Vlaams Instituut voor de Zee vzw
Flanders Marine Institute

Aquatic plastic catchers: Overview of current technologies, knowledge gaps and future opportunities

Policy Informing Brief

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Flemish Marine Institute

Policy Informing Brief

Preface

Flanders Marine Institute (VLIZ) can provide policy-relevant information free of charge at the request of its target groups, as well as on its own initiative. This information is made available in the form of policy information briefs (in Dutch: Beleidsinformerende nota's - BIN).

The content of the policy information notes is based on current scientific insights and objective information and data. VLIZ relies as much as possible on the expertise of coastal and marine scientists in the network of marine research groups in Flanders/Belgium and the international network.

The policy information notes reflect the neutral and unbound character of the VLIZ and strive for a maximum translation of the basic principles of sustainability and an ecosystem-based approach as endorsed in the European Integrated Maritime Policy and Coastal Zone Management.

More information about the core tasks, principles and preconditions of the VLIZ: http://www.vliz.be/en/mission.

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PLUXIN-project

The PLUXIN-project (cSBO, VLAIO) acts as a platform with actors from knowledge institutions, blue economy, civil society organizations and policy and aims to provide the necessary knowledge for initiating innovation to reduce aquatic plastic debris in Flanders. Insight in the distribution of plastics and their behaviour in space and time is essential to cost-efficiently remove plastics from the aquatic environment. As an outcome, PLUXIN will be able to define accumulation zones or problematic areas in the context of plastic waste in Flanders. The integration of actors from industry, policy/government and knowledge institutions/universities will stimulate new interdisciplinary innovation projects, and new business opportunities for the Flemish actors that are active in waterworks, surveillance, remediation, and waste processing.

As part of the project, an innovation trajectory - led by VLIZ - was initiated in which the existing systems for collecting plastic in aquatic environments are mapped out. This overview serves as a knowledge base to inform the PLUXIN-actors and to unlock further valorisation opportunities for Flanders. This policy informing brief is an outcome of the PLUXIN-project.

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Contents

Summary

The increasing presence of marine litter is one of the grand societal challenges of our time. Societal organizations, policy-makers and industry are increasingly looking at developing and deploying solutions for tackling the problem of marine litter. Preventative measures, in order to reduce the amount of plastics entering the environment (e.g. through behavioural change and policy actions), are the most important and effective solutions. However, preventing plastics from entering our oceans by collecting it in inland waterways as well as cleaning up the plastics already accumulated in our seas and oceans also contributes to reducing the global marine litter problem.

In the framework of the Blue Cluster PLUXIN project, funded by VLAIO, an innovation trajectory was started at the end of 2020 by VLIZ in which the existing systems for collecting plastics in aquatic environments are compiled. The current Policy Informing Brief (PIB), presents a comprehensive global overview of plastics pollution solutions that collect (and remove) plastics from the aquatic (including marine) environment. These include methods and technologies which have been developed to prevent more litter from entering the ocean, and also technologies that clean the already accumulated litter from the rivers and oceans.

For the purpose of this PIB, a desktop study was undertaken using recent publications, project reports and web-based information. A screening of all information resulted in a list of 74 macroplastics-oriented catcher systems that are either in testing phase or already fully operational. Additionally, 6 conceptual designs for mainly offshore application, 6 systems for beach and riverbank clean-up and 7 technologies focusing on microplastics were found. The plastic catchers can be categorized by means of the type of technology, the mobility of the system and the type of control. In this PIB the plastic catchers are described per field of application (stormwater drains, inland water(ways), ports and harbours and the coastal waters and open ocean).

Most plastic catchers are designed to operate in inland waterways (46%). Also, multiple plastic catchers are intended to operate in stormwater drains (15%), ports (22%) and coastal waters areas (15%). Only 3 systems however were identified that are designed for catching plastics from the open ocean.

Currently, in Belgium several plastic catchers have been installed in inland waterways and ports, ranging from simple booms and traps to larger scaled innovative designs. Most of the installations are part of research and innovation projects or tests and will provide the different initiators with relevant information for future developments.

This PIB indicates that the most important developments needed are (1) the optimization of the efficiency of the plastic catcher, (2) knowledge on the impact of the plastic catcher on the environment and (3) the need for automatization of the system. The major barriers that need

to be addressed in order to allow these developments, find cost-efficient solutions and actually realise more plastic traps in the field, are also discussed. These include the need for more scientific and technological knowledge as a basis for the design, additional funding for pilot installations in the field and a regulatory and legal framework related to the plastic pollution problem which can then lead to balanced costs and viable business models.

Additional research is needed to gain insights into the environmental impact and improve the efficiency of the plastic catchers. Combining the results from research with the know-how and expertise from different marine/maritime sectors (e.g. shipping, fishing, dredging,…) may well lead to novel technical developments resulting in more efficient plastic catchers that are able to remove a large percentage of the plastic, before it reaches the marine environment.

This PIB provides professional actors (industry & policy) with the state of the art on solutions for the collection (and removal) of plastics from aquatic (including marine) environment. An overview is provided about the knowledge gaps and research needs, ongoing development, financial and governance stimuli. Insight is given into the status and potential of plastic catchers so that interested companies, policy makers and water managers can take profound decisions on future installation and objectively integrate all strategic information needed to position themselves in this field.

Samenvatting

De toenemende aanwezigheid van zwerfvuil in het marien milieu is één van de grote maatschappelijke uitdagingen van onze tijd. Publieke organisaties, beleidsmakers en het bedrijfsleven kijken steeds vaker naar het ontwikkelen en inzetten van oplossingen om het probleem van zwerfvuil op zee aan te pakken. Preventieve maatregelen, om de hoeveelheid plastic die in het milieu terechtkomt te verminderen (bijvoorbeeld door gedragsverandering en beleidsmaatregelen), zijn de belangrijkste en meest effectieve oplossingen. Maar voorkomen dat plastic de oceaan bereikt door het in de binnenwateren te verwijderen en het opruimen van plastic dat zich reeds in de oceaan heeft opgehoopt, draagt ook bij aan het verminderen van het wereldwijde zwerfvuilprobleem.

In het kader van het Blauwe Cluster project PLUXIN, gefinancierd door VLAIO, werd eind 2020 door het VLIZ een innovatietraject opgestart waarin op aansturen van de stuurgroep de bestaande systemen voor het inzamelen van plastic in aquatische milieus in kaart zouden worden gebracht. De huidige nota presenteert de resultaten van dit traject.

De informatie in deze Beleidsinformerende Nota (BIN) werd verzameld door middel van een desktopstudie, gebaseerd op recente publicaties, projectrapporten en webgebaseerde informatie. Een screening van alle informatie resulteerde in een lijst van 74 macroplastic-georiënteerde vangsystemen die zich in de testfase bevinden of al volledig operationeel zijn. Daarnaast werden 6 conceptuele ontwerpen gevonden voornamelijk voor offshore toepassing, 6 systemen voor strand- en oeversanering en 7 technologieën specifiek gericht op microplastics. De plasticvangers zijn in te delen naar type technologie, de mobiliteit van het systeem en het type besturing, en worden beschreven per toepassingsgebied (rioolafwatering, binnenwater(lopen), havens en de kustwateren en open zee).

De meeste plasticvangers zijn ontworpen voor gebruik in de binnenwater(lopen) (46%). Ook zijn meerdere plasticvangers ontworpen voor gebruik in regenwaterafvoeren (15%), havens (22%) en kustwateren (15%). Slechts 3 systemen werden geïdentificeerd die zijn ontworpen om plastic uit de open oceaan te vangen.

Momenteel zijn in België verschillende plasticvangers geïnstalleerd in binnenwater(lopen) en havens, variërend van eenvoudige drijvende vangarmen en kooien tot grootschalige innovatieve ontwerpen. De meeste installaties maken deel uit van onderzoeks- en innovatieprojecten of testen en zullen de verschillende initiatiefnemers relevante informatie opleveren voor toekomstige ontwikkelingen.

Deze BIN haalt ook de nodige toekomstige ontwikkelingen aan zoals de optimalisatie van de efficiëntie van de plastic catcher, kennis over de impact van de plastic catcher op het milieu en de noodzaak tot automatisering van het systeem. Ook wordt gewezen op de belangrijkste hindernissen die moeten worden aangepakt om deze ontwikkelingen te realiseren en aldus

kostenefficiënte oplossingen te vinden en meer plasticvangsystemen in het veld te realiseren. Deze zijn voornamelijk: de behoefte aan meer wetenschappelijke en technologische kennis als basis voor het ontwerp, aanvullende financiering voor proefinstallaties in het veld en een regelgevend en wettelijk kader met betrekking tot het probleem van plasticvervuiling, wat vervolgens kan leiden tot een sluitend kostenmodel.

Aanvullend onderzoek is nodig om inzicht te krijgen in de milieu-impact en de efficiëntie van de plasticvanger te verbeteren. Het combineren van de onderzoeksresultaten met de knowhow en expertise uit verschillende mariene/maritieme sectoren (vb. scheepvaart, visserij, baggeren,…) kan leiden tot nieuwe technische ontwikkelingen die resulteren in efficiëntere plasticvangers.

Deze BIN biedt spelers uit de industrie en het beleid inzicht in de kennishiaten en behoeftes (op vlak van onderzoek, ontwikkeling, finaciering en beleid) en de status en het potentieel van plasticvangers. De BIN hoopt bij te dragen aan de kennis ter ondersteuning voor toekomstige ontwikkelingen en installaties en de strategische positionering van Vlaamse expertise in dit veld.

1. Introduction

The presence of marine litter is a global problem that continues to grow in the marine environment. Plastic debris makes up 80% of all marine debris from surface waters to deep-sea sediments (IUCN). Globally, plastic production continues to increase annually, by around 11.1 million tonnes since 2011 (global production: 368 million tonnes in 2019 (PlasticsEurope, 2020)). Worldwide, an estimated 4.8 to 12.7 million tonnes of plastic waste ends up in the sea every year (Jambeck et al., 2015).

In Belgium, research on the presence and possible effects of marine litter in the North Sea (and adjacent beaches) has been carried out since 2002. A comprehensive overview of this research field in Belgium and actions from policy is provided by Devriese and Janssen, 2021. Currently, about 80 scientific articles have been published in international peer-reviewed journals on anthropogenic debris or microplastics of which at least one researcher is connected to a Belgian university association or scientific institution (Devriese and Janssen, 2021). Past years, freshwater plastics research has also gained interest as evidenced by some recent publications that focus on the freshwater environment. In addition, the first large-scale research projects on the sources and presence of litter and microplastics in Belgian inland waterways have been started (Devriese and Janssen, 2021). Given the societal importance of this problem, not only the Flemish researchers and policy makers are committing themselves, but there is also a growing awareness and interest among players in the Blue Economy.

In 2018, a new spearhead cluster 'Blue Cluster' was approved by the Flanders Innovation & Entrepreneurship (VLAIO). The Blue Cluster aims to develop innovative projects that address the economic potential of our North Sea. The 'Ocean Pollution and Waste Solutions' domain focuses, among others, on business-driven R&D activities, linked to innovation, economic valorisation and societal interest that can contribute to solutions for various aspects related to plastic litter. Within this domain, three different strategies are being investigated: (1) ways to prevent plastics from ending up in the sea, (2) technologies to efficiently remove plastics from the sea and (3) solutions for recycling (marine) plastics or applying biodegradable plastics in the marine environment (e.g. Coastbusters 2.0-project).

In order to be able to prevent plastic from ending up in the sea, basic information is required on the source, the amount and the fate and behaviour of plastics in the aquatic environment. In order to quantify and map the transport of plastic litter to the sea in Flanders, the cSBO project proposal PLUXIN was approved by VLAIO (Blue Cluster) in 2020. The project acts as a platform with actors from knowledge institutions, blue economy, civil society organizations and policy, and will provide the necessary knowledge for initiating innovative concepts to reduce plastic debris in aquatic environments in Flanders.

Within the framework of the PLUXIN project, the pressing issues, knowledge gaps and fields of interest of the companies, policy makers and other stakeholders is surveyed (e.g. through bilateral consultations and polls during meetings). When presented a list of possible pressing issues in the framework of solutions for macroplastics debris, based on the input from the bilateral consultations, there was large support for the topic: *Knowledge on the existing plastic remediation technologies and installation and their removal efficiency*. Based on the input of the stakeholders, an innovation trajectory was started at the end of 2020 by VLIZ to compile an overview of existing systems for collecting plastics from aquatic environments

This Policy Informing Brief (PIB) provides professional actors (industry & policy) with the state of the art on solutions for the collection (and removal) of plastics from aquatic (including marine) environment. An overview is provided about the knowledge gaps and research needs, ongoing development, financial and governance stimuli. Insight is given into the status and potential of plastic catchers so that interested companies, policy makers and water managers can take profound decisions on future installation and objectively integrate all strategic information needed to position themselves in this field.

2. Approach used to assemble and assess the Plastic Catchers inventory.

Search and screening process

Recently several publications have reviewed existing plastic catcher systems that aim to tackle the worldwide problem of aquatic plastic litter (Falk-Andersson et al. 2020, Schmaltz et al. 2020, BEO 2021 and Dijkstra et al. 2021). For the purpose of this PIB and for the PLUXIN project, all relevant technologies and systems listed in these publications were combined. In addition, a desktop study on websites, papers, news articles, etc. was performed using (combinations of) the search words in Table 1. From the search results, all discrete technologies were included in the inventory that intend to either prevent the leakage of plastic debris into waterways or collect existing plastic debris.

Table 1 : Overview of the words used for the web-based search.

SEARCH WORDS	
“removal” or “removing”	“plastic”
“collecting” or “collection”	“waterway”
“catcher” or “catching”	“river”
“marine debris”	“ocean”
“marine litter”	“system”
“marine plastic”	“technology”
“marine waste”	“trap”
“ocean plastic”	“booms”
“ocean litter”	

The resulting longlist was revised and immature ideas, redundant methods and clean-up initiatives (e.g. beach clean-up actions) were removed. To avoid duplication, identical systems were removed from the list. Despite the thorough search procedure, we acknowledge that the current overview may not be fully exhaustive in the sense that not all existing devices were included. This is mainly due to the fact that this field of research is rapidly evolving. Also, prototypes of new systems stay long below the radar due to the high commercial value of the plastic catchers. For each of the systems taken up in our overview, we completed a list of characteristics and variables queried and searched for at the internet and explored in other publications. Figure 1 gives an overview of the assimilation process used to compile the information.

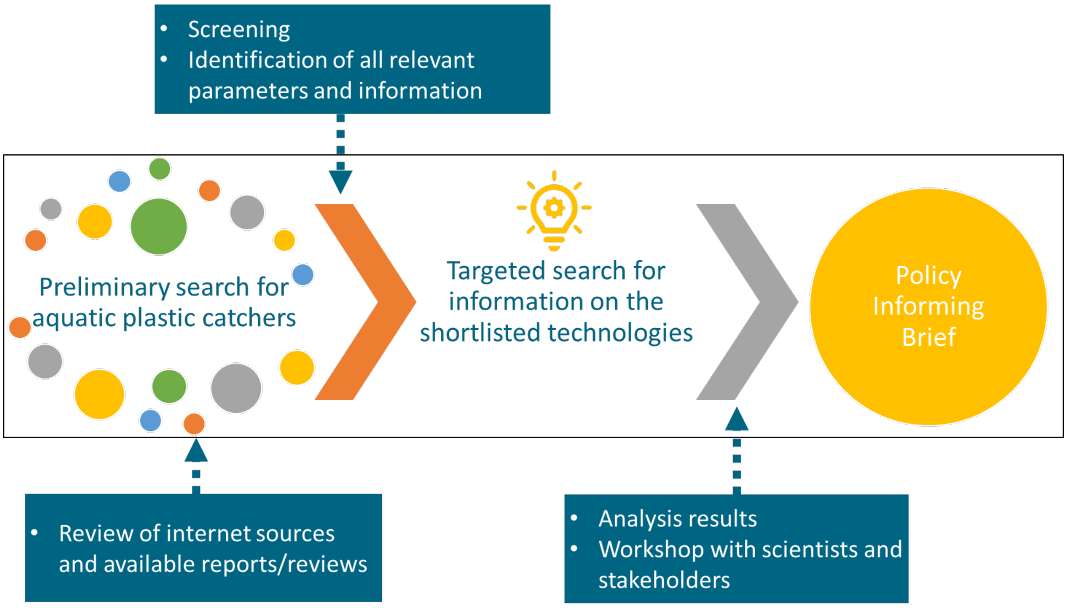


Figure 1 : Process used to compile the inventory.

Patents

During this desktop study, several patent databases (e.g. Espacenet, European Patent Register, Patentscope, Google Patents and Benelux Patent Platform) were screened on plastic catcher systems. Several search words from the above mentioned table 1 were used to filter the large amount of data. A remarkable result is the large number of Asian patents (especially Chinese) compared to the number of technologies in our overview from Asian developers. The broad outcome, the poor descriptions and the lack of developmental stage information, makes the implementation of these patents difficult. This combined with the assumption that most patented systems are still in the conceptual stage, led to the non-inclusion of these patents into the inventory. There were no plastic catcher systems found in the Belgian patent register.

Box 1 : Patents on plastic catcher technologies

Data parameters

The characteristics of each technique were defined and gathered taking into account the aim of the inventory. The primary characteristics to be completed were the way of identification of the technique used, field of application, collection method, mobility (mobile or fixed system) and autonomy (controlled or automated device). In addition, information on the year of development, the origin, the inventor, collection speed and volume, the cost for purchase and maintenance, energy consumption, etc. of the device were gathered. Finally, some additional practical confounding factors that may hamper the actual implementation of the system were included such as minimum and maximum depth requirements, size, navigation, minimum and maximum flow velocity, etc. The complete list and additional information on the characteristics can be found in Appendix 1.

Since a major part of the information is confidential and not publicly shared, often little detailed information is available about the underlying technology. We acknowledge that for some of the systems listed in this note not all information is complete. In order to get more inside information and system specific details further contact with the developers should be made.

Categories

The currently designed aquatic plastic catcher systems can be categorised by several characteristics (see also above). First of all, a distinction can be made between systems designed to collect macroplastics[1] and systems for microplastics[2]. Our overview focusses on macroplastics since the majority of aquatic plastic catchers are designed for the latter category. Nonetheless, some further information on microplastics solutions is described in Box 2.

For the purpose of this PIB, distinction between mobile and fixed systems was made. All fixed systems were then divided into passive and active systems. Mobile systems were further subdivided into crewed and uncrewed systems. The systems can also be categorised by the specific collection method and fields of application. These categories will be used further in the discussion, which will enable us to make specific suggestions for further research and innovation and targeted solutions for certain problems. However, it should be noted that this categorisation holds a certain grey area as systems may combine several technologies. Below are the definitions used for the purpose of this PIB:

[1] Macroplastics: For the purpose of this brief macroplastics are defined as all plastics larger than 5mm

[2] Microplastics: Although most scientists refer to microplastics as plastic particles smaller then 1mm (and larger then 1 μm), for the purpose of this brief microplastics are defined as the plastic particles smaller than 5mm, since that is what most of the developers take as definition (also as according to the U.S. National Oceanic and Atmospheric Administration (NOAA) and the European Chemicals Agency).

- Mobile: Systems that are not installed on a fixed location but are moving around to collect plastic;
- Fixed: Systems that are installed at a fixed location, by means of e.g. poles or anchors. These systems do not actively move around to catch plastic but the plastic is expected to be directed (by natural or induced currents) towards the catchment;
- Passive: Passive systems are those systems that only use the natural currents available to catch the plastic;
- Active: Active systems are those that, in addition to the natural currents, use induced currents or powered technologies to attract the plastic;
- Crewed: Crewed systems are those systems that have to have people on board for operating the systems;
- Uncrewed: Uncrewed systems are those systems that are remotely operated or autonomous.

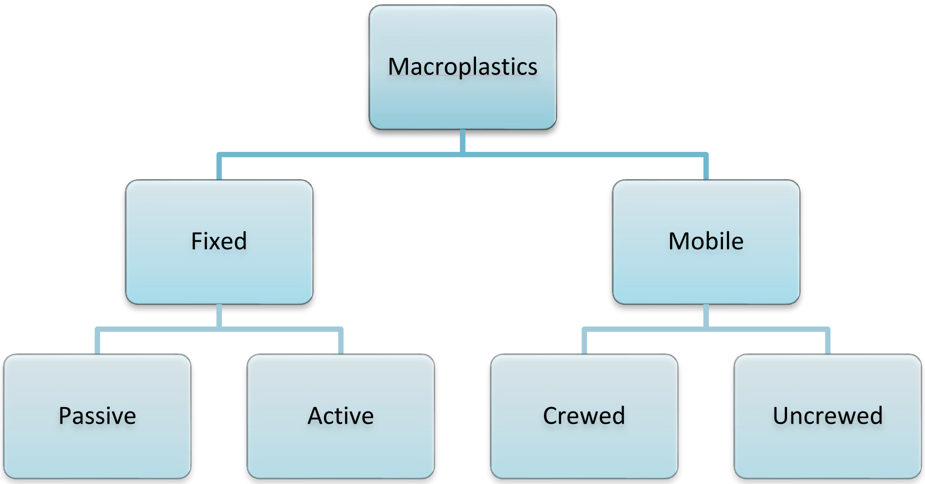


Figure 2: Categorisation of macroplastic catchers.

For the purpose of this report the following field of application categories were chosen:

- Stormwater drain (storm drain, storm sewer, surface water drain/sewer): infrastructure designed to drain excess rain- and groundwater from impervious surfaces such as paved streets, car parks, parking lots, footpaths, sidewalks, and roofs. Storm drains vary in design from small residential dry wells to large municipal systems. Drains receive water from street gutters on most motorways, freeways and other busy roads, as well as towns in areas with heavy rainfall that leads to flooding, and coastal towns with regular storms. Even gutters from houses and buildings can connect to the storm drain. Many storm drainage systems are gravity sewers that drain untreated storm water into rivers or streams;

- Inland water(ways): All standing or flowing water on the surface of the land. This includes rivers, estuaries, canals, streams, lakes, including both brackish and fresh water systems and tidal and non-tidal influenced systems;
- Ports: includes all commercial and recreational inland and coastal ports and harbours;
- Coastal waters: The marine area between the coastline and the open ocean, typically characterized by a shallow continental shelf and in close proximity to land;
- Open ocean: The area of the ocean away from land, beyond the edge of the continental shelves.

Stakeholder engagement

Within the Blue Cluster project PLUXIN, funded by VLAIO, research, industry, policy and NGOs are grouped in the so-called PLUXIN ecosystem. Throughout the entire project, all members of the ecosystem are involved in steering the project, from indicating the research needs and fine-tuning the research questions to identifying innovation and valorisation opportunities and developing follow-up projects.

The draft inventory of the available techniques was revised by all partners of the PLUXIN project and was subsequently presented to 35 PLUXIN stakeholders (members of the steering group committee as well as the consortium partners) during a workshop in March 2021. These stakeholders were invited to provide input and feedback on the compiled information. Additionally, input was gathered on drivers and barriers for the implementation of plastic catcher systems and opportunities for future innovation and valorisation trajectories were discussed. The gathered information was used for the compilation of this PIB.

3. Overview of Existing systems and technologies

The inventory contains information on systems that are designed to collect macroplastics from all types of aquatic environments: wastewater and stormwater flows, inland waterways, ports and oceans. Some of these systems are also capable of collecting microplastics, but only a limited number of technologies are specifically designed to collect microplastics (see Box 2 for more information on microplastics collections).

The compiled overview is a non-exhaustive list and therefore, actual numbers given in this PIB should be regarded as a relative indication. In total, 74 different systems for collecting plastics have been selected for further discussion, of which 58 are currently operational and 16 are still in testing phase. A full overview of the plastic catchers included in this PIB is presented in Appendix 2. Additionally (and not included in the overview of 74 technologies), seven technologies were found that aim at collecting microplastics from residential wastewater and six technologies for removing plastics from beaches or riversides. Also, six technologies were found that are only in a very early conceptual design phase (mainly for offshore application), which may have great potential but currently lack funding to further development.

When looking at the country of invention/development of the different aquatic plastic catchers included in our overview (Figure 3), the largest proportion of technologies are designed in the USA (24,3%). It is noteworthy that a large number of designs also originate from Dutch developers (13,5%) and Australian developers (10,8%). All European technologies together account for just over half (54,1%) of our inventory. In our overview, very few of the systems that are currently operational or being tested are Asian developments. We acknowledge that this is likely a bias due to the language in which the query was performed (i.e. English). This hypothesis is supported by the fact the large number of the patents found originate from China or other Asian countries (Box 1).

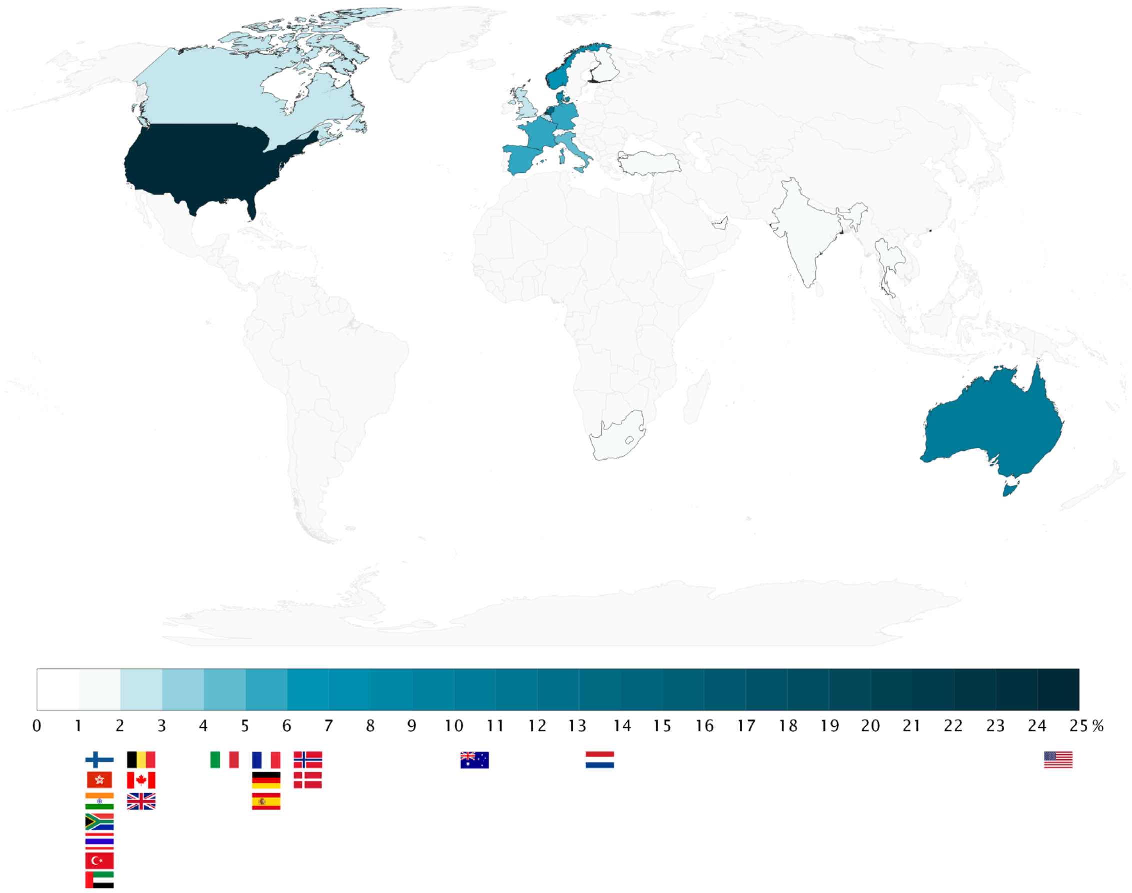


Figure 3 : Overview of the different countries where the plastic catchers are developed with indication of their share in the overall number.

Microplastics

The collection of microplastic particles that are present in the environment (both in the water column and in the riverine and marine sediments), is much harder than collecting macroplastics. The number of collection devices to remove microplastics is limited (7) compared to the ones for macroplastics (74) and mainly focus on collecting the particles close to the source:

- The currently existing microplastics collection devices are mainly designed to capture microplastics from washing machines waste water. Multiple acknowledged filter systems are currently commercially available (e.g. Coraball, Filtrol lint filter, PlanetCare microfiber filter, Xfiltra). Their effectiveness is very variable and might result to a reduction of up to 78% of the microfibres that end up in the waste water (Napper et al, 2020).
- Waste Water Treatment Plants (WWTP) have the purpose of treating domestic and industrial wastewater before it is released into the environment. However, in Flanders these water treatment plants may be insufficiently equipped to efficiently remove microplastics from wastewater. Van Cauwenberghe (2015) studied the treatment plant of Destelbergen and showed that an average of only 50% of the microplastics present in the (received) waste water were not removed by the water treatment plant and thus end up in the watercourse. Recently, UGent performed a general study into the distribution of microplastics in Flemish rivers and drinking water (including WWTP). Results will be published by VMM in September 2021.
- Some macroplastics aquatic catcher systems claim that the system is capable of catching microplastics from the aquatic environment. Examples of these are the systems using air bubbles and small meshed nets (e.g. the great bubble barrier) or filters (e.g. Marine Trash Skimmer, Seabin and Clewat vessel). However, all of these are only capable of filtering and removing the upper limits of the microplastic range of particles (>0.5 or 1mm). Other remediation techniques for filtering microplastics from the water column by means of e.g. sanitation techniques are currently being studied by the University of Ghent, i.e. by using the mussel *Mytilus edulis* (De Bie 2019) or via desalination plants for example through the pre-treatment of reverse osmosis (RO) plants (Saldi, 2019).
- Apart from the microplastics in the water, the sediments often contain a large number of microplastics. Higher concentrations are found in areas with higher population densities and port activities, like vessel maintenance works, and areas with low flow/currents where particles can settle (Van Cauwenberghe et al., 2015; Su et al, 2020). Research is currently ongoing into remediation techniques for filtering microplastics from sediments by means of e.g. centrifugal separation and (froth) flotation (Van Melkebeke et al., 2020).

Although research into the origin, detection, spreading and remediation of microplastics has an increased attention over the last decade further research and innovation on the removal of microplastics from the marine environment is needed (Devriese and Janssen, 2021).

Box 2 : Solutions for reducing and capturing microplastics from the aquatic environment.

3.1. Categorisation and characterization of the plastic catchers

The 74 plastic catchers considered, can be divided into three large types of systems: Boats, traps, and drones & robots. All of them use different technologies to catch and remove the plastic from the aquatic environment.

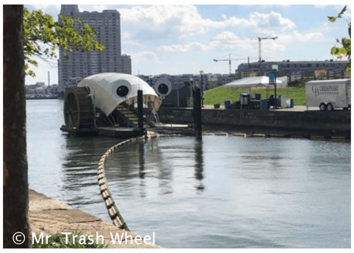
Type	**Method of collection and removal**	**Examples**	
Boats	conveyor belt, cage, nets or combination		
Traps	booms, nets, cage, conveyor belt or combination		
Drones & robots	conveyor belt, baskets, nets or combination		

Table 2 : *Three types of plastic catchers: Boats, trap, Drones and robots*

Mobile versus fixed setups

Figure 4 shows the number of plastic catchers in relation to the system used (bottom axis), and the field of application (5 columns as indicated at the top of the graph), divided into fixed and mobile systems. The figure shows that although most of the fixed systems operate passively, some systems use a powered device to attract the plastic towards the catcher. The boats and drones and robots are all mobile systems. The traps are mainly fixed systems although some systems are mobile (either towed or floating autonomously).

The mobile systems are either (1) operated by a person who is physically on the device or (2) operated by a person who is on a boat that is towing the device, (3) remotely operated from the shore or (4) operating autonomously by models, software and/or AI. The Ocean clean-up system 001 is currently the only system (trap) that is designed to free float with the natural currents.

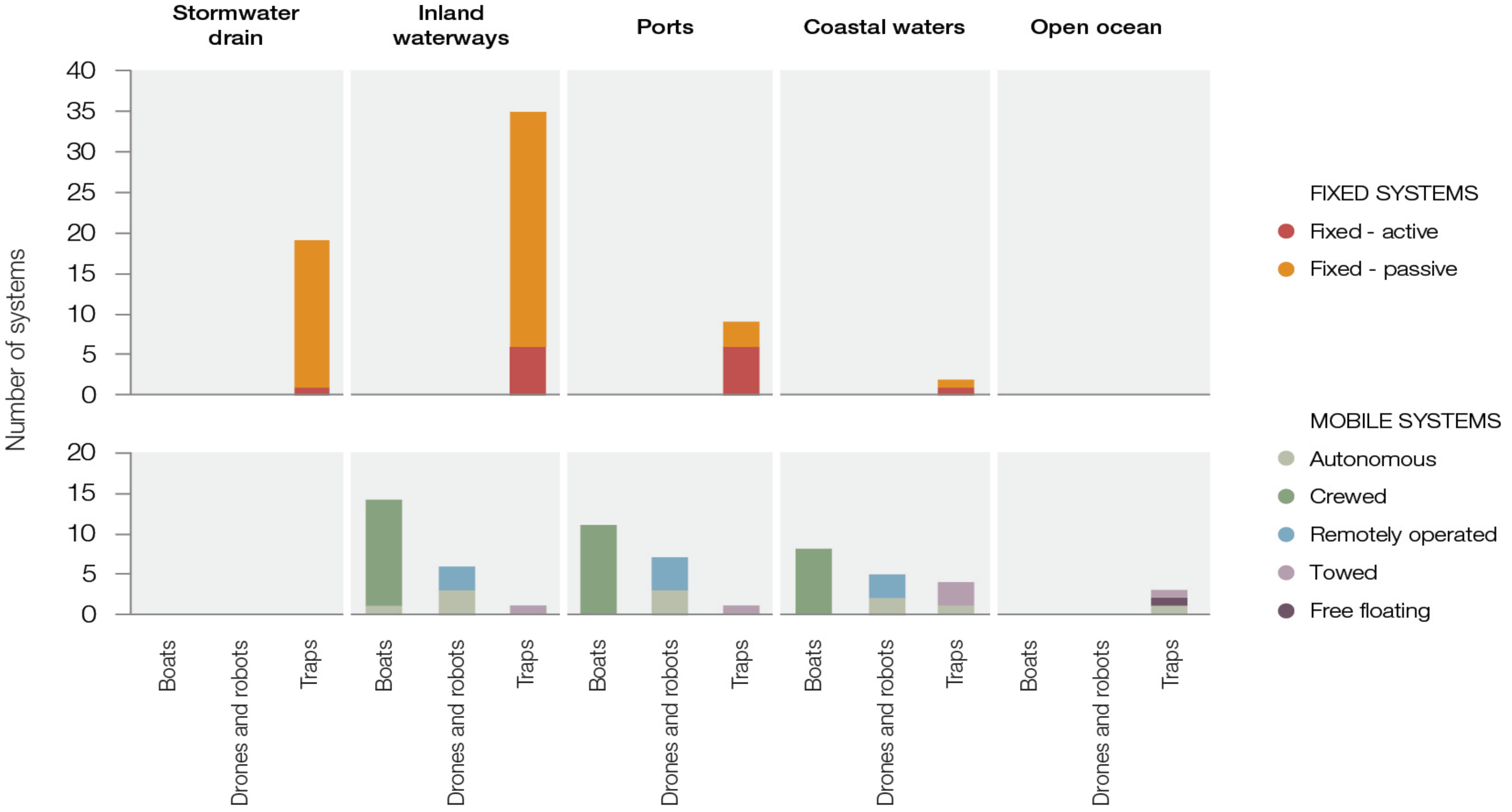


Figure 4 : Categorisation and numbers of the existing macroplastics catcher systems and technologies.

Different collection methods

Figure 5 shows the major types of plastic catchers (Boats, Traps, Drones & Robots) with indication of the collection method used (booms/nets/cages, conveyor belts, other). It is clear that booms, nets and cages are the most commonly used plastic collection systems (n=59). The design of these 59 collection systems varies significantly. They are often used as standalone fixed systems, but are also integrated into boats and drones & robots to collect and hold the plastics.

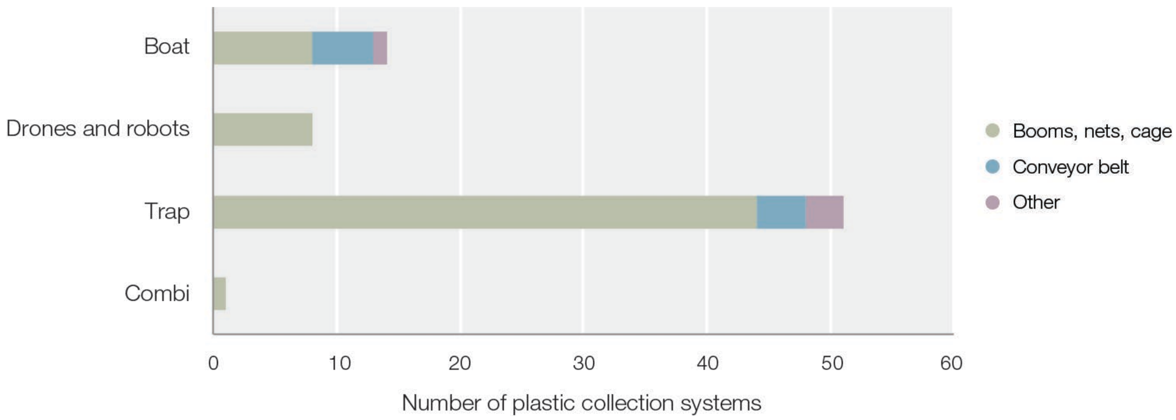


Figure 5 : Type of plastic catcher versus the collection and removal method used.

Figure 6 : Examples of Booms, nets and traps as collection method

Conveyor belts are often used to automatically remove plastic from the water or plastic trapped within a collection device (e.g. from boom, net or cage) into easily transportable units. These conveyor belts can be deployed from boats, pontoons or from the shore. Often both methods are combined to not only trap and collect the plastics but also remove it from the water and dispose it in containers/cages on barges for easy exchange and transport (e.g. the Interceptor, Mr. Trash Wheel). Some plastic catchers are capable of sorting the collected plastic according to size (e.g. Patje Plastic, Port of Antwerp).

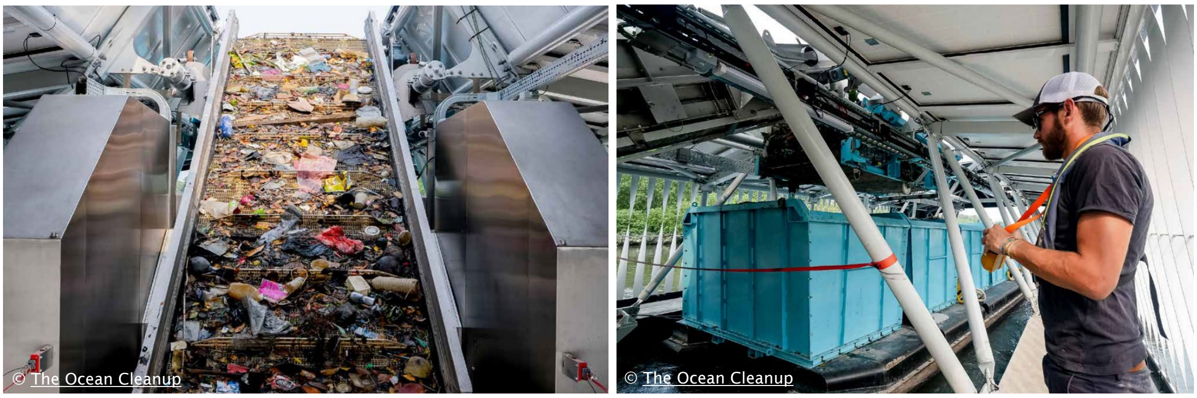


Figure 7 : Close up of a Conveyor belt system used to collect the plastic from the water (left) and the barge containers for easy transport and exchange of containers (right).

Other methods used to collect and remove the plastics from the upper layer of the water column are suction devices (Bio-Vac), air bubbles (the great bubble barrier), water wheels (Noria's CirCleaner) and rotating floating devices (River Cleaning system).

Figure 8 : Examples of alternative techniques to remove the plastic from the water: a waterwheel (Noria's CirCleaner) and a vacuum cleaning device (Buffalo Bayou's Bio-Vac).

Active plastic catcher systems are still mainly powered by fuel engines or are using external power provision. The newest designs however, are more and more using internal batteries and/or solar energy to power the plastic catcher (e.g. Marine Litter Hunter, the Interceptor, Mr. Trash Wheel).

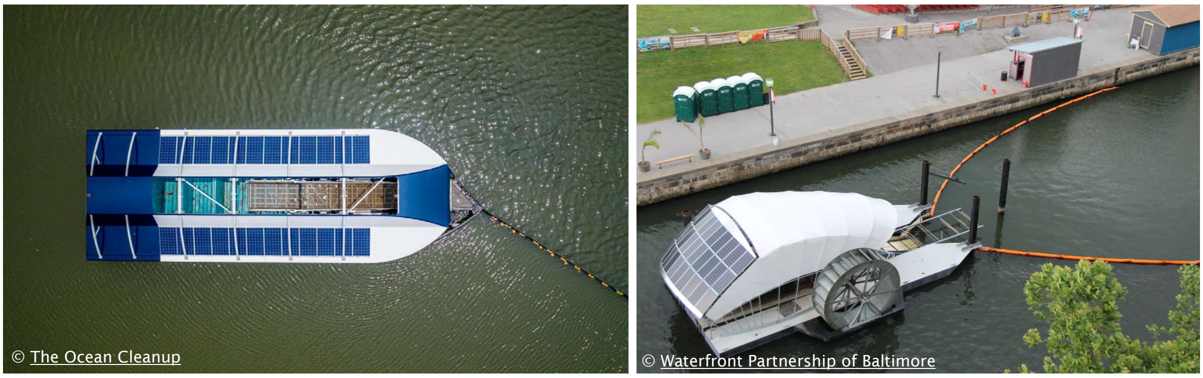


Figure 9 : Examples of plastic catchers using solar energy to help power the system.

3.2. Fields of application

For the purpose of this PIB, the application fields were divided into the following categories: Stormwater drain, inland waterways, ports, coastal waters and open ocean (see section 2).

Figure 10 shows that most plastic catchers are designed to operate in inland waterways (46%). Also, multiple plastic catchers are meant for operations in stormwater drains (15%), ports (22%) and coastal waters (15%). Only 3 systems were identified that are designed of catching plastic from the open ocean.

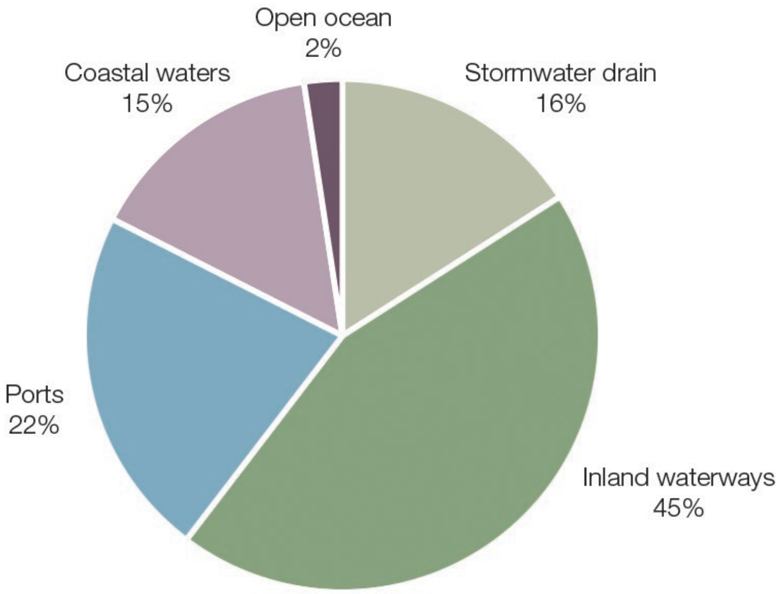


Figure 10 : Graph showing the different fields of application and the percentage of found plastic catcher systems designed and/or used in that field of application.

Figure 11 shows the different systems that are used in the different type of environments. In the section below, the plastic catcher systems are further discussed per type of environment or field of application.

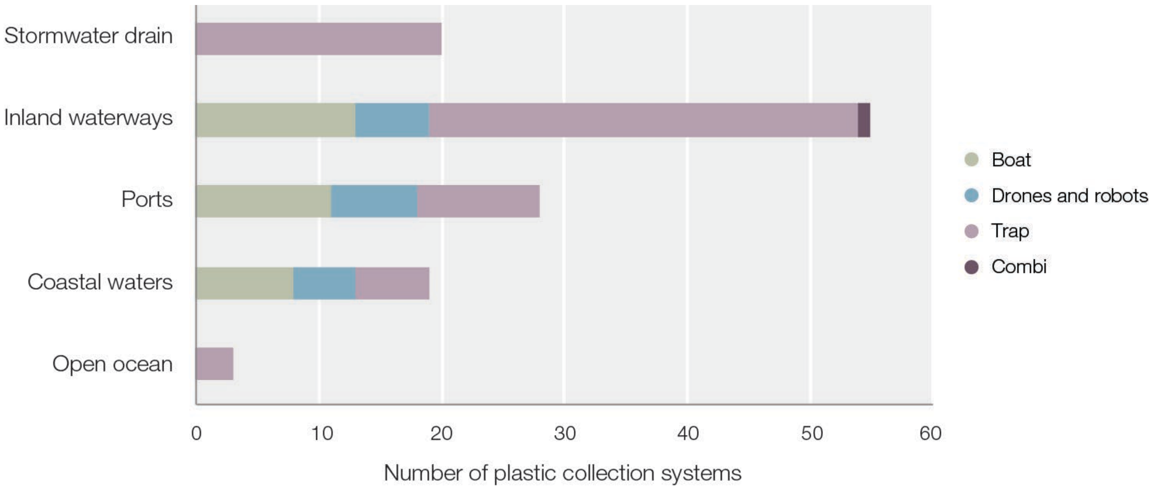


Figure 11 : Overview of the different fields of application and the different type of systems that are used in these environments

Stormwater drains

While runoff water is flowing to a storm drain or nearby water body, it picks up pollutants and debris along its path. Plastic (and other waste) in the run-off water can be prevented from flowing into the storm drains by installing cages/nets or filter systems around or in the storm drain inlets (e.g. Ecosol Litter basket and Osprey's Litter Interceptor). However, these types of catching devices in the drain inlet individually need frequent maintenance to allow the sufficient inflow of stormwater.

Once plastics have entered the drainage system, the main technique used to trap the plastics from this stormwater system are cages or nets. These are installed either inside or alongside the drain or mounted at the outflows of these drains (in-line, off-line or end-of-line) and they allow water to flow through but capture all (organic and non-organic) waste (see Figure 12 middle and right). Examples of this kind of application are numerous (e.g. Stormtrap Trashtrap, StrormX Netting Trash Trap, Watergoat Trash Trap, Ecosol Net Tech or Guard and Ecosol GPT), and mainly implemented in the USA and Australia. In case of larger open drains, often a combination of booms and/or cages are used to trap the plastics before they enter the larger inland waterways and the ocean (e.g. Watergoat's Trash Trap, Elastec's Brut Bin Trash Collector, Osprey's Litter Gitter, Desmi's Enhancer, Bandalong's Litter Trap) (see Figure 12 left).

Figure 12 : Examples of different type of larger stormwater drain plastic catchers

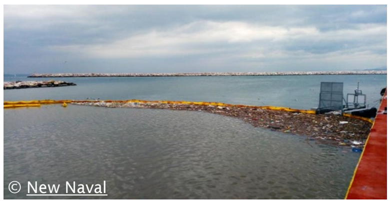
Inland waterflows

Plastics may end up in inland waterflows (streams, rivers, estuaries, channels, etc.) from stormwater drains, directly via stormwater run-off from land, by wind or directly by men from land or ships/vessels. Inland waterflows are the main method of transporting plastics towards the marine environment (Devriese and Janssen, 2021).

When designing solutions to remove plastic from inland waterways, some important parameters need to be considered: the width of the waterway, the depth, the tidal cycle, the flow velocity, the accessibility from land and from the water, the possible traffic of vessels and passage of aquatic species.

Because of the large differences in inland waterflows, the currently designed and developed systems for catching plastics from inland waterways are very diverse and are often adjustable to site-specific conditions: (1) Simple static traps made out of booms, cages and/or nets; (2) static (automated) systems with conveyor belts and own energy production (e.g. via solar); (3) mobile systems like boats and pontoons; (4) innovative autonomous systems or (5) combined systems. Some examples can be found in Table 3.

Table 3 : Examples of different plastic catcher systems for application in inland waterways

Description of plastic catcher system	**Examples**	**Illustration**
Simple static traps made out of booms, cages and/or nets	Bandalong boom Plastic Fischer Trash boom New Naval's Clean Trash	 © New Naval
Static (automated) trap systems with integrated active collection/removal techniques and own energy production	Blue Barriers Mr. Trash Wheel The Interceptor Blue Eco Line River Cleaner	 © SEADS
Mobile systems like boats and pontoons	Everwave's CollectiX SeeHamster and Seekuh Omni Catemaran	 © Everwave
Innovative autonomous systems	Jellyfishbot Seadrone cleaner Aware Trash remover	 © ONA Safe and Clean
Combined systems	Marine Litter Hunter	 © DEME
Other	The Great Bubble Barrier River cleaning system Bio-Vac CirCleaner	 © River Cleaning

Ports and harbours

Ports and (yacht)harbours are areas where plastic waste can easily accumulate due to low currents and the connection with several potential sources of plastic pollution (outflows from stormwater drains and rivers and port activities). Because of this, ports and harbours are often places were plastics clusters, which gives opportunities for efficient collection and removal. Moreover, it is often required to remove the waste (containing plastics) for safety and navigational reasons. However, an important issue with ports and harbours is that the design of the plastic catchers needs to consider the large number of maritime traffic and other shipping/port activities. Because of the many different types of ports and different characteristics, a wide variety of techniques are operational worldwide to collect plastics from within port environments: Boats and pontoons, static traps and automatic or remotely operated drones and robots.

Small recreational harbours

In small recreational harbours mostly used solutions are small traps that either actively or passively collect the plastic. Examples are the Seabin, Aquapod, Marina Trash Skimmer or the Portbin tide. These systems are however only capable of catching a limited amount of plastic and the catchment device needs to be emptied and maintained frequently. Another solution in smaller harbours are drones and robots that are either remotely operated or autonomously sail around while catching plastic along their route. Examples of these are Bluephin, Portbin robot, WasteShark, Jellyfishbot. The operational software of these systems is still in development to optimize their automatization related to efficiency and autonomy with regard to (maritime) safety. Besides, their sizes are limited resulting in frequent need of emptying the collection device.

Larger harbours and ports

In larger yacht harbours and commercial ports, the above-mentioned systems are too small and are therefore not efficient to collect the large amount of plastic. Often small, easily manoeuvrable boats are used in these situations. Another alternative is the use of large traps (e.g. Allseas trap installed in the Port of Antwerp), however, this technique needs to be positioned in areas of the port where they don't hinder the port activities. Using bubble curtains to guide the plastic towards a trap is a promising solution since it does not have an impact on the port activities and enables the capture of plastic from deeper layers in the water column. However, the energy demand of the compressors needed to produce the air bubbles and therefore also the cost can be quite high, especially in deep water and larger ports since the length of the Bubble Barrier has a significant influence on the necessary energy usage (The Bubble Barrier).

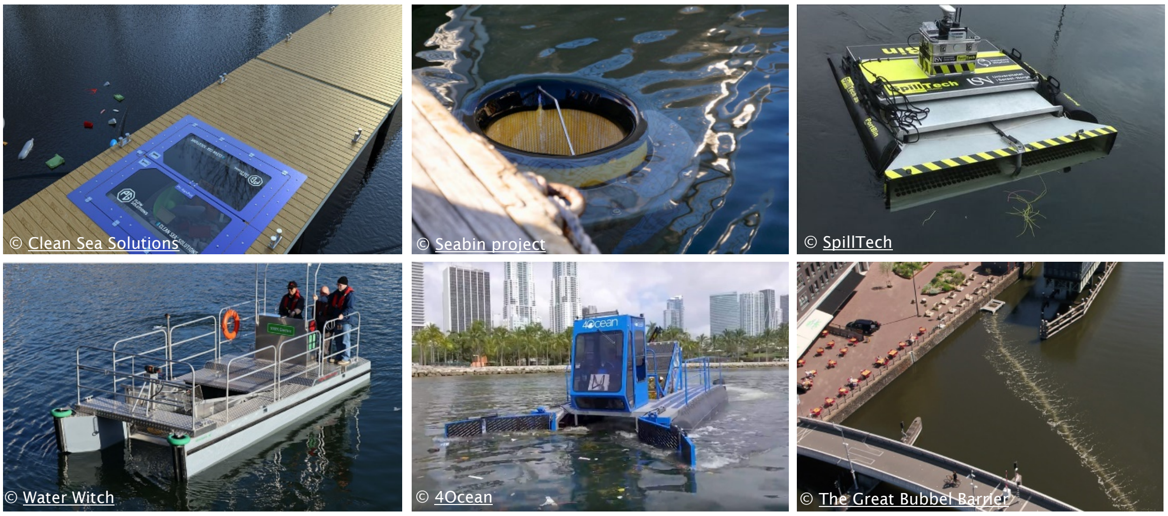


Figure 13 : Examples of plastic catcher solutions in ports and harbours.

Seas and Oceans

As opposed to plastic in inland water, once plastic reaches the ocean, it is much more distributed and therefore much more challenging to remove it from the environment. Once plastic reaches the sea, a large part is washed up or buried along the world's shorelines (Lebreton et al., 2019; Harris et al., 2021). The remainder is directed by winds and ocean currents, degrades into microplastics along the way, sinks to deeper layers and the seafloor or ends up in one of the ocean plastic hot spots or 'gyres' (Lebreton et al.,2018).

Beaches and intertidal areas

Several systems have been designed and are used worldwide to clean plastic from beaches. Most of these systems are vacuum cleaning or mechanical filtering systems, which are ideal solutions for single beach applications at tourist beaches. There has been however a lot of discussion and concern regarding the impact of mechanical beach cleanup systems and the need for more research-based guidelines (Dominguez and Belpaeme, 2006; Ghesquire et al. 2006; Zielinski et al. 2019).

Similar as for beaches, technologies are being designed to remove plastics from other tidal coastal plains and riverbanks, i.e. the Nul-o-plastic.

Box 3 : Catching plastic from the beach and intertidal areas

Coastal waters

Plastic in the coastal waters can cluster near breakwaters or inside bays, but are mainly floating with the wind and ocean currents. Collecting and removing plastic from these areas is therefore in general not evident, nor efficient. Additionally, installing plastic catchers in coastal (high-current and wave-dominated) marine environments is logistically much more complex, challenging and expensive than in inland waters. Therefore, only a limited number of techniques has been designed and is in operation to collect plastic from these areas. The existing techniques are mainly towed booms and traps or boats with nets or traps installed.

Figure 15 : Some examples of coastal water plastic catchers.

Open ocean

Since large amounts of plastics accumulate in offshore 'gyres' (Lebreton et al., 2018), it can be worthwhile designing an efficient technique to collect and remove plastics from these locations. However, the development of efficient and economically feasible systems takes a lot of research and innovation. The Ocean Cleanup initiative is one of the major initiatives developing such an offshore collection device. Their System 001 was developed as a passive method using natural currents only. However, based on the learnings from System 001, active propulsion has now been incorporated into the new design. System 002 is comprised of a long U-shaped barrier that will guide the plastic into a retention zone at its far end (see Figure 16). Through active propulsion, a slow forward speed is maintained, and with the help of computational modelling, the system navigates towards the areas with the highest plastics concentration. Once full, the retention zone will be hauled on board a service vessel to be emptied. System 002 will be tested at sea for the first time later in 2021.

Figure 16 : The Ocean Cleanup SYSTEM 002 during tests in the Pacific Ocean Garbage Patch.

Other ocean-based ideas are being conceptualized (PGS bubble tow, ERVIS, SeaVax, FRED, Manta, Ocean Phoenix), however they are currently lacking the required investments to further develop the concept into an actual design and start testing.

Figure 17 : Examples of some open ocean plastic catcher concepts.

3.3. Plastic catchers installed in Flanders

Currently in Flanders 6 initiatives have installed plastic catchers on inland waterways or in ports. Figure 18 shows the different locations where these are currently installed. A short description of each of the initiatives is given below.

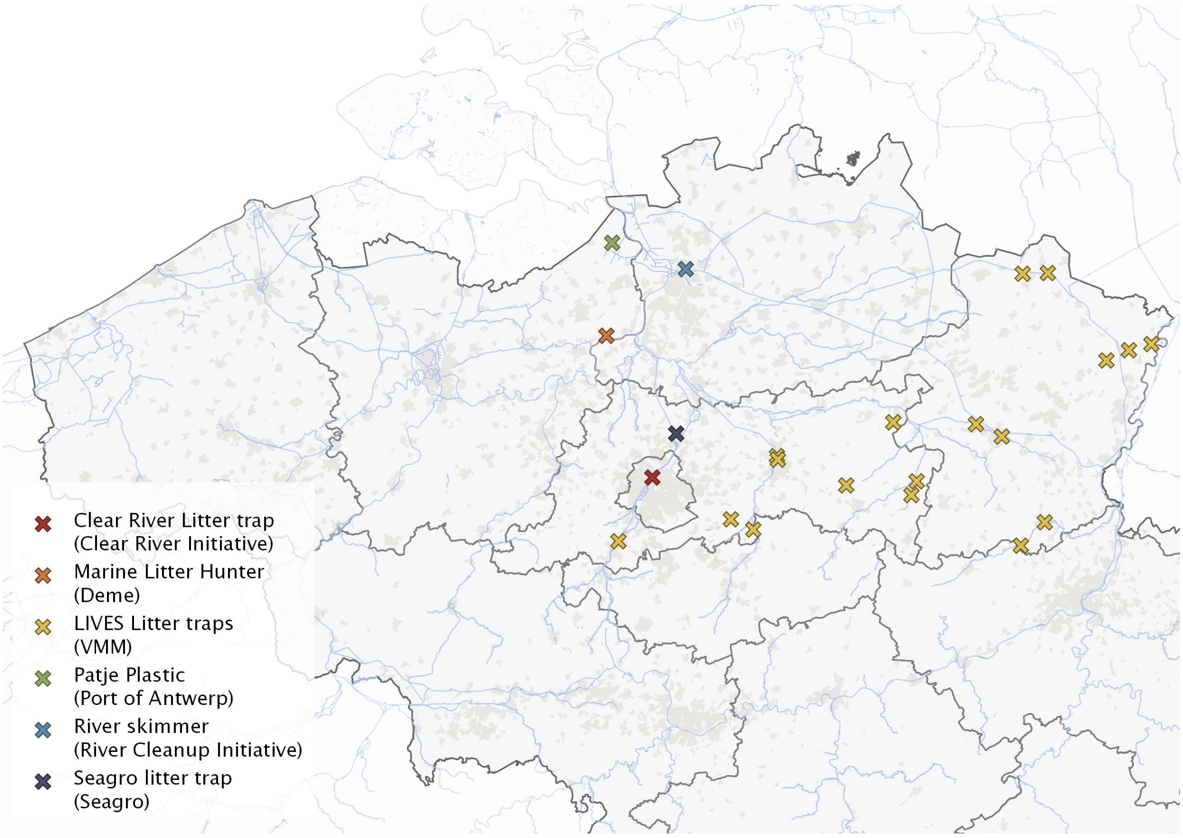


Figure 18 : Map with locations of the plastic catchers installed on inland waterways and in ports in Flanders.

In 2019, the Vlaamse Waterweg NV launched a call for companies to automatically remove plastic from the Scheldt. In this way, companies and / or organizations could test an innovative installation or technology on the Scheldt for a year, in close collaboration with the University of Antwerp and the Institute for Nature and Forest Research (INBO). Both Deme and Seagro responded to this initiative.

- DEME Environmental Contractors (DEC), the environmental branch of DEME installed in 2020 at the Scheldt Bridge in Temse, the Marine Litter Hunter. This test setup consists of a fixed installation that passively collects floating and suspended waste from the upper 0.5m of the water column and a mobile system that actively collects the waste from the remainder of river near the Bridge of Temse.
- The Seagro installation was launched at the Willemsbrug in Grimbergen. Their design uses negative pressure to suck in plastic waste. It can therefore be used on still as well as running water. Moreover, it is a smaller installation that can be used in places where space is limited.

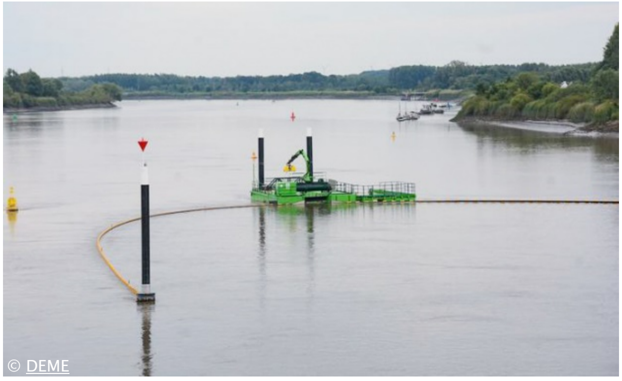


Figure 19 : Deme's Marine Litter Hunter (left) and Seagro's plastic catcher installation in Grimbergen (right).

The port of Antwerp is currently using a boat - the Condor - and so-called harbour tornadoes teams that carry out special cleaning operations - to remove all kinds of waste from the water. In addition, a plastic trap, named *Patje Plastic*, was installed in the Doel dock in 2019, where large amounts of waste are congregated by the wind. The system was developed by the Dutch company Allseas Engineering. The plastic catcher consists of a large boom of 100m and 1.5m depth and a pontoon with a set of cages to trap and sort the waste by size. When the wind turns, a non-return valve prevents the waste from drifting out of the cages again. As such, no extra energy is needed. The device is completely passive and counts on the help of wind, water and gravity to collect the waste. A crane truck lifts the collection cages with a capacity of 8 cubic meters from the plastic catcher.

Figure 20 : 'Patje Plastic' the Port of Antwerp's plastic catcher installed at Doel dock

The River Cleanup initiative has installed the River Skimmer at Oostkaai in Merksem. The River Skimmer is an initiative of River Clean-up, the Belgian non-profit organization that raises awareness on plastic pollution along rivers. The *River Skimmer* was adapted to the specific set-up of the dock in Merksem with the technical experts of Multimasters Group and the Vlaamse Waterweg NV. Like a large pool skimmer, it uses a pump to suck the waste in, and with the continuous flow of water, it creates a whirlpool effect, preventing the waste from escaping. Once the storage container is full, it can be lifted to remove the waste.

Figure 21 : The River cleanup initiative's River Skimmer installed at Oostkaai in Merksem

Figure 22 : The litter trap, a Clear River's initiative, installed in the port of Brussels

Together with the Audi Environmental Foundation, The Clear Rivers organisation (NL) successfully installed a Litter Trap in the harbour basin of Brussels after a positive test phase. The Litter Trap consists of a boom and pontoon with a trapping cage which is emptied on average twice a week. The average amount of waste collected is 1.5m³ per month.

The Flanders Environment Agency (Vlaamse Milieu maatschappij; VMM) has placed a total of 18 litter traps in the Meuse and Demer catchment areas as part of the Interreg project LIVES. The aim of the LIVES project partners is to jointly reduce (plastic) waste in rivers and streams by at least half. The VMM joins forces with Belgian, Dutch and German partners for this project.

Figure 23 : One of the plastic catchers installed by VMM as part of the LIVES project

Currently the Flemish government launched a new PIP (Program for Innovative Procurement) - Innovative organisation of the collection and removal of floating waste in marinas along the coast. The PIP is currently in preparation and will give the opportunity to companies to submit innovative waste catching solutions for implementation in the yacht clubs along the Belgian coast.

4. Knowledge gaps and opportunities in the context of plastic catchers

Knowledge gaps

The most important developments needed, as indicated by different stakeholders during the PLUXIN workshop, are the optimization of **the efficiency of the plastic catcher, knowledge on the impact of the plastic catcher on the environment** and the need for **automation of the system**. A recent publication by Bellou et al. (2021) on innovative solutions to tackle marine litter also indicated that none of the solutions provided information on their efficiency and environmental impact and that the next generation of collection solutions are increasingly focusing on using machine learning, robotics, big data analytics and modelling.

1. In order to be able to **improve the efficiency of a plastic catcher** additional monitoring efforts and more research is needed to have better insights into the flux and the hotspots of plastic in the aquatic environment, the spatial and temporal variation of these hotspots, the density of these spots and the vertical dimension and characteristics of the plastic (Falk-Andersson et al. 2020). The monitoring and modelling work currently undertaken within the Blue cluster project PLUXIN is already a first major step. Also, the University of Antwerp (ECOBE & SPHERE) is currently studying the occurrence, behavior and flowpath of floating and submerged macroplastics in the river Schelde with the aim to quantify the plastic flux for the entire Schelde basin (Teunkens et al., 2021). All this research will give input to find the best locations for plastic collection and to improve the design of the plastic catchers with the aim of increasing the catch- and cost-efficiency of the plastic catcher. Recently more research is also being undertaken into the behaviour and occurrence of microplastics (e.g. Everaert et al. 2020 and the ongoing projects HOTMIC, FACTS and iPlastics). In addition, research and innovation for more efficient monitoring techniques are needed, including the development of automated techniques. Also, some European research and innovation projects focus on developing novel detection techniques in the field for macroplastic (e.g. Hyper) as well for micro and nanoplastics (e.g. Andromeda).
2. The **impact on the environment** of plastic catchers is a major concern, especially the bycatch of aquatic flora and fauna (larger sea mammals, fish and neuston) and the damage to habitats and the marine ecosystem as a whole (Falk-Andersson et al. 2020). Plastic catchers should therefore be evaluated in terms of their potential environmental impact which requires an understanding of the relative abundance and distribution in time and space of marine life in relation to the target plastic debris, their likely interactions with the technology, and the consequences of these interactions (Falk-Andersson et al. 2020). In general very limited attention has been devoted to this topic during development of aquatic plastic collection technologies. Recently however, there has been an increased

focus on the environmental impact during the design phase of new developments: the Ocean Cleanup has undertaken an Environmental Impact Assessment (CSA, 2018) and is doing additional monitoring and research into the impact of their developments on the environment (Seiche 2019; Egger et al. 2021) and the PGS bubble curtain tow has studied the potential impacts of the cleaning technology on marine life as part of their feasibility study (Falk-Andersson et al. 2018). Further research is clearly already being undertaken (e.g.. Egger et al. 2021) however, further studies and monitoring is very much needed to be able to define the net impact of different types of plastic catcher techniques on the environment, monitoring of bycatch and to set guidelines for future development and required monitoring of species bycatch (Falk-Andersson et al. 2020).

3. Similar to the conclusions of Bellou et al. (2021), there is clearly an overlap or repetition of technology and methodological principles underlying most plastic catchers presented in this PIB. For example, several analogue types of traps consisting of booms, nets and cages are used to prevent plastics entering the marine environment. In line with the increasing research and innovation in autonomous shipping, the use of drones, Artificial Intelligence and digital twins, there is however an evolution towards **automated** and even **autonomous plastic catchers** which reduces the operational costs and increases the systems' efficiency. Investing in more research and innovation projects and setting up cooperation between different sectors, national and international research institutes and companies will support and speed up this development.

It is also pointed out that there are currently 3 major barriers that need to be addressed in order to address these developments, find cost-efficient solutions and actually realise more plastic traps in the field: **more scientific and technological knowledge** as a basis for the design, additional **funding** for pilot installations in the field and a **regulatory and legal framework** related to the plastic pollution problem which can then lead to balanced cost and viable business models. Both the need for the integration of litter management measures into policy instruments appointing responsibility for the prevention and cleaning of marine litter in national and international areas of accumulation, as well as the need for bringing more solutions to the market by creating more funding schemes that enable new start-ups or cooperation between the scientific community and industry to hand over prototype solutions to commercial product providers has also been pointed out by Bellou et al. (2021). Also Grid-Arendal (2021) recommends that steps should be taken to develop a legally binding (inter)national framework that overcomes the current accountability and monitoring challenges in combatting the plastic pollution crisis and secures worldwide equal engagement.

Opportunities and way forward

Only 1% of plastics ending up in the ocean is found floating on the surface whereas the rest leaves the surface through beaching or sinking and occurs in suspension in the water column or accumulates on and in the sediment (Lebreton et al., 2019). Also, in inland water(ways) and ports a large number of plastic particles are found in the water column and the sediment (Devriese and Janssen, 2021). Since current techniques all more or less focus on floating plastic and are not able to catch the plastic in other levels of the water column (suspended) or on or in the sediment, attention is also needed to recover this plastic.

New recent research has estimated that more than 1,000 rivers account for 80% of global annual emissions, which range between 0.8 million and 2.7 million tonnes per year, with small urban rivers among the most polluting (Meijer et al, 2021). Catching plastic from inland waterways, from small streams to large rivers, will therefore help in reducing the amount of plastic ending up in the open ocean. Catching plastics closer to the source on land and from stormwater drains and inland water(ways) is also a more economic and efficient way to apply solutions in the short term compared to open ocean solutions which need a much more demanding design, construction and operation and high maintenance costs.

Since marine plastic pollution is a worldwide problem, this provides opportunities to the Flemish blue innovation community to export their knowledge and expertise. Since the largest amount of plastic reaching the ocean originates from mainly the large rivers in Asia, Africa and South America (Meijer et al., 2021), there are ample opportunities to develop plastic catcher solutions for these rivers to reduce the debris transported to the open ocean. Moreover, vulnerable coastal ecosystems like mangroves are at risk from plastic pollution (Harris et al., 2021). Since some Flemish research institutes are focusing on mangroves and other coastal habitats and Flemish companies are experts in coastal and marine works worldwide, cooperation between research units to improve the knowledge of the impact of plastics on these ecosystems and Flemish companies/innovators may result in novel solutions to reduce the impact.

An interesting conclusion from Bellou et al. (2021) is that most of the marine plastic cleaning solutions arose from cooperations, where the scientific community developed most of the monitoring solutions and NGOs initiated most of the prevention solutions. This indicates that each function is addressed by different actors in marine litter management. Greater international cooperation, cross-disciplinary collaboration and merging of economic and scientific knowledge are key in solving the knowledge gaps and reaching innovative sustainable solutions. As pointed out e.g. by Falk-Andersson et al. (2020) some things can be learned from the fisheries sector on how to tackle the issues of catch efficiency and environmental impact.

In order to have sustainable cost models for aquatic plastic collection, solutions need to be found for the re-use and recycling of the collected plastics. Some of the solutions that are currently being conceptualized are already focusing on developing a multifunction approach, for example, simultaneous prevention and cleaning, together with recycling and reuse. But an important factor is the value of plastic. By closing the loop on plastics production and encouraging innovative reuse, plastics would no longer be classified as waste but could be a key source of value and result in valuable business opportunities (Lacy et al. 2019). In the end, hopefully, recognizing the value of plastic will also result in less plastic ending up in the ocean.

Ongoing initiatives/EU funded projects focusing on solutions for the removal of plastic from the aquatic environment and/or the development of plastic catchers

Currently several nationally and internationally funded research and innovation programs are ongoing focusing on clean-up technologies for plastics from the aquatic environment. Below table summarizes some of them. A full overview of projects (with BE partners) focusing on marine plastics in general can be found in Devriese and Janssen, 2021.

Name	funding	Description
DEMARC (2021-2023)	Martera	This research project focuses on the combination of plastic flux modelling in rivers, inline plastics monitoring, air bubble collection, a conveyor belt removal system, zero emission and unmanned operation. Belgian partners: IMDC and MULTI.engineering.
MAELSTROM (2021-2024)	Horizon 2020 (EU)	MAELSTROM's main goal is to find strategies to reduce the impacts of marine litter in coastal ecosystems, by identifying accumulation hotspots and by implementing innovative and environmentally sustainable technologies for removing the existing litter from the water column of rivers before it reaches the sea and from the coastal seabed.
InNoPlastic (2021-2023)	Horizon 2020 (EU)	In-No-Plastic is project that works on development and application of clean-up technologies in the aquatic ecosystems. The approach taken is a combination of social and technical removal strategies targeting the industrial hotspots through cooling water systems (CWS), harbours, lagoons, shores and the shallow sea water Belgian partner: ArcelorMittal Belgium
SouPLess (2018-2021)	Life (EU) 2017- 2021	The SouPLess project aims to demonstrate three new systems for riverine plastic removal and an innovative software tool to predict movement and accumulation hotspots of plastic litter in rivers. One of these systems is *Patje Plastic* in the Port of Antwerp.
CLAIM (2017-2021)	Horizon 2020 (EU)	CLAIM will power 5 new technologies to innovate the ways in which we clean our seas and oceans. Data modelling will produce maps of concentrations of macro and micro litter, while ecosystem service approaches will identify areas where intervention has the greatest potential to secure impact on human well-being.

Box 4 : Ongoing initiatives/EU funded projects focusing solutions for the removal of plastic from the aquatic environment and/or the development of plastic catchers

5. Concluding remarks

Highlights

- Most plastic catchers are designed to capture floating plastic from stormwater drains and inland waterways. Catching plastics before it reaches the sea and ocean is a more cost-efficient and technologically feasible solution than removing the plastics from the marine environment.
- To have a high catch-efficiency and be cost-efficient, plastic catcher designs need to take a lot of parameters into account and data is needed to guide the decision.
- Information on the operational efficiency and environmental impact of the solutions is lacking and definitely needs more attention in the future.
- Improved and automated techniques for both monitoring and collection are crucial to develop efficient and economically feasible solutions for catching plastic from aquatic environments.
- Multiple systems are currently being tested in Belgium from public, private and non-profit initiatives, showing the broad willingness to look for solutions to the marine plastic pollution problem. No plastic catchers have been installed along/off the Belgian coast.
- Currently sustainable business models are lacking. Policy can facilitate by setting a sound legal and regulatory framework and provide opportunities for funding.

Further research and development is recently being undertaken to improve the methods for removing plastic from the aquatic environment (both on national and European level for which some examples of ongoing projects are given in Box 4). However, more research is needed to gain insight into the net environmental impact of the plastic catchers and to improve their catch- and cost-efficiency. Combining data and knowledge from research on the characteristics and behaviour of the plastic in the aquatic environment and the impact of plastic and plastic removal on marine ecosystems with the know-how and expertise from different marine sectors (e.g. shipping, fishing, dredging, etc.) will lead to innovative developments resulting in efficient plastic catchers.

International studies show that technological innovation to clean up marine litter will, however, not by itself be sufficient to solve all ecological problems related to environmental plastic contamination (Cordier and Uehara, 2019). This PIB focusses only on the curative measures as described by Cordier and Uehara (2019) and these end-of-pipe solutions and especially only ocean clean-up solutions will not be able to solve the problem. However, a combination of multiple strategies, focusing i.a. on litter avoidance and stopping and cleaning up at source (preventative measures), is necessary to tackle the problem of plastic in our seas and oceans. This is also pointed out by several recent publications looking at the worldwide plastic initiatives currently in place (Grid-Arendal, 2021; Schmaltz et al. 2020; Dijkstra et al. 2021).

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Appendices

Appendix 1 – Data fields

The table below gives an overview of all information that is or will be gathered for each of the techniques.

Type of information	Description
Name	
Size of plastic	(1) macroplastics only, (2) macroplastics and microplastics (3) microplastics only
Field of application	(1) Stormwater drain (2) Inland water(way) (3) Port (4) Coastal waters (5) Offshore
Type of application	(1) Trap (2) Boat (3) Drone and robot (4) Combi
Method of collection	(1) Booms, nets and traps (2) Conveyor belt (3) Other
Mobile/fixed system	Information on the mobility of the system: mobile or fixed system.
Active/passive system	Does the system actively attracts or sails around to catch the plastics or does it rely only on natural flow/currents?
Anchoring	Information on the method of anchoring or fixations, in case of a fixed system.
Control system	manual, remotely controlled or autonomous.
Scale/impact	Information on the scale of the impact: (1) local, (2) regional, (3) global.
Description	A short description of the working principle.
Development stage	Information on the development stage of the system: (1) Concept/Design stage, (2) Testing stage and (3) Operational stage.
Year	Information on the year the system was invented (in case it is still in design or testing stage) or operational (in case it is in operational stage).
Country invented	Information on the country in which it was invented.
Company	Information on the name of the company who own the rights.
Patent	Information on the patenting. In case a patent exists and available, the patent number is listed.

Website	Details the website of the company or of the system in specific.
Dimensions	Information on the dimensions of the system.
Area coverage	Information on the area it covers (in case the system is a mobile system) or the volume of water it filters (in case of a fixed system).
Capacity of waste removal	Information on the amount of waste it generally removes from the water.
Capacity of waste storage	Information on the amount of waste it can store before the storage containers need to be emptied.
How is the waste storage emptied?	Information on how the collected waste is removed: by hand or is a crane or a boat required.
Energy consumption	Information on the energy consumption that is required to operate the system.
Cost	Information on the cost of the system. If no details on this are available, please indicate low/medium/high.
Maintenance requirements	Information on the required maintenance.
Total cost (incl maintenance)	Information on the cost of the system, incl maintenance cost. If no details on this are available, an indication is given by indicating low, medium or high.
Environmental impact	Information on the impact of the technique on the environment. Source of information here is important (from owners' webpage, from EIA, from scientific publication).
Geographical region implemented	Information on the countries in which this system has already been used.
Applicable in tidal environment	Information if the system can be used in tidal environments.
Minimum water level requirement	Information if the system can withstand occasional low water levels or even fully drained periods.
Impact on Navigation	Specifies if the installation of the system hinders or blocks navigation.
Maximum current environments	Information on the maximum currents the system can be used in.
Minimum width of the waterway	Information on the minimum width requirements of the water(way) in which it should be used.

Appendix 2 – Overview of plastic catchers

Name	Field of application	Type of system	Method of collection	Mobile/ fixed	Active/ passive	Control system	Status	Company	Country invented	Website
AlphaMERS Floating Barrier	inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	AlphaMERS Ltd.	India	https://www.alphamers.com/home
Bandalong Boom	inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Bandalong International	Australia	https://www.bandalong.com.au/bandalong-boom-system.html
Bandalong Litter Trap	stormwater drain, inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Bandalong International	Australia	https://www.bandalong.com.au/bandalong-litter-trap.html
BluePhin	inland waterways, ports	drones & robots	booms, nets, cage	mobile - autonomous	active	uncrewed	testing	BluePhin Technologies	UAE	https://bluephin.io/
Clear River Litter Trap	inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Recycled Island Foundation	The Netherlands	https://www.clearrivers.eu/litter-traps
Holy Turtle	coastal waters, open ocean	trap	booms, nets, cage	mobile – towed	active	crewed	operational	Sodastream	USA	https://www.businessinsider.nl/sodastreams-holy-turtle-cleans-plastic-from-ocean-in-honduras-2018-10?international=true&r=US
ECOSOL Gross Pollutant Trap (GPT)	stormwater drain	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Urban Asset Solutions	Australia	https://urbanassetsolutions.com.au/
Jellyfishbot	inland waterways, ports, coastal waters	drones & robots	booms, nets, cage	mobile - remotely operated	active	uncrewed	operational	IADYS	France	https://www.iadys.com/en/jellyfishbot-2/
Bio-Vac	inland waterways, ports	boat	other	mobile - crewed	active	crewed	operational	Buffalo Bayou Partnership	USA	https://www.facebook.com/watch/?v=689245671914474
Mr Trash Wheel	inland waterways, ports	trap	conveyor belt	fixed	passive	uncrewed	operational	Clearwater Mills, LLC.	USA	https://www.mrtrashwheel.com/technology/
Ocean Cleanup System001	open ocean	trap	booms, nets, cage	mobile - free floating	passive	uncrewed	testing	The ocean cleanup	The Netherlands	https://theoceancleanup.com

Name	Field of application	Type of system	Method of collection	Mobile/ fixed	Active/ passive	Control system	Status	Company	Country invented	Website
Ocean Cleanup System002	open ocean	trap	booms, nets, cage	mobile – towed	active	uncrewed	testing	The ocean cleanup	The Netherlands	https://theoceancleanup.com
One Earth-One Ocean Seekuh	inland waterways, coastal waters	boat	conveyor belt	mobile - crewed	active	crewed	operational	OEOO	Germany	https://oneearth-oneocean.com/
One Earth-One Ocean SeeHamster	inland waterways	boat	conveyor belt	mobile - crewed	active	crewed	operational	OEOO	Germany	https://oneearth-oneocean.com/
Plastic Fischer Trash	inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Plastic Fischer GmbH	Germany	https://plasticfischer.com/trashbooms
Ecosol Net tech/Guard	stormwater drain	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Urban Asset Solutions	Australia	https://urbanassetsolutions.com.au/
PumpGuard	stormwater drain	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Stormtrap	USA	https://stormtrap.com/products/pumpguard/
SCG Litter Trap	inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	SCG-DMCR	Thailand	https://www.scg.com/sustainability/circular-economy/en/collaboration-projects/dmcr-litter-trap/
StormTrap TrashTrap	stormwater drain	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Stormtrap	USA	https://stormtrap.com/products/trashtrap/
StormX Netting Trash Trap	stormwater drain	trap	booms, nets, cage	fixed	passive	uncrewed	operational	StormwaterSystems	Australia	https://stormwatersystems.com/trash-traps/
The Interceptor	inland waterways	trap	conveyor belt	fixed	passive	uncrewed	operational	The ocean cleanup	The Netherlands	https://theoceancleanup.com/rivers/
The Litterboom Project	inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	The Litterboom Project	South Africa	https://www.thelitterboomproject.com/
Trash catcher	inland waterways, ports, coastal waters	trap	booms, nets, cage	mobile - towed	active	crewed	operational	Thomsea	France	http://thomsea.com/
Versi-Cat Trash Skimmer Boat	inland waterways, ports	boat	booms, nets, cage	mobile - crewed	active	crewed	operational	Water Witch	UK	https://waterwitch.com/ww/versi-cat-2/

Name	Field of application	Type of system	Method of collection	Mobile/ fixed	Active/ passive	Control system	Status	Company	Country invented	Website
CollectiX	inland waterways, ports	boat	conveyor belt	mobile - crewed	active	crewed	operational	Everwave and Berky	Germany	https://everwave.de/en/innovation/; https://garbage-boat.com/en/
Allseas plastics removal system	inland waterways, ports	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Allseas	The Netherlands	https://allseas.com/allseas-river-plastics-removal-project/
WasteShark	inland waterways, coastal waters	drones & robots	booms, nets, cage	mobile - autonomous	active	uncrewed	operational	RanMarine Technology	The Netherlands	https://www.wasteshark.com/
Watergoat Trash Trap	stormwater drain, inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Watergoat	USA	https://www.watergoat.org/products.html
Trash skimmer boats	inland waterways, ports, coastal waters	boat	conveyor belt	mobile - crewed	active	crewed	operational	Mavi Deniz	Turkey	https://mavideniz.com.tr/our-production/vessels-boats/trash-debris-cleanup-vessel/
Nash Run Trash Trap	inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Anacostia Watershed Society	USA	https://www.anacostiaws.org/what-we-do/river-restoration-projects/pollution-reduction/trash-traps.html
CTU-Systeem	inland waterways	trap	conveyor belt	fixed	passive	crewed	operational	SK International	The Netherlands	http://www.skinternational.nl/producten/zwerfvuil-uit-de-rivier/
Sargaboat	inland waterways, coastal waters	boat	conveyor belt	mobile - crewed	active	crewed	operational	The Ocean Cleaner	Canada	https://theoceancleaner.com/
Shoreliner	ports	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Tauw	The Netherlands	https://www.tauw.com/news/news/shoreliner-voted-most-sustainable-port-project.html
PortBin Robot	ports	drones & robots	booms, nets, cage	mobile - autonomous	active	uncrewed	testing	Spilltech	Norway	https://spilltech.no/portbin-toolbox/portbin-robot/

Name	Field of application	Type of system	Method of collection	Mobile/ fixed	Active/ passive	Control system	Status	Company	Country invented	Website
PortBin Trash Trawl	inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Spilltech	Norway	https://spilltech.no/portbin-toolbox/portbin-trashtrawl/
PortBin Tide	ports	trap	booms, nets, cage	fixed	active	uncrewed	operational	Spilltech	Norway	https://spilltech.no/portbin-toolbox/portbin/
Blue Barriers	inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	testing	SEADS	Italy	https://www.seadefencesolutions.com/blue-barriers/
Marine Litter Hunter	inland waterways	combi	booms, nets, cage	mobile and fixed	passive/ active	uncrewed	testing	Deme	Belgium	https://www.deme-group.com/news/deme-deploys-autonomous-plastic-collector-river-scheldt
River Skimmer	inland waterways, ports	trap	booms, nets, cage	fixed	active	uncrewed	operational	River Cleanup	Belgium	https://river-clean-up.prezly.com/breakthrough-technology-first-river-skimmer-in-belgium-captures-floating-litter-as-of-today
4Ocean mobile skimmer	inland waterways, ports	boat	conveyor belt	mobile - crewed	active	crewed	testing	4Ocean	USA	https://www.4ocean.com/blogs/blog/skimming-the-surface
Floating Trash Trap	stormwater drain	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Stormtrap	USA	https://stormtrap.com/project/floating-trashtrap-oxnard-ca/
The Great Bubble barrier	inland waterways, ports	trap	booms, nets, cage	fixed	active	uncrewed	operational for macro - tests ongoing for micro	The great bubble barrier	The Netherlands	https://thegreatbubblebarrier.com/
OC-Tech	coastal waters	boat	conveyor belt	mobile - crewed	active	crewed	testing	Ocean Cleaner Technology S.L.	Spain	https://www.oceancleaner.es/products/
Marina Trash Skimmer	ports	trap	booms, nets, cage	fixed	active	uncrewed	operational	Keco Pump & Equipment	USA	http://www.marinatrashskimmer.com/

Name	Field of application	Type of system	Method of collection	Mobile/ fixed	Active/ passive	Control system	Status	Company	Country invented	Website
Seabin	inland waterways, ports	trap	booms, nets, cage	fixed	active	uncrewed	operational	Seabin	Australia	https://seabinproject.com/
River Cleaner System	inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	testing	Blue Eco Line	Italy	https://blueecoline.com/river-cleaner-impianto-ecosostenibile-per-ripulire-i-fiumi/
DeltaSea Marine Debris Collection System	coastal waters, open ocean	trap	booms, nets, cage	mobile - autonomous	active	uncrewed	testing	Technika Engineering Ltd.	Canada	https://www.delta-sea.com/marine-debris-collection
Drain buddy	stormwater drain	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Cleanwater Group	Australia	https://cleanwatergroup.com.au/products/
Debris boom Ocean Crusador	stormwater drain, inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Ocean Crusadors/Chatoyer	Australia	https://oceancrusaders.org/clean/debrisbooms/
Orion Floating Trash Boom and Barriers	stormwater drain, inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	GEI works	USA	https://www.erosionpollution.com/index-2.html
heavy duty debris barriers	inland waterways, coastal waters	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Abasco	USA	https://www.abasco.com/debris-and-trash-barriers.html
Clean Trash Marine Litter Containment Floating	stormwater drain, inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	testing	New Naval	France	https://www.oilspillresponse.gr/service-item.php?sid=1
Watersweepr	stormwater drain, inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Watersweepr	USA	https://www.watersweepr.com/
Desmi trash remover - Enhancer series	stormwater drain, inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	DESMI	Denmark	https://www.desmi.com/segments/enviro-clean/enviro-care-clean-waterways/

Name	Field of application	Type of system	Method of collection	Mobile/ fixed	Active/ passive	Control system	Status	Company	Country invented	Website
Desmi trash remover - Treat series	stormwater drain, inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	DESMI	Denmark	https://www.desmi.com/segments/enviro-clean/enviro-care-clean-waterways/
Desmi trash remover - Sweep	coastal waters	trap	booms, nets, cage	mobile - towed	active	crewed	operational	DESMI	Denmark	https://www.desmi.com/segments/enviro-clean/enviro-care-clean-waterways/
Desmi trash remover – Aware	inland waterways, ports, coastal waters	drones & robots	booms, nets, cage	mobile - remotely operated	active	uncrewed	operational	DESMI	Denmark	https://www.desmi.com/segments/enviro-clean/enviro-care-clean-waterways/
Desmi trash remover – Rise	stormwater drain, inland waterways	trap	booms, nets, cage	fixed	active	uncrewed	operational	DESMI	Denmark	https://www.desmi.com/segments/enviro-clean/enviro-care-clean-waterways/
Litter Gitter	stormwater drain, inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Osprey Initiative	USA	https://osprey.world/litter-collection-devices
Litter Interceptor	stormwater drain	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Osprey Initiative	USA	https://osprey.world/litter-collection-devices
Elastec Omni Catemaran	inland waterways, ports	boat	booms, nets, cage	mobile - crewed	active	crewed	operational	Elastec	USA	https://www.elastec.com/marine-waste-floating-debris-technology/
Brute boom	stormwater drain, inland waterways	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Elastec	USA	https://www.elastec.com/marine-waste-floating-debris-technology/
Brute Bin Trash Collector	stormwater drain	trap	booms, nets, cage	fixed	passive	uncrewed	operational	Elastec	USA	https://www.elastec.com/marine-waste-floating-debris-technology/
Efinor Waste Cleaners	inland waterways, ports, coastal waters	boat	booms, nets, cage	mobile - crewed	active	crewed	operational	Efinor Sea Cleaner	France	https://seacleaner.efinor.com/en/gammes/waste-cleaner-en/
Ichtyon Azure	inland waterways	trap	conveyor belt	fixed	passive	uncrewed	testing	Ichtyon	UK	https://ichthion.com/technology/

Name	Field of application	Type of system	Method of collection	Mobile/ fixed	Active/ passive	Control system	Status	Company	Country invented	Website
Clearbot	inland waterways, ports, coastal waters	drones & robots	booms, nets, cage	mobile - autonomous	active	uncrewed	testing	Clearbot	Hongkong	https://www.facebook.com/clearbot
Clewat	inland waterways, ports, coastal waters	boat	booms, nets, cage	mobile - crewed	active	crewed	operational	Clewat	Finland	https://clewat.com/en/research/
ONA Seadron	ports	drones & robots	booms, nets, cage	mobile - remotely operated	active	uncrewed	operational	ONA Safe and Clean	Spain	http://www.onasafeandclean.com/en/seadroncleaner/
ONA catclean	inland waterways, ports, coastal waters	boat	booms, nets, cage	mobile - crewed	active	crewed	operational	ONA Safe and Clean	Spain	http://www.onasafeandclean.com/en/seadroncleaner/
ONA Sac Nets	inland waterways, ports, coastal waters	boat	booms, nets, cage	mobile - crewed	active	crewed	operational	ONA Safe and Clean	Spain	http://www.onasafeandclean.com/en/seadroncleaner/
Aquapod	inland waterways, ports, coastal waters	trap	booms, nets, cage	fixed	active	uncrewed	operational	Cleanseasolutions	Norway	https://www.cleanseasolutions.no/product-aquapod
Aquadrone	inland waterways, ports, coastal waters	drones & robots	booms, nets, cage	mobile - remotely operated	active	uncrewed	testing	Cleanseasolutions/ Maritime Robotics	Norway	https://www.cleanseasolutions.no/
River Cleaning	inland waterways	trap	other	fixed	passive	uncrewed	testing	Rivercleaning	Italy	https://rivercleaning.com/river-cleaning-system/
Circleaner	inland waterways	trap	other	fixed	passive	uncrewed	operational	Noria	The Netherlands	https://www.noria.earth/
Canal cleaner	inland waterways	trap	other	fixed	active	uncrewed	testing	Noria	The Netherlands	https://www.noria.earth/