition of the requirements of the facility and waste collection scheme (3.1) to ensure seamless port integration.
- Characterization of the different types of materials present in the EOL fishing gear waste stream (3.2) to understand the chemical and physical properties of the incoming waste.
- Definition, configuration, and materialization of a Blue Point (3.3) alongside the precise design and layout of the site and facilities (3.4).
- Selection of advanced techniques for the identification and characterisation of materials (3.5) to optimize sorting efficiency.
- Development of procedures for waste management in port (3.6) to guide daily operations safely.
- Administrative/legal requirements, costs and key performance indicators (3.7) to monitor and evaluate the overall performance of the facility.
- Integrated management and valorisation of additional marine litter streams (3.8) to expand the ecological benefits across the wider Basque coastal region.

Finally, Chapter 4 focuses on the validation of port-based solution model for a sustainable EOL fishing gear management. This concluding section demonstrates the feasibility and scalability of the proposed framework. It verifies the operational viability through the validation of a smart port-based “Blue Point” model for EOL fishing gear (4.1) and explores advanced chemical recycling pathways via the validation of industrial scale pyrolysis demonstration (4.2), offering a definitive roadmap toward a zero-waste maritime sector.

Summary

This deliverable presents the development, implementation, and validation of a port-based solution for the sustainable management of EOL fishing gear within the framework of the SEARCULAR project. The work primarily addresses the objectives of Task 4.1 (design of the Blue Point at port) and Task 4.4 (validation of the port-based solution model), while incorporating key inputs and results derived from Task 4.2 (reverse logistics) and Task 4.3 (plastic-to-plastic pyrolysis).

The increasing generation of marine litter, particularly from fishing activities, has highlighted the need for integrated and circular management systems capable of addressing the entire lifecycle of fishing gear. In this context, the concept of a "Smart Blue Point" has been developed as a centralized and replicable infrastructure designed to enable the proper collection, sorting, conditioning, traceability, and valorisation of EOL fishing gear generated in port environments. The approach has been specifically tailored to the case study of the Basque Country, where significant quantities of fishing gear waste—estimated in the range of at least 500 tonnes per year—require dedicated management solutions.

The Blue Point concept builds upon the established model of municipal "green points" (waste collection facilities widely implemented in Spain since the late 1990s), adapting it to the specific characteristics and challenges associated with fishing gear waste streams. Unlike conventional waste collection systems, the proposed Blue Point integrates not only collection and sorting functions, but also advanced pre-treatment and conditioning operations. These include dismantling, cleaning, shredding, and material-specific separation processes aimed at producing secondary raw materials that meet the technical requirements for both mechanical and chemical recycling routes. This added functionality is essential due to the complex nature of fishing gear, which is typically composed of multi-material plastics, contaminated with organic matter, salt, and other impurities, and often presents challenging physical formats for processing.

The design of the Smart Blue Point (Task 4.1), led by GAIKER, has been supported by a combination of methodological approaches. These include (i) benchmarking and analysis of similar initiatives and best practices implemented across Europe, (ii) extensive stakeholder engagement involving port authorities, waste managers, and fishing sector representatives, and (iii) a physical pilot-scale simulation of Blue Point operations. In this simulation, more than 9 tonnes of EOL fishing gear collected from Basque ports were processed, allowing for the validation of operational procedures, material flows, and technical feasibility.

A key component of the Smart Blue Point concept is the integration of digitalization and traceability tools. An intelligent traceability system has been designed and piloted to ensure full tracking of material flows from origin to final destination. This system enables the assignment of a unique digital passport to each material stream, incorporating information on material type, source, processing steps, and associated environmental indicators, such as carbon footprint and avoided environmental impacts through recycling. This “smart” approach enhances transparency, supports regulatory compliance, and facilitates the monitoring of Key Performance Indicators (KPIs) related to system performance.

The outcomes of Task 4.2 have contributed to defining and optimizing the reverse logistics network associated with the Blue Point, from fishing vessels to final recycling facilities. Different supply chain scenarios have been evaluated based on economic, environmental, and operational criteria, providing essential input for the design and scalability of the system. In parallel, Task 4.3 has assessed the feasibility of chemical recycling via pyrolysis for non-recyclable fishing gear fractions, establishing processing parameters and validating the production of high-quality pyrolysis oil (TACOIL) suitable for reintroduction into plastic manufacturing processes. These results are critical for ensuring that the Blue Point is fully integrated within a circular value chain, enabling multiple valorisation pathways depending on material characteristics.

Finally, Task 4.4 focuses on the validation of the overall system at a relevant technological readiness level (TRL 7), demonstrating the operational feasibility of the Smart Blue Point model in real conditions. This includes the collection, sorting, and pre-treatment of EOL fishing gear, as well as the validation of downstream recycling routes, including both mechanical recycling and chemical recycling via pyrolysis. The integration of all these elements provides a comprehensive and scalable solution for the sustainable management of fishing gear waste, contributing to the reduction of marine litter and the transition towards a circular economy in the fisheries sector.

This deliverable provides a comprehensive and detailed account of the work carried out within this work package. It includes a thorough description of the investigations performed, the site visits conducted across the selected ports, and the stakeholder engagement activities, including meetings with public authorities, port managers, and waste management operators. Furthermore, it presents the results obtained at each stage of the study, covering material characterization, process validation, and system design. Finally, the deliverable addresses the validation of the Smart Blue Point concept, including the development and assessment of its 3D design, ensuring its technical feasibility, operational functionality, and alignment with the requirements of a scalable and circular waste management system.

1. Case Study – Basque Country region

The Cantabrian coast is a region with a rich and vast tradition of fishing and shipbuilding. This also applies to the Basque region (Figure 1 top), with historical reports highlighting the importance of whaling, and cod and sardine fishing since the 1100s. This is heavily reflected on the number of ports and the relevance of sea related industries on the modern Basque economy, as well as the cultural heritage these activities, which remain visible today as festivities or cultural events. Nowadays, the Basque government recognizes 17 different ports in the region, of which 15 are controlled by the regional government and 2 by the Spanish state (Bilbao and Pasaia). The vary in size from the smaller ports dedicated to recreational activities of the inhabitants of nearby towns, such as the port of Algorta, to major ports dedicated to the exchange of goods or shipbuilding such as the ports of Bilbao, which ranks as the 5th biggest port of Spain by tonnage moved and holds the position as the most important port in the northern Spain. In Figure 1 bottom, a map with the location of the different ports can be seen.

Due to the human and commercial activities that take place in port, a variety of waste streams are generated, which are related to the fishing industries and/or the maintenance of ships. In all Basque ports, the management of ship generated waste is carried out in accordance with the MARPOL Convention (73/78), which establishes a comprehensive regulatory framework covering all main categories of maritime waste, including oily residues (Annex I), noxious liquid substances (Annex II), harmful substances in packaged form (Annex III), sewage (Annex IV), garbage (Annex V), and air emission (Annex VI). Under this framework, ports are required to provide adequate reception facilities to ensure that all waste generated during vessel operations is delivered ashore for proper treatment, minimising discharges into the marine environment. Within this system, fishing gear waste —including ropes, nets and other operational residues— is typically collected and temporarily stored in port reception facilities as part of the garbage streams regulated under Annex V, which explicitly includes fishing gear among ship generated waste. However, due to its heterogeneous composition, contamination and limited separation feasibility, the main current destination for this type of waste remains landfill disposal. Whenever possible, efforts are made to redirect these materials towards reuse or recycling pathways, although such valorisation routes are not yet fully established or systematically implemented in all ports. However, this has started to change, driven by stricter regulations on residue handling (e.g. Directive (EU) 2019/883 on Port Reception Facilities) and an increasingly environmentally conscious population.

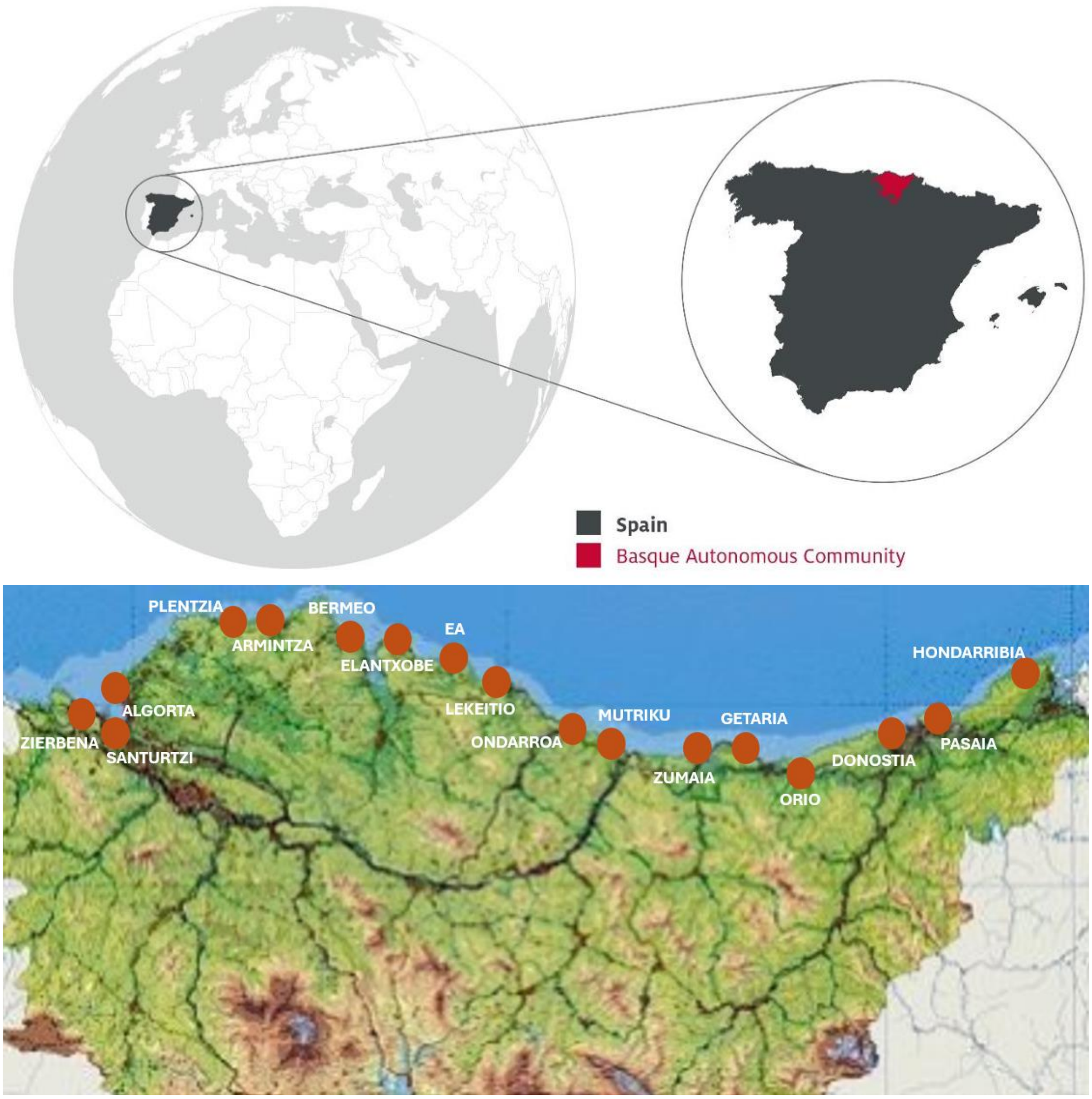


Figure 1. Baque Country region[1] (top) and distribution of ports along the coast of the Basque Country (bottom)

[1] Source: Romero Caro, Francisco Javier, and Leire Escajedo San-Epifanio. 2020. “Basque Country”. In Autonomy Arrangements in the World. www.world-autonomies.info.

Within the scope of the SEARCULAR project, special attention has been placed on those ports that are still actively involved in fishing activities, as they generate specialised waste streams with high potential for valorisation, offering both economic and environmental benefits. The Basque Country has four main fishing ports: two located in the province of Bizkaia (Bermeo and Ondarroa) and two in the province of Gipuzkoa (Getaria and Hondarribia) (Figure 1). Additionally, it has two major commercial ports in Bilbao and Pasaia; fishing activities also take place in the port of Pasaia. All these ports generate certain amounts of fishing gear and ship generated waste. Similar initiatives have been implemented in other ports all around Europe, as explained in deliverable D4.1 of SEARCULAR (Guidelines on Good Management Practices for EOL fishing gear), and have successfully reduced the amount of waste generated by fishing-related activities while promoting the development of specialised recovery and treatment processes with economic value. Due to the similarities between the ports where these novel processing plants were established and the infrastructure present on the fishing ports located along the Basque coast, it has been considered that the implementation of a similar waste treatment facility could be beneficial for the local populations and environment.

The ports selected to potentially host a Blue Point are: Bermeo, Ondarroa, Hondarribia, Getaria, Bilbao, and Pasaia. These locations were chosen as they are the main fishing and commercial ports in the Basque Country and collectively represent the primary hubs where EOL fishing gear waste is generated. To better understand the waste generated by their activities and the current waste management practices, visits and consultation were conducted on the selected ports (explained in section 1.1). These visits helped to obtain first-hand knowledge on the operations of each port and gather relevant information on available infrastructure, existing EOL fishing gear management systems, and the current practices on material revalorization. This information was later used for the design of the Blue Point and for the overall improvement of their management in the region. In addition, meetings were held with representatives of the Basque Government, fishermen's guilds, and the management companies BIDEZAIN[2], TREDEBE[3], (Bizkaia) and ARREGI[4], SERBITZU[5] (Gipuzkoa), which are responsible for the public management service in each province. The data recollected from this activity has been compiled on Table 1.

Similarly, the ports of Bilbao and Pasaia were also visited and consulted regarding their waste generation and treatment practices. Although they do not currently host permanent fishing activities, they generate significant amounts of waste from other sources, mainly related to surface and logistical activities, as well as from fishing vessels that deposit used nets and gear for management. The waste streams generated in these ports may be compatible with some of the valorisation chains intended for implementation in fishing ports, particularly ropes used for ship mooring operations and EOL fishing gear.

[2] https://gestoresderesiduos.org/manager_centers/bidezain-s-l
[3] https://www.tradebe.com/
[4] https://arregi.eus/
[5] http://www.serbitzu.com/

Table 1. Type of activity, type of waste and the amount of waste for each of the main ports coordinated by Basque Government.

Port	Type of activity	Type of Waste	Amount of waste (kg)
Bermeo	Deepsea and Inshore Fishing	Main: Small scale longline, small-scale gillnet, purse seine, longline, gillnet Secondary: trolling, longline, pole and line.	6,492
Ondarroa	Deepsea Fishing	Main: Small scale longline, small-scale gillnet, purse seine, longline, gillnet Secondary: trolling, longline, pole and line.	104,730
Hondarribia	Inshore Fishing	Main: Small scale gillnet, small scale longline, purse seine Secondary: Trolling or longline, pole and line.	255
Getaria	Inshore Fishing	Main: Small scale gillnet, small scale longline, purse seine Secondary: Trolling or trammel nets, longlines, pots, pole and line.	410

Table 2. Type of activity, type of waste and the amount of waste for each of the nationally governed ports (also designated as ports of general interest).

Port	Type of activity	Type of Waste	Amount of waste
Bilbao	Industrial and bulk cargo operations and multi-purpose port operations and fishing (only Pasaia)	Ropes used for ship mooring operations and EOL fishing gear	200-300 t/year
Pasaia			>20 t/year

During the visits, it was observed that in very few cases sorting procedures were performed for EOL fishing gear, as a result, the waste generated by the different activities was directly sent to landfills or stored in the facilities without a clear objective in mind, as was the case with old fish nets, clearly deteriorated by their previous use. This raised concerns about the environmental and social impact generated by these practices. A clear need for waste valorisation was identified, and the implementation of a blue point in the region could help address this gap. The implementation of the so-called Blue Points could prove a strategic opportunity to advance toward a more sustainable and replicable model for EOL fishing gear management. From the conversations held with managers and involved entities —including fishermen's guilds and public administrations— it was observed that there is interest in their implementation. This demonstrates a willingness to establish the processes necessary for the valorisation of these waste streams that are currently being sent to landfills. Nevertheless, there is still a need to inform the workers at the different facilities about how and where EOL fishing gear should be deposited, as some of these activities long stablished and the people involved in them might not immediately see the incentives of being involved in waste valorisation initiatives. Therefore, there is a clear need to develop awareness campaigns and establish effective channels for transmitting information. Also, we must keep in mind that some waste valorisation technologies that might be limited by the proximity of these ports to natural reserves that exist on the Basque coast.

1.1. Visits to Ports in the Basque Country

The visits conducted made it possible to gain first-hand knowledge of the operations of each port, to gather relevant information on available infrastructure, current EOL fishing gear management systems, and the practices used in material revalorization. In addition, during the process, meetings were held with representatives of the Basque Government, fishermen's guilds, and the management companies BIDEZAIN (Bizkaia) and SERBITZU (Gipuzkoa), which are responsible for the public management service in each province. Also, good practices and areas for improvement were identified as well as the most suitable locations for the potential implementation of the Blue Point were determined.

The visits to the ports of the Basque Country had the following main objectives:

1. To identify the existing infrastructure in each port for the collection of EOL fishing gear and other MARPOL waste.
2. To analyse waste management systems, including waste sorting, storage, traceability, management by authorized companies, and final destination (reuse, recycling, incineration, or landfill).
3. To assess the feasibility of incorporating a Blue Point in one or more ports, adapted to their specific characteristics and needs, while considering the rest of the ports.
4. To quantify and classify waste associated with fishing gear, considering both its generation frequency and the predominant materials (nets, ropes, mooring lines, buoys, wood, packaging, hazardous waste, etc.).

5. To gather information on best practices in reverse logistics for optimizing waste flows to the Blue Point facilities as well as to recycling facilities, identifying operational, economic, or social barriers, along with opportunities for improvement toward a shared circular model among ports.
6. To develop guidelines and recommendations to improve waste management in ports and to facilitate the integration of a Blue Point in one of them, linked to the circular value chain of all EOL fishing gear generated in the different ports of the Basque Country.
7. To lay the foundations for a harmonized system between the ports of Bizkaia and Gipuzkoa that enhances sustainability, control, and the valorisation of waste generated by fishing activity.

The visits carried out to each of the selected ports are detailed below.

BERMEO Port

Date of visit	2025/11/20
Location	Muelle Nardiz Tar Benanzio, 31D, 48370 Bermeo, Bizkaia
Participants in the meeting	Port Authority and Waste Managers
Responsible waste management company	Bidezain
Number of operational vessels	28 vessels
Type of fishing	Inshore fishing
Coordinated by	Basque Government

Bermeo, one of the most significant fishing ports in the Basque Country in terms of both activity volume and strong fishing tradition, has a relatively advanced system for the collection of general waste and a large, well-equipped waste collection area, consisting of a storage yard of approximately 700 m² and an auxiliary building of 250 m². However, the absence of a specific system dedicated to the management of EOL fishing gear was noted. Although there is general infrastructure for the collection of marine litter, EOL fishing gear is not clearly differentiated and, in most cases, does not undergo any form of valorisation.

During the visit, it was observed that waste generated by fishing activities is mainly stored in big bags, 1,000-liter containers, or even directly on the ground, and is later transferred by the waste management service to the corresponding containers. While certain materials such as packaging, glass, or wood already have established recycling routes, most fishing gear—especially nets and ropes—is managed through landfill disposal, at an approximate cost of at least €80 per tonne, plus transport costs.

Figure 2. Images of space and materials in the waste collection area of BERMEO port.

ONDARROA Port

Date of visit	2025/11/20
Location	48700 Ondarroa, Bizkaia
Participants in the meeting	Waste Managers
Responsible waste management company	Bidezain
Number of operational vessels	≈ 10 bottom otter trawlers and 1 pair trawlers
Type of fishing	Mainly deep-sea fishing
Coordinated by	Basque Government

The Port of Ondarroa, located in one of the most active fishing areas of the Basque Country, was another key site included in the visits. This port has intense and specialized fishing activity (mainly trawling), although its infrastructure for the management of EOL fishing gear is limited. It has a small waste collection area with two enclosed 20 m³ containers, which is well organized but has limited capacity. The construction of a new larger facility is planned. The amount of waste generated is not high and its frequency is low (every 3–4 months). Fishermen deposit nets and mooring lines without separation, and most of this waste is also sent to landfill, at a cost of at least €80 per tonne plus transport costs. One of the main concerns expressed at the port is the national debate on Extended Producer Responsibility (EPR) as applied to fishing gear, which could have economic repercussions on an already highly weakened fishing sector.

Figure 3. Images of space and materials in the waste collection area of ONDARROA port

Figure 4. Images of space and materials in the waste collection area of ONDARROA port

HONDARRIBIA Port

Date of visit	2025/11/24
Location	Ramon Iribarren Pasealekua Ibilbidea, s/n, 20280 Hondarribia, Gipuzkoa
Participants in the meeting	Waste Managers
Responsible waste management company	Serbitzu
Number of operational vessels	15 purse seine and 21 – 22 small scale vessels.
Type of fishing	Inshore fishing
Coordinated by	Basque Government

Hondarribia stands out for its orderliness and the effective coordination between the fishermen's guild and the waste management companies. Fishermen carry out careful pre-sorting: nets, ropes, buoys, filters, and packaging are properly classified prior to storage. The port has a very well-organized waste collection area of approximately 20 × 20 m, where waste management company SERBITZU reorganizes ropes of greater length and volume. Although part of the waste has recycling or reuse pathways (for example, hard buoys, ropes reused in gyms or farmhouses, and nets sent to Ukraine for anti-drone defense), fishing gear that cannot be reused is sent to landfill or incineration, with significant technical limitations imposed by the incineration plant.

Figure 5. Images of space and materials in the waste collection area of HONDARRIBIA port.

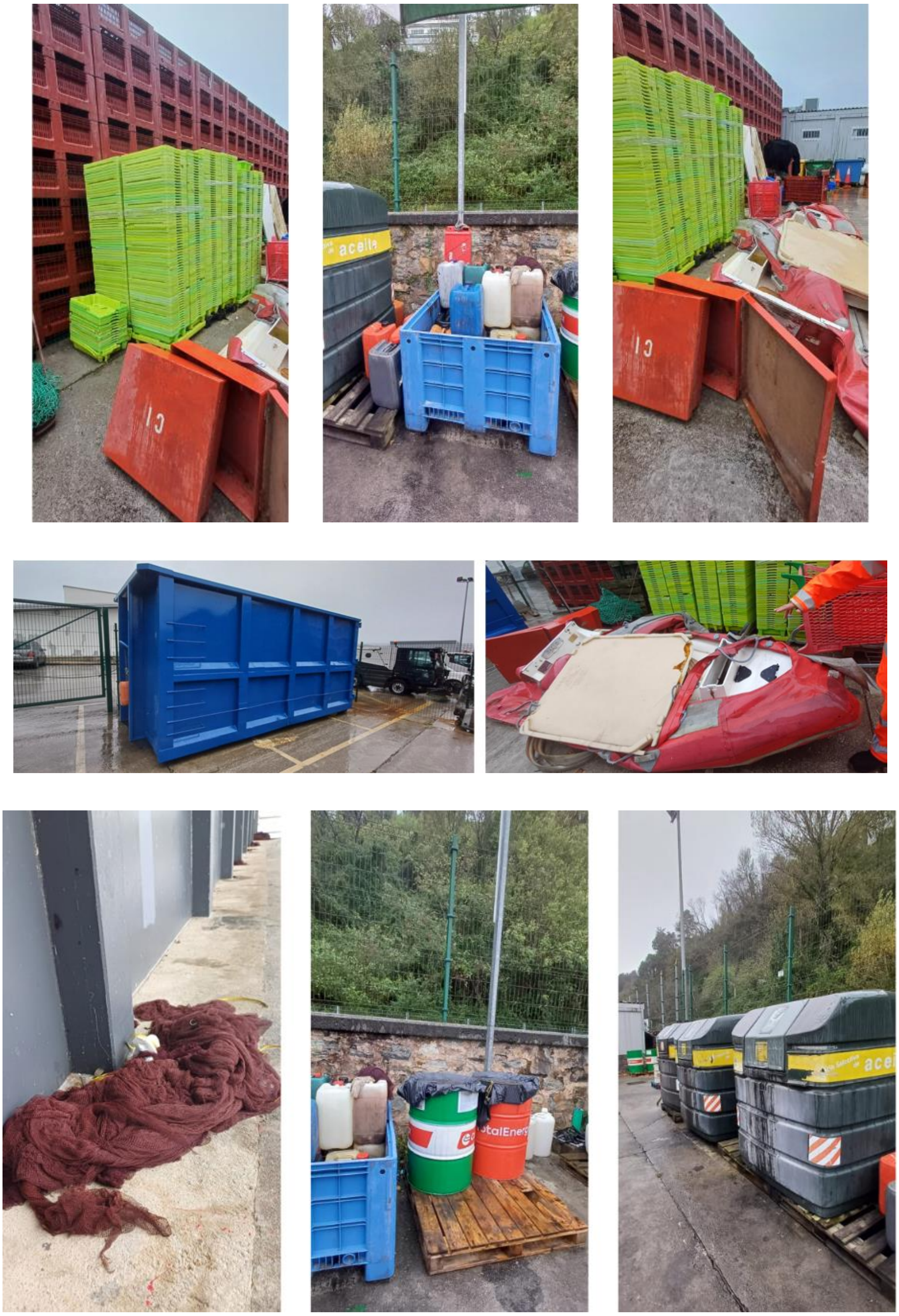


Figure 6. Images of space and materials in the waste collection area of HONDARRIBIA port.

GETARIA Port

Date of visit	2025/11/24
Location	Portua Kalea, 3, 20808 Getaria, Gipuzkoa
Participants in the meeting	Waste Managers
Responsible waste management company	Serbitzu
Number of operational vessels	15 vessels
Type of fishing	Inshore fishing
Coordinated by	Basque Government

Getaria has a small waste collection point of limited size (approximately 18 × 25 m). Although it has containers for various types of waste, the space is more constrained and less orderly compared to other ports. The port also hosts the activity of a group of women dedicated to net mending, which generates small additional volumes of waste. The generation of fishing gear waste is moderate and, as in the other ports, most of it ends up in landfill due to the lack of viable valorisation alternatives.

Figure 7. Images of space and materials in the waste collection area of GETARIA port

Figure 8. Images of space and materials in the waste collection area of GETARIA port.

Figure 9. Space for nets repair in GETARIA port.

BILBAO Port

Date of visit	2023/12/12; 28/11/2025; 2026/02/20; 2026/04/24
Location	Mlle. Ampliación, s/n, 48980 Santurtzi, Bizkaia
Participants in the meeting	Port Authority
Responsible waste management company	Port Authority and Waste Managers
Number of operational vessels	2-3 (at port of Santurtzi)
Type of fishing	N/A
Coordinated by	Spanish Government

The Port of Bilbao, one of the largest and most dynamic ports in Iberian Peninsula, is a key hub for industrial and commercial activity. It is not predominantly a fishing port; therefore, the most significant waste streams originate from the shipping activities occurring at port and from logistical activities associated with maritime traffic. A large share of this waste is sent to landfill; however, the port has a well-established waste management company (TRADEBE), which collects, treats and valorises approximately 200–300 tonnes of waste per year. Most of the EOL fishing gear consisted mainly of mooring lines, ropes, and hawsers used for berthing and securing vessels.

The infrastructure of the Port of Bilbao allows for the easy integration of the Blue Point solution. Members of the environmental department of the port authority expressed a positive attitude toward the concept of a Blue Point, recognizing the importance of properly managing EOL fishing gear and optimizing the recycling process.

Figure 10. Map of the Bilbao port.

Figure 11. Images of space and materials in the waste collection area of BILBAO port.

PASAIA Port

Date of visit	04/12/2025
Location	Ámbito Portuario Kalea, s/n, Pasai Antxo, 20100 Pasai Donibane, Gipuzkoa
Participants in the meeting	Port Authority and Environmental department
Responsible waste management company	Port Authority
Number of operational vessels	14 or 15 inshore and 2 or 3 offshore (San Pedro Fishermen's Association)
Type of fishing	
Coordinated by	Spanish Government

Pasaia, a traditional commercial and fishing port with activity closely linked to distant fishing fleet, was also visited to evaluate waste management. It was noted in Pasaia that many vessels calling port do not have a permanent base in the port, which makes controlling waste generation difficult. The implementation of an advanced system such as a Blue Point faces economic and administrative barriers, particularly regarding funding. There is a waste collection point that collects certain types of waste (not fishing gear), and part of the used oil is reused. If any EOL fishing gear appears, an authorized manager collects it, generally for disposal in landfill. In any case, this type of waste should ideally not appear in the port, as its management depends on each vessel or fishermen's guild. The port has some well-established waste management companies (ARREGI, TRADEBE and SANEMAR) and they also have contact with local recyclers. Interesting data shows that they do not have available land, and that strong traceability systems and a lot of awareness work are required.

Figure 12. mages of space and materials in the waste collection area of PASAIA port.

Figure 13. Images of oil recovery area in PASAIA port.

Results of the questionnaire conducted during meetings with the different ports

Annual generation and waste types

The ports with the highest generation of EOL fishing gear are Bilbao, Bermeo and Ondarroa in Bizkaia (according to TRADEBE and BIDEZAIN) and Pasaia, Hondarribia and Getaria in Gipuzkoa (according to SERBITZU, ARREGI and TRADEBE). In the other ports, waste generation is marginal.

Table 3. Annually produced Basque region EOL FG plastics waste quantities in fishing ports (kg).

Ondarroa	Bermeo	Getaria	Hondarribia
104,730	9,700	410	255

Table 4. Annually produced Basque region EOL FG plastics waste quantities in commercial ports (t).

Bilbao	Pasaia
200-300	› 20

Generation frequency

- **Bermeo:** highly variable, small quantities almost daily.
- **Ondarroa:** every 3–4 months.
- **Hondarribia and Getaria:** irregular generation, dependent on the fishing season.
- **Bilbao and Pasaia:** The fishing gear waste from Bilbao comes mainly from the small fishing port of Santutzi, which has 2-3 small scale vessels. It is generated irregularly and in small quantities. However, large quantities of mooring ropes and other similar waste are generated and deposited in the commercial port of Bilbao (1 container truck every 2 months). Similarly, in Pasaia, quantities are generated mainly associated with fishing nets from boats that deposit them in Pasaia (they are not Basque) and mooring ropes, although the estimated quantity has not been reported to date, other than the certainty of having to manage at least 15 tonnes of nets per year (2026), mainly polyamide, both monofilament and multifilament.

Management and final destination

In both the Basque fishing ports and the state commercial ports, these sites are managed by waste management companies responsible for correct storage and coding before transporting them to waste management points. Regarding nets, ropes, and other EOL fishing gear elements, these management companies opt for reuse whenever possible—the priority path in the waste management hierarchy established by the current European Directive (Directive 2008/98/EC). This is done through personalized delivery for local agricultural or livestock activities, physical education centres such as gyms or crossfit centres, and recently, through requests from associations to send nets to Ukraine as anti-drone elements. However, this reuse management path is not implemented as an established, stable, or formalized circuit, nor does it have a supporting infrastructure. Consequently, the **most common option is landfill disposal**, as energy recovery facilities restrict their inclusion due to operational issues (As a side note, the cost of incineration would be around €200/tonne.). The morphology of nets and ropes can cause blockages and damage to the equipment in such facilities. On the other hand, there is sometimes the option of using an external waste manager where there is no full certainty of proper mechanical recycling—although it is often marketed as such. Furthermore, this service is economically costly and involves transporting the waste outside the territory, resulting in high transport costs and emissions. Additionally, some materials have established valorisation routes following MARPOL Convention (73/78), such as plastic packaging, glass, shredded wood, hard buoys, and metals.

Management costs

- Landfill (Bizkaia): > 80 €/t + transport (> 120 €/t) (≈ 250 €/t)
- Incineration (Gipuzkoa): ~200 €/t

Transport

In all ports, waste is transported by container truck.

Form of deposit

- **Bermeo:** big bags, 1,000 L containers, or direct deposit on the ground.
- **Ondarroa:** containers without separation.
- **Hondarribia:** very careful pre-sorting by fishermen.
- **Getaria:** initial mixed deposit, with subsequent sorting by SERBITZU.
- **Bilbao and Pasaia:** containers, big-bags depending on the batch type, the origin...

Most common materials

Nets, ropes, mooring lines, buoys, wood, metal, packaging, bulky items, hazardous waste (paint cans, filters), mixed waste.
Ondarroa shows a higher presence of polyolefins and seine ropes; in general, polyamide (PA) nets are less frequent.

Available area

- **Bermeo:** 700 m² yard + 250 m² building.
- **Ondarroa:** small area with two 20 m³ containers.
- **Hondarribia:** ≈ 20×20 m.
- **Getaria:** ≈ 18×25 m.
- **Bilbao and Getaria:** Available area of the Waste Managers in port. Bilbao has an additional available area of at least 150 m².

Samples

Bilbao, Bermeo, Ondarroa, Hondarribia and Getaria have provided samples for SEARCULAR Project.

Identified improvements

- Need for increased awareness and better separation in some ports.
- Space limitations (Ondarroa, Pasaia, Hondarribia, Getaria).
- Risk that EPR may increase costs for fishermen.
- Need to improve traceability (Getaria).
- Good relationship with the fishermen's guild is a key factor (Hondarribia).

Conclusions from port visits

The visits to the ports of the Basque Country have provided a detailed and comparative understanding of waste from fishing vessels management, the available infrastructure, and the level of progress of each facility in terms of sustainability. In general, it is observed that, despite the existence of relatively organized systems for the collection of general waste and, in some cases, large and well-equipped facilities such as waste collection areas, most ports lack specific mechanisms for managing EOL fishing gear. This absence is evident both in the lack of dedicated spaces and in the absence of clear valorisation routes, resulting in most of these materials, especially nets and ropes, being sent to landfill, with the corresponding economic and environmental impacts.

The situation observed in ports such as Bermeo illustrates that they do have advanced infrastructure for general waste management, even if fishing gear are stored heterogeneously in big bags or 1,000-liter containers, without a systematic process to facilitate its valorisation. In this context, the implementation of Blue Points presents a strategic opportunity to advance toward a more sustainable and replicable model for EOL fishing gear management. Conversations with waste managers and involved entities (including fishermen's guilds and public administrations) have been positive, demonstrating a willingness to collaborate in developing these solutions. This institutional and sectoral response provides a solid foundation for progressing toward more efficient reverse logistics systems and for the incorporation of valorisation technologies capable of transforming materials currently sent to landfill.

Based on the studies, analyses and port visits carried out within this work, as well as on the information gathered through meetings with port managers, port authorities and waste management operators, it has been concluded that, considering available space, volumes of materials generated and overall operational feasibility, **the ports where an Smart Blue Point could potentially be implemented are Bermeo and Bilbao**. Among these, **Bilbao appears to be the most favourable option in terms of available space and logistical capacity**. In addition, the planned construction of a pyrolysis plant within the Port of Bilbao would significantly facilitate the management of those waste streams destined for this type of valorisation, reducing transportation distances and associated costs within the framework of an efficient reverse logistics system.

Nevertheless, it should be noted that Bilbao is a nationally governed port, which depends on Spanish Government ("Puertos del Estado") and it is managed by Port Authorities. Therefore, the specific competencies, administrative frameworks and potential constraints associated with handling waste originating from ports managed by the Basque Government are not fully known at this stage. In any case, the feasibility of such an arrangement would need to be assessed and validated by the competent authorities. From a technical and operational perspective, this research identifies Bilbao as the optimal port for the implementation of an intelligent Blue Point. However, should this option ultimately prove unviable, Bermeo emerges as a strong alternative. Although Hondarribia initially appeared to be a suitable candidate, Bermeo is considered a more robust option due to its higher volumes of fishing-related waste and its existing infrastructure. Bermeo was initially excluded because of the intention to implement a pyrolysis plant with the Blue Point and its proximity to a Biosphere Reserve; however, based on the quantities of materials generated, it is no longer considered necessary to install a pyrolysis facility at the Blue Point itself. Under this revised approach, Bermeo once again represents an optimal location for the proposed implementation.

1.2. Types of waste streams in the case study of the ports Basque Country region

The visits, technical assessments, and consultations carried out at the ports selected within the Basque Country case study made it possible to obtain a more comprehensive understanding of the different waste streams generated by port-related activities, as well as the current practices used for their collection, handling, and management. These activities provided valuable first-hand information regarding the typology, composition, quantities, and variability of the materials reaching the ports, together with the existing infrastructure available for their temporary storage and treatment.

Ports generate a wide variety of waste streams originating from fishing activities, ship maintenance operations, logistics, and maritime transport. These residues include plastics, metals, wood, ropes, fishing nets, fish traps, floats, packaging waste, organic matter, oils, and mixed municipal waste, among others. Some of these streams may require specific handling conditions due to their hazardous nature, their heterogeneous composition, or the operational difficulties associated with their management and valorisation.

In the ports of the Basque Country, MARPOL wastes are already managed through established recycling and recovery schemes, particularly in the case of oils, metallic scrap or other conventional industrial residues. However, the assessments carried out during the project revealed that there is still considerable room for improvement regarding the management and valorisation of EOL fishing gear and associated marine litter streams. In many cases, these materials are currently handled through mixed collection systems or are directed toward landfill or energy recovery due to the absence of dedicated sorting, traceability, and recycling routes specifically adapted to fishing gear waste. This situation not only limits the recovery potential of valuable materials, but also generates additional economic costs associated with waste disposal.

As part of the study, a comprehensive compilation of the different waste streams present in the ports of the Basque Country was carried out, together with an evaluation of the available waste collection, storage, and handling infrastructure at each facility. The different residues identified and collected in each port are summarized Table 5.

Table 5. Different waste streams present in the ports of the Basque Country

Residue	Location	Photo
Fishing nets	Bermeo Ondarroa Hondarribia Getaria Pasaia	
Fish traps	Bermeo Ondarroa	

Ropes and Mooring lines	Bermeo Ondarroa Hondarribia Getaria Pasaia Bilbao	
Tires	Bermeo Ondarroa Hondarribia Getaria	
Glass	Bermeo Ondarroa Hondarribia Getaria Pasaia	
Scrap metal	Bermeo Ondarroa Hondarribia Getaria Pasaia	
Wood	Bermeo Ondarroa Hondarribia Getaria Pasaia	
Trays	Bermeo Ondarroa Hondarribia Getaria	

Sanitary products	Bermeo Ondarroa Hondarribia Getaria Pasaia Bilbao	
Used Oil	Bermeo Ondarroa Hondarribia Getaria Pasaia Bilbao	
Ship parts (metal)	Bermeo Ondarroa Hondarribia Getaria	
Ship parts (glass fibre)	Bermeo Ondarroa Hondarribia Getaria	
Ship parts (Sails)	Bermeo Ondarroa Hondarribia Getaria	
Tubes	Bermeo Ondarroa Hondarribia Getaria	

Floaters	Bermeo Ondarroa Hondarribia Getaria	

It should also be considered that the generation of several of these waste streams is highly variable and strongly influenced by the seasonality of fishing activities. EOL Fishing gear generation is directly linked to fishing campaigns, maintenance periods, species capture permits, and weather conditions, resulting in fluctuating quantities throughout the year. For this reason, information regarding waste generation frequency and operational patterns was also collected in order to support the future planning and dimensioning of the proposed Blue Point facility and its associated logistics system.

The assessments performed in the different ports indicated the following general generation patterns:

1. **Bermeo:** highly variable generation, with relatively small quantities being generated almost daily due to the intensity of fishing activities.
2. **Ondarroa:** waste generation concentrated approximately every 3–4 months, generally associated with maintenance and replacement operations.
3. **Hondarribia and Getaria:** irregular generation patterns closely linked to fishing seasons and operational activity.
4. **Pasaia and Bilbao:** regular flow of mooring lines and vessel berthing ropes, followed by an irregular generation strongly influenced by meteorological conditions and by waste collected from the water surface and port areas.

In addition to regularly generated waste streams, extreme meteorological events were identified as another important factor influencing both the quantity and composition of marine litter reaching the ports. Storms, heavy rainfall, and adverse sea conditions may cause fishing gear, mooring lines, ropes, and other floating materials to break, drift, and accumulate in port waters and coastal areas. Consequently, ports are occasionally required to recover substantial quantities of additional waste from the water surface in order to guarantee safe navigation and operational conditions.

These events can temporarily increase the annual quantities of EOL fishing gear and ropes/lines from other origin managed at the ports. However, due to their irregular and unpredictable nature, these waste streams cannot currently be quantified or forecasted as stable generation flows. Examples of mooring lines and floating marine litter collected after extreme meteorological events are shown in Figure 14.

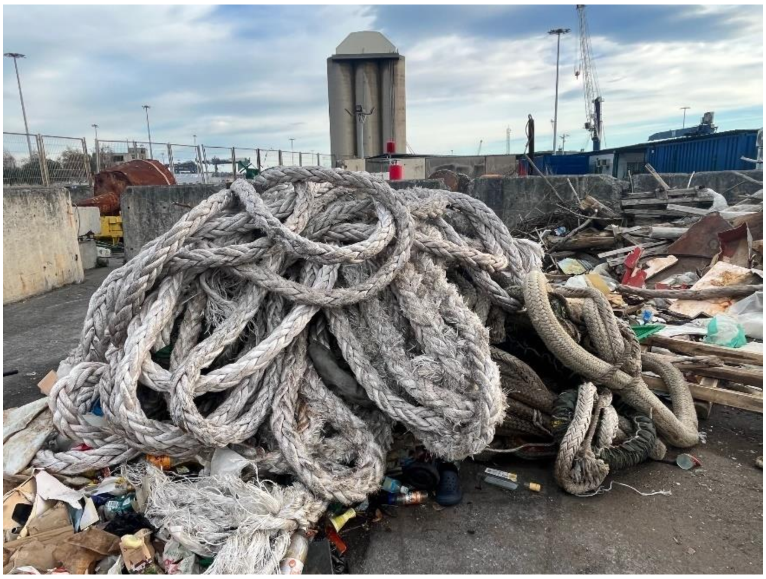


Figure 14. Mooring lines and floating marine litter collected after extreme meteorological events in the port of Bilbao

Furthermore, these meteorological events do not only affect fishing gear and mooring systems but also transport significant quantities of additional marine litter and river-borne waste into ports and beaches. Port authorities and waste management operators consulted during the study highlighted that, following storm events and periods of intense rainfall, substantial accumulations of branches, algae, plastics, household items, packaging waste, and other urban litter are frequently collected from port waters and coastal areas. Since ports are responsible for removing these materials from the water surface to ensure navigational safety and prevent damage to vessels and infrastructure, these additional waste streams were also considered within the scope of the Blue Point concept.

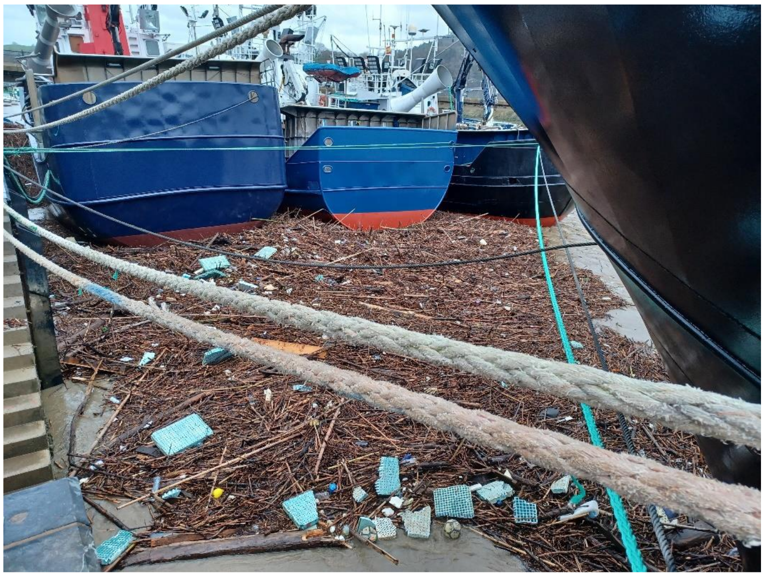


Figure 15. River-borne wood waste

Consequently, the possibility of integrating complementary treatment and valorisation solutions for these materials within the Blue Point infrastructure was identified as a relevant opportunity. This approach could contribute not only to improving the environmental management of fishing-related waste, but also to enhancing the overall management of marine litter and climate-related waste streams in coastal areas.

The study also highlighted those certain residues with relatively high economic value, such as metallic scrap or specific industrial waste fractions, are already managed through established waste management operators, including BIDEZAIN, TRADEBE, and SERBITZU. Nevertheless, other streams such as fishing nets, ropes, fish traps, floats, and mixed fishing gear still lack consolidated valorisation routes and remain insufficiently integrated into circular economy schemes. These materials represent the primary target streams addressed by the SEARCULAR project.

Another relevant aspect identified during the consultations with fishermen and port stakeholders was the growing concern regarding the future implementation of EPR frameworks for fishing gear. The potential introduction of these regulatory obligations reinforces the importance of establishing efficient collection systems, traceability mechanisms, and viable recycling and valorisation routes for EOL fishing gear and other marine waste.

Finally, the visits and technical evaluations carried out during the project demonstrated that the ports included in the case study generally possess sufficient space and basic infrastructure to support the implementation of decentralized collection points associated with the proposed Blue Point system. In several ports, preliminary collection areas for EOL fishing gear already exist and could potentially be adapted, optimized, and integrated into a more coordinated and traceable waste management network under the Smart Blue Point approach proposed within the SEARCULAR project.

1.2.1. Contaminants associated with EOL fishing nets

EOL fishing gear typically present a high level of heterogeneity and contamination, resulting from their prolonged use in marine environments, on-board handling, repair practices and storage conditions. Identifying and characterising these contaminants is a critical step in the classification and conditioning stages, as they directly influence material quality, process selection, occupational safety and the feasibility of mechanical or chemical recycling routes. A systematic assessment of contaminants enables informed decision-making regarding sorting efficiency, cleaning requirements, rejection criteria and final destination, while also supporting traceability, quality control and compliance with recycling specifications. The following table provides an overview of the main types of contaminants commonly found in EOL fishing gear, serving as a reference framework for classification and pre-treatment activities within the Blue Point model.

Table 6. Typical contaminants found in EOL fishing gear

Contaminant category	Type of contaminant	Description / origin	Impact on recycling processes
Organic contaminants	Marine biomass	Algae, biofouling, shells, microorganisms attached during use at sea	Increases moisture, causes odours, requires washing
	Fish residues	Fish remains, oils, organic matter	Degradation during storage, affects material quality
Inorganic contaminants	Sand and sediments	Sand, mud, seabed particles embedded in fibres	Abrasive wear in shredders, reduces yield
	Salts	Sodium chloride and other marine salts	Corrosion issues, affects material stability
Foreign materials (solids)	Metals	Chains, weights, hooks, wires	Major risk for equipment damage
	Rubber parts	Floats, protective coatings	Incompatible with plastic recycling
	Wood	Stakes, spacers, fragments	Causes impurities and sorting issues
Polymer cross-contamination	Mixed plastics	PE, PP, PA, PET mixed in one gear	Limits mechanical recycling quality
	Non-target polymers	PVC, PU coatings or reinforcements	Requires separation or rejection
Chemical contaminants	Oils and greases	Lubricants from vessels or equipment	Affects flake cleanliness
	Fuel residues	Diesel, hydrocarbons from boats	Safety and emissions concerns
Weathering and degradation products	Microplastics	Fragmented fibres due to ageing	Loss of mechanical properties
	UV-degraded material	Embrittled or oxidised polymers	Limited recyclability
Operational contaminants	Paints and coatings	Anti-fouling paints, coloured coatings	Interferes with polymer purity
	Adhesives / tapes	Repair materials applied on board	Difficult to remove
Packaging and accidental waste	Plastics waste	Bags, films, packaging mixed during collection	Reduces traceability accuracy

2. Blue Points at Port

2.1. Definition of the requirements of the facility and waste collection scheme for the port location

As part of the development of the SEARCULAR Smart Blue Point concept, a comprehensive assessment was carried out to define the technical, operational, logistical, and environmental requirements necessary for the implementation of an efficient collection and treatment scheme EOL fishing gear in the Basque Country region. This assessment was not limited to the analysis of local conditions but also included an extensive review of existing European and international initiatives focused on the collection, management, recycling, and valorisation of fishing-industry-related waste streams. The objective of this benchmarking activity was to identify best practices, common operational approaches, existing technological solutions, and potential limitations associated with current systems, in order to define an optimized and replicable Blue Point model adapted to the specific characteristics of the Basque fishing sector.

Across Europe, several initiatives have already demonstrated the feasibility of organized collection and recycling systems for fishing-industry waste. In Norway, for example, the national strategy aims to recycle up to 81% of the waste generated by the fishing industry by 2040 through the implementation of dedicated collection points distributed across ports, from which waste is subsequently transferred to specialized treatment facilities. In Iceland and Ireland, existing initiatives are primarily focused on extending the service life of fishing gear through repair and reuse activities, while highly degraded materials are separated and transferred to recycling centres for valorisation. In countries such as France and the United Kingdom, greater emphasis has been placed on the selective recovery of specific polymer fractions, particularly nylon-based materials, through advanced sorting systems intended to maximize recycling efficiency and minimize residual waste generation. A map with a compilation of these different projects can be seen in Figure 16.

Outside Europe, several relevant initiatives were also analysed. Particularly noteworthy is the REFINVERSE Group initiative in Japan, which demonstrates the technical and economic viability of privately operated fishing-net recycling systems. This initiative, mainly focused on nylon recovery, currently processes more than 7,000 tonnes of EOL fishing gear annually while achieving significant reductions in greenhouse gas emissions compared to virgin polymer production. The recycled polymers obtained are subsequently commercialized in sectors such as automotive manufacturing, fashion, and plastics production, demonstrating the potential economic value associated with well-structured valorisation systems.

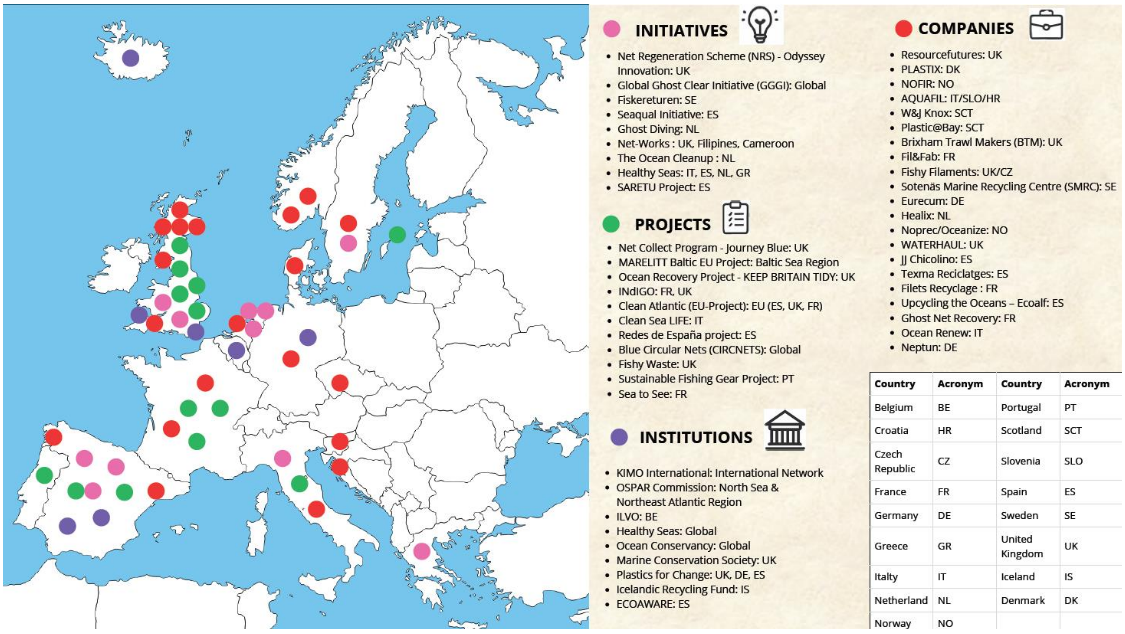


Figure 16. Compilation of different initiatives, projects, institutions and companies across Europe

The comparative analysis of these initiatives revealed several common characteristics that were considered fundamental for the conceptualization and definition of the SEARCULAR Smart Blue Point model. Firstly, waste collection is systematically organized at local port level, enabling proximity-based collection schemes that facilitate participation by fishing operators and reduce uncontrolled disposal. Secondly, centralized or semi-centralized treatment hubs are generally implemented to perform the characterization, sorting, conditioning, and preparation of materials prior to recycling or recovery. Thirdly, all analysed systems rely heavily on manual or semi-manual material classification processes due to the highly heterogeneous composition of fishing gear waste, which often includes plastics, metals, textiles, ropes, floats, and other components integrated into the same equipment. Finally, dedicated management routes are always required for those waste fractions that cannot be mechanically recycled, including chemical recycling, energy recovery, or controlled landfill disposal.

These findings were used as the basis for defining the infrastructure requirements, operational procedures, and collection scheme associated with the Smart Blue Point proposed within the SEARCULAR project. The system was designed considering the estimated generation of approximately **500 tonnes per year** of EOL fishing gear in the Basque coastal region, based on data collected through port visits, stakeholder consultations, waste characterization campaigns, and reverse logistics analyses carried out throughout the project.

The proposed Blue Point concept is based on a centralized facility connected to decentralized local collection points distributed across the main fishing ports of the Basque Country. At local level, ports are required to provide designated collection areas equipped with appropriate infrastructure, including weather-resistant containers, covered storage systems, big-bag solutions, and temporary storage areas allowing the separate collection of different fishing-gear-related waste streams. During the assessment phase, significant differences were identified among ports regarding available space, infrastructure quality, and operational organization. While certain ports already possess relatively organized and spacious waste collection areas, others operate with very limited storage capacity and insufficient segregation systems. Furthermore, a generalized lack of traceability mechanisms for incoming waste streams was identified across nearly all assessed ports, making it difficult to accurately monitor waste quantities, material composition, and final treatment routes.

The location of collection points within ports was therefore considered a critical aspect in the facility design process. Collection areas must be easily accessible both for fishing vessels during unloading operations and for external logistics operators responsible for transportation to the central Blue Point facility. In addition, these areas must minimize interference with normal port activities while ensuring safe handling conditions and preventing environmental leakage into the marine environment. Consequently, the implementation of impermeable flooring, drainage systems, spill control infrastructure, and adequate weather protection systems was identified as a fundamental requirement for all collection areas.

Once collected locally, the EOL fishing gear would be transported to the centralized Blue Point facility, where characterization, dismantling, sorting, conditioning, storage, and preparation for valorisation would take place. Three main valorisation routes were defined within the proposed management scheme.

The first valorisation route corresponds to mechanical recycling. In this case also, materials are manually characterized, sorted, washed, dried, and shredded in order to obtain sufficiently clean and homogeneous plastic fractions suitable for extrusion and pelletisation processes. Mechanical recycling was identified as one of the most technically mature and environmentally favourable alternatives for several fishing-gear-related polymers, particularly polyamides and certain polyolefin fractions. The inclusion of extrusion and pelletizing stages was additionally considered highly beneficial for increasing the market value of the recovered materials and facilitating their commercialization into new industrial applications.

The second valorisation route corresponds to chemical recycling through pyrolysis. This route was specifically considered for plastic fractions that are difficult to mechanically recycle due to contamination, degradation, or complex composition. Following characterization, sorting, and conditioning operations, suitable polymers—primarily polyethylene (PE) and polypropylene (PP) and its mixtures—can be processed through pyrolysis to obtain high-value pyrolysis oils intended to produce new plastics. The inclusion of chemical recycling pathways was considered particularly relevant within the SEARCULAR framework due to the heterogeneous nature of fishing-gear waste and the limited recycling alternatives currently available for certain fractions.

The third valorisation route consists of direct transfer to specialized recyclers for specific material streams such as metals, wood, and other non-plastic fractions. Since dedicated recycling infrastructures for these materials already exist, only basic operations such as cleaning, dismantling, or temporary storage would be required at the Blue Point before transportation to external recovery operators.

Due to the complexity and heterogeneity of EOL fishing gear, manual characterization and dismantling activities were identified as essential operational stages. Fishing gear frequently consists of multi-material structures combining plastics, metallic elements, textiles, and composite components within the same product. As a result, fully automated classification systems are currently not technically or economically feasible under the expected waste volumes of the Basque region. Manual inspection and characterization are therefore necessary to identify the number of material fractions present in each fishing gear component and determine their corresponding polymeric or material composition.

Based on the operational simulations and pilot-scale activities carried out during the project, it was estimated that the Blue Point facility would require an overall operational area of approximately 3,600–4,000 m², including an industrial building of **approximately 750 m² dedicated to processing activities**. The studies conducted and the pilot-scale simulation involving approximately 14 tonnes of EOL fishing gear demonstrated the technical feasibility of operating this type of facility under real conditions and allowed the estimation of the human resources required for full-scale operation. Personnel requirements will ultimately depend on the annual material throughput, the diversity of incoming waste streams, and the level of processing and valorisation implemented at the facility.

Regarding the logistics and workforce involved during the pilot-scale activities, two operators participated in the characterization, classification and conditioning tasks over a period of two working days, with approximately five operational hours per day. Under these conditions, it was estimated that an entire container of EOL fishing gear could be processed within this timeframe, corresponding to approximately 1,500 kg of material in two days. These results provided a realistic estimation of the operational capacity and labour requirements associated with the proposed Blue Point model.

A wide range of machinery and manual tools was required to perform the cutting, handling and movement operations associated with the processing of EOL fishing gear. The equipment used included scissors, pruning shears of different sizes, saws, axes, electric scissors and a hydraulic cutter, allowing the dismantling and separation of highly heterogeneous and resistant materials. In addition, a crane equipped with a grabber was employed for the handling, unloading and movement of heavier fishing gear elements and containers, facilitating safe and efficient material management throughout the simulation activities.

The facility must incorporate a wide range of equipment and infrastructure specifically adapted to the handling of bulky, heavy, contaminated, and heterogeneous EOL fishing-gear-related. Required equipment includes cutting tools, electric scissors, saws, chisels, pulleys, lifting systems, forklifts, cranes equipped with grapple systems, and adequate containers for both incoming and classified materials. In particular, cranes and grapple systems are considered essential for unloading large fishing gear components, moving containers, emptying bulk material onto sorting areas, and separating heavy waste fractions. Overhead pulley systems are also necessary to facilitate the movement and handling of individual fishing gear units during dismantling and characterization operations.

The characterization and identification of materials additionally require the incorporation of portable analytical technologies. Specifically, handheld near-infrared (NIR) spectrometers were identified as necessary tools for polymer identification and classification, while portable X-ray fluorescence (XRF) systems were considered highly valuable for metallic fraction identification and separation.

In addition to classification activities, the Blue Point facility must include adequate conditioning technologies capable of preparing the materials for subsequent valorisation processes. This includes shredding systems specifically adapted for fishing-gear-related materials, together with washing and drying systems designed to remove salt, sand, organic matter, humidity, and other contaminants typically associated with marine waste streams. These conditioning stages are considered essential to ensure that the processed materials comply with the technical specifications required for mechanical and chemical recycling processes, while simultaneously increasing their market value.

Environmental protection and occupational safety requirements were also identified as critical design criteria. Consequently, the facility must incorporate impermeable flooring, drainage and wastewater treatment systems, spill containment infrastructure, and appropriate cleaning equipment to prevent environmental contamination. In parallel, the implementation of operational protocols, emergency response procedures, and specific personnel training programs was considered necessary to ensure safe and efficient operation of the facility under both normal and accidental scenarios. Appropriate personal protective equipment (PPE) must also be provided to all operators involved in material handling and processing activities.

A preliminary cost assessment related to the implementation of the BluePoint is presented in D5.2 – Sustainability Validation of SEARCULAR Solutions. The analysis showed that the main cost drivers are the staff expenses (including a director and two operators), energy consumption, and the rental of the BluePoint building. Together, these account for approximately 90% and 92% of total costs for annual collection volumes of 300 and 500 tons of EOL fishing gear respectively. In absolute terms, total costs are expected to range from €1.04 to €1.20 per kg for 300 tons collected, and from €0.84 to €0.94 per kg for 500 tons. If the BluePoint building rental cost is excluded, these figures are expected to decrease to between €0.94 and €1.02 per kg for 300 tons, and between €0.79 and €0.83 per kg for 500 tonnes. More detailed information about methodologies as well as data (and their sources) used for these analyses will be available in D5.2.

All operational areas within the facility—including collection, characterization, dismantling, classification, conditioning, and storage zones—must be appropriately signposted and organized to facilitate safe operation and efficient material flow management. Furthermore, the implementation of an intelligent digital traceability system was identified as one of the core requirements of the Smart Blue Point concept. This system will allow continuous monitoring of all material flows from their arrival at port collection points to their final valorisation route. In addition to ensuring traceability, the system will enable the collection and analysis of Key Performance Indicators (KPIs) related to operational efficiency, material recovery rates, environmental performance, and carbon footprint metrics associated with the management and valorisation processes.

The continuous monitoring and analysis of operational and environmental data through digital systems will additionally support predictive maintenance strategies, allowing early detection of equipment malfunctions and optimization of energy consumption and facility performance.

Finally, based on the various technical studies, stakeholder consultations, reverse logistics analyses, meetings with port authorities, and site visits carried out during the project, the Port of Bilbao was identified as the most suitable location for the implementation of the centralized Blue Point facility. This selection was primarily supported by its available space, existing industrial infrastructure, advanced logistical capacity, and strategic connectivity within regional transport networks. Nevertheless, since the Port of Bilbao is administered by the Spanish national government rather than by the Basque regional authorities, additional administrative and regulatory analyses will be required to fully assess the feasibility of integrating waste streams originating from ports managed under different institutional frameworks.

For the remaining ports within the Basque coastal network, the currently available infrastructures were considered generally suitable for temporary waste storage prior to transportation to the centralized Blue Point facility. Regarding transportation logistics, both maritime and road transport alternatives were evaluated. Maritime transport was identified as the preferred option from an environmental and energy-efficiency perspective, particularly for heavy and bulky waste streams. However, road transport may still be required under specific operational conditions, such as limited vessel availability, adverse weather conditions, or logistical constraints associated with loading and unloading operations.

2.2. Development of a Smart Digital Traceability and Operational Management System for the Blue Point: A Port-Based Model for Sustainable EOL Fishing Gear Valorisation

2.2.1. Smart functionality of the Blue Point for waste management

The Blue Point has been designed as a smart, port based industrial solution for the sustainable management of EOL fishing gear waste. Its “smart” functionality goes beyond logistics or material pre-treatment and is based on the full digitalisation of waste flows, ensuring transparency, control, traceability and environmental accountability across the entire value chain. The Smart Blue Point concept incorporates the following key elements[6,7,8]:

- **Digital traceability system (AI ready)** enabling the monitoring and control of all incoming and outgoing waste flows, as well as intermediate sub flows generated within the facility.
- **Real time monitoring dashboards**, integrating process control indicators and operational performance within a centralised control system.
- **Intelligent QR code identification** and **Digital Product Passport** and for all materials and output flows generated at the Blue Point.
- **Smart warehouse management**, optimising storage location, material movements and inventory control.
- **Intelligent labelling**, combining QR codes with a colour coding system as a visual operational support.
- **Ergonomic working areas**, including zero gravity tools and assisted handling systems. 7. Ergonomic work areas and operator safety. The Blue Point incorporates ergonomic workstations designed to reduce physical strain during handling of bulky fishing nets and ropes. These include: (1) Ergonomic working tables, specifically designed for manual operations, (2) Zero gravity tools to minimise operator effort, (3) Pulley and hoisting systems, similar to those used on fishing vessels, for lifting and positioning nets.
- **Operator safety systems**, based on sensors and control elements to reduce occupational risks.

In this context, the Blue Point would operate as a digital and physical control hub, integrating material handling, data capture, environmental indicators and compliance requirements in a single operational framework

2.2.2. Traceability in waste management: legal and environmental relevance

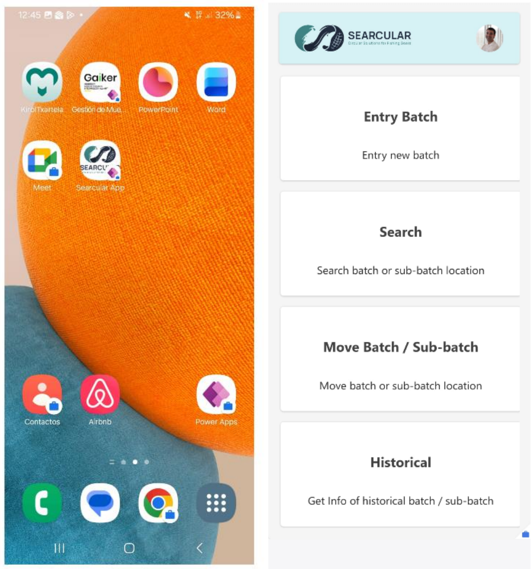
Traceability in waste management is synonymous with trust, control and environmental commitment. Spain’s Law 7/2022 on Waste and Contaminated Soils for a Circular Economy has elevated traceability to a core legal obligation, making it no longer sufficient to rely on declarative commitments. Waste managers must demonstrate, through verifiable data, what waste is generated, how it is transformed, and where it finally ends up.

[6] N 15343:2007. [https://se...s/original I Undefined], [RE: SEARCU...Blue Point I Outlook]
[7] RecyClass Recycling Process – certification documents [https://se...s/original I Undefined], [RE: SEARCU...Blue Point I Outlook]
[8] RecyClass Recycled Plastics Traceability – certification documents [https://se...s/original I Undefined], [RE: SEARCU...Blue Point I Outlook]

Traceability is defined as the procedure that allows tracking each waste material from its point of generation to its final treatment or valorisation, including all actors involved in the chain. This framework aims to prevent uncontrolled disposal, illegal dumping or inappropriate mixing of waste streams, while fostering transparency and confidence among stakeholders. The legal framework governing traceability is based on: Law 7/2022, of 8 April, on waste and contaminated soils for a circular economy, and Royal Decree 1055/2022, of 27 December, on packaging and packaging waste. In addition, Spanish legislation reinforces digital control of waste transfers through platforms such as the eSIR (MITECO electronic system for waste transfer notifications), which supports prior notifications, waste identification documents and acceptance/rejection communications for waste movements within Spain.

2.2.3. SEARCULAR – Smart Blue Point traceability application (SEARCULAR APP)

To comply with these regulatory and operational requirements, the SEARCULAR – Smart Blue Point application has been designed and implemented as the digital backbone for waste traceability within the project. This digital system is operated directly by Blue Point personnel during daily activities; enables univocal identification and traceability of all materials and flows; generates a Digital Passport for waste materials and processed outputs; and is prepared for future enhancement through artificial intelligence tools (predictive analysis, optimisation and anomaly detection). Traceability is ensured through QR code-based identification, linking all operational, material, logistical and environmental information to each waste batch and intermediate stream.



2.2.4. Structure of the Blue Point Traceability System

The traceability system is structured around three main processing stages, each fully digitised and interconnected. Following, the different drop-down menus and information blocks recorded in the application for each of the stages are indicated:

Stage 1 – Waste Reception

At reception, the origin and logistics data of the waste are registered. Each incoming batch is assigned a unique QR code, establishing the initial traceability anchor.

Table 7. Parameters recorded in Stage 1

Category	Parameters
Waste origin	Port or facility of origin
	Company or entity delivering the waste
Logistics	Transport distance
	Transport type
	Estimated transport energy consumption
Quantity	Total weight received (kg)
Identification	Initial QR code
Traceability	Link to subsequent stages

CODE	Port or facility of origin
BI	BILBAO
BE	BERMEO
GE	GETARIA
HO	HONDARRIBI
ON	ONDARRU
PA	PASAIA
OT	Others

CODE	Company or entity delivering the waste
BZ	BIDEZAIN
SB	SERBITZU
OC	Other Company

Stage 2 – Waste Classification

During classification, waste is separated by material type and quality, maintaining full traceability with Stage-1 data. At this stage, direct sale of classified materials may already occur if a suitable market outlet exists.

Table 8. Parameters recorded in Stage 2

Category	Parameters
Identification	Intermediate QR code (linked to QR Stage 1)
Waste type	Type of EOL fishing gear
Material	Polymer/Material type
	NIR identification data
Quantity	Kilograms classified by material
Quality	Type of contaminant detected
Operation	Classification time
	Energy or operational consumption
End-of-chain	Direct sale / conditioning
Traceability	Link to previous and subsequent stages

CODE	Type of EOL fishing gear
FN	Fishing nets
FT	Fish traps
R	Ropes and Mooring lines/Hawsers
S	Slings/Mooring Straps
F	Floaters
T	Tires
G	Glass
SM	Scrap metal
W	Wood
T	Trays
SP	Sanitary products
UO	Used Oil
SM	Ship parts (metal)
SGF	Ship parts (glass fibre)
SS	Ship parts (Sails)
T	Tubes

CODE	Type of EOL fishing gear
FN	Fishing nets
FT	Fish traps
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W	Wood
T	Trays
SP	Sanitary products
UO	Used Oil
SM	Ship parts (metal)
SGF	Ship parts (glass fibre)
SS	Ship parts (Sails)
T	Tubes

CODE	Polymer/Material Type
PO	**Polyolefins**
PO+M	**Polyolefins + metal**
PA	**Polyamide**
MM	Multimaterial
OP	Other polymers
M	**Metal**

CODE	Contaminant category	Type of contaminant
OC	**Organic contaminants**	Marine biomass
		Fish residues
IC	**Inorganic contaminants**	Sand and sediments
		Salts
FM	**Foreign materials (solids)**	Metals
		Rubber parts
		Wood
PC	**Polymer cross-contamination**	Mixed plastics
		Non-target polymers
ChC	**Chemical contaminants**	Oils and greases
		Fuel residues
WDP	**Weathering and degradation products**	Microplastics
		UV-degraded material
OC	**Operational contaminants**	Paints and coatings
		Adhesives / tapes
PW	**Packaging and accidental waste**	Plastics waste

CODE	End-of-chain
DS	Direct sale
CO	Conditioning

Stage 3 – Waste Conditioning

In the conditioning stage, materials undergo shredding and, where applicable, washing and drying. A final QR code is assigned, consolidating the full traceability record and linking it to environmental impact indicators.

Table 9. Parameters recorded in Stage 3

Category	Parameters
Identification	Final QR code
Process	Type of conditioning
	Process conditions
	Energy consumption
Quantity	Conditioned material (kg)
Environmental impact	Indicator (e.g. kg CO_2 avoided)
Final destination	Mechanical recycling / Chemical recycling
Traceability	Link to subsequent stages

CODE	Type of Conditioning
SH	Shredding
WA	Washing
IW	Intensive Washing

DW	Dry Washing
DR	Drying

CODE	Final Destination
DS	Mechanical recycling
CO	Chemical recycling

The final QR-coded Digital Passport may include indicators such as avoided CO_2 emissions, reinforcing the sustainability credentials of the material.

Final destinations and traceability closure

Three traceable final destinations are defined:

1. **Direct sale in Stage 2**, where classified material meets market demand.
2. **Sale to mechanical recycling companies**, using conditioned material from Stage 3.
3. **Sale to chemical recycling companies**, using conditioned material from Stage 3.

In all cases, the final QR code ensures full traceability, regulatory compliance and environmental verification.

The Blue Point traceability system has been designed in accordance with:

- **EN 15343:2007** – Plastics recycling traceability and assessment of conformity and recycled content.
- The requirements and principles of **RecyClass Recycling Process Certification** and **RecyClass Recycled Plastics Traceability Certification**, which were considered when defining traceability requirements across all Blue Point processing steps (collection, classification and conditioning).

Definitively, the Smart Blue Point Traceability System:

- Provides **full transparency and auditability** of waste flows.
- Ensures **legal compliance** with national and EU traceability frameworks.
- Supports **environmental reporting, KPIs and impact assessment**.
- Enhances **trust among stakeholders, EPR schemes and authorities**.
- Strengthens **replicability and scalability** of the Blue Point model across European ports.

Next some main conclusions are included:

- The Smart Blue Point Traceability System has been designed not only as a regulatory compliance tool, but as an integrated operational and strategic asset supporting transparency, efficiency and sustainability in waste management.
- From a regulatory perspective, the system is fully aligned with the Spanish legal framework on waste traceability, particularly Law 7/2022 on Waste and Contaminated Soils for a Circular Economy and Royal Decree 1055/2022 on packaging and packaging waste, ensuring traceable, documented and auditable

waste flows throughout the entire management chain. The Blue Point is conceived as an operational digital layer, capable of generating structured and verifiable data that can support or feed official waste transfer and reporting systems, such as eSIR, without duplicating information.

- From an operational standpoint, traceability is embedded directly into daily activities at the Blue Point through the SEARCULAR – Smart Blue Point digital application. Data capture is performed at source by operators, ensuring real-time registration of waste origin, material classification, processing conditions and final destination. The use of QR-code-based identification and Digital Passports guarantees continuity of information across reception, classification and conditioning stages, as well as along downstream recycling or valorisation routes.
- The system has been designed with a future-ready architecture, enabling progressive integration of advanced analytics and artificial intelligence tools. These capabilities may support pattern recognition, optimisation of processing routes, early detection of non-conformities and identification of new valorisation opportunities. Optional integration of distributed ledger technologies (e.g. blockchain) may further reinforce data integrity and trust for high-value or highly regulated material streams.
- Beyond legal compliance, the Blue Point traceability system acts as a key enabler for environmental performance assessment, allowing material flows to be linked to indicators such as avoided CO_2 emissions or circularity performance. In this way, traceability becomes a measurable instrument for demonstrating environmental impact, supporting sustainability reporting, EPR schemes and evidence-based decision-making.
- Finally, by integrating digital traceability, ergonomic workplace design, safety systems and smart logistics, the Blue Point reinforces its role as a transparent, auditable and replicable port-based solution, fully aligned with European circular economy objectives and ready for deployment at scale across different port contexts.

2.3. Characterization of the different types of materials present in EOL fishing gear

One of the most critical stages in the development of the Blue Point concept is the exhaustive characterization of the materials present within the EOL fishing gear waste streams. Accurate characterization is essential to ensure the correct identification, classification, traceability, and subsequent valorisation of the collected residues through the most suitable recycling or recovery routes. Due to the heterogeneous nature of fishing gear waste, which frequently combines different polymers, metallic components, textiles, organic matter, and marine contaminants, the implementation of a robust characterization methodology was considered fundamental for the proper design and operation of the proposed Blue Point system.

For this purpose, NIR spectroscopy was selected as the main characterization technology, enabling the identification and classification of polymeric materials according to their chemical composition. The primary objective of this characterization process was to separate the collected fishing gear waste into the following material categories: (1) polyolefins (PO), mainly polyethylene (PE) and polypropylene (PP); (2) polyamide (PA); (3) other polymers, particularly polyethylene terephthalate (PET); (4) multimaterial fractions composed of mixtures of different polymers (e.g., PO+PA, PO+PET, PA+PET); (5) metallic fractions; and finally (6) "rest", corresponding to non-fishing-gear-related residues such as sand, mud, marine litter, organic matter, and miscellaneous contaminants associated with the collected waste streams.

Amount of EOL fishing gear

A total of 13.71 tonnes of EOL fishing gear waste was characterized during the study. The materials were collected from the ports of Bilbao, Getaria, Hondarribia, Bermeo, and Ondarroa, which represent some of the most relevant fishing and maritime activity hubs within the Basque Country region. Macroscopically, significant differences were observed among the waste streams collected at each port, reflecting the specific activities and operational characteristics associated with each location.

In the case of the Port of Bilbao, approximately 4,680 kg of material was collected, mainly consisting of fishing gear and maritime residues recovered directly from the water surface, including mooring ropes, stakes, and various types of marine ropes. In contrast, the materials collected from the ports of Getaria and Hondarribia corresponded predominantly to EOL fishing gear arriving at the ports after reaching the end of their operational lifetime. These residues mainly consisted of fishing nets and accounted for approximately 4,350.46 kg. Finally, the materials collected from the ports of Bermeo (1,221.43 kg) and Ondarroa (3,458.56 kg) were mainly composed of fishing nets and ropes associated with fishing fleet activities.

As previously described in earlier sections, the collected materials were first subjected to a macroscopic separation process in order to facilitate representative subsampling and subsequent detailed characterization of each individual fishing gear component. This preliminary manual classification step was essential due to the complexity and heterogeneity of the collected waste streams.

The simulation and characterization activities were conducted in three independent batches. In the first batch, approximately 4.7 tonnes of fishing gear residues collected from the water surface of the Port of Bilbao were processed. Subsequently, a second batch comprising approximately 4.35 tonnes of material collected from the ports of Hondarribia and Getaria was characterized. Finally, in order to obtain a more representative overview of the major fishing ports within the Basque Country region, additional EOL fishing gear waste streams were collected and characterized from the ports of Bermeo (1.22 tonnes) and Ondarroa (3.46 tonnes).

Following the characterization activities, the corresponding characterization tables obtained for each of the three main batches are presented in the following sections.

Table 10. Characterization results for the port of Bilbao

Port of BILBAO		
STREAM	WEIGHT (kg)	WEIGHT (%)
Polyolefins	1,960	42
Polyamide	36	1
Multimaterial	1,240	26
Other polymers	1,024	22
Metal	3	0.10
Rest	34	1
Losses	383	8
TOTAL	4,680	100

Table 11. Characterization results for the port of Hondarribia and Getaria

PORTS OF HONDARRIBIA AND GETARIA		
STREAM	WEIGHT (kg)	WEIGHT (%)
Polyolefins	21	0
Polyamide	4,050	93
Multimaterial	101	2
Other polymers	6	0
Metal	4	0
Rest	17	0
Losses	150	3
TOTAL	4,350	100

Table 12. Characterization results for the port of Ondarroa

PORT OF ONDARROA		
STREAM	WEIGHT (kg)	WEIGHT (%)
Polyolefins	1,740	50.31
Polyamide	11	0.32
Polyolefins + metal	1,380	39.90
Other polymers	15	0.45
Elastomers	10	0.28
Fishing buoys (ABS)	58	1.69
Disc float	192	5.55
Metal	7	0.20
Rest	45	1.31
TOTAL	3,459	100.00

Table 13. Characterization results for the port of Bermeo

PORT OF BERMEO		
STREAM	WEIGHT (kg)	WEIGHT (%)
Polyolefins	58	4.72
Polyamide	1162	95.16
Metal	1.5	0.12
TOTAL	1,221	100.00

To provide a better understanding of the classification methodology and the distribution of polymers identified during the study, Figure 17 presents a more detailed example of polymer characterization for one of the containers of materials collected at the Port of Bilbao.

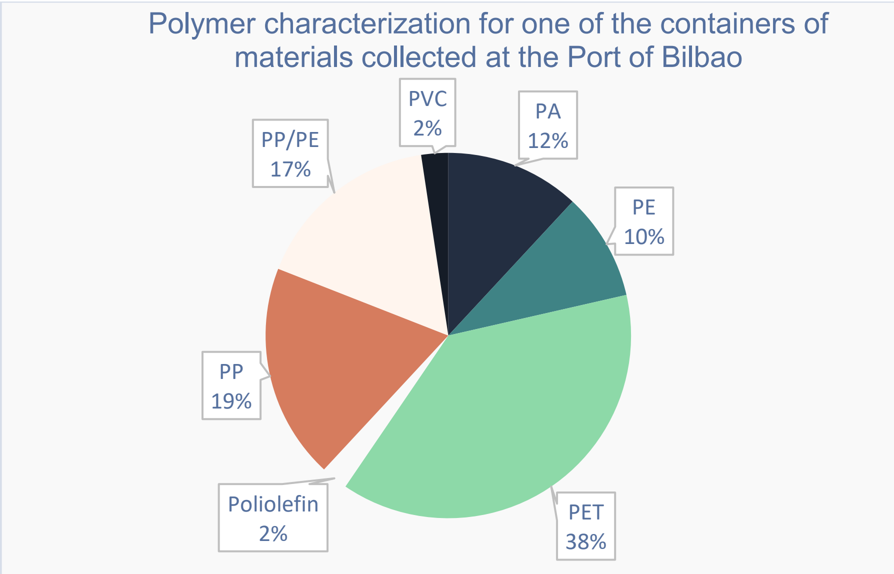


Figure 17. Polymer characterization for one of the containers of materials collected at the Port of Bilbao

Finally, the Table 14 compiles the global characterization results obtained from all analysed ports, providing an overall representation of the material typologies and polymer compositions present in EOL fishing gear waste streams generated within the Basque Country region.

Characterisation of EOL fishing gear

The characterization campaign carried out on the EOL fishing gear collected from the main ports of the Basque Country provided a comprehensive understanding of the composition, heterogeneity, and distribution of the different waste streams generated in the region. In total, 13.71 tonnes of material were characterized and classified according to the methodology developed within the SEARCULAR project. The obtained results demonstrate the significant variability in the composition of fishing gear waste depending on the typology of port activities, the origin of the residues, and the collection conditions.

Table 14. Global characterization summary of all analysed ports

ALL PORTS		
STREAM	WEIGHT (kg)	WEIGHT (%)
Polyolefins	3,779	27.6%
Polyolefins + metal	1,380	10.1%
Polyamide	5,260	38.4%
Multimaterial	1,533	11.2%
Other polymers	1,113	8.1%
Metal	16	0.1%
Rest	96	0.7%
Losses	533	3.9%
TOTAL	13,710	100.0%

The characterization performed on the material collected from the Port of Bilbao revealed a highly heterogeneous waste stream composition. This batch, mainly composed of ropes, mooring lines, and fishing gear recovered from the water surface, presented a high proportion of polyolefins (42 wt.%), followed by multimaterial fractions (26 wt.%) and other polymers (22 wt.%). The elevated presence of multimaterial fractions highlights the complexity associated with fishing gear residues collected from the water sheet, where degradation, contamination, and the coexistence of different polymeric materials complicate the separation and valorisation processes. In addition, the relatively high percentage of "other polymers" indicates the presence of materials such as PET and other non-priority polymers that may require alternative recycling routes or additional separation stages. Losses represented approximately 8 wt.% of the total processed material, mainly associated with dirt, humidity, sand, and impurities removed during the conditioning operations.

In contrast, the characterization results obtained from the ports of Hondarribia and Getaria showed a markedly different composition. In this case, the waste stream was overwhelmingly dominated by polyamide (93 wt.%), corresponding mainly to fishing nets reaching their EOL directly from fishing activities. The low percentages of multimaterial fractions and other polymers demonstrate that these residues were more homogeneous than those recovered from the Port of Bilbao. These results are particularly relevant from a recycling perspective, as polyamide constitutes one of the most valuable polymers for mechanical recycling applications due to its high market value and recyclability potential. The relatively low losses generated during processing (3 wt.%) further confirm the better preservation state and lower contamination level of these fishing gear residues.

The material characterized from the Port of Ondarroa also exhibited a strong presence of polyolefin-based materials, representing approximately 50 wt.% of the total waste stream. In addition, a significant fraction composed of polyolefin-metal combinations (39.9 wt.%) was identified, highlighting the complexity of certain fishing gear components that incorporate metallic reinforcements. Smaller quantities of elastomers, fishing buoys, and disc floats were also detected, reflecting the diversity of fishing-related equipment managed within this port. These results confirm that certain ports generate more complex and diversified waste streams, requiring more intensive manual dismantling and characterization procedures before valorisation. Nevertheless, the high proportion of polyolefin-containing materials reinforces the relevance of chemical recycling routes such as pyrolysis for these fractions.

Similarly, the characterization of the material collected from the Port of Bermeo showed a highly homogeneous composition dominated almost entirely by polyamide (95.16 wt.%). As observed in Hondarribia and Getaria, this result is mainly associated with the collection of EOL fishing nets directly generated by fishing activities. The negligible presence of metals and other fractions demonstrates the suitability of these waste streams for mechanical recycling processes after appropriate conditioning operations.

When considering the global characterization of all the ports together, polyamide constituted the largest fraction, representing 38.4 wt.% of the total characterized material, followed by polyolefins with 27.6 wt.%. Multimaterial fractions accounted for 11.2 wt.%, while polyolefin-metal combinations represented an additional 10.1 wt.%. Other polymers, metals, and non-target residues were found in smaller proportions. These results clearly demonstrate that polyamide and polyolefins are the dominant polymeric fractions present in EOL fishing gear waste streams generated in the Basque Country, validating the selection of these materials as the primary targets for the valorisation strategies developed within the SEARCULAR project.

From a valorisation perspective, the obtained results confirm the necessity of implementing a combination of mechanical and chemical recycling routes to adequately manage the heterogeneity of the generated waste streams. While relatively pure polyamide fractions are highly suitable for mechanical recycling applications, mixed polyolefin-rich fractions and multimaterial residues can be redirected toward chemical recycling processes such as pyrolysis to produce high-quality pyrolysis oils following the Plastic2Plastic strategy.

Overall, the results obtained during this large-scale characterization campaign validate the technical feasibility of the proposed Blue Point concept for the Basque Country region. The developed methodology proved capable of processing and accurately classifying highly heterogeneous fishing gear waste streams generated across different ports and operational scenarios. In addition, the data obtained provide a robust technical basis for scaling the system toward a larger industrial implementation capable of managing the annual quantities of EOL fishing gear generated within the region.

2.4. Definition, configuration, and materialization of a “Blue Point”

As part of the SEARCULAR project, a pilot-scale simulation of the Smart Blue Point concept was carried out in an industrial facility in order to validate the operational feasibility of the proposed collection, characterization, classification, and conditioning processes for EOL fishing gear generated in the Basque Country region. This simulation represented a practical demonstration of the main operational stages envisaged for the future implementation of a full-scale Blue Point facility.

Figure 18. Photo of the Blue Point simulation space

For this purpose, an industrial area of approximately 100 m² was allocated specifically for the characterization, sorting, and handling of fishing gear waste streams. The facility was equipped with the necessary infrastructure and technical resources to safely manage bulky and heterogeneous fishing gear materials. These included lifting systems and crane equipment fitted with grapple attachments for handling heavy fishing gear, dedicated worktables for manual dismantling and classification operations, portable NIR spectroscopy equipment for polymer identification and material characterization, and a complete set of cutting and dismantling tools required for the separation of the different material fractions.

In addition to the characterization and classification area, the simulation included conditioning technologies intended to prepare the materials for subsequent valorisation processes. A shredding system and a washing tank were used for the pre-treatment and conditioning of the polyolefin fraction, enabling the reduction of material size and the removal of impurities, organic matter, and salt residues prior to recycling operations. These conditioning steps were considered essential to ensure that the treated materials met the technical requirements necessary for subsequent chemical recycling processes, particularly pyrolysis.

During the simulation activities, nearly 14 tonnes of fishing gear waste and associated materials were processed. The materials originated from several of the main fishing ports of the Basque Country, including Bilbao, Getaria, Ondarroa, Bermeo, and Hondarribia. The inclusion of materials from different ports made it possible to obtain a more representative understanding of the diversity of waste streams generated in the region, as well as their physical characteristics, operational challenges, and chemical composition.

Once the materials had been characterized, classified, and adequately conditioned, selected plastic fractions were prepared and supplied to the project partner Plastic Energy for laboratory-scale pyrolysis trials. These preliminary tests allowed the evaluation of the suitability of the conditioned fishing gear waste as feedstock for chemical recycling following the Plastic2Plastic strategy developed within the project framework (as described in D4.2 Deliverable). Subsequently, the process was successfully scaled up to industrial level, enabling the pyrolysis of approximately one tonne of fishing gear waste for the production of a high-quality pyrolysis oil known as TACOIL, intended for the manufacture of new plastic materials within a circular economy approach.

Overall, the pilot-scale simulation demonstrated the technical feasibility of implementing a Smart Blue Point system capable of managing, conditioning, and valorising significant quantities of EOL fishing gear generated in the Basque Country region. Furthermore, the activities carried out during the simulation provided valuable operational knowledge regarding material handling, classification procedures, pre-treatment requirements, traceability needs, and downstream recycling compatibility.

The following sections describe in detail the different operational stages carried out during the simulation process, including material reception, characterization, sorting, conditioning, and preparation for subsequent valorisation routes.

1. Unloading of the material**:** All the material unloaded from the container is placed on the floor of the industrial building. Figure 19 shows the condition of the samples upon arrival at the plant.

Figure 19. Material collected in containers

2. Opening of ropes, stakes, and nets: Using the grapple crane and other tools, the different ropes, stakes and nets were opened and organized on the floor for their subsequent analysis.

Figure 20. Opening process for the ropes, stakes and nets

3. Representative Sampling: From each apparently different sample, a representative sample was cut to allow a later exhaustive analysis.

Figure 21. Representative samples.

4. Labelling and Preparation for NIR Analysis: Each sample collected was properly labelled and all subsamples were prepared for analysis by NIR spectroscopy.

Figure 22. Labelling and NIR analysis preparation.

5. NIR Characterization: NIR characterization of the samples was carried out to determine the polymers present in each fishing gear.

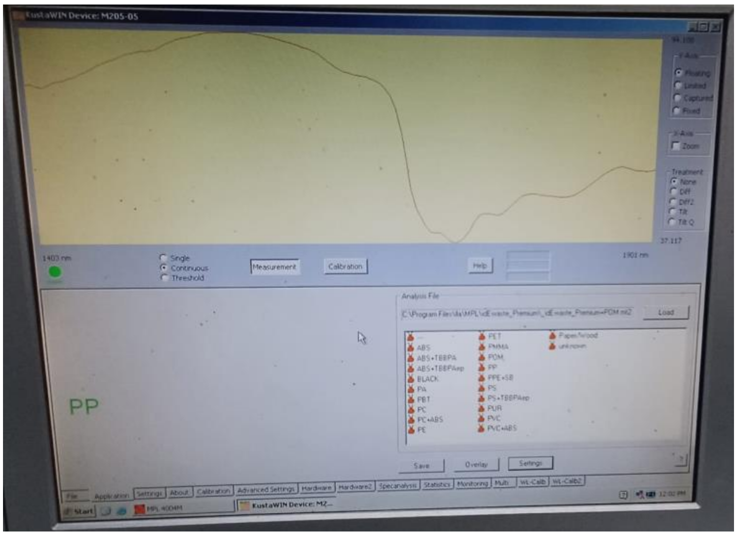


Figure 23. NIR characterization result (PP)

6. Classification and Separation of Materials: Once the polymers present were identified, the materials were classified and separated into the following groups: polyamide, polyolefins, other polymers present in the fishing gears such as polyethylene terephthalate, multimaterial such as polyamide with polyolefins and metals.

Figure 24. Materials classified and separated by composition in different groups

7. Exhaustive Review and Elimination of Impurities: An exhaustive review of the materials was carried out to eliminate impurities such as adhesive tape, labels, coatings, etc.

Figure 25. Impurities elimination process

8. Material Classification, Grouping, and Mass Balancing: Once the characterization and classification processes were completed, the fishing gear and associated material fractions were grouped according to their category and intended valorisation route. Subsequently, each material group was weighed in order to establish a mass balance of the processed waste streams and to determine the percentage (by weight) of key polymer fractions, particularly polyolefins and polyamides, present in the collected materials.

This procedure was repeated until a sufficient quantity of homogeneous material had been accumulated to proceed to the subsequent processing stage. In the present study, a target batch size of approximately 150 kg was established. Once the materials had been fully characterized, classified, and grouped according to their polymer composition and intended valorisation route, mechanical shredding was carried out in order to reduce the particle size to approximately 4 mm. Following the size-reduction step, the material underwent washing and drying processes to remove impurities, organic residues, moisture, and salt contamination, thereby improving its suitability for downstream recycling operations. The resulting shredded material is shown in Figure 26. Finally, the conditioned polyolefin (PO) fraction was supplied as feedstock for pyrolysis processing aimed at the production of high-quality TACOIL.

In section Validation of a smart port-based "Blue Point" model for EOL fishing gears, the validation process carried out after these initial simulations is detailed, together with a diagram illustrating the material flow as well as the corresponding mass balance.

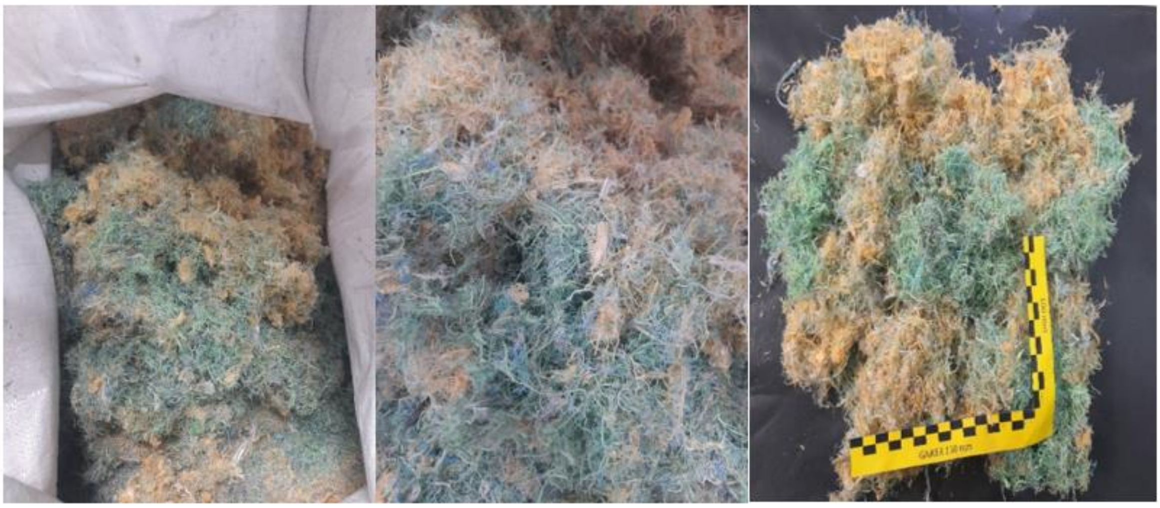


Figure 26. Shredded and washed material

2.5. Design and layout of the site and facilities

The design approach presented builds on the combined experience and practical insights gained by GAIKER through the SEARCULAR project, complemented by proven industrial references from existing recycling initiatives. In particular, the Smart Blue Point concept has been informed by the operational lessons learned from the SOTENAS case, as well as by the industrial-scale implementation developed by REFINVERSE Group, a Japanese company specializing in the transformation of waste materials into high-value recycled products. Their approach demonstrates that fishing nets and other fishing gear, traditionally treated as waste, can be effectively processed and converted into regenerated materials, such as nylon resins, through dedicated recycling technologies and controlled processing chains. By integrating knowledge derived from these successful cases with the project's own experimental and pilot-scale activities and with previous researching activities (e.g. HELCOM (2026) - *An inventory of best practices of the collection and separation of ALDFG/EOLFG (RS6)*, OSPAR (2020) - *OSPAR scoping study on best practices for the design and recycling of fishing gear as a means to reduce quantities of fishing gear found as marine litter in the North-East Atlantic)*, the proposed design ensures both technical feasibility and alignment with real industrial practices, strengthening its relevance for replication and deployment within European port environments.

The present design is protected by GAIKER under industrial secrecy registration MT-SI-09, filed on 27 April 2026, under the title *"Blue Economy: Smart Blue Points and strategies for the management and recycling of waste derived from the blue economy for the production of new value-added products."*

2.5.1. Design and Layout of the Site and Facilities (Blue Point) – Technical Engineering

This section defines the **industrial design concept and facility layout** required to implement a port-based **Blue Point** for **EOL fishing gear** management, including reception, manual sorting/classification, size reduction (shredding), and washing/conditioning and drying prior to downstream mechanical or chemical recycling. The layout has been engineered around the following key drivers:

- **Safe and efficient one-direction material flow** (from dirty reception → sorting → conditioning → clean outputs).
- **Separation of "dirty" and "clean" zones** to minimise cross-contamination and to improve product quality for recycling.
- **Compatibility with bulky, low-density fishing gear** handling (nets/ropes), including ergonomic manual operations and mechanical handling.
- **Integration of core equipment packages** for shredding and washing, as provided in the technical dossiers.
- **Truck and container logistics** ensuring straightforward access, outdoor container staging, and safe manoeuvring.

The Blue Point requires an **external logistics yard** designed to support:

- **Inbound deliveries** (waste streams of nets/ropes and other types of residues in containers, bulk bags or cages).
- **Temporary outdoor storage** of empty/full containers (segregated by "incoming" vs "processed" materials).
- **Truck circulation and safe turning/queuing**, avoiding interference with pedestrian routes and indoor forklift operations.
- **Clearly marked traffic separation** (heavy vehicles vs pedestrian walkways), including signage and controlled crossing points.

The yard layout has been designed to support unidirectional truck circulation, ensuring a continuous flow from entry through drop-off and/or pick-up operations to final exit. This single-direction logistics principle minimizes traffic conflicts, enhances safety, and simplifies operational control by reducing crossing points and congestion within the facility. The main industrial hall of the Blue Point facility has been designed as a flexible, **port-compatible processing space** adapted to the operational requirements of EOL fishing gear management. The building layout supports a **clear linear material flow**, from reception and unloading to manual classification, conditioning and final shipping, while ensuring safe circulation of personnel, forklifts and trucks. The hall geometry and access configuration respond to the specific needs of handling the **bulky, low-density fishing gear waste streams and the extremely heavy fractions derived from seine rope waste**, integrating large access gates on both façades to enable independent entry and exit of materials. The internal clear heights and spans have been dimensioned to accommodate industrial equipment, ergonomic workstations and overhead handling systems, while maintaining sufficient clearance for maintenance and future scalability.

The following table summarises the key geometric dimensions of the main industrial hall as defined in the architectural and sectional drawings.

Table 15. Main Industrial Hall: Key Dimensions

Parameter	Value	Unit	Description
Overall building length	30.0	m	Longitudinal dimension of the main hall
Overall building width	25.0	m	Transversal dimension of the main hall
Gross floor area	**750**	**m²**	Approximate usable industrial surface
Internal clear width	21.8	m	Clear span between structural elements
Main access gate width (each)	6.0	m	Large industrial gates for trucks / containers
Number of main access gates	4	–	Two gates per façade (entry / exit strategy)
Free internal height (eaves)	4.9	m	Minimum operational clear height
Maximum internal height (ridge)	7.5	m	Maximum clear height under roof
Roof overhang	3.4	m	Provides weather protection at façades
External manoeuvring clearance	≥5.0	m	Space for truck and container operations

The dimensions of the main industrial hall have been defined to reliably support an **annual treatment capacity of approximately 500 tonnes of EOL fishing nets and gear**, which is consistent with the operational objectives of the Blue Point model. The **available floor area of 750 m²**, combined with the clear internal spans and heights, allows the simultaneous operation of reception areas, ergonomic manual sorting stations, conditioning equipment (shredding and washing), and intermediate storage buffers without creating bottlenecks. Previously, 300-400 m2 was defined as the usable surface area for the main building; however, after the design, it was decided to increase this space so that the arrangement of equipment and the flow of streams within the building guarantees a safe and comfortable operation, avoiding overcrowding or excessively concentrated working areas. Definitively, this configuration enables continuous material flow, safe internal logistics and sufficient temporary storage to absorb variability in incoming volumes. Moreover, the spatial margins incorporated in the layout provide flexibility for future operational optimisation or moderate capacity increases without requiring structural modifications to the building. The following figures present the layout drawings of the Blue Point Main Waste Treatment Industrial Facility:

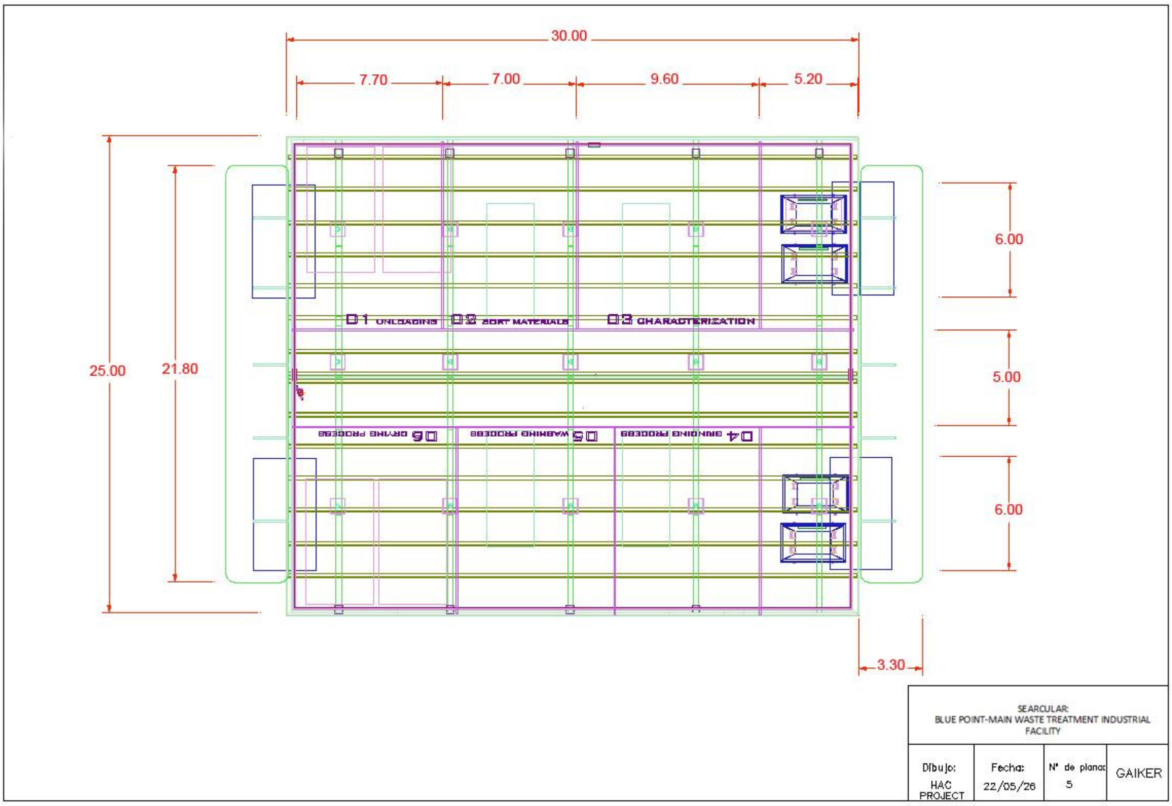


Figure 27. Drawings of the Blue Point – Main Waste Treatment Industrial Facility

Figure 28. Drawings of the Blue Point – Main Waste Treatment Industrial Facility

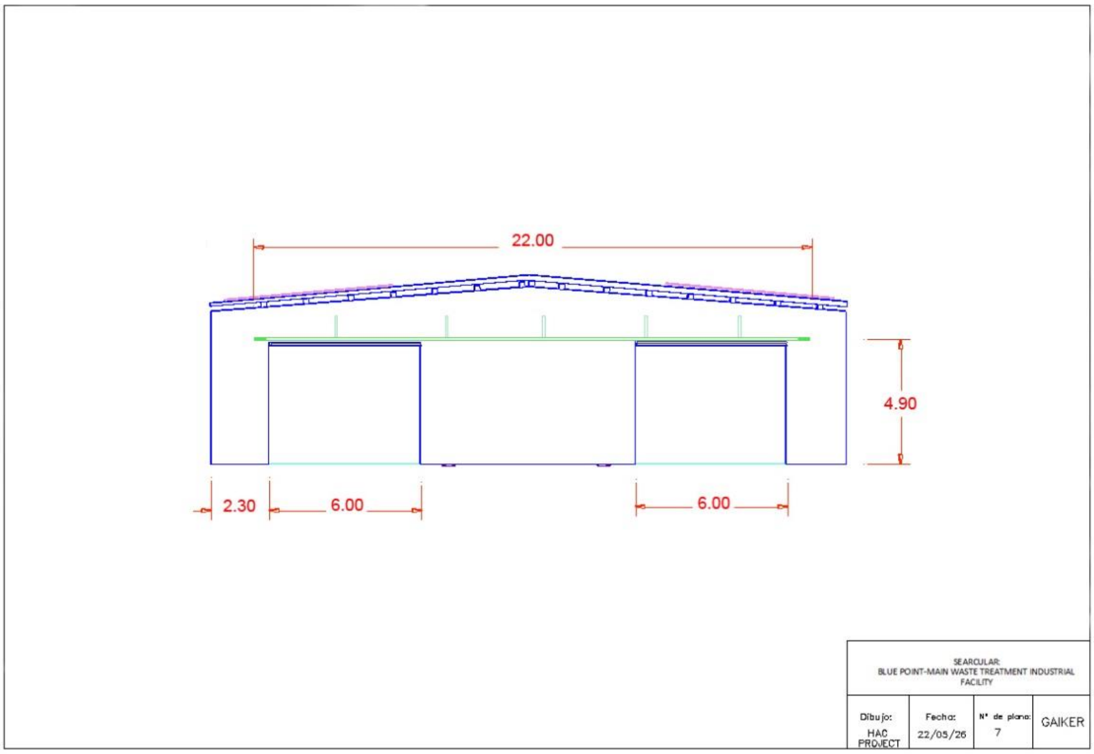


Figure 29. Drawings of the Blue Point – Main Waste Treatment Industrial Facility

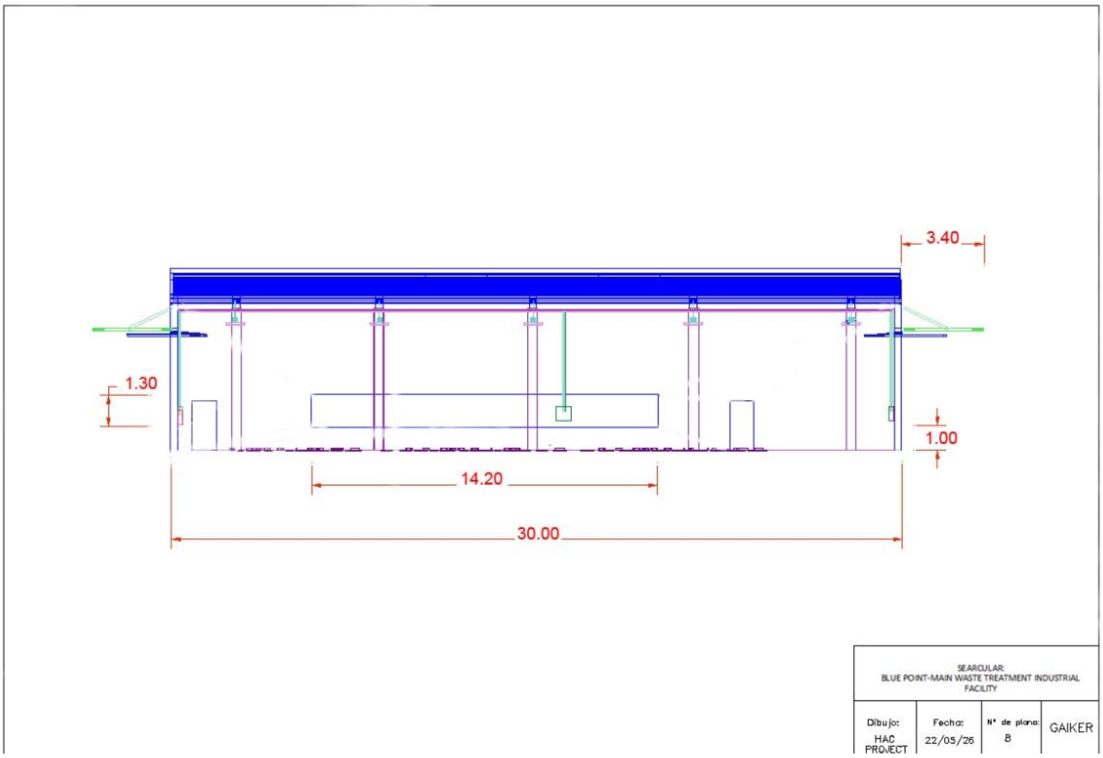


Figure 30. Drawings of the Blue Point – Main Waste Treatment Industrial Facility

The industrial hall is configured with two large doors on each of the two opposite façades (i.e., two gates per side), enabling a **controlled circulation-based material flow strategy**.

- **Door set A (Façade 1):** The first door is dedicated to the **incoming EOL fishing gear and associated inbound logistics**. The second door on the same façade is used for the **outgoing conditioned materials** (e.g., classified bales, shredded flakes/picadillo, washed outputs), following a circular internal flow.
- **Door set B (Façade 2):** The doors on the opposite façade are dedicated to the **dispatch of non-conditioned materials**, including **manually classified fishing nets and fractions suitable for direct sale**, ensuring separation between conditioned outputs and secondary material streams.

This arrangement supports **physical segregation** between incoming waste handling (higher contamination) and outgoing product logistics (controlled quality), while enabling flexible operations (e.g., maintenance access, emergency routing, peak load handling).

The design includes some **key architectural features**, such as doors sized to accommodate forklifts, pallet trucks, and container handling operations, with final dimensions to be defined in accordance with port logistics requirements and applicable local building codes. In addition, internal loading and unloading apron zones are positioned directly adjacent to these doors, ensuring smooth material flow, preventing congestion, and maintaining clear and safe circulation paths for forklift operations.

The facility is divided into **three functional macro-zones** aligned with the Blue Point operational chain:

Zone 1 – Reception & pre-inspection ("dirty zone")

- Covered unloading area for nets/ropes and initial inspection.
- Temporary staging of incoming batches (segregated by source/traceability QR).
- Dedicated area for removal of bulky non-plastics (e.g., metal parts), prior to further processing.

For the handling, movement, and segregation activities of the different types of waste streams, hydraulic grabs specifically designed for scrap handling will be used. These grab systems enable efficient and controlled manipulation of bulky, heterogeneous, and irregular materials, facilitating loading, sorting, and transfer operations within the facility while ensuring flexibility and operational safety across the different processing areas.

Zone 2 – Manual separation & classification (controlled zone)

- **Ergonomic manual sorting workstation** (to be referenced with your workstation drawings and plans).

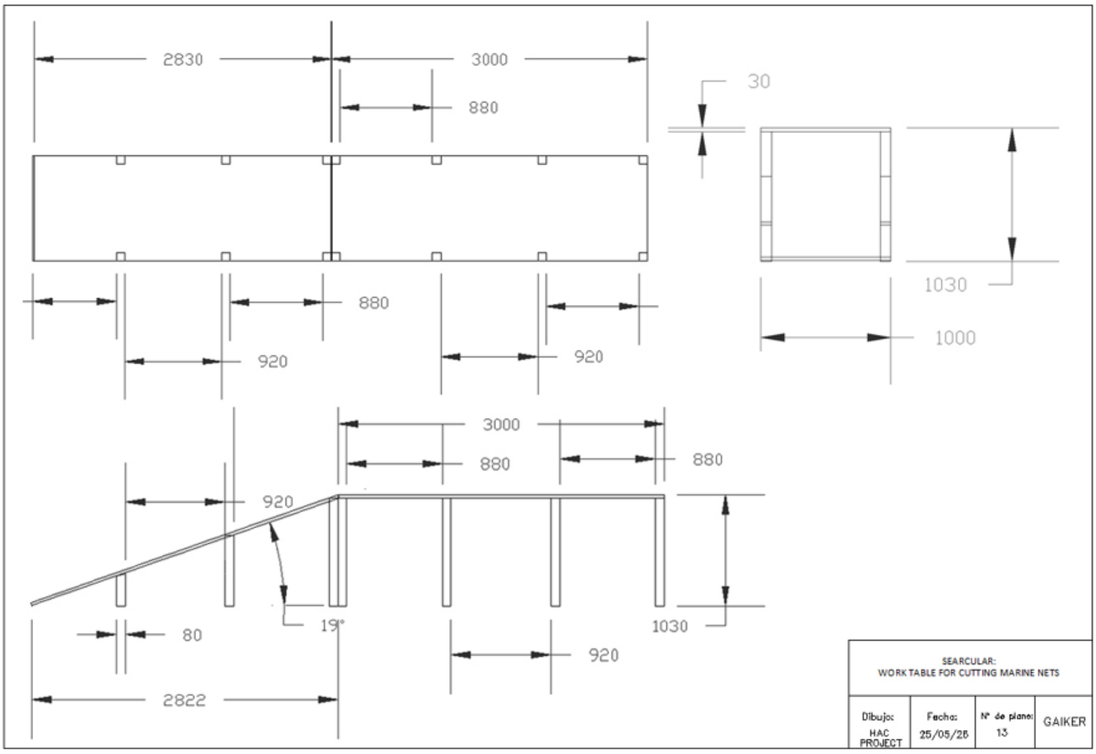


Figure 31. Dimensions and plans of ergonomic manual sorting workstation drawings (table + handling aids)

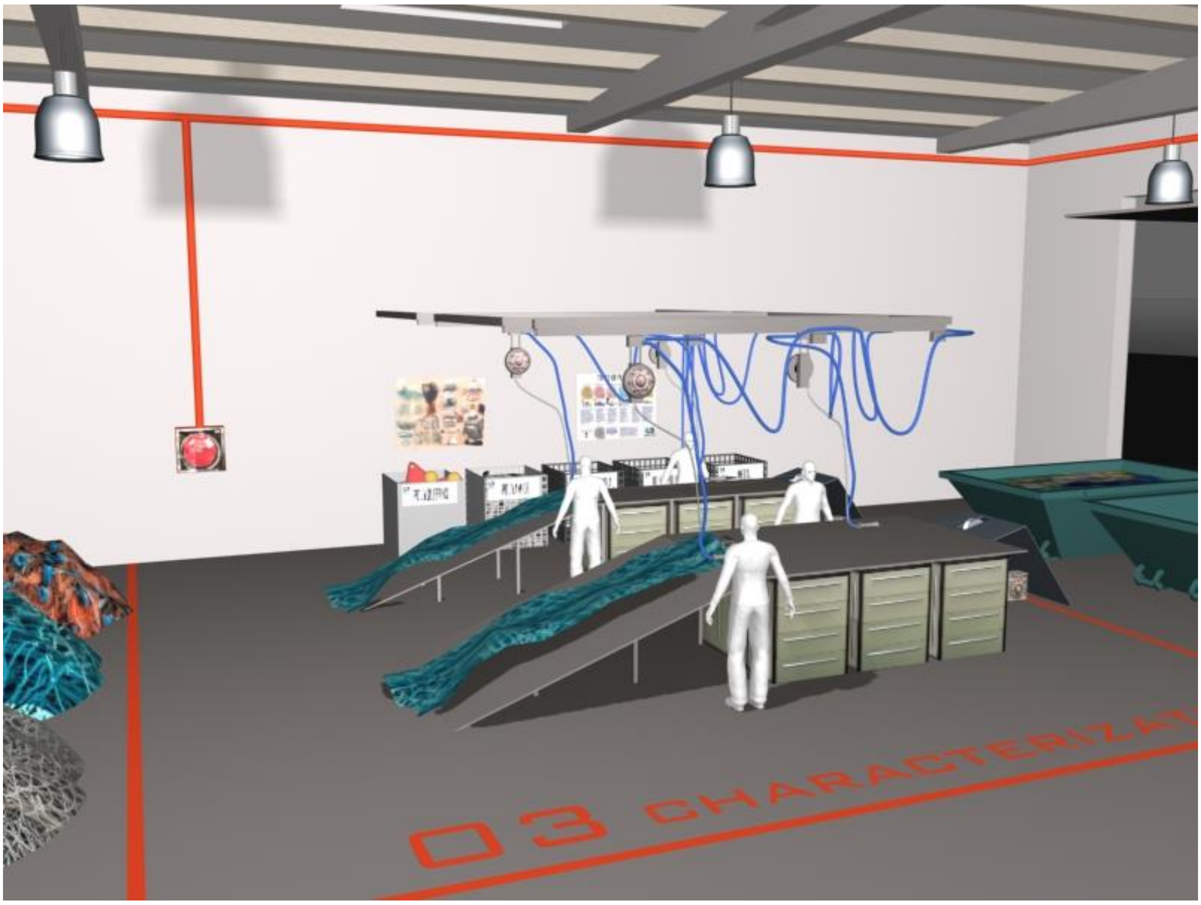


Figure 32. Ergonomic manual sorting workstation drawings (table + handling aids)

- Integration point for **NIR identification** (handheld), enabling polymer confirmation and traceable classification.
- Packaging of classified fractions into dedicated containers/big-bags for either direct sale or conditioning.

The **common plastic nets and other fishing gear waste** are classified and separated logically supported by advanced classification systems. The handling of the nets is more manageable, and although they may be large bundles and require initial size reduction, they are simple operations to be carried out by two operators using traditional cutting tools, which allow obtaining smaller batches for classification and processing in a feasible manner. However, it is considered appropriate to indicate that in these areas the handling and processing of the **extremely heavy fractions derived from seine rope waste** will also take place. And due to their particular weight, morphology, and specific and complex structure (polymer + metal **twisted cylindrical geometry**); a brief description of the specific operation to be carried out with these heavy ropes, in both Zone 1 and Zone 2, is included.

Seine ropes (also referred to as trawl ropes or warps depending on their position in the fishing gear system) are high-performance ropes designed to withstand extreme mechanical loads, abrasion and marine exposure. Externally, they typically present a thick, twisted or multi-strand cylindrical construction, with diameters commonly in the centimetre range and increasing with vessel size and application. In Danish seining applications, commercially available seine ropes may incorporate metallic elements (e.g., leaded or galvanized steel configurations) combined with protective coverings (e.g., abrasion-resistant jackets) and are commonly manufactured as 3- or 4-strand ropes. From an end-of-life perspective, this multi-material composition (polymers plus metals and other embedded elements) is one of the key reasons why seine ropes are technically challenging to recycle, as also highlighted in best-practice and barrier analyses for fishing gear waste management. Therefore, within the SEARCULAR Blue Point approach, these ropes are managed through progressive pre-processing steps—cutting, dismantling/separation to the extent feasible, and preparation for recycling—with particular attention to isolating metallic fractions and minimising contamination before routing to suitable valorisation pathways. The proposed processing sequence for seine ropes requires primary size reduction, whereby ropes are cut into manageable sections using heavy-duty mechanical equipment, enabling subsequent handling and processing steps. This is followed by mechanical opening or structural disruption, which depends on the rope architecture (braided or twisted) and aims to loosen the structure and partially separate components without necessarily achieving full fibre-level separation. Where feasible, a limited separation of components may then be carried out, particularly in cases where identifiable internal cores or inserts are present, although complete separation is often technically constrained and labour-intensive, especially for highly integrated material systems.

Given the mechanical characteristics of the nets, and specifically of the seine ropes, their processing requires the use of robust industrial equipment. This includes heavy-duty cutting systems, such as hydraulic shear cutters or reinforced industrial blades, which are necessary for the initial segmentation of thick and highly resistant ropes. Depending on the rope composition, auxiliary equipment may also be required, including mechanical separators for the removal of metallic components and washing systems for decontamination. As highlighted in the OSPAR (2020) and HELCOM (2026) reports, pre-processing steps such as cutting, and separation are critical enablers for recycling, but also represent one of the most resource-intensive stages in the overall treatment chain.

Zone 3 – Conditioning line (shredding + washing + dewatering) (“wet/processing zone”)

This area integrates the equipment chain for mechanical conditioning. Two alternative shredding concepts can be installed depending on the targeted throughput and conditioning strategy:

- **Option A: WEIMA WLK 1000 single-shaft shredder line** for nets/ropes size reduction to ~50 mm, with throughput up to **600–800 kg/h**, feeding opening **1,000 × 1,450 mm**, and main dimensions **3.030 × 2.320 × 2.130 m**, motor **75 kW**, total weight **~5,500 kg**.
    - Optional outfeed conveyor with discharge height **2,000 mm** (supporting downstream handling/transfer).
    - The associated WEIMA drawing indicates recommended service/maintenance space concepts for the WLK1000 family and highlights the need to allocate maintenance clearances around the unit.

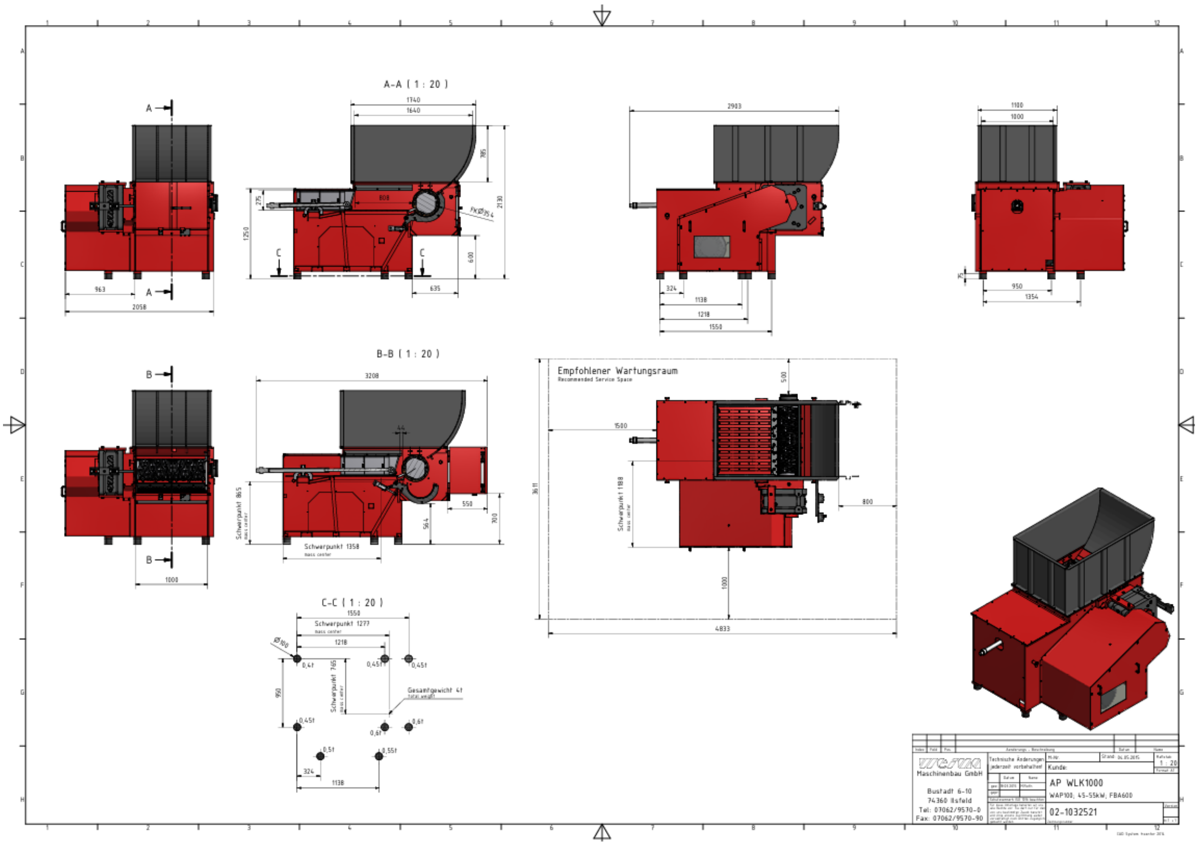


Figure 33. WEIMA WLK 1000 single-shaft shredder (option A)

- **Option B: DOMENECH primary shredder DES-500.1500** with inlet mouth **1,520 × 1,000 mm**, rotor cutting length **1,500 mm**, installed power **90 kW**, and output grid **50 mm**; overall dimensions **2,570 mm length**, **2,620 mm width**, **3,800 mm height**.

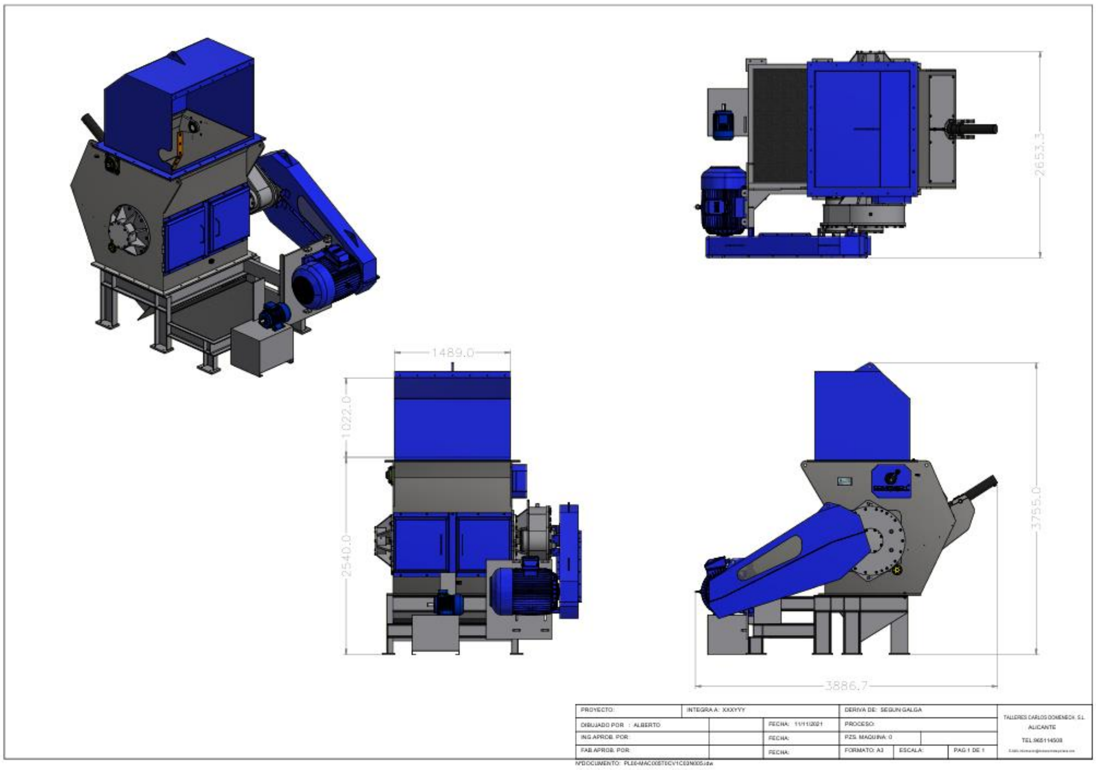


Figure 34. DOMENECH primary shredder (Option B)

For washing/cleaning and moisture reduction, the conditioning line is formed by:

- **DOMENECH sink-float / washing tank TL-1000** (tank width **1,000 mm**, length **4,000 mm**, total length **4,600 mm**, height **2,200 mm**, water volume **2,000 L**, motors **3×1.1 kW + 2.2 kW**).

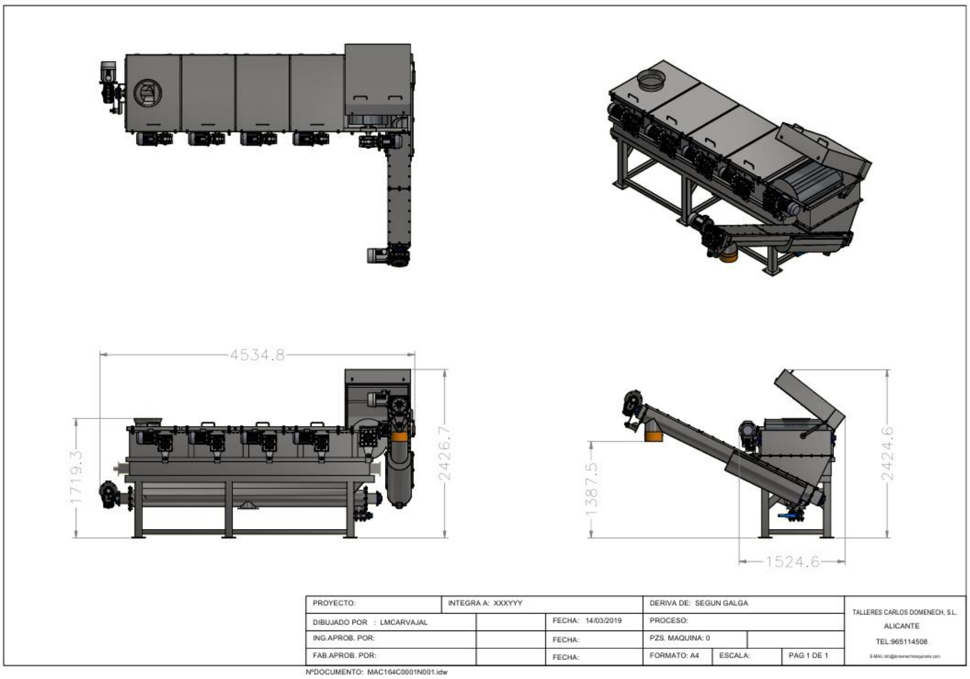


Figure 35. DOMENECH sink float / washing tank

- **DOMENECH friction washer LVP-600×3000** (rotor length **3,000 mm**, rotor speed **1,000 rpm**, motor **37 kW**, approx. water flow **8 m³/h**, weight **1,400 kg**). Although not strictly required, its implementation is recommended due to the expected positive performance in the treatment of specific target material fractions.

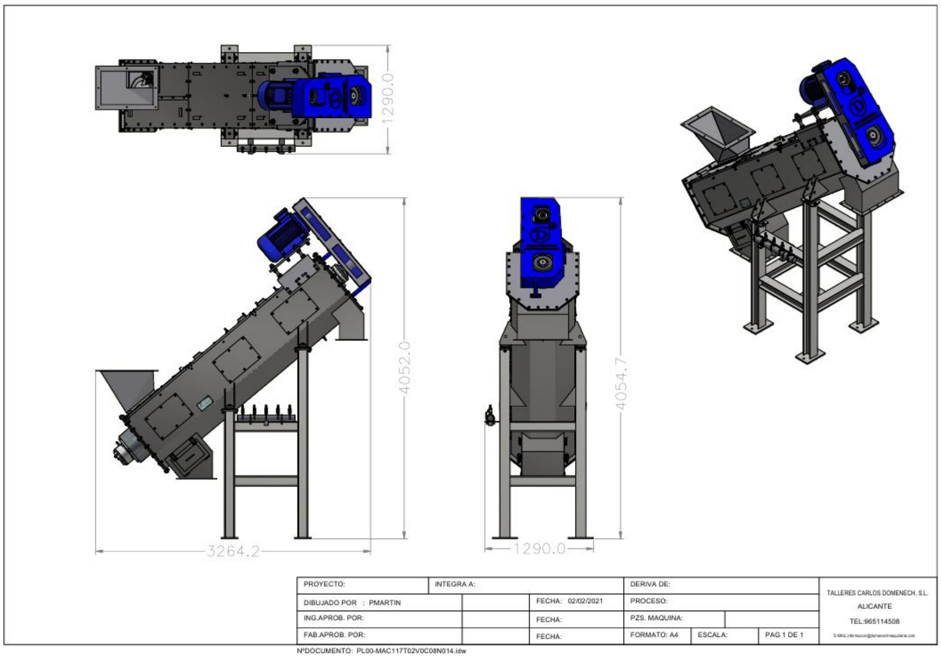


Figure 36. DOMENECH friction washer

- **DOMENECH centrifuge CGA-550.1500** (rotor motor **55 kW**, dimensions **2,200 × 1,750 × 1,570 mm**, sieve **3 mm**).

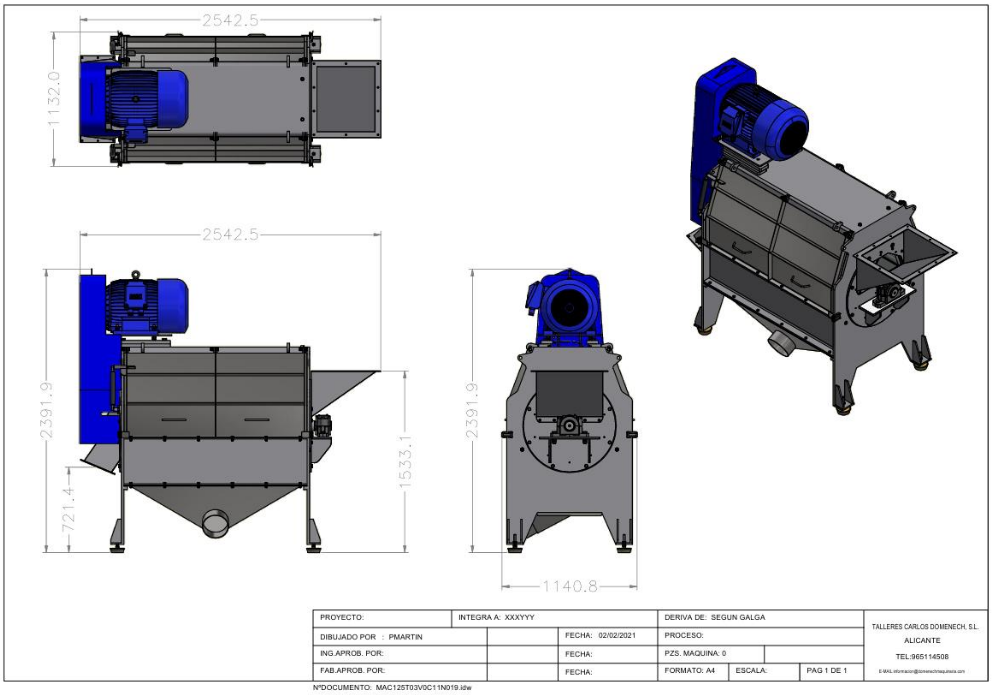
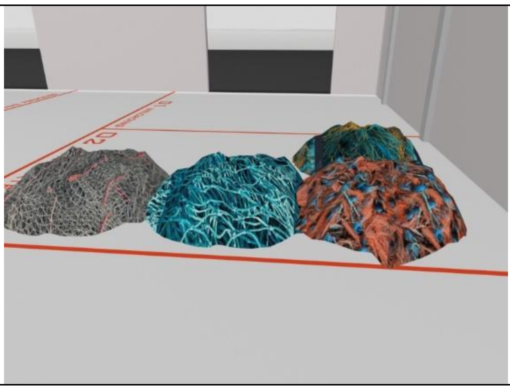
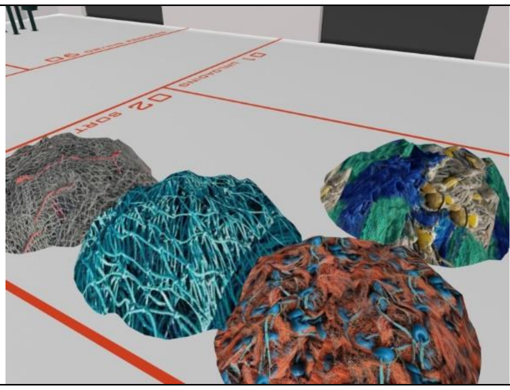


Figure 37. DOMENECH centrifuge

Next, 3D equipment drawings are included to support exact positioning, elevations, and integration requirements.

Table 16. 3D figures for equipment included to support exact positioning, elevations, and integration requirements


POLYOLEFINS
POLYAMIDE
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CAT
POLYOLEFINS
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MULTIMATERIAL
TYPES OF PLASTICS
TYPES OF PLASTICS
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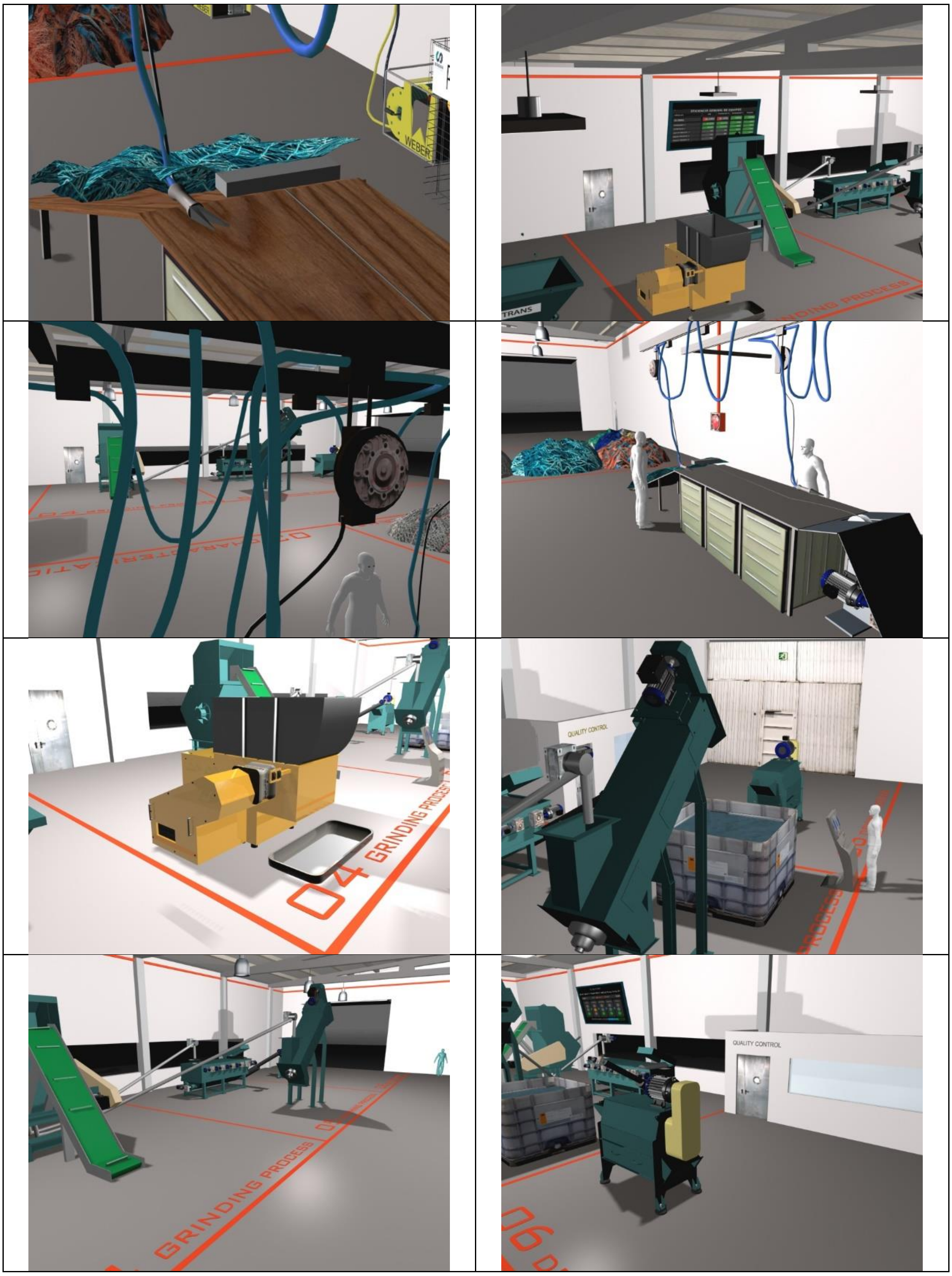
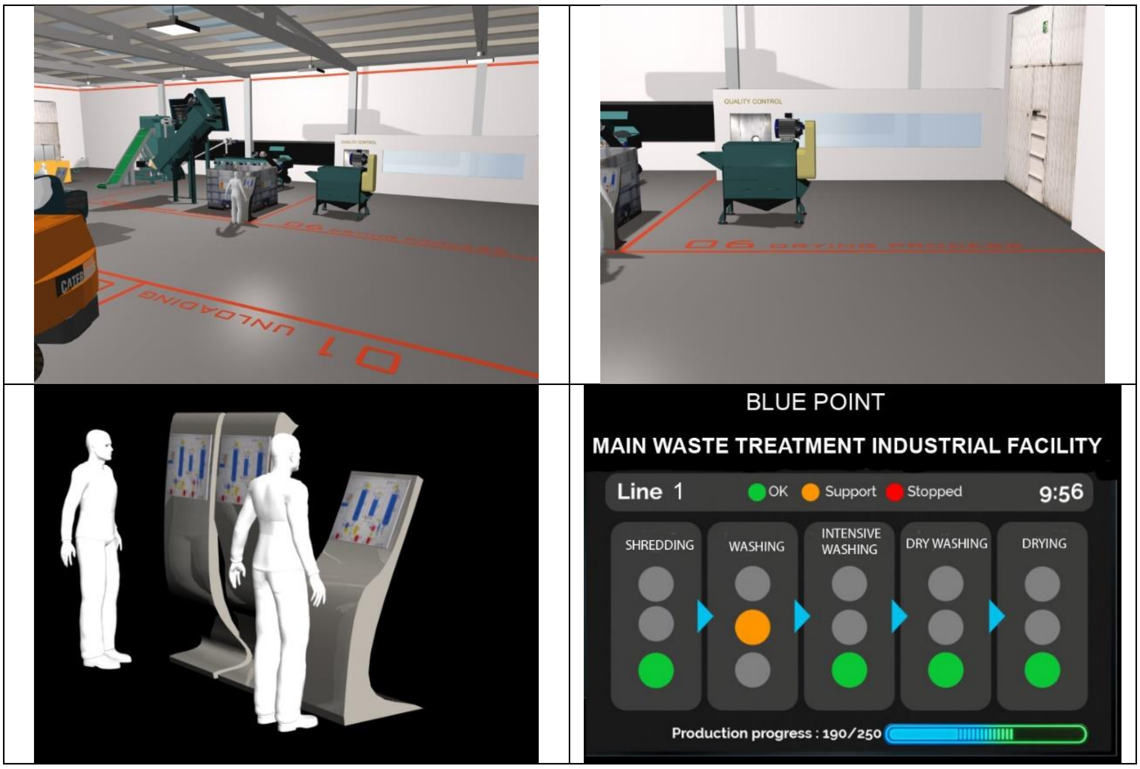

WEBER
TRANS
04 GRINDING PROCESS
QUALITY CONTROL
GRINDING PROCESS
QUALITY CONTROL



As can be seen in the pictures the robust layout follows a **cleanliness gradient**:

1. **Inbound storage (dirty)** near inbound doors and yard interface
2. **Manual sorting & NIR confirmation** in a controlled area (reduced cross-traffic)
3. **Shredding** positioned to minimise manual handling distance and enable safe feeding (forklift or conveyor)
4. **Washing + separation + dewatering** grouped as a dedicated wet-process block (with drainage and water management)
5. **Clean product storage** near outbound doors (dry, clearly segregated)
6. **Rejects / non-conforming fractions** stored separately, with clear routing to authorised disposal/alternative recovery.

The **storage strategy** combines both internal and external solutions to ensure operational efficiency and controlled material flows. Internally, short-term buffer areas are provided to maintain process continuity, typically covering one to two shifts of material, and are organised according to polymer class and processing status to facilitate handling and traceability. Externally, designated areas are arranged for container staging and truck access, with the yard layout designed to accommodate both inbound and outbound container flows without cross-mixing, thereby reducing logistical conflicts and improving overall operational control.

The equipment packages explicitly define the need to ensure correct **utilities and civil works interfaces**, including:

- **Electrical power distribution** sized for high installed powers (e.g., shredders up to 75–90 kW, centrifuge 55 kW, etc.) and local safety requirements.

- **Water supply** for washing (e.g., 2,000 L volume of the tank).
- **Drainage and wastewater management**, including collection of wash fines/sediments and appropriate handling as per applicable permits.

The facility design must integrate safety by layout:

- **Segregated lanes** with marked pedestrian exclusion zones.
- **Emergency stop access** and maintenance clearance around rotating equipment (shredder, washer, centrifuge).
- **Wet area containment** (anti-slip surfaces, drainage channels, splash guards).
- **Noise and dust management** around shredding, with appropriate enclosure/ventilation strategy.
- **Ergonomic manual sorting zone**: workstation positioning should minimise lifting distances, enable safe net handling, and support efficient visual inspection and NIR confirmation.
- Compliance with **EU safety directives** for supplied equipment and highlights that site installations must comply with workplace safety requirements.

Table 17. Functional layout blocks and key design intent

Area / block	Main function	Key design intent
Reception & pre-inspection	Unloading, initial checks, batch staging	“Dirty zone” near inbound doors; easy forklift access
Manual sorting & NIR	Manual separation + polymer confirmation	Ergonomic workstation; controlled cross-traffic
Shredding station	Size reduction to target fraction	Safe feeding; allocate maintenance/service clearance
Washing & separation	Removal of sediments/salts/organics; density separation	Dedicated wet area with drainage; water supply sized to equipment
Dewatering	Moisture reduction prior to storage/shipment	Close to washing; clean product routing
Clean product storage	Output buffer for shipment	Near outbound doors; contamination control
Rejects / non-conforming	Controlled storage for disposal/alternative recovery	Segregated from clean outputs

2.5.2. Evolution of the Blue Point System

The initial Blue Point concept, defined as a **single industrial facility for the treatment of EOL fishing gear**, has been further developed into a **multi-facility integrated infrastructure**, enabling higher levels of valorisation, diversification of waste streams and increased economic sustainability.

This evolution consists of the addition of two new industrial buildings to complement the original facility:

(1) Blue Point – Main Waste Treatment Industrial Facility (already defined): reception, classification and conditioning of fishing nets and gear.

(2) Blue Point – Material Recycling Facility: advanced processing (extrusion and pyrolysis) to generate high-value secondary raw materials.

(3) Blue Point – Beach Waste Treatment Facility and Marine Litter Monitoring: dedicated treatment of coastal and beach waste streams (plastics, mixed waste, wood and sand fractions) and for storing monitoring equipment and elements.

Together, these three facilities form a **comprehensive Blue Point ecosystem**, capable of covering the following key points: (1) Pretreatment and conditioning of the EOL fishing gear waste, (2) Plastic Material recycling (mechanical and chemical routes), (3) Coastal main waste streams treatment and marine monitoring and digital support.

2. Blue Point – Material Recycling Facility (Building 2)

The **Material Recycling Facility** represents the **most value-upgrading stage** of the Smart Blue Point system, enabling the transformation of conditioned plastic waste into secondary raw materials with higher market value. The facility is designed to process inputs from the Main Waste Treatment Facility (mainly shredded and cleaned plastics) and also, if required, selected external plastic streams. Regarding the process configuration, the facility integrates **two extrusion lines** for the production of **plastic pellets, s**uitable for polyolefin fractions (PE, PP) and PA streams; and a **small-scale pyrolysis unit** for the conversion of non-recyclable plastic fractions into pyrolysis oils and energy products, supporting the chemical recycling pathway. The layout is designed with a clear separation between mechanical and chemical recycling zones, with a strict ventilation and safety zones for pyrolysis operations and material buffer areas to stabilise feedstock variability; with a direct connection with Building 1 to minimise logistics. The building geometry, based on the available drawings, consists of an approximate footprint of **25 m × 25 m (around 625 m²)**, with an internal height ranging from approximately 4.9 m to 6.4 m and a roof height of about 6.4 m.

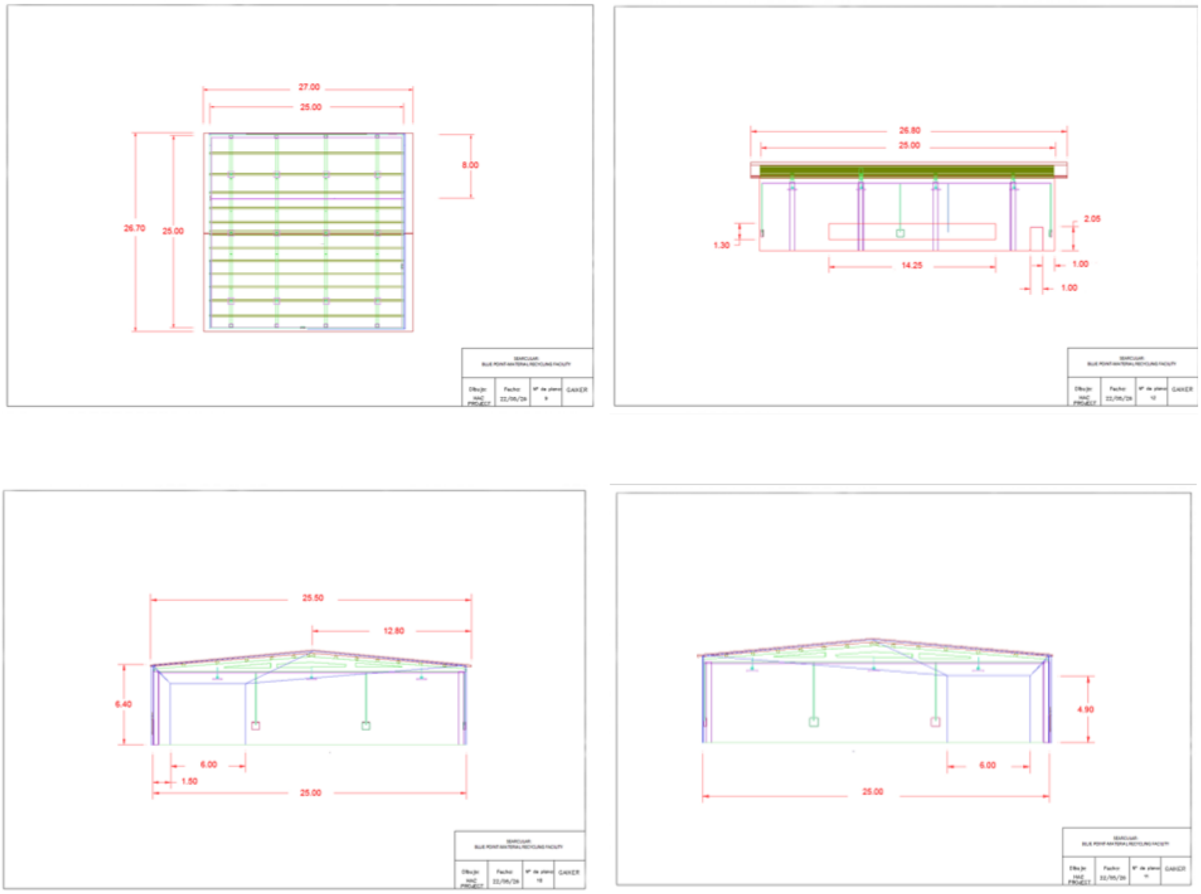
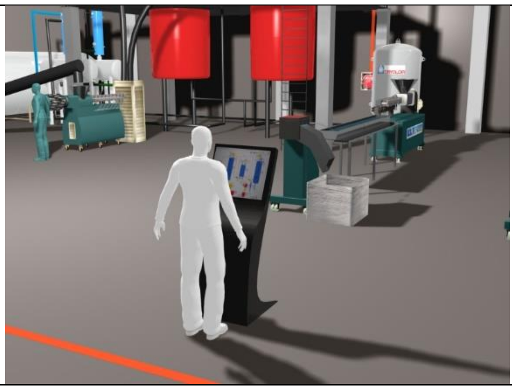
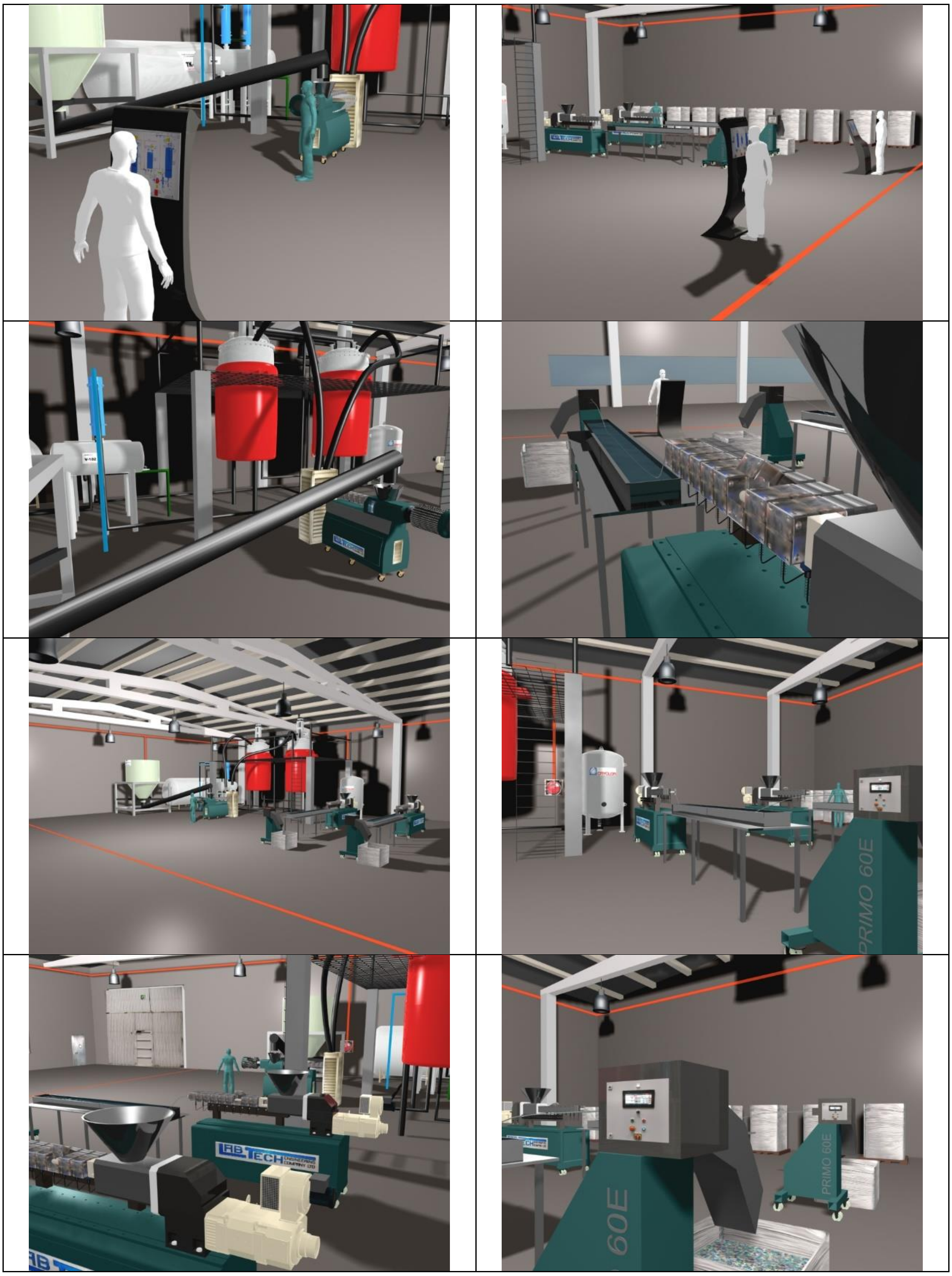


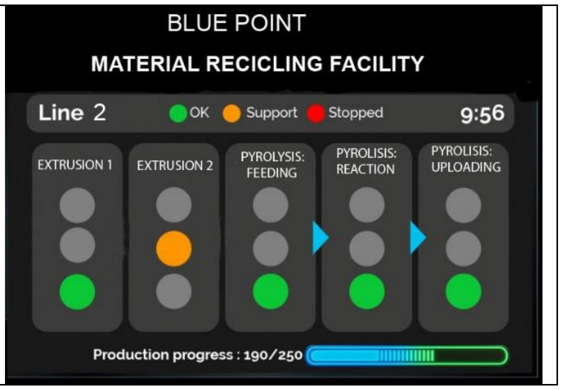
Figure 38. Drawings of the Blue Point – Material Recycling Facility

Next, 3D equipment drawings are included to support exact positioning, elevations, and integration requirements.

Table 18. 3D figures for equipment included to support exact positioning, elevations, and integration requirements.


PRIMO 60E
60E



3. Blue Point – Beach litter Treatment Facility (Building 3)

The **Beach Litter Treatment Facility** is dedicated to the management of **coastal and beach-derived waste streams**, expanding the Blue Point scope beyond fishing gear; and also, for storing **monitoring equipment** and elements. The facility is designed to address **two main categories of incoming material streams**; firstly, seasonal beach litter, which is comparable to municipal solid waste (MSW), including packaging materials such as plastics packaging, cans and mixed waste generated during peak tourism periods. Secondly, natural and mixed litter resulting from storms and coastal accumulation processes, including wood, branches, driftwood and sand-contaminated materials. To manage these streams, the process configuration integrates several key systems. An optical sorting system, based on PELLENC/TITECH-type technology, is used for polymer identification and the separation of recyclable fractions from the seasonal beach litter. This is complemented by screening and mechanical separation equipment (McClosk R105 durable screenerte) dedicated to wood–sand separation and the removal of mineral fractions. For wood treatment, the facility incorporates two industrial wood-chippers (TW280 PHB type), enabling conversion into chips suitable for biomass valorisation or energy recovery.

In addition, the facility includes **marine litter monitoring systems** based on three types of drone technologies: aerial drones for coastal surveillance, a surface autonomous vehicle (SeaCAT USV multi-drone platform) capable of deploying ROVs and UAVs with extended endurance and high payload capacity, and underwater drones (ROVs), including portable micro-ROV systems (up to ~150 m depth) and high-performance units (up to ~500 m depth). The most suitable drone platforms for marine monitoring and inspection within the Blue Point system are those developed by SUBSEA TECH[9], a specialised engineering company focused on marine and underwater technologies. These technologies support the monitoring of marine litter accumulation, the identification of pollution hotspots, and the enhancement of traceability within Blue Point operations.

From a design and layout perspective, the facility is conceived as a robust and flexible treatment hall adapted to highly heterogeneous and contaminated materials. It includes segregated operational zones for coarse waste handling, plastic sorting and wood

[9] https://www.subsea-tech.com/

processing, along with high accessibility for heavy materials and integration with outdoor staging areas. According to the design drawings, the building has an approximate footprint of **20 m × 20 m (around 400 m²)**, an internal height ranging from approximately 4.9 m to 6.1 m, and a maximum roof height of about 7.5 m.

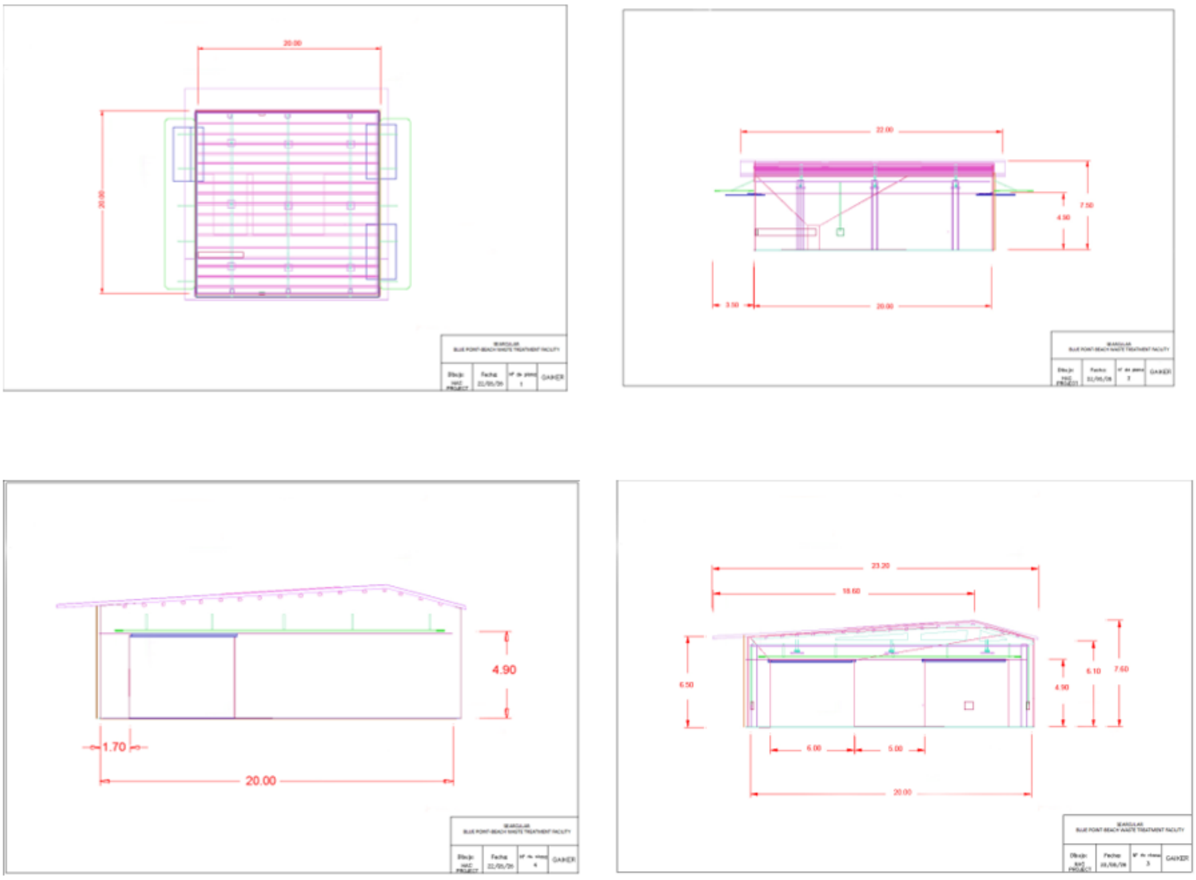
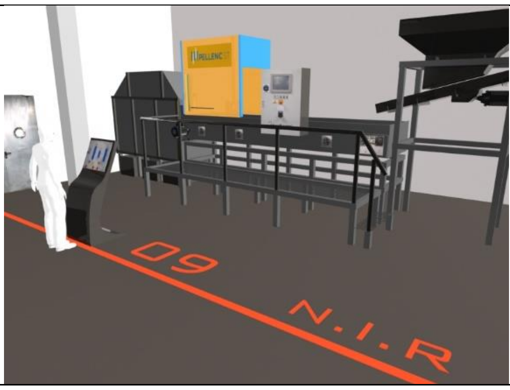
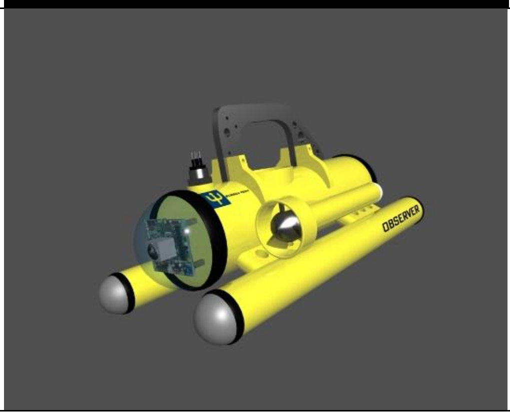


Figure 39. Drawings of the Blue Point – Beach Waste Treatment Facility and Marine Litter Monitoring

Next, 3D equipment drawings are included to support exact positioning, elevations, and integration requirements.

Table 19. 3D figures for equipment included to support exact positioning, elevations, and integration requirements



Global Building Summary Table

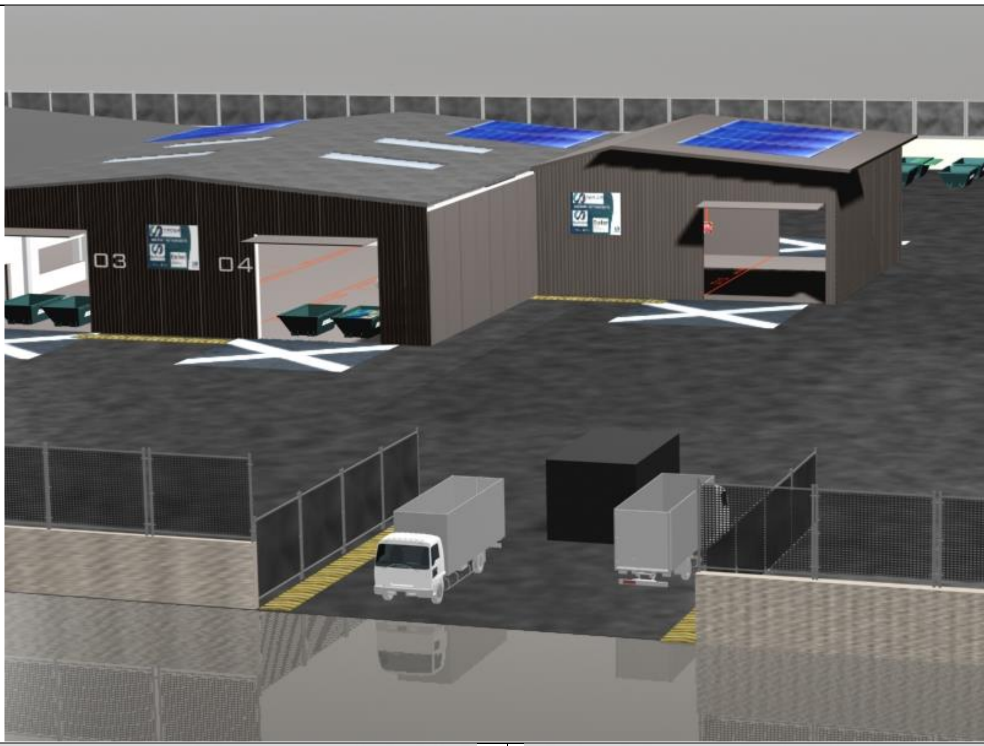
The evolution from a single Blue Point facility to a three-building integrated infrastructure significantly enhances overall system performance by improving material recovery efficiency, increasing economic viability through the implementation of multiple valorisation routes, and expanding the environmental scope to address both marine and coastal litter streams. In addition, this configuration strengthens technological robustness through the integration of smart systems and environmental monitoring tools. As a result, this extended setup represents a **next-generation Blue Point model**, **with strong potential for replication across European coastal regions**.

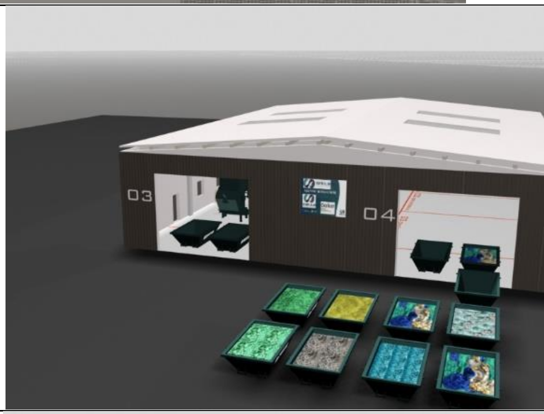
Table 20. Blue Point Facilities: Consolidated Technical Overview.

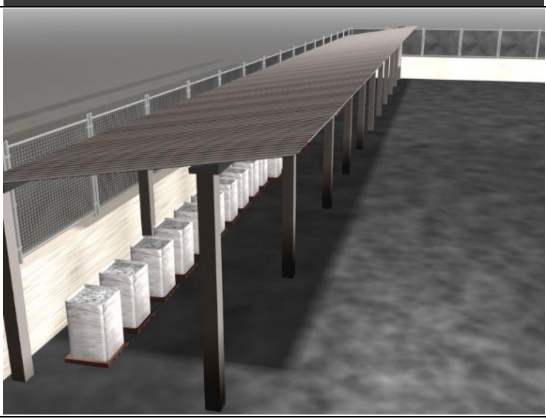
Parameter	Building 1 Main Facility	Building 2 Recycling Facility	Building 3 Beach Facility	TOTAL
Length (m)	30	25	20	–
Width (m)	25	25	20	–
Footprint (m^2)	750	625	400	**1,775 m^2**
Internal height (m)	4.9 – 7.5	4.9 – 6.4	4.9 – 7.5	–
Main function	Sorting & Conditioning	Recycling (extrusion + pyrolysis)	Beach waste treatment + Monitoring	Integrated system
Number of buildings	1	1	1	**3**
Operational scope	Fishing gear	Plastic recycling valorisation	Coastal marine litter + monitoring	Full Blue Point ecosystem

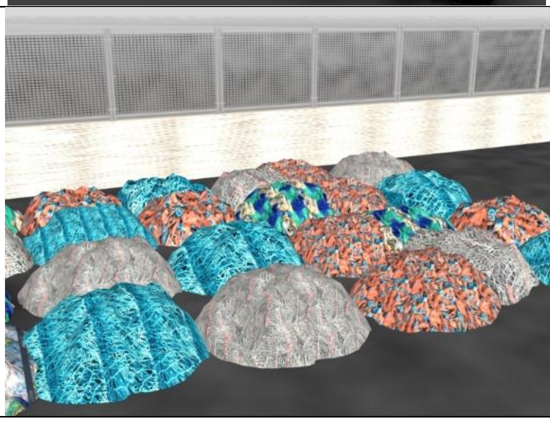
Next, 3D equipment drawings are included:

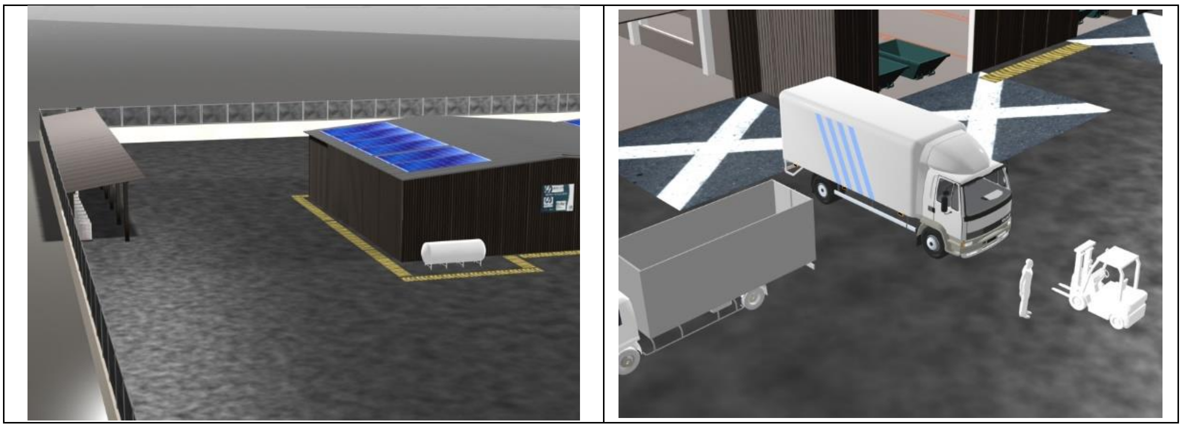
Table 21. 3D figures for equipment included to support exact positioning, elevations, and integration requirements











Below is a plan of the layout of the entire grouped installation, which includes an estimation of the measurements made upwards and without space limitations.

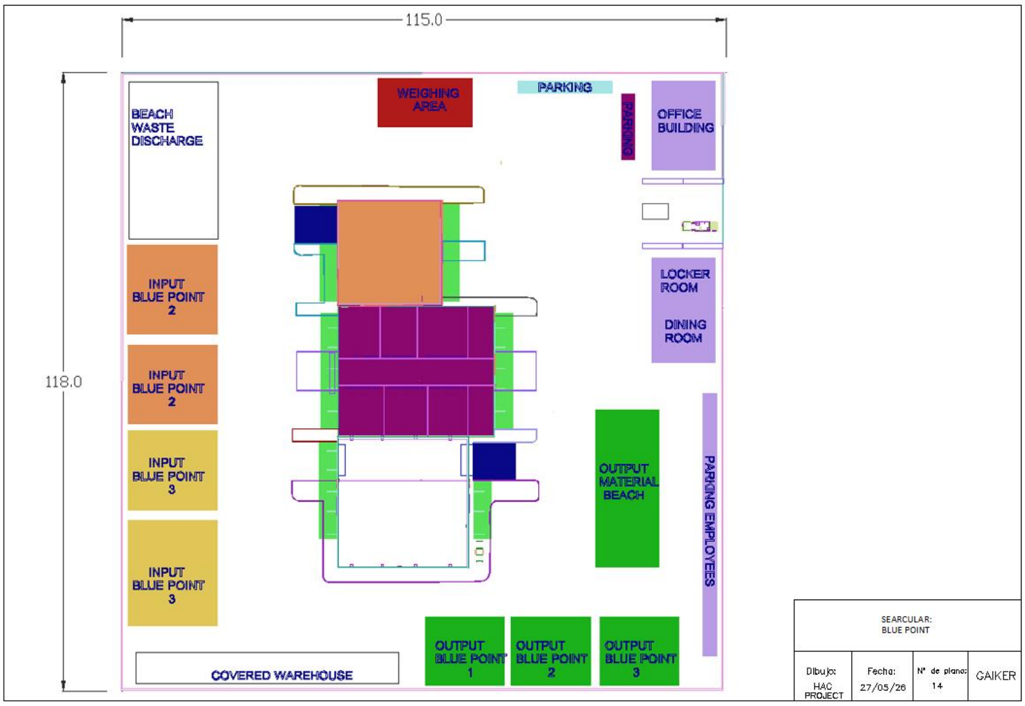


Figure 40. Floor drawing of the evolution of the entire grouped Smart SEARCULAR Blue Point

2.6. Selection of advanced techniques for the identification and characterisation of materials

One of the most critical steps for the proper processing and valorisation of waste streams is the accurate characterization of the composition of fishing nets and associated materials. To achieve this objective, NIR spectroscopy was selected as the main identification technique, as it is widely implemented within the recycling industry due to its numerous advantages over other material identification technologies, including low operational cost, rapid analysis, ease of use, and high availability. NIR technology is particularly suitable for plastic characterization because the analysed spectral range corresponds to the resonant frequencies of organic molecular bonds, enabling reliable identification of polymeric materials.

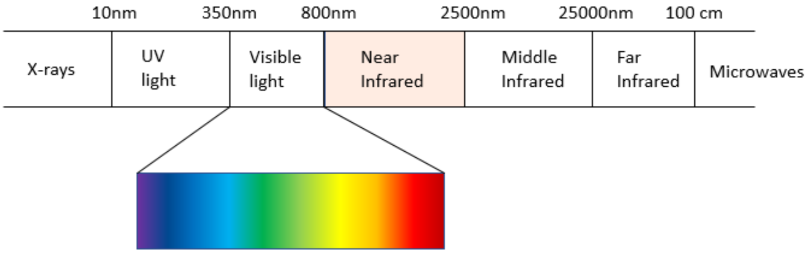


Figure 41. Infrared wavelengths (IR) between 800mm – 2500mm

The characterization of the samples was carried out using a KUMSTA 4004M32 multiplexing NIR spectrometer (1000–2500 nm) equipped with 32 scanning heads from LLA Instruments GMBH, capable of acquiring spectral measurements within 20 ms. In the laboratory setup developed during the project, one of the scanning heads was connected to a handheld device in order to simulate the operational conditions expected in a future Blue Point facility. Nevertheless, the implementation of this specific laboratory-scale equipment in an industrial environment would be excessive for routine operations. Therefore, a more suitable alternative for industrial deployment would be the Visum Palm system from Iris Technologies, an integrated handheld NIR spectrometer with automatic material recognition capabilities specifically designed for field applications.

In addition to polymeric materials, other components present within EOL fishing gear waste streams, such as fishing net sinkers and metallic elements, must also be properly characterized to enable efficient sorting and recycling. Since NIR spectroscopy is not suitable for metal identification due to the absence of organic molecular bonds in metallic compounds, X-ray fluorescence spectroscopy (XRF) was proposed as a complementary analytical technique for determining the elemental composition of metallic residues. XRF is a well-established characterization methodology based on the analysis of secondary photons generated after the interaction between X-rays and the atomic structure of the material, producing characteristic spectral emissions that allow elemental identification.

Similarly to the NIR approach, material identification can also be performed using portable XRF equipment under operational conditions comparable to those expected in the Blue Point facility. Preliminary laboratory-scale tests were carried out using an Olympus Vanta C Series portable XRF analyser equipped with a silver anode X-ray tube (8–50 keV, 5–200 μA) and a silicon drift detector. The use of this type of portable analytical equipment would significantly improve the efficiency and accuracy of fishing gear waste sorting operations, while simultaneously enhancing the recovery of valuable metallic fractions. Consequently, the implementation of these characterization technologies could contribute not only to increasing recycling yields, but also to improving the economic viability and overall sustainability of future valorisation facilities.

Figure 42. Olympus Vanta C Series portable XRF analyser (Gaiker)

2.7. Development of procedures for waste management in port

In other to correctly processes the incoming fishing related litter, the following steps must be followed for the correct characterization of the residues:

- **Unloading of the material:** All the material in each container is placed on the floor of the industrial building.
- **Opening of ropes, stakes, and nets:** Using a crane or similar tool, the different ropes, stakes and nets are opened on the floor for their subsequent analysis.
- **Representative Sampling: From each sample, a representative sample is cut to allow a later exhaustive analysis.**
- **Labelling and Preparation for NIR Analysis:** Each sample collected is properly labelled and all subsamples are prepared for analysis by NIR spectroscopy.
- **NIR Characterization:** NIR characterization of the samples is carried out to determine the polymers present in each fishing gear.
- **Classification and Separation of Materials:** Once the polymers present are identified, the materials are classified and separated into the following groups: PO, PA, multimaterial, other polymers, metals, and rest.
- **Exhaustive Review and Elimination of Impurities:** An exhaustive review of the materials is carried out to eliminate impurities such as adhesive tape, labels, coatings, etc.
- **Material Weighing and Balancing:** Quantities of each material group are weighed to balance the total input material and determine the percentage (by weight) of PO and PA present.
- **Fishing Gear Grouping:** Once the classification process is completed, the fishing gear is grouped according to its category for further processing.
- **Shredding of PO/PA waste fraction:** The pyrolyzable PO fraction is shredded to 4 mm.
- **Washing of PO/PA waste fraction:** Once the material is shredded, it is washed in a washing tank for the removal of the undesirable and limited dirt, sand, salt, and organic matter residues as input to the Plastic Energy's pyrolysis reactors.

- **Drying of the PO/PA waste fraction:** After the processing the waste, the shredded plastic is dried using an oven to reduce the water content present in the samples, until it water content is adequate of its use in pyrolysis in the case of PO or for storage, in the case of PA.
- **Pyrolization of the PO waste fraction:** The PO fraction is pyrolyzed and TACOIL and other subproducts of interest are obtained.
- **Preparation for transport for realization:** The obtained substances are stored and prepared for their transport to facilities or enterprise for their use.

2.8. Administrative/legal requirements, costs and KPIs to monitor the "Blue Point" performance

2.8.1. Administrative/legal requirements

The implementation and operation of the Blue Point infrastructure involve activities related to the collection, transport, storage and treatment of EOL fishing gear and marine litter. Consequently, the system must comply with a multi-level regulatory framework comprising international, European, national and regional legislation governing waste management, marine litter prevention and circular economy practices.

At international level, the International Maritime Organization framework established under the MARPOL Convention Annex V prohibits the discharge of plastics at sea and requires ports to provide adequate Port Reception Facilities for waste delivery. This regulation constitutes one of the main pillars supporting marine waste management systems, including the handling and treatment of EOL fishing gear.

At European level, several regulatory instruments directly affect the implementation of the Blue Point system. The Directive (EU) 2019/883 establishes the obligation for vessels to deliver waste to ports and requires the availability of adequate infrastructure adapted to operational needs. Nevertheless, differences in implementation among Member States continue to generate variability in waste management performance and operational efficiency across ports. In parallel, the Directive (EU) 2019/904 introduces EPR schemes for fishing gear containing plastic, requiring producers to finance the collection, transport and treatment of waste fishing gear. Since December 2024, Member States are also required to implement operational EPR systems including reporting obligations, collection targets, traceability mechanisms and financing structures for EOL fishing gear management.

In the Spanish context, waste-related activities are regulated at regional level by the autonomous communities[10]. Therefore, all permits and authorizations associated with the Blue Point infrastructure must be issued by the Basque administration, as both the facilities and operations considered in this study are located within the Basque Country. In accordance with national requirements, waste operators must ensure the existence of designated and properly labelled storage areas, adequate classification and traceability of collected waste streams, and delivery of waste exclusively to authorized treatment facilities. In addition, authorized waste managers are required to comply with documentation and record-keeping obligations, maintain separate management of different waste fractions, and guarantee that all operations are conducted under the conditions established in their permits.

Specifically, within the Basque Country, waste management entities must be registered in the *Registro de Producción y Gestión de Residuos* under the category *E02 Gestor de tratamiento de residuos no peligrosos*. Furthermore, according to Ley 10/2021 de Administración Ambiental de Euskadi, the implementation of the Blue Point requires an *Autorización Ambiental Única*. This authorization is managed by the Viceconsejería de Sostenibilidad Ambiental of the Basque Government and consolidates into a single administrative procedure all environmental authorizations related to waste management, atmospheric emissions, wastewater discharges and activities affecting the public maritime-terrestrial domain[11].

Beyond regulatory compliance, governance and coordination among stakeholders represent a critical aspect for the successful operation of the Blue Point system. Responsibilities associated with collection, transport, storage, treatment and reporting are often distributed among port authorities, municipalities, producers, waste operators and public administrations. Consequently, a clear definition of stakeholder roles and responsibilities is essential to avoid overlaps, inefficiencies and administrative barriers. Likewise, integration with existing port waste management plans and PRF systems, together with the adoption of digital traceability tools or product passport systems, is considered necessary to ensure transparency and compliance with EPR obligations.

To evaluate the feasibility of the Blue Point concept, a preliminary economic assessment is currently being carried out to support the selection of the most suitable location for the facility, comparing two potential sites: Bilbao and Bermeo. The assessment considers the main economic drivers of the system, including transportation costs from collection hubs to the Blue Point, investment in machinery, building rental, consumables, and personnel costs. Different operational scenarios have been analysed, incorporating both conservative and optimistic assumptions in order to reflect the expected variability in real operating conditions and provide a robust comparison between locations. The objective

[10] Gestión de residuos - Productos - Empresas - Tus derechos y obligaciones en la UE - Tu espacio europeo - Punto de Acceso General

[11] https://www.euskadi.eus/gobierno-vasco/-/faqs/preguntas-frecuentes-sobre-autorizacion-ambiental-unica/

of this study is to identify potential differences in overall treatment costs depending on the selected site and operational configuration. The final results of this analysis will be formally presented in Deliverable D5.1.

Further information regarding the economic assessment and the associated cost-benefit analysis of the SEARCULAR solutions developed within WP4 will be provided in Deliverable 5.2. Therefore, only a general overview of the economic evaluation is included in the present document.

In parallel, the monitoring of the Blue Point performance should rely on a set of KPIs covering operational, environmental and circularity-related aspects. Relevant indicators include the quantity of EOL fishing gear collected and treated, material recovery rates, transport and treatment costs, traceability performance, greenhouse gas emissions associated with logistics and processing, stakeholder participation levels, and compliance with EPR reporting obligations. These indicators will allow continuous evaluation of the system efficiency, environmental performance and long-term scalability of the Blue Point concept.

2.8.2. Economic relevance of the Blue Point model for the valorisation of EOL fishing gear waste

EOL fishing gear currently represent a negative-value waste stream, with overall management costs typically in the order of at least −250 €/t, mainly driven by logistics and disposal. Transport alone can account for approximately 120 €/t, due to the low bulk density, high volume and handling complexity of fishing nets and ropes. In the absence of adequate pre-treatment and material conditioning, these wastes are commonly managed through landfill or low-value disposal routes, resulting in a pure operational cost with no economic return.

The Blue Point model plays a critical role in reversing this cost structure by acting as a port-based hub for material conditioning and value creation. By enabling structured collection, polymer-based sorting, removal of impurities and controlled pre-treatment, the Blue Point transforms heterogeneous fishing gear waste into defined material fractions that are compatible with recycling markets. Through cutting, shredding and, where required, washing and drying, the Blue Point enables the production of plastic flakes or shredded material ("picadillo") with improved homogeneity, bulk density and processability. These conditioned outputs can be placed on mechanical or chemical recycling markets at price levels that are significantly more favourable than untreated waste, thereby substantially improving the economic balance of EOL fishing gear management.

In addition, the Blue Point model also enables direct sale options without mechanical size reduction. Once fishing gears are properly separated by polymer type, cleaned and free of improprieties, they can be marketed as sorted plastic waste streams. Market practice indicates that such materials, although still low-value, can achieve positive prices typically at least 50€/t, depending on polymer type, cleanliness, volumes and local demand. When further conditioned through shredding, and especially through shredding combined with intensive washing, the material value increases substantially. Depending on polymer type (polyolefins vs. polyamides), moisture content and contamination level, shredded and washed fishing-gear plastics can reach price ranges that approach or exceed break-even conditions, and in some cases generate a clearly positive revenue stream. Overall, by reducing disposal costs and enabling access to recycling markets, the Blue Point model significantly improves the economic sustainability, robustness and bankability of EOL fishing gear management schemes, complementing its environmental and circularity benefits.

Table 22. Indicative cost and value ranges for EOL fishing gear management scenarios

Management scenario	Material condition	Estimated cost / value	Unit	Technical remarks
Conventional management (landfill)	Mixed, untreated	−250	€/t	Includes transport, gate fee and treatment
Transport only	Mixed, untreated	−120	€/t	Typical long-distance logistics cost
Blue Point – classified (not shredded)	Sorted by polymer, clean, no impurities	‹ 150	€/t	‹ 150 €/t as conservative reference
Blue Point – shredded (picadillo)	Shredded, size-controlled	+150 to +300	€/t	Depending on polymer and moisture
Blue Point – shredded and washed	Clean and dry flakes	+300 to +750	€/t	Suitable for recycling
Blue Point – chemical recycling feedstock	Polyolefin-rich, quality-controlled	+150 to +300	€/t	Contract- and volume-dependent

2.8.3. Key Performance Indicators

The performance of the Blue Point port-based model has been monitored through a defined set of **quantitative and qualitative KPIs**, designed to assess its operational efficiency, technical robustness, regulatory compliance and contribution to circular economy objectives. The selected KPIs are fully aligned with the technical validation activities implemented under WP4, and in particular with the results obtained in Task 4.1. They enable a transparent evaluation of the system's capacity to manage real EOL fishing gear streams under industrial conditions, while ensuring traceability, compliance with waste management regulations and compatibility with downstream recycling routes.

KPI framework and monitoring approach

The KPIs focus on five key performance dimensions:

- **Operational performance**, measured through the quantity of EOL fishing gear collected and treated under the Blue Point model.
- **Material recovery efficiency**, assessed by the amount of polymer-specific material streams generated and conditioned for recycling.
- **Industrial validation**, verified through the effective use of industrial facilities and recycling plants.
- **Environmental performance**, evaluated through the demonstrated diversion of waste flows from landfill disposal routes.
- **Technology maturity**, reflected by the achieved Technology Readiness Level (TRL).

Monitoring of these KPIs has been carried out using **documented mass balances, sorting and pre-treatment logs, and industrial processing confirmations**, ensuring full traceability and auditability of the results.

Table 23. Key Performance Indicators for the Blue Point model.

KPI	Description	Target value	Monitoring method
KPI-1	EOL fishing gears collected and treated under the Blue Point model	≥ 5 t	Weighing records, logistics and reception documentation
KPI-2	Polyolefin-based material conditioned for chemical recycling	1 t	Mass balance of sorting and pre-treatment processes
KPI-3	Validation of chemical recycling route at industrial scale (pyrolysis)	Yes	Industrial processing confirmation at Plastic Energy
KPI-4	Demonstrated reduction of landfill disposal pathways	Qualitative	Comparison with baseline waste management practices
KPI-5	Operational validation level of the Blue Point model	TRL 7	EC TRL criteria and validation evidence
KPI-6	Potential recovery rate for the Smart Blue Point	≥ 50%	Mass balance and diagram flow

KPI relevance for administrative and legal assessment

From an administrative and legal perspective, these KPIs provide evidence that the Blue Point model operates within the framework of **authorised waste management activities**, complies with **traceability and reporting obligations**, and delivers measurable results aligned with EU waste hierarchy principles and circular economy policies.

The achievement of the defined KPIs confirms that the Blue Point model is not limited to conceptual or pilot-scale demonstrations, but functions as an **operational system integrated into existing port and waste management structures**, capable of supporting decision-making, cost assessment and future replication at regional and European level.

2.9. Integrated management and valorisation of additional marine litter streams in the Basque coastal region

As discussed throughout this study, marine litter associated with coastal and port environments is not exclusively linked to EOL fishing gear generated by fishing activities. In addition to waste originating directly from fishing vessels and port operations, meteorological and hydrological events have been identified as an important source of additional marine litter streams affecting the Basque coastline. Intense storms, heavy rainfall episodes, and river flooding events frequently lead to the transport of large quantities of natural and anthropogenic waste from inland and riverbank areas toward coastal zones, ports, and beaches. Consequently, these phenomena generate a differentiated and highly heterogeneous waste stream that must also be considered within future marine litter management strategies.

According to observations and records collected by Basque Government (Diputación de Gipuzkoa[12]), these episodic waste accumulations are mainly composed of branches, trunks, and other woody biomass transported by river currents, together with significant quantities of urban waste and floating debris. The anthropogenic fraction typically includes plastic fragments, packaging waste, metallic cans, bottles, footwear, expanded polystyrene pieces, household objects, and other mixed municipal residues. In parallel, organic matter such as algae and vegetal remains is also frequently present within these accumulations. Particularly relevant is the presence of fragmented plastic materials and expanded polystyrene, which can easily degrade into microplastics if not rapidly collected and properly managed.

These waste streams not only generate important environmental impacts along beaches and coastal ecosystems but also create operational and safety-related challenges within ports. Before vessels can safely leave port facilities, floating waste and debris accumulated on the water surface must be removed, since these materials may damage propellers, obstruct maneuvering operations, or block seawater cooling systems in vessel engines, potentially causing severe mechanical failures. As a consequence, port authorities and local administrations are often required to carry out emergency collection operations immediately after storm events (Figure 43).

[12] https://www.gipuzkoa.eus/eu/

Figure 43. Floating waste and debris accumulated on the water surface.

In most cases, the collected waste is managed as mixed residual waste and directly transported to landfill due to the lack of adequate infrastructures for characterization, sorting, and recovery. This situation represents a significant loss of potentially valuable materials and increases both environmental burdens and waste management costs. For this reason, the present study identifies the integration of marine litter treatment capabilities within the Smart Blue Point concept as a highly relevant and strategic opportunity. In addition to the management of EOL fishing gear, the proposed Blue Point infrastructure could incorporate an adjacent treatment area specifically dedicated to the characterization, sorting, conditioning, and valorisation of marine litter collected from beaches, coastal areas, ports, and storm-related clean-up operations. The implementation of this complementary infrastructure would allow the separation of recyclable fractions, the recovery of valuable materials, and the reduction of landfill disposal volumes.

Within this framework, plastics could be identified and classified using the portable polymer identification technologies already considered for the Blue Point facility, including NIR automatic spectroscopy systems. Once identified and separated according to polymer composition, recyclable plastic fractions could be redirected toward mechanical or chemical recycling routes depending on their quality and composition. In parallel, woody biomass such as branches, trunks, and other organic materials could be processed through shredding systems to produce wood chips suitable for subsequent valorisation pathways, including pellet production or other wood-derived applications. The incorporation of these additional treatment capabilities would improve the environmental and economic performance of the proposed facility while increasing regional preparedness for future extreme weather events, whose frequency and intensity are expected to increase due to climate change.

To better understand the magnitude and composition of these additional marine litter streams, characterization studies carried out by the Government of Gipuzkoa during 2025 on the beaches of Hondarribia, Orio, Zarautz, Mutriku, Getaria, Zumaia, and Deba were analysed. These studies quantified the main material fractions collected annually from beach cleaning and coastal maintenance activities, including both anthropogenic marine litter and storm-derived waste streams.

Table 24. Characterization results carried out by the Government of Gipuzkoa during 2025 on the beaches of Hondarribia, Orio, Zarautz, Mutriku, Getaria, Zumaia, and Deba.

Material	t/year	%
Waste / Residue	866	91%
Organic matter	0	0%
Packaging	11	1%
Glass	2	0%
Wood	74	8%
TOTAL	**953**	

The results of these characterizations reveal that the predominant fraction corresponds to mixed waste and residual materials, representing approximately 91% of the total annual collected mass (866 t/year). Woody biomass constitutes the second most important fraction, accounting for approximately 74 t/year (8%), mainly associated with branches, trunks, and natural debris transported during storm events. Smaller fractions correspond to packaging waste (11 t/year), glass (2 t/year), and other minor materials.

Although plastic packaging represents a relatively small percentage of the total collected waste stream, the annual quantities generated remain highly significant from a material recovery perspective. Indeed, several tonnes per year of plastic waste are still being collected along the Basque coastline and are currently not being adequately valorised. This highlights the importance of incorporating dedicated characterization, sorting, and recycling capabilities into future Blue Point infrastructures in order to recover high-value secondary raw materials and reduce the environmental impacts associated with marine litter accumulation and landfill disposal.

Overall, these findings reinforce the need to expand the scope of the Smart Blue Point concept beyond EOL fishing gear management alone, moving toward a more integrated coastal waste management model capable of addressing the multiple marine litter streams affecting the Basque coastal region.

3. Validation of port-based solution model for a sustainable EOL gears management

3.1. Validation of a smart port-based "Blue Point" model for EOL fishing gears

The present section aims to validate the proposed system under TRL 7 conditions, with the objective of demonstrating the feasibility of processing and revalorising 1 tonne of EOL fishing gear material through pyrolysis.

3.1.1. Validation methodology and operational implementation

The validation was conducted by deploying the Blue Point model in operational fishing ports where SEARCULAR partners maintain direct engagement with port authorities, fishing fleets and waste managers, particularly in Basque ports, ensuring representativeness, logistical relevance and availability of sufficient EOL fishing gear streams.

The validation methodology consisted of:

- Real-scale **collection, handling and logistics** of EOL fishing gear at port level **(≈14 t)**
- **Polymer-specific classification** using NIR sorting technology
- **Mechanical pre-treatment** (size reduction, shredding, washing and drying)
- Allocation of treated material streams to **mechanical recycling or chemical recycling routes**
- Quantitative assessment of material flows through a detailed **mass balance analysis**

3.1.2. Validation site and industrial facilities

The physical validation of the Blue Point port-based model and the associated pre-treatment chain was carried out at the industrial facilities of **Zorroza Gestión S.L.**, an authorised waste management company located in the Basque Country (Polígono Industrial de Ayala nº4, Murga, Álava, Spain). Zorroza Gestión S.L. is a long-established industrial actor with more than 40 years of experience in the collection, classification, and valorisation of non-hazardous waste, with a strong focus on plastic waste streams. Its facilities are equipped with dedicated infrastructure for waste reception, polymer sorting, mechanical size reduction, shredding, washing and drying operations, supported by a modern fleet of transport vehicles and specialised handling equipment. These capabilities enable the implementation of industrial-scale pre-treatment processes under controlled and traceable conditions, fully aligned with the requirements of the Blue Point model validation at TRL 7. Further information on the company's industrial facilities and technical capabilities is available on its corporate website: Zorroza Gestión – Waste management and recycling services.

3.1.3. Collection, sorting and pre-treatment performance

Over the validation period, **more than 5 tonnes of EOL fishing gears** were collected, sorted and conditioned following the Blue Point operational protocols. These materials, which would typically have been managed through landfill disposal, were instead redirected towards circular treatment routes.

The collected fishing gears were subjected to a standardized treatment sequence:

1. Reception and preliminary inspection at port facilities
2. **NIR-based polymer sorting**, enabling the separation of polyolefins, polyamides, metals and minor fractions at the simulated BLUE POINT in the industrial facilities of the waste managing company Zorroza Gestión
3. Size adaptation through shredding
4. Washing for removal of salts, sediments and organic contamination
5. Drying to achieve moisture levels compatible with downstream industrial processing

As a result of this process, closed to **1 tonne of shredded polyolefin-based nets and ropes** was generated, meeting the quality specifications required for chemical recycling through pyrolysis.

This material was delivered to **Plastic Energy's industrial pyrolysis facilities in Spain**, where pyrolysis was validated as an alternative EOL option for fishing gear fractions not suitable for mechanical recycling. The demonstration confirmed the feasibility of converting these materials into a **recycled feedstock oil** capable of replacing fossil-based naphtha in olefin production.

3.1.4. Mass balance and process efficiency (basis: 1 tonne of EOL fishing gear)

A detailed mass balance was established to quantify the performance and efficiency of the pre-treatment chain. Figure 44 shows the material fractions recovered and losses generated during the processing of EOL fishing gear management (normalised for 1 tonne).

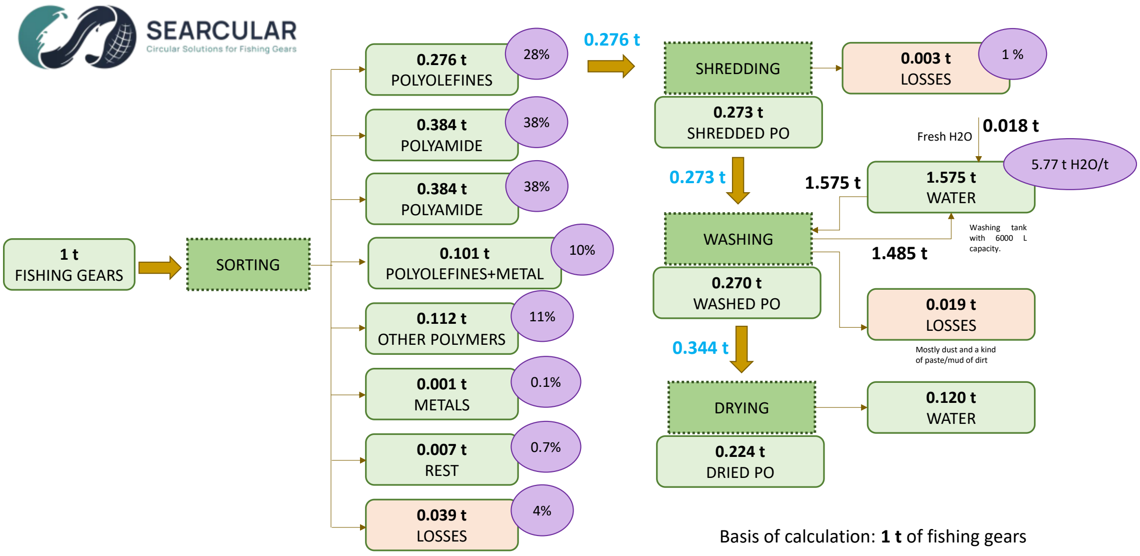


Figure 44. Mass Balance for the treatment of 1 tonne of EOL fishing gear

Table 25. Mass balance of sorting stage (basis: 1 t input)

Material fraction	Mass (t)	Share (%)
Polyolefins	0.276	28
Polyamides	0.384	38
Polyolefins + metals	0.101	10
Other polymers	0.112	11
Metals	0.001	0.1
Residual fraction	0.007	0.7
Sorting losses	0.039	4

In the case of 1 t of EOL fishing gear, the **polyolefin fraction (0.276 t)** was the target stream for chemical recycling validation. During shredding, process losses were limited to **0.003 t (~1%)**, resulting in **0.273 t of shredded polyolefins**. The washing stage required **1.575 t of process water**, equivalent to **5.77 t H_2O per tonne of polyolefin input**, and led to **0.019 t of washing losses**, mainly consisting of dirt, fines and adhered sediments. After washing and drying, the final output was **0.224 t of dried polyolefin material** suitable for pyrolysis, with **0.120 t of residual water** removed during drying.

Within the framework of the SEARCULAR Project, nearly 14 tonnes of fishing gear waste generated in both fishing and commercial ports have been characterized, specifically in five of the aforementioned ports (Bilbao, Bermeo, Ondarroa, Getaria, and Hondarribia). Specifically, 13,710.47 kg of EOL fishing gear were analysed, consisting mainly of the project's target fractions: nets, hawsers/towlines, and plastic or plastic/metal ropes/towlines. This type of fractions are problematic, as there is no established path for its correct recovery to prevent the loss of material and economic value through landfilling.

Grouping the data obtained from all characterized ports, it was observed that more than 25% of the material consists of polyolefin hawsers/towlines and some small portions of nets; near 40% consists of polyamide nets (both multifilament and monofilament depending on the type of fishing); 10% consists of polyolefin+metal hawsers/towlines; 11% is made of multi-material ropes and hawsers (mainly polyolefins plus polyamides, with polyester beginning to gain prominence); and nearly 8% consists of other polymers, mainly polyester in the form of hawsers, ropes, and slings or mooring straps. Less than 1% consists of other materials not related to fishing gear; the presence of metals is minimal (around 0.1%); and 4% material loss has been quantified, mainly due to moisture and the loss of small fractions during sample handling. By grouping the potentially recoverable fractions—polyolefins, polyamides, polyolefin+metal, and metals—the BluePoint designed within SEARCULAR could provide a solution for more than 75% of the material (Recovery Rate).

This percentage would be higher in a more optimistic scenario assuming that part of the multi-material or other polymer fractions can also be recovered and recycled. For example, considering a conservative 35% recoverability for multi-material and other polymers, recovery ratios for the Blue Point could exceed 80%.

These findings underscore the complexity of fishing gear composition and the need to implement effective recycling and waste management strategies to reduce environmental impact and achieve high recovery rates. In conclusion, the diversity of identified polymers highlights the importance of an integrated approach to marine waste management, involving both precise material identification and the implementation of sustainable recycling and reuse practices.

Table 26. Global characterization summary of all analyzed ports

ALL PORTS		
STREAM	WEIGHT (kg)	WEIGHT (%)
Polyolefins	3,779	27.6%
Polyolefins + metal	1,380	10.1%
Polyamide	5,260	38.4%
Multimaterial	1,533	11.2%
Other polymers	1,113	8.1%
Metal	16	0.1%
Rest	96	0.7%
Losses	533	3.9%
TOTAL	13,710	100.0%

Table 27. Potentially recoverable fractions.

POTENTIALLY RECOVERABLE FRACTIONS	
Potential Recovery Rate 1: PO+PA+PO/METAL+METAL	76.11%
Multimaterial (%35)	3.91%
Other polymers (%35)	2.84%
Potential Recovery Rate 2:	**82.86%**

The SEARCULAR Project has been a significant milestone, as the analysis of nearly 14 tonnes of EOL fishing gear constitutes a rigorously representative sample. This represents 0.84% of all annual fishing gear waste generated in Spain (1643 t/year), 12.25% of the waste recorded in the fishing ports of the Basque Country (111.89 t/year)—the specific case study—and 5.17% of the waste identified within state commercial ports (at least 265 t/year) located in the Basque Country region.

Table 28. Total amount of fishing gears (t/y) collected in the ports coordinated by Basque and Spanish Governments

	t/year	%
Total FG Spain	1,643	-
Total FG waste in Basque Country	377	22.94%
Total FG Waste by Basque Government	112	6.81%
Total FG Waste by Spanish Government 250 (Bilbao) + >15 (Pasaia)	265	16,13%

Table 29. The percentage of material characterized and treated in SEARCULAR project, compared to the total amount recorded in the state

SEARCULAR Blue Point Real Simulation, (T)	13,71
% SEARCULAR by Total FG waste in Spain	0.83%
% SEARCULAR by Total FG waste in Basque Country	3.64%
% SEARCULAR by Total FG waste managed by Basque Government	12.25%
% SEARCULAR by Total FG waste managed by Spanish Government	5.17%

This mass balance confirms the **technical robustness, traceability and scalability** of the Blue Point pre-treatment chain.

3.1.5. KPI achievement and performance indicators

The validation activities directly contribute to the achievement of KPIs defined in WP4.

Table 30. Main KPIs achieved in Task 4.1.

KPI	Description	Target value	Achieved
KPI-1	EOL fishing gears collected and treated under the Blue Point model	≥ 5 t	**› 5 t**
KPI-2	Polyolefin-based material conditioned for chemical recycling	1 t	**1 t**
KPI-3	Validation of chemical recycling route at industrial scale (pyrolysis)	Yes	**Achieved**
KPI-4	Demonstrated reduction of landfill disposal pathways	Qualitative	**Demonstrated**
KPI-5	Operational validation level of the Blue Point model	TRL 7	**Achieved**
KPI-6	Potential recovery rate for the Smart Blue Point	≥ 50%	**≥ 75%**

The activities performed under Task 4.1 fulfil all criteria required for **Technology Readiness Level 7**, as defined by the European Commission:

- The Blue Point model was deployed in **operational fishing ports**,
- Real EOL fishing gear flows were managed under **industrial and logistical constraints**,
- Full-scale sorting, pre-treatment and logistics were applied,
- Output materials were processed in **industrial recycling facilities**, including chemical recycling via pyrolysis,
- Performance was validated through **quantified KPIs and mass balance data**.

This demonstrates a **system prototype operating in an operational environment**, confirming TRL 7 maturity.

The validation of the Blue Point model contributes directly to SEARCULAR impact pathways:

- **Environmental impact:** reduction of landfilling and unmanaged disposal of fishing gears, lower fossil feedstock demand through naphtha substitution.
- **Circularity impact:** integration of EOL fishing gears into both mechanical and chemical recycling loops.
- **Systemic impact:** demonstration of a replicable, port-based reverse logistics model applicable to other European fishing regions.
- **Industrial impact:** validation of pyrolysis as a complementary route for complex polymeric fishing gear waste streams.

3.1.6. Visual documentation of the validation process, facilities and equipment

This section provides visual evidence supporting the physical validation of the Blue Point port-based model. The photographs document the key stages of the process implemented, including the reception and handling of EOL fishing gears, polymer-based sorting, mechanical pre-treatment operations, and the industrial facilities and equipment used for shredding, washing and drying. The images complement the technical description provided in the previous sections and serve as demonstrative proof of the industrial-scale implementation of the solution under real operational conditions.

Figure 45. Photos of the Smart Blue Point validation process.

Figure 46. Photos of the Smart Blue Point validation process.

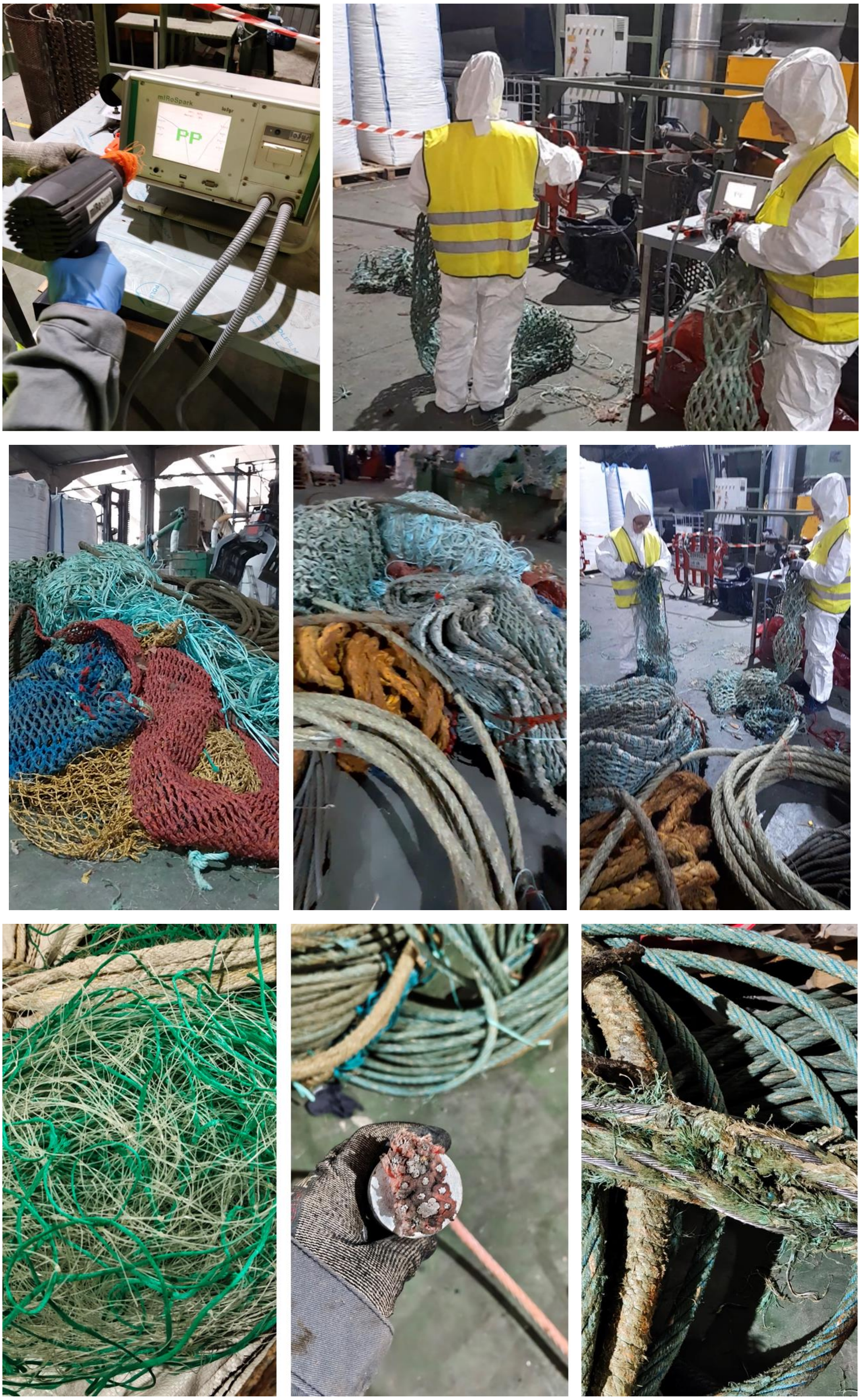


Figure 47. Photos of the Smart Blue Point validation process.

Figure 48. Photos of the Smart Blue Point validation process.

3.2. Validation of industrial scale pyrolysis demonstration.

3.2.1. Feedstock characterization and lab scale trial

As previously described in Deliverable D4.2 *"EOL Fishing Gears Pyrolysis for Plastic2Plastic Strategy"*, preliminary laboratory-scale pyrolysis trials were carried out using conditioned EOL fishing gear feedstock supplied by GAIKER to Plastic Energy. Although the initial results demonstrated that both the feedstock properties and the quality of the obtained pyrolysis oil (TACOIL) were suitable for chemical recycling applications, several operational issues were identified during the processing stage. In particular, recurring overpressure events were observed within the laboratory-scale reactor system due to the formation of inorganic deposits associated with residual salt, sand, and other inorganic contaminants still present in the feedstock after the initial conditioning process.

As a consequence of these operational limitations, an additional optimization stage of the feedstock conditioning process was required before proceeding toward industrial-scale validation. GAIKER therefore conducted a detailed reassessment of the material preparation methodology, focusing particularly on improving the washing and conditioning stages in order to reduce the concentration of inorganic contaminants while maintaining the polymeric composition required for pyrolysis valorisation.

Following this optimization process, a new washed feedstock sample was prepared and supplied to Plastic Energy for a second laboratory-scale evaluation. The objective of this additional assessment was to determine whether the improved conditioning strategy could reduce the operational issues previously observed during pyrolysis while preserving the quality and suitability of the resulting TACOIL for chemical recycling applications.

To facilitate comparison between both conditioning strategies, the original treated feedstock was designated as *Sample A*, while the newly washed and conditioned material was designated as *Sample B*. Feedstock characterization results demonstrated that both samples maintained a very similar polymeric composition, with polyolefins representing the dominant fraction. NIR characterization revealed polypropylene contents of 97.19 wt.% for Sample A and 99.35 wt.% for Sample B, confirming that the washing process did not negatively affect the target polymeric composition of the feedstock. Similarly, polyethylene content remained low in both samples, while the proportion of unidentified or secondary materials decreased significantly after washing (Table 31).

Table 31. presents the comparative feedstock characterization results obtained for both treated and optimized washed feedstock samples prior to pyrolysis testing

Test Method	Component	Units	Sample A	Sample B
NIR	Polypropylene	%	97.19	99.35
	Polyethylene	%	1.22	0.53
	Other	%	1.59	0.12
EDX	Sulphur	ppm	83.9	95.3
	Chlorine	ppm	285.1	139
	Silicon	ppm	1061.1	814.3
Moisture content		Wt.%	0.27	8.2

Additional EDX analysis revealed a reduction in chlorine- and silicon-containing species within the washed feedstock. Chlorine concentrations decreased from 285.1 ppm in Sample A to 139 ppm in Sample B, while silicon concentrations were reduced from 1061.1 ppm to 814.3 ppm. These results confirmed that the washing stage contributed to the partial removal of inorganic contaminants likely associated with marine salts, sediments, and surface fouling accumulated during the operational life of the fishing gear.

Nevertheless, despite the positive reduction in inorganic contamination, the washing stage also introduced a significant increase in feedstock moisture content. While the treated sample presented a moisture content of only 0.27 wt.%, the optimized washed feedstock reached 8.2 wt.%, substantially exceeding Plastic Energy's standard feedstock specification of below 1.5 wt.%. Consequently, the need for an additional drying stage after washing was identified as a critical requirement for future scale-up operations.

Based on the positive results obtained during the feedstock characterization stage, Plastic Energy recommended proceeding toward additional laboratory-scale pyrolysis trials using the washed material. The pyrolysis products obtained from both feedstocks were subsequently compared in order to evaluate the influence of the improved conditioning process on TACOIL quality and process stability.

The analytical results obtained for the produced TACOIL demonstrated that both feedstocks generated pyrolysis oils with properties compatible with the requirements of the chemical recycling industry. However, the washed feedstock led to a significant improvement in several critical parameters. Sulphur concentration decreased from 55.8 ppm in Sample A to 26.6 ppm in Sample B, while chlorine content was reduced from 239.9 ppm to 63 ppm after the washing treatment. In addition, nitrogen compounds were no longer detected in the TACOIL derived from the washed feedstock. Carbon and hydrogen contents remained within the desired specification ranges in both cases, confirming the suitability of the material for Plastic2Plastic valorisation routes.

The complete comparison of the physicochemical properties of the TACOIL samples obtained from treated and optimized washed feedstocks is presented in Table 32.

Table 32. complete comparison of the physicochemical properties of the TACOIL samples

Parameter	Test Method	Units	Sample A (average)	Sample B (average)	Suitability to chemical Recycling Industry (RAG)
Density	IP 559	g cm-3	0.7708	0.7722	
Sulphur	EDX	ppm	55.8	26.6	
Chlorine	EDX	ppm	239.9	63	
Total Carbon	ASTM D591	Wt.%	86.88	86.13	
Total Hydrogen	ASTM D591	Wt.%	13.99	13.71	
Total Nitrogen	ASTM D591	ppm	504	Not detected	
Total oxygen	ASTM D591	ppm	3,21	3,916	
Diene	UOP 326-17	g 100g-1	6.14	5.47	

One of the most relevant findings of this second evaluation was related to the operational behaviour of the pyrolysis system. During the previous trials performed with feedstock, deposit formation inside the reactor and downstream equipment generated pressure increases and partial blockages within the processing lines. In contrast, during the processing of the optimized washed feedstock, no significant overpressure events were observed. Although minor deposits were still detected after the pyrolysis reactions, their quantity was considerably reduced compared to the previous material. Representative images of the deposits observed after the pyrolysis reactions using treated and optimized washed feedstocks are shown in Figure 49.

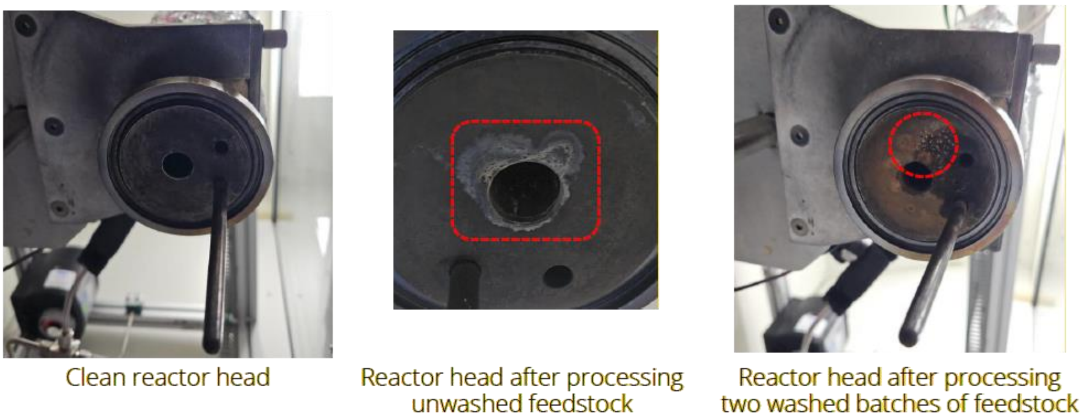


Figure 49. Comparison between the reactor's head after processing each of the feedstock

Further characterization of these deposits confirmed that part of the residues corresponded to carbonized material typically generated during pyrolysis, while the remaining white crystalline deposits were associated with inorganic contaminants originally present in the fishing gear surface. FT-IR analysis demonstrated that these deposits were chemically similar to those observed during the previous trials, suggesting that residual surface contamination was still present in the feedstock, although at substantially lower levels after washing. Additionally, solubility tests were performed on the isolated residues in order to evaluate the possibility of removing the deposits from downstream processing equipment. The results obtained from these tests are summarized in Table 33.

Table 33. Solubility tests results

Solvent	Solubility
DI Water	Particle
Acetone	Sparingly
Methanol	Sparingly
Petroleum ether	N
Toluene	N

The analyses revealed that the reddish deposits exhibited partial solubility in polar solvents such as acetone and methanol, whereas the blackened residues correspond mainly to carbonized material generated during pyrolysis reactions. In contrast, the white crystalline deposits remained insoluble in most of the solvents evaluated, further supporting the hypothesis that these residues originated from inorganic surface contaminants associated with the fishing gear feedstock.

Overall, the results obtained confirmed that the optimized washing and conditioning strategy significantly improved the processability of the feedstock and reduced the operational risks associated with inorganic fouling during pyrolysis. Although the implementation of an additional drying stage remains necessary to control feedstock moisture content, both the feedstock characteristics and the TACOIL properties demonstrated that the material is technically suitable for scale-up toward industrial-scale pyrolysis operations.

Based on these findings, Plastic Energy recommended proceeding toward Stage 3 industrial-scale validation trials, using the conditioned fishing gear feedstock blended with conventional EOL plastic waste streams at an approximate ratio of 10 wt.%. This strategy would minimize operational risks while allowing the progressive integration of EOL fishing gear waste into existing chemical recycling infrastructures.

The successful completion of these laboratory-scale validation activities therefore demonstrated the technical feasibility of valorising properly conditioned EOL fishing gear waste through pyrolysis processes within the framework of the Plastic2Plastic strategy. Furthermore, these results established the necessary technical basis for scaling the process toward the industrial demonstration stage, ultimately enabling the pyrolysis of approximately one tonne of EOL fishing gear waste. The following section presents the results obtained during the industrial-scale pyrolysis demonstration trials.

3.2.2. Industrial scale validation

This section presents the results obtained from a pyrolysis trial conducted to evaluate the operational performance and product quality associated with the introduction of SEARCULAR feedstock into the existing processing system. The main objective of the study was to assess both the process behaviour and the quality of the resulting pyrolysis oil (TACOIL) when co-feeding a novel secondary raw material under industrial operating conditions.

The SEARCULAR feedstock primarily consists of polypropylene fibres recovered from EOL fishing gear. Given its origin and physical characteristics, particular attention was given to its handling behaviour, feeding stability, and potential influence on process performance and final product specifications.

A blending ratio of 10% SEARCULAR feedstock and 90% conventional plastic feedstock was maintained in order to ensure a controlled and representative evaluation of its behaviour within the system. A total of 1,000 kg of SEARCULAR material was introduced into the process, combined with the standard feedstock used in normal operation. Throughout the test, multiple samples of the produced pyrolysis oil (TACOIL) were collected at different shifts for laboratory analysis, with the aim of monitoring any possible variations in product quality associated with feedstock changes.

From an operational perspective, the SEARCULAR material was received at the plant in eight big bags of approximately 120 kg each. Due to its inherently low bulk density and fibrous structure, the material required additional handling prior to feeding. Specifically, it was necessary to fully open the bags and manually loosen the material in order to prevent compaction and ensure a continuous flow into the auxiliary conveyor system. When this pre-conditioning step was not properly performed, the material showed a tendency to form bridges and partial blockages at the feeding stage, highlighting the importance of adequate mechanical preparation before introduction into the process.

Figure 50. Material feeding process

Once properly conditioned, the material followed the standard feeding sequence of the plant, passing through the auxiliary conveyor system into the silo, where it was further distributed via screw extraction systems. From there, the material was transported through inclined belt conveyors towards the weighing system and subsequently fed into the cutter unit. Overall, once the correct handling procedure was established, the feeding behaviour remained stable and compatible with normal plant operation.

The mass balance performed during the trial confirmed stable processing conditions and successful integration of the SEARCULAR feedstock into the existing operation. A total of 12,907 kg of raw material was processed during the test period, with an average moisture content of approximately 4%. From this total, 10,756 kg were effectively converted into processed plastic feed, while 2,151 kg were classified as rejected material, corresponding mainly to operational separation and non-processable fractions.

Table 34. Mass balance performed during the pyrolysis industrial trial

Gross-Raw Material	Rejected material	Humidity	Plastic Fed	Char Generated	Feeding/hour
12,907	2,151	4	10,756	900	448
	20%		**83.33%**	**7%**	

The system operated with a char generation of approximately 900 kg, representing around 7% of the total input. Importantly, none of the SEARCULAR material introduced into the system was rejected during feeding, confirming its full compatibility with the process once properly conditioned.

The overall processing capacity during the test was maintained at approximately 448 kg/h, demonstrating stable throughput without bottlenecks or interruptions attributable to the new feedstock.

In terms of conversion efficiency, the process achieved an oil yield of 9.679 units (as recorded in plant measurement systems), corresponding to a volumetric yield of approximately 90% and a mass-based yield of 71%. These results indicate a high level of conversion efficiency and confirm that the inclusion of SEARCULAR material did not negatively affect overall oil production performance.

Table 35. The yield of the pyrolysis industrial trial.

Oil Production lt	Yield vol/mass	Yield mass/mass
9.679	90%	71%

On the other hand, energy consumption during the trial remained within expected operational ranges for continuous pyrolysis conditions. Gas consumption was recorded through a differential reading, showing a reduction from 39.27% to 31.20%, corresponding to an estimated consumption of 288,906 Nm^3 and an associated energy demand of approximately 31,335 kWh. This reflects stable thermal operation throughout the test period without abnormal fluctuations in fuel demand.

Table 36. Energy consumption of the pyrolysis industrial trial.

Initial reading	Final Reading	Consumption (Nm^3)	Consumption (kwh)
39.27%	31.20%	288,906	31,335

Electricity consumption was also monitored, showing a total consumption of 9,197 kWh based on meter readings between 18,835,264 kWh and 18,844,461 kWh. This level of electrical demand is consistent with normal plant operation and indicates that the introduction of SEARCULAR material did not generate additional mechanical or electrical load on the system.

Table 37. Electricity consumption of the pyrolysis industrial trial.

Initial reading	Final Reading	Consumption (kwh)
18,835,264	18,844,461	9,197

The quality of the resulting pyrolysis oil (TACOIL) was evaluated through routine sampling across different shifts over the two-day period. The main parameters analysed included density, chlorine content, and sulfur content, as these are key indicators of product suitability and downstream usability.

Density values remained highly stable throughout the sampling period, ranging between 782 and 785 kg/m^3. This narrow variation demonstrates a consistent conversion process and indicates that the introduction of SEARCULAR feedstock did not introduce measurable instability in product composition.

Table 38. The quality of the resulting industrial scale pyrolysis oil (TACOIL).

Shift	TACOIL		
	Density	Cl (ppm)	S (ppm)
22/05 TM	783	189	53

22/05 TT	782	165	52
22/05 TN	785	103	44
23/05 TM	784	94	53
23/05 TT	783	94	55
23/05 TN	784	178	52

Chlorine content showed some variation across samples, ranging from 94 to 189 ppm. Although fluctuations were observed, these remained within acceptable operational limits and are likely associated with normal variability in feedstock composition rather than process instability. Similarly, sulfur content remained relatively stable, fluctuating between 44 and 55 ppm, confirming consistent desulfurization performance under the tested conditions. Overall, **the analytical results confirm that product quality remained stable and within the expected specifications** throughout the trial period.

The produced TACOIL was fully traced and stored in tank T-305 for subsequent dispatch, scheduled for 1 June 2026. All feedstock batches processed between 20 and 25 May 2026 were included in this storage tank, ensuring complete traceability from input material to final product storage. This full traceability confirms that the trial results are representative of a continuous and well-documented production campaign, without interruptions or undocumented feedstock changes.

The results obtained from this trial demonstrate that **SEARCULAR feedstock can be successfully integrated into the existing pyrolysis process when used at a 10% blending ratio with conventional feedstock**. From an operational standpoint, no process disruptions, equipment failures, or feeding limitations were observed, provided that adequate pre-conditioning of the material was performed prior to feeding.

The mass balance and production data confirm stable conversion performance, with no negative impact on throughput, oil yield, or char formation. Energy consumption remained within normal operational ranges, indicating that the material does not introduce additional energetic burden to the system.

In terms of product quality, all measured parameters of TACOIL remain within expected specifications, with stable density and controlled levels of chlorine and sulfur. Minor variations observed in chlorine content are considered normal process fluctuations and do not indicate any degradation in product quality.

Overall, the SEARCULAR feedstock has demonstrated full compatibility with the existing industrial pyrolysis process. It can therefore be concluded that the material is suitable for regular processing under current operating conditions, provided that appropriate handling and feeding preparation procedures are maintained.

4. Conclusions

Throughout the SEARCULAR Project, GAIKER has carried out an assessment of the composition of EOL fishing gear collected in the Basque Country region. The Basque Country has four main fishing ports: two located in the province of Bizkaia (Bermeo and Ondarroa) and two in the province of Gipuzkoa (Getaria and Hondarribia). Additionally, it has two major commercial ports in Bilbao and Pasaia, and Pasaia is also a fishing port; it has a dual function. All these ports generate certain amounts of EOL fishing gear and similar waste, from which samples have been taken for characterization and composition analysis. These samples were obtained after following various meetings with the authorities responsible for the management and direction of each port (Port Authorities of Spain's state-owned commercial ports, Port Directors of the Basque Country's fishing ports and their respective fisheries and environment departments, and waste management companies), who were open to the study and supported the research conducted within SEARCULAR.

The port visits confirmed that, although relatively structured systems for general waste collection are already in place in the Basque Country ports, specific management schemes for EOL fishing gear are still largely absent. In most cases, EOL fishing nets, ropes and related materials are not collected through dedicated and traceable routes, which results in landfilling remaining the main destination despite its economic and environmental drawbacks.

The visits also showed significant differences among ports in terms of available space, organisation, sorting practices and operational maturity. Ports such as Hondarribia stand out for their careful pre-sorting and effective coordination between fishermen and waste managers, whereas in other locations materials are deposited mixed or without clear differentiation. These differences demonstrate that the regional system is still fragmented and that a harmonised approach is needed. From a strategic perspective, the visits provided strong evidence that the implementation of a Smart Blue Point would respond to a real operational need. Stakeholders showed a generally positive attitude towards improved valorisation pathways, although the study also identified important enabling conditions, including awareness raising, better traceability, adequate space availability, and institutional coordination. Based on the technical and logistical assessment, Bilbao emerged as the most favourable location for implementation, with Bermeo identified as the strongest alternative.

The analysis of waste streams confirmed that Basque ports generate a broad and heterogeneous range of materials derived from fishing activity, ship maintenance, maritime transport and weather-related marine litter inputs. These streams include fishing nets, ropes, mooring lines, fish traps, floats, wood, metals, oils, packaging waste and mixed residues, each with different management requirements and valorisation potential. A key conclusion is that, while some conventional streams such as metals or oils already follow established recovery routes, EOL fishing gear and associated marine litter streams still lack dedicated and consolidated valorisation chains. As a result, many of these materials continue to be managed through mixed collection systems or are diverted to landfill or energy recovery, limiting circularity and increasing disposal costs.

The study also highlighted that waste generation is highly variable and strongly influenced by seasonality and extreme meteorological events. This variability affects both the quantity and the composition of materials arriving at ports, which reinforces the need for a flexible and adaptive port-based management model. In this context, the Blue Point concept is particularly relevant because it is designed not only to address EOL fishing gear, but also to potentially integrate additional marine / beach litter and climate-related coastal waste streams into a more coordinated circular management system.

The assessment carried has demonstrated that the proposed Blue Point must be conceived as a centralised facility connected to decentralised local collection points, allowing the Basque port network to operate as an integrated and traceable system. This model is consistent with the waste generation patterns identified in the region and with the best practices observed in European and international reference cases. The analysis also confirmed that the Blue Point requires a combination of manual, mechanical and digital capabilities. As EOL fishing gear is bulky, contaminated and highly heterogeneous, the system must incorporate manual dismantling and classification, supported by lifting equipment, handling tools, shredding, washing and drying units, as well as analytical technologies such as NIR and XRF for material identification. This operational configuration is essential to prepare the waste for both mechanical and chemical recycling routes.

Furthermore, based on the pilot-scale simulations and operational activities carried out during the project, it was estimated that the regular operation of the Blue Point facility could be performed by approximately two operators under standard processing conditions. In this context, the proposed system could also represent an important social opportunity, as these operational activities could potentially be oriented towards the inclusion and employment of people at risk of social exclusion. The implementation of this type of inclusive circular economy model could generate positive social impacts within coastal communities by creating stable employment opportunities linked to sustainable waste management activities. In addition, the development of specialised training programmes associated with the Smart Blue Point operations could promote professional integration, improve technical skills related to circular economy sectors, and strengthen environmental awareness among workers and local stakeholders.

Another major conclusion is that the Blue Point concept is technically feasible at the scale required for the Basque Country, estimated at around 500 tonnes per year of EOL fishing gear. The work demonstrated that the facility should include properly designed collection areas, safe and impermeable surfaces, drainage and environmental protection systems, and an intelligent traceability framework capable of monitoring incoming and outgoing flows. In line with the previous section, Bilbao was again identified as the most suitable site for the central facility from a technical and logistical perspective.

The digital traceability system is not a secondary feature of the Blue Point, but rather one of its cores enabling elements. The proposed smart system allows full monitoring of material flows from reception to classification, conditioning and final destination, thereby supporting both operational efficiency and legal compliance. The traceability architecture developed within the project is structured around three fully interconnected processing stages—reception, classification and conditioning—each linked through QR-based identification and digital recording of operational, material and environmental data. This structure ensures that each waste batch can be tracked throughout the entire management chain, while also enabling the generation of a Digital Passport for materials and outputs.

The Smart Blue Point traceability system is aligned with the applicable Spanish and European regulatory framework and, at the same time, creates added value beyond compliance. It supports transparency, auditability, KPI monitoring and environmental reporting, including the possibility of linking processed materials to indicators such as avoided CO_2 emissions. Moreover, the system has been designed with a future-ready logic, making it suitable for progressive integration of AI-based optimisation and predictive functionalities.

The characterization campaign demonstrated that EOL fishing gear waste streams in the Basque Country are highly heterogeneous, with significant differences depending on the port and the origin of the collected material. In total, 13.71 tonnes of material were characterised, including 4,680 kg from Bilbao, 4,350.46 kg from Hondarribia and Getaria, 3,458.56 kg from Ondarroa, and 1,221.43 kg from Bermeo. The results confirmed that polyamide (38.4 wt.%) and polyolefins (27.6 wt.%) are the dominant polymer fractions in the regional waste stream, followed by multimaterial fractions (11.2 wt.%) and polyolefin-metal combinations (10.1 wt.%). Polyamide was particularly prevalent in materials collected directly from fishing activities, representing 93 wt.% of the characterised material from Hondarribia and Getaria and 95.16 wt.% in Bermeo, where the waste stream was mainly composed of fishing nets. In contrast, materials from Bilbao and Ondarroa showed a more complex composition. In Bilbao, the characterised waste stream consisted of 42 wt.% polyolefins, 26 wt.% multimaterial fractions, 22 wt.% other polymers, and only 1 wt.% polyamide, while in Ondarroa the stream was dominated by 50.31 wt.% polyolefins and 39.90 wt.% polyolefin-metal combinations, with only 0.32 wt.% polyamide. These results confirm the strong variability of the Basque EOL fishing gear waste stream and provide a robust technical basis for the design of the Blue Point system.

From a valorisation perspective, the results strongly support the need for a dual recycling strategy. The relatively pure polyamide fractions are well suited to mechanical recycling, whereas polyolefin-rich and mixed fractions are more appropriately directed to chemical recycling routes such as pyrolysis. Overall, the characterization work validates the technical rationale of the Blue Point concept and confirms that a port-based system combining sorting, conditioning and multiple valorisation pathways is feasible and justified for the Basque Country context.

The design and layout work confirmed that the Blue Point can be translated into a technically robust and operationally coherent industrial facility, specifically adapted to the treatment of bulky, heterogeneous and often contaminated EOL fishing gear. The proposed configuration is based on a linear and segregated material flow, moving from reception and pre-inspection through manual sorting, shredding, washing and drying, and finally toward dispatch of conditioned outputs. This layout minimises cross-contamination, improves occupational safety, and supports traceability and quality control throughout the chain. A key conclusion is that the proposed building dimensions and internal distribution are consistent with the target treatment capacity of approximately 500 tonnes per year. The gross floor area of around 750 m², together with the associated external logistics yard and circulation areas, provides sufficient space for reception, ergonomic manual sorting, conditioning equipment, temporary storage and internal logistics without causing operational bottlenecks. The design also incorporates flexibility for future optimisation or moderate scale-up without requiring major structural modifications.

The Blue Point layout has been conceived with a clear understanding of the specific mechanical and handling challenges posed by fishing nets, ropes and especially heavy seine-rope fractions. The integration of dedicated access gates, hydraulic grabs, ergonomic sorting stations, shredding and washing systems, and protected "dirty" and "clean" zones confirms that the facility is not only conceptually sound but also engineering-feasible under real port-industrial conditions. In this sense, the Smart Blue Point design provides a credible physical basis for implementation and replication in European port environments.

The selected identification techniques for the sorting activity, mainly portable NIR devices, are not intended to replace manual expertise, but rather to complement and strengthen the manual classification process. Because fishing gear waste often contains mixed polymers, coatings, reinforcements and metallic inserts, visual inspection alone is insufficient to ensure accurate routing to recycling pathways. The selected technologies therefore play a decisive role in increasing classification reliability and in supporting the production of cleaner and more homogeneous fractions suitable for mechanical or chemical recycling.

The effectiveness of the Blue Point model depends not only on infrastructure and equipment, but also on the establishment of clear, standardised and operationally realistic procedures for waste handling in ports. Given the diversity of port conditions, stakeholders and waste streams, the development of common procedures is essential to ensure consistency, safety, traceability and replicability across the regional network. A key conclusion is that port waste management procedures must cover the entire operational chain, from waste identification, source separation, temporary storage and internal handling to transport, classification and final destination. These procedures are particularly important for EOL fishing gear, because these materials are bulky, irregular, contaminated and frequently poorly separated at source. Standardisation therefore becomes necessary to reduce inefficiencies, improve sorting quality and support downstream valorisation routes.

Successful implementation also requires these procedures to be accompanied by training, awareness-raising and coordination mechanisms involving fishermen, waste managers, port authorities, public administrations and other relevant stakeholders. In this context, the Blue Point model could additionally generate positive social impacts by integrating employment opportunities for people at risk of social exclusion into the operational activities of the facility. Therefore, the alignment and collaboration of all stakeholders become especially important, not only to ensure the efficient management and valorisation of waste streams, but also to promote a socially inclusive circular economy model. The participation of public administrations, social organisations, waste management entities and local communities could facilitate the development of specialised training schemes, safe working procedures and long-term employment opportunities linked to sustainable port waste management. Consequently, the Blue Point concept represents not only an environmental and industrial solution, but also a potential social innovation model capable of generating environmental, economic and social value simultaneously.

The Blue Point model is supported by a clear regulatory rationale but also operates within a complex administrative environment that must be carefully managed. The system must comply with applicable Spanish and European waste legislation, including traceability, storage, transport and treatment obligations, while also anticipating future developments such as the implementation of EPR schemes for fishing gear.

From an economic perspective, the current management model, largely based on landfill and, in some cases, incineration, is associated with significant direct and indirect costs, including disposal fees, transport and the loss of material value. In contrast, the Blue Point creates the basis for a more circular and potentially more efficient model by preparing materials for valorisation and reducing dependence on final disposal routes. Although the system requires investment and coordinated implementation, the analysis shows that the existing disposal model is already economically burdensome and environmentally suboptimal.

A further major conclusion is that the proposed KPIs provide a necessary framework to monitor the technical, environmental and operational performance of the Blue Point. These indicators allow the system to move from a purely waste-handling logic to a performance-based circular management model, capable of measuring recovery rates, treatment efficiency, traceability, environmental benefits and operational effectiveness. As such, this section confirms that the Blue Point is not only a physical facility, but also a measurable and governable management model aligned with European circular economy expectations.

The study shows that ports in the Basque coastal region are also affected by a broader set of marine litter and climate-related waste streams, including floating debris, river-borne wood, ropes, mixed plastic residues and materials mobilised by storms and extreme weather events. These streams represent an additional environmental burden and, at the same time, an opportunity for more integrated circular management. Therefore, the Blue Point can act as a multi-stream coastal waste management hub, provided that treatment and sorting solutions are adapted to the specific nature of each incoming fraction.

In this sense, the layout evolution demonstrates that the Smart SEARCULAR Blue Point has been conceived as a progressively integrated and scalable infrastructure, rather than as an isolated treatment unit. As shown by the floor drawing of the evolution of the entire grouped Smart SEARCULAR Blue Point, the concept evolves from a single waste treatment logic toward a coordinated multi-building system that combines reception, manual sorting, conditioning, recycling preparation and complementary waste stream management within one coherent industrial framework. The consolidated technical design confirms that the complete Smart Blue Point is structured around **three complementary facility blocks**, each with a specific operational role within the overall management chain. The **Main Waste Treatment Industrial Facility** has a **gross floor area of 750 m²** and overall dimensions of **30.0 m × 25.0 m**, forming the core area for reception, manual sorting, shredding, washing and conditioning operations. In addition, the design includes a **Material Recycling Facility** (**625 m²**) and a **Beach Waste Treatment Facility and Marine Litter Monitoring** block (**400 m²**), which together complete the grouped Smart Blue Point concept. According to the consolidated technical overview of the Blue Point facilities, the three buildings together form a **functionally differentiated and modular infrastructure**, combining industrial treatment capacity with recycling support and marine-litter-related activities. This confirms that the Blue Point has been dimensioned not as a single isolated warehouse, but as a **multi-building technical complex** capable of supporting the full operational scope foreseen in the SEARCULAR model.

The validation activities carried out confirm that the Smart Blue Point model is technically feasible under relevant operational conditions (processing > 5 tonnes of waste); and can effectively process representative EOL fishing gear waste streams generated in the Basque Country. The pilot-scale simulation and associated operational tests demonstrated the viability of the full sequence of actions, including reception, manual sorting, characterization, conditioning and routing to valorisation pathways. A major conclusion is that the Blue Point is not only a theoretical concept but a validated operational model, supported by the treatment of substantial material quantities (tonnes) and by the practical verification of equipment, procedures, logistics and workforce requirements. The validation confirmed the relevance of combining manual expertise with analytical tools and conditioning technologies in order to obtain recoverable fractions from complex fishing-gear waste streams.

Definitively, the Blue Point can function as a replicable and scalable port-based solution contributing to TRL 7 validation within the SEARCULAR framework. The work shows that the model can integrate traceability, material preparation and valorisation in a coherent way, thereby providing a credible route toward regional deployment. Overall, the validation confirms that the Blue Point constitutes a realistic and mature solution for sustainable EOL fishing gear management in port environments.

Additionally, the results of the validation of industrial scale pyrolysis demonstration confirm that industrial-scale pyrolysis is a feasible valorisation route for those fishing gear fractions that are difficult to recycle mechanically, particularly polyolefin-rich and mixed plastic streams. Following the characterization, classification and conditioning stages carried out within the Blue Point framework, approximately one tonne of suitable material was processed through pyrolysis, demonstrating that the pre-treated feedstock can be successfully transformed into a high-quality pyrolysis oil. A key conclusion is that the pyrolysis demonstration validates the role of chemical recycling as an essential complement to mechanical recycling within the overall Blue Point strategy. Because the Basque fishing-gear waste stream contains not only relatively pure polyamide fractions but also mixed, degraded and contaminated polyolefin fractions, the availability of an industrial-scale chemical recycling option is crucial to ensure that a larger share of the waste can be valorised rather than landfilled or incinerated.

The industrial-scale validation represents a major milestone within the SEARCULAR project, as it demonstrates, under relevant industrial operating conditions and at a technological readiness level above TRL 7, the technical feasibility of incorporating a marine-origin plastic waste stream into an industrial pyrolysis process. In this **demonstration, approximately 1 tonne of conditioned SEARCULAR fishing gear-derived material was successfully incorporated into the industrial feedstock at a 10% substitution r**atio, confirming that EOL fishing gear waste can be integrated into a real industrial chemical recycling process beyond laboratory or pilot scale.

This result should be regarded as a clear technical success. The significance of the trial lies not only in the fact that it was completed at industrial scale, but also in the successful use of a 10% substitution rate, which is a highly appropriate and technically meaningful proportion for industrial demonstration conditions. In industrial pyrolysis systems, the introduction of alternative waste-derived feedstocks is generally performed progressively in order to control variability in composition, maintain thermal and operational stability, and minimize process risks associated with heterogeneous or novel input streams. In this context, a 10% incorporation level is sufficiently high to provide a robust and representative validation of industrial compatibility, while still ensuring a controlled operating framework that does not compromise plant stability. The successful performance observed at this substitution level therefore provides strong evidence that the proposed route is technically realistic and scalable for future deployment.

From a conversion-efficiency perspective, the process achieved an **oil production** corresponding to a volumetric yield of approximately 90% and a mass-based yield of **71%**. These values demonstrate a high level of liquid conversion efficiency and confirm that the inclusion of SEARCULAR material did not negatively affect overall oil production performance. This is a particularly relevant result, as it demonstrates that marine-origin plastic waste derived from fishing gear can be successfully transformed into an industrially relevant high added value liquid output under real operating conditions.

From an energy-performance perspective, the industrial trial also remained within expected operational ranges for continuous pyrolysis conditions, further confirming the stability of the process. Gas consumption, determined through differential readings, decreased from 39.27% to 31.20%, corresponding to an estimated consumption of 288,906 Nm^3 and an associated energy demand of approximately 31,335 kWh. In parallel, electricity consumption was recorded at 9,197 kWh, based on meter readings between 18,835,264 kWh and 18,844,461 kWh. These results indicate that the introduction of SEARCULAR material did not generate abnormal thermal demand, nor did it impose any additional mechanical or electrical burden on the system, thereby reinforcing the operational compatibility of the marine plastic fraction with the industrial pyrolysis installation.

Overall, the industrial-scale validation confirms that chemical recycling via pyrolysis is a technically viable route for marine-origin plastic waste streams that are difficult to recycle mechanically due to heterogeneity, contamination or complex composition. The successful incorporation of conditioned fishing gear waste into the pyrolysis process, combined with high liquid yield, stable energy performance, and the production of **TACOIL of industrially relevant quality**, substantially strengthens the technical credibility of the SEARCULAR approach. In terms of product quality, the resulting TACOIL remained stable throughout the industrial trial. Density values ranged narrowly between 782 and 785 kg/m^3, confirming a consistent conversion process and indicating that the incorporation of SEARCULAR feedstock did not introduce measurable instability in product composition. Likewise, the analytical results showed that chlorine content ranged from 94 to 189 ppm and sulfur content from 44 to 55 ppm, both remaining within acceptable operational limits and consistent with normal feedstock variability. Overall, these results confirm that the quality of the industrial-scale pyrolysis oil remained stable and within the expected specifications throughout the full test period. In this sense, the trial does not merely validate an individual process step but demonstrates that port-based conditioning of EOL fishing gear can be effectively connected to industrial-scale valorisation, providing a realistic route to reduce dependence on landfill or incineration for complex marine plastic waste fractions.

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