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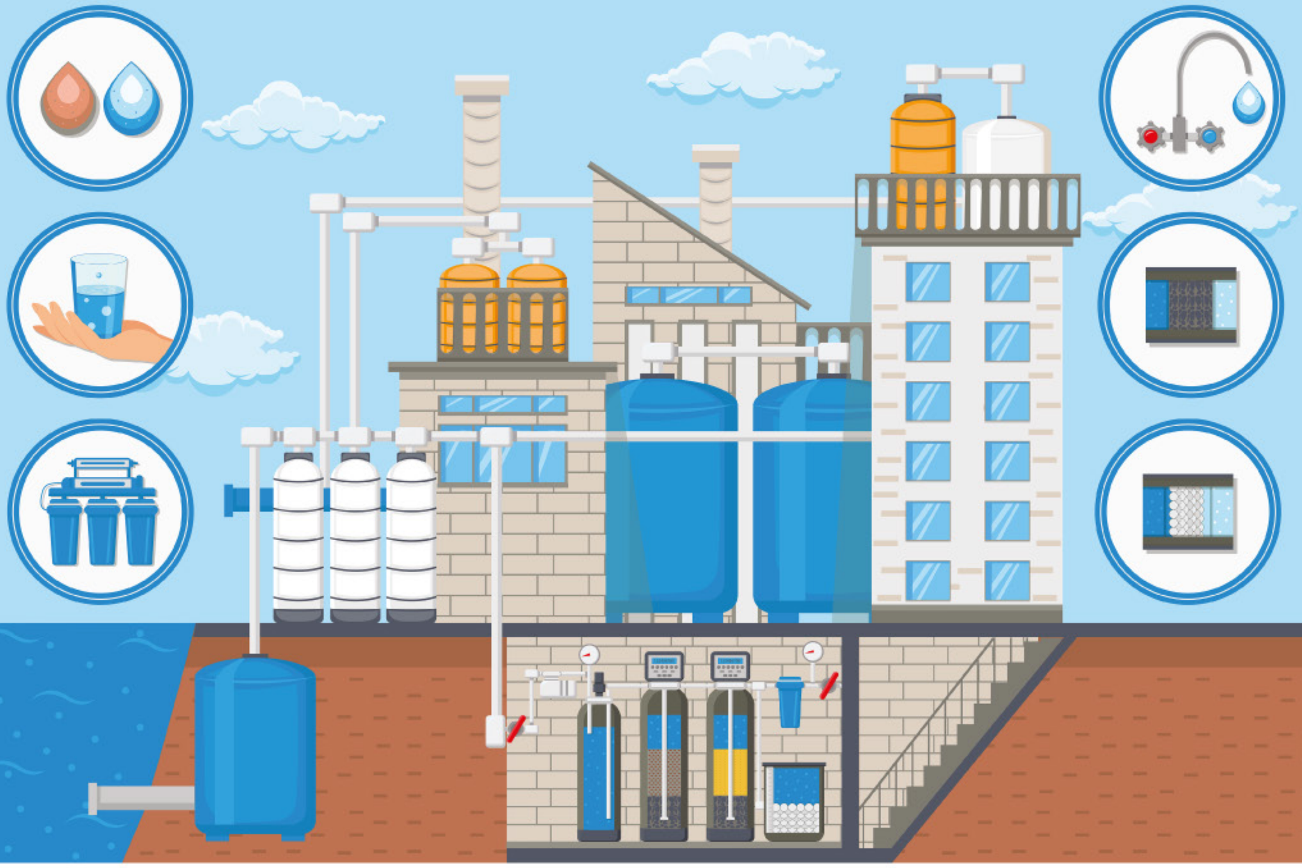
Catalogue of Technologies to Address the Risks of Contamination of Water Bodies with Plastics and Microplastics



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Catalogue of Technologies to Address the Risks of Contamination of Water Bodies with Plastics and Microplastics

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Table of Contents

Introduction

The world demands and produces more and more plastic every year. In 2018 global production of plastics reached 360 million metric tons (MT) (PlasticsEurope 2019). This figure is even higher if we include plastics used to produce in manufacturing synthetic textiles, synthetic rubber and plastic additives. It has been estimated that as of 2015, 60 per cent of the 8,300 metric tonnes of plastic ever produced had been discarded and was accumulating in landfills, open dumps and the environment (Geyer, Jambeck and Law 2017). Part of this plastic finds its way to rivers, lakes and the oceans. If current consumption patterns and waste management practices do not change, it has been estimated that by 2050 there will be approximately 12 billion metric tons of plastic litter in landfills and the natural environment (Geyer, Jambeck and Law 2017).

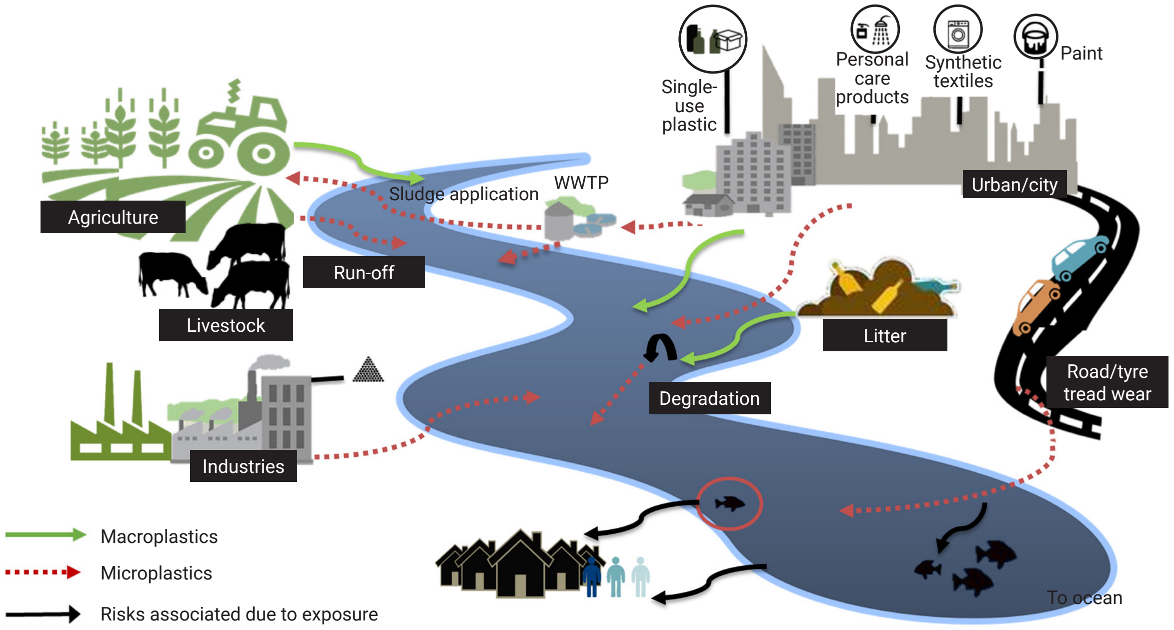
Waste management in most cities of developing countries is an expensive, labour intensive and low-margin business, which explains why a large share of the solid waste generated is inadequately managed. For example, up to 50 per cent of the waste (including plastics) generated in urban areas may not be collected because of various factors including poor collection systems and road networks; equipment failure; or inadequate waste management budgets, often due to citizens' unwillingness to pay waste management charges. Uncollected waste is either burned, recycled informally or illegally dumped, to end up on land or in run-off drainage channels connecting to rivers and wetlands, thus becoming a source of water contamination. This has serious environmental, health and economic impacts, including but not limited to blocking of canals and sewers, the creation of breeding habitats for mosquitoes, loss of the recreational and touristic value of landscapes, and obstruction of the airways and stomachs of animals.

Once they are in the environment, and with time, plastic items tend to degrade to smaller particles through natural weathering processes and can become microplastics (commonly defined as less than 5 mm in diameter). Other microplastics are directly released into the environment. They may have been intentionally added to consumer products, such as personal care and cosmetic products (PCCPs), or they can result from the abrasion of objects containing plastic (e.g. tyres and synthetic textiles).

Municipal wastewater comes from residential, domestic, industrial, commercial and run-off sources. It may be collected through a single pipe and channelled to a wastewater treatment plant (WWTP) and/or discharged directly into water bodies. In other cases separate sewers may exist, especially to carry away run-off. The contaminants, including those in municipal wastewater, include plastics, microplastics and other debris. It is very important to reduce and remove plastic waste before it enters the WWTP system or freshwater bodies, as it is a major source of environmental contamination.

Analysis of water and sediment worldwide indicates that plastics and microplastics are ubiquitous in aquatic environments, including marine and freshwater ecosystems. The main sources of macroplastics (that is, plastic particles larger in size than microplastics) and microplastics, and their pathways to water, are shown in Figure 1. In this publication macroplastics are frequently referred to as plastics.

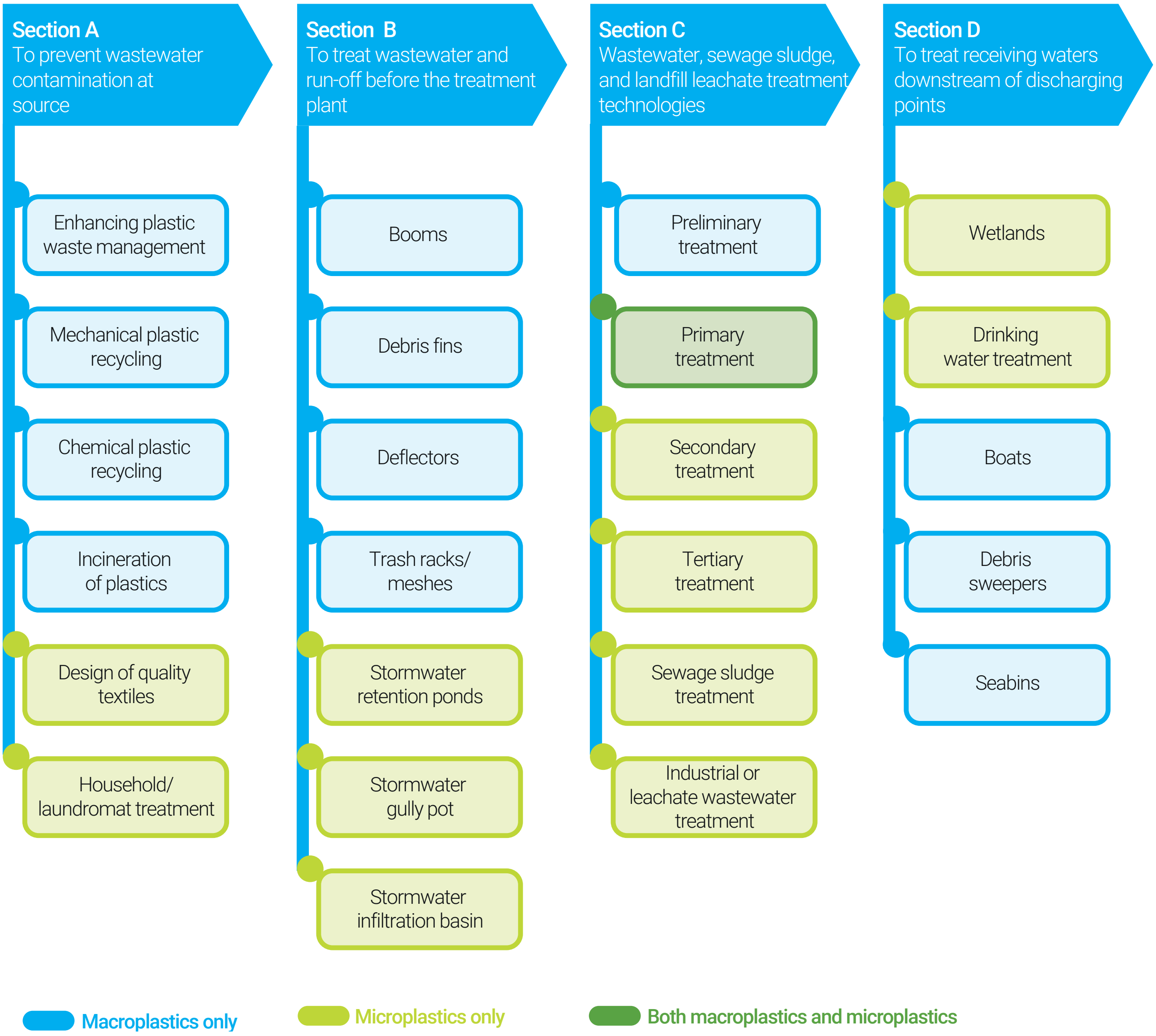
Figure 1. Main sources of macroplastics and microplastics and their pathways to water



To reduce environmental contamination by plastics and microplastics, as well as human exposure to the potentially dangerous pollutants they may contain, several technical solutions can be explored (Figure 2). Some are needed to address the design, production, consumption, recycling and disposal of plastics that are likely to continue to be used in decades to come. Others are needed to limit the export of pollutants from cities and elsewhere through the treatment of wastewater and run-off, and to safely manage sewage sludge. These technical solutions must be supported by legislation, economic instruments, education and awareness if real change is ultimately to take place.

When planning the mitigation of water pollution by plastics and microplastics, decision-makers and experts need to agree on desired water quality in the local context and plan accordingly. Once water quality objectives for plastics and microplastics are set, the most relevant pollutant sources and pathways to water need to be identified. For example, in one watershed plastics could be the most critical source of contamination, while in another microfibres from synthetic textiles or microplastics from tyre abrasion, with road run-off, could be the most relevant sources and pathways. Based on this understanding, decision-makers, in consultation with local stakeholders, can select the most cost-effective and sustainable combination of solutions. For example, to achieve a desired maximum number of microplastics in drinking water, a recycling solution for plastic waste (upstream) could be combined with secondary wastewater treatment and conventional drinking water treatment (downstream). The final selection will mainly depend on the combination of solutions that is feasible in the local context and that can be achieved at acceptable costs. However, costs and effectiveness will not be the only guiding criteria. The capacities and perceptions of local stakeholders, together with other practical challenges with regard to the adoption of certain solutions in a local context, will all influence the final selection and need to be considered.

Figure 2. Technical solutions explored in this report



In this catalogue there are brief descriptions of technologies that can be implemented to address the contamination of water bodies by plastics and microplastics.[1] For each technology the information provided includes a description and examples of applications, opportunities, barriers and typical costs of implementation.

There is also a qualitative assessment of each solution in terms of investment cost, operational cost, the solution's maturity, and the level of extra policy support needed for successful implementation. The classifications adopted for the qualitative assessment of each solution are shown in Table 1.

Table 1. Classifications adopted for the qualitative assessment of each solution

Scale	Solution maturity	Impact of supporting policies
1	Tested and validated at laboratory or pilot scale	Basic (e.g. establishing a favourable legal framework plus basic monitoring)
2	Tested and validated at industrial or pilot scale	
3	Demonstrated in some cases, but global adoption is pending	Moderate (e.g. setting a favourable legal framework plus extended efforts towards enforcement and monitoring)
4	Adopted to some extent, but there are some critical unknowns	
5	Widely adopted and mostly understood	Critical (strong supportive policies are essential)

The solutions explored in this catalogue to address the risks of contamination of water bodies with plastics and microplastics are not always gender-neutral. There are important aspects that have to be considered, not only in terms of gender equality and women's economic empowerment opportunities with respect to waste management, but also in terms of differentiated human health impacts.

> *"Gender analysis reveals that while systemic environmental problems typically manifest in physical landscapes and ecosystems, the state of the environment can only be explained by examining social, cultural and economic systems and arrangements. Those structures are 'gendered': they are shaped by socially constructed roles and relationships between women and men." (United Nations Environment Programme 2019b)*

Hence, inclusive stakeholder engagement is key in all sustainable consumption and production practices and in value chain assessments in waste management. This is also essential to guide the selection and implementation pathway of the technologies described in this report.

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[1] The solutions presented in this catalogue are taken from Nikiema, J., Mateo-Sagasta, J., Asiedu, Z., Saad, D. and Lamizana, B. (2020). *Water Pollution by Plastics and Microplastics: A Review of Technical Solutions from Source to Sea.* Nairobi: United Nations Environment Programme (UNEP).

A

Technologies to Prevent Wastewater Contamination at Source

1. Enhancing plastic waste management

Objective: Manage solid waste to facilitate value generation from wastes

Costs

Investment	Annual operation and maintenance (O&M)
Variable, depending on adopted solution	Current investment for O&M in developing countries is insufficient and should be increased considerably (e.g. a several times increase is required in some Asian countries).

Profitability	Maturity	Policy support need
Enhancing plastic waste management is a necessary condition for recycling to occur. Profitability is usually not expected to be achieved. The target is cost recovery.	4-5	5

Description

Adequate leakage management is the first step towards controlling plastic pollution. It requires an increasing percentage of waste recycling and ensuring the availability of suitable waste handling facilities. Overall, collection, storage, transport and final disposal must be financially sustainable, technically feasible, socially and legally acceptable, and environmentally friendly.

Implementation

In many developing countries the collection and transport of municipal solid waste is usually contracted to private companies which operate, in principle, under the supervision of local authorities and technical line agencies. However, monitoring is often poor, leading to these companies focusing more on profits than effective performance. Most collected waste is sent to open dumps. Even when engineered landfills exist, their maintenance could remain poor, leading to waste (including plastic waste) leakage. Leakage management can include upstream recycling using mechanical, chemical, incineration and/or other innovative technologies (e.g. irradiation technologies), utilization in tertiary products such as construction materials, and co-processing using existing high-temperature processes (e.g. cement kilns).

Example: the cost of selected solutions

McKinsey and Company and the Ocean Conservancy (2015) modelled 21 solutions for mitigating the leakage of plastics in China, Indonesia, the Philippines, Thailand and Viet Nam. It was concluded that the best solutions for plastic waste management would involve gasification, incineration, setting up materials recycling facilities and improving haulier systems, although the last two might not be financially profitable.

Based on that study, plastic waste management systems can be improved by:

- Source segregation of waste and improved transportation to promote waste recycling;
- Effective legislation for plastic and microplastic waste management (e.g. guidelines for plastic litter management, while control of production and transport related spills could be upgraded to integrate safe microplastics management);
- Enforcement of policies to reduce illegal dumping;
- Supportive policies to reduce landfilling and promote recycling.

To achieve this sustainably, it is important to highlight opportunities for waste management efforts, beginning at the households/communities level. Hence, their needs and structures must be included in all waste management plans. The alienation of men and boys from domestic and community waste management activities has significant social and economic costs, which will undermine any waste sector reforms if left unaddressed. There is a need to assess the value of contributions to the protection of ecosystem services by women who manage waste in households and communities on an unpaid basis. Households may be the pivotal site for reform, given also that in many cases they currently have the least formal engagement with the waste sector's power and policy structures. Women have tremendous collective capacity to optimize the flow of waste into the system, both through consumption practices and waste management and recycling strategies. Engaging households would make it possible for policies to be based on a more accurate view of the waste value chain.

Opportunities and barriers

Often waste management is viewed as an essential utility service governed by the public sector. However, it is frequently implemented in partnership with the private sector. In both the public and private sectors men hold most upper-level administration roles, from city managers and planners to landfill operators and managers of waste collection companies. Women are more engaged in informal, household and neighbourhood activities related to waste, which are typically voluntary, unpaid or minimally compensated. To improve plastic waste management:

Industry should	**Government should**	**Citizens should**
• Measure, monitor, manage and report plastic use • Mitigate ecological risks and increase recycling of plastic products	• Enforce policies aimed at reducing per capita plastic waste generation, waste mismanagement and landfilling, and policies that promote recycling • Promote tools that allow consumers (including women and other marginalized groups) to enhance their awareness of the management of plastic and plastic waste • Openly support alternatives to plastic and encourage industries to move to environmentally friendly packaging • Create/upgrade solid waste collection and treatment	• Make sound consumption decisions, e.g. to reduce or avoid plastic waste generation • Change habits and lifestyles that require plastic usage, e.g. through reducing reliance on single-use plastics or through source separation
• Governments/the private sector should be encouraged to include households/communities and specifically take affirmative action to ensure that women are invited to take part in discussions as key stakeholders. It is crucial that governments and the private sector promote gender equal employment in the waste sector more actively.		

2. Mechanical recycling

Objective: Recycle sorted and clean plastics

Costs

Investment	Annual operation and maintenance
• United States dollars (USD) 7,000-10,000 for the facility • USD 15,000-50,000 for equipment (capacity 100-1,000 kg per hour) • Land requirement: >45 square metres	• USD 13,000-35,000 for the facility
USD 2,000-10,000 to process 1 ton/day capacity	USD 500-1,500 to process 1 metric ton/day capacity in India, including cost to acquire raw plastics

Profitability	Maturity	Policy support need
A plant can become profitable in less than a year if value chains for quality plastic collection and diversification of products and revenues are established.	5	1 The business can be profitable and it may require less policy support.

Description

This technology processes sorted and cleaned single-type plastic waste into a raw material or product without significantly changing the plastic's chemical structure. It works well for thermoplastics that are:

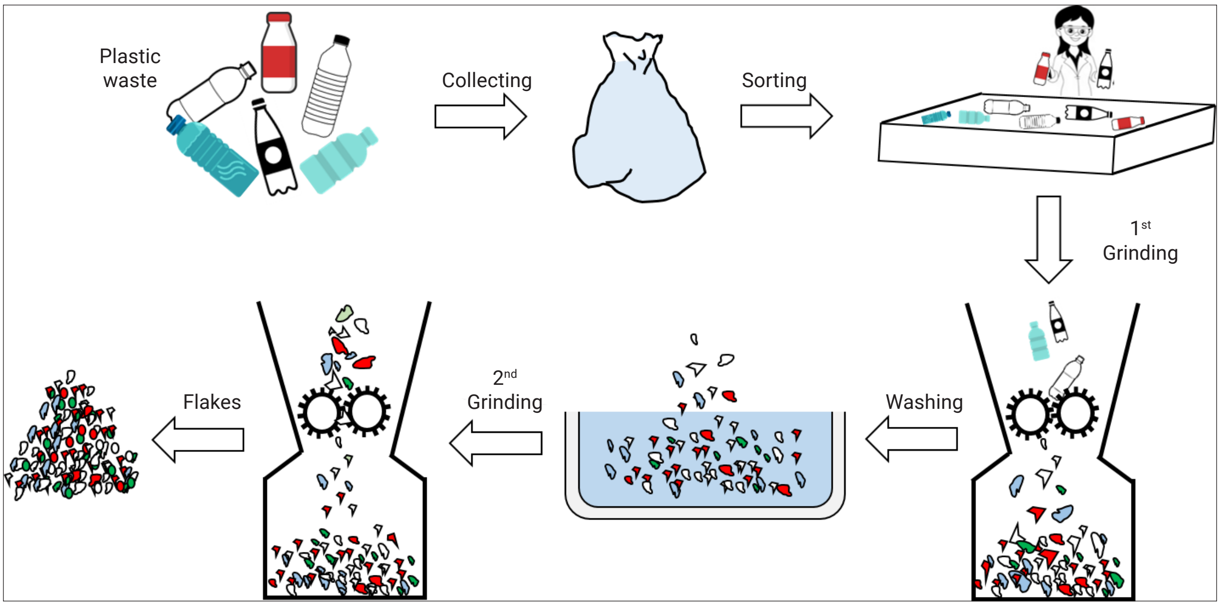
- semi-crystalline, e.g. polypropylene (PP), low-density polyethylene (LDPE), high-density polyethylene (HDPE) and polyethylene terephthalate (PET);
- amorphous, e.g. polyvinyl chloride (PVC).

The technology is also suitable for other semi-crystalline polymers, which combine properties of the first two types and include polyester polybutylene terephthalate (PBT) and polyamide Imide (PAI).

Implementation

Mechanical recycling is the main type of recycling worldwide. In Europe, 99 per cent of recycled plastics undergo such a process. It is particularly suited for recycling clean plastic waste with a single composition. This recycling process includes the following steps: collection and sorting, washing, grinding, and drying. Granulating and compounding may eventually follow. It is mostly used in recycling PP, polyethylene (PE) and PET.

It is important that implementation of these processes also considers gender equality. Currently, in many developing countries, gender inequalities are embedded in almost all aspects of waste management including the distribution of responsibilities and roles which shape the position of waste in social and economic systems. Within the informal waste economy studies show that women are often limited to lower-income tasks, such as waste picking, sweeping and waste separation, and could even be displaced by men when informal or voluntary waste-related activities become formalized with pay.



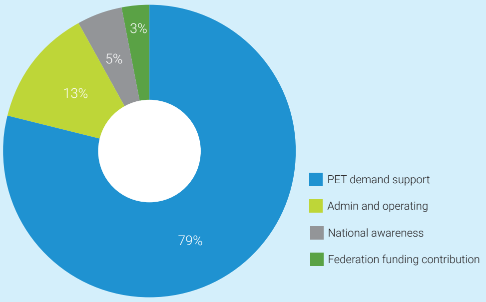
Note: In industrial systems, grinding is done before washing

Source: Ragaert, Delva and Geem (2017)

Example

South Africa: when industry forefronts plastic recycling
PETCO is the trade name of the not-for-profit PET Recycling Company NPC South Africa, incorporated in 2004. It is an industry driven and financed environmental solution for post-consumer PET recycling. This initiative is funded through a voluntary fee paid by bottle manufacturers which purchase PET resin. New PET packaging can be made from up to 100 per cent recycled PET.

The cost of PET recycling in South Africa was USD 76.5 per metric ton in 2018, with cost distribution as shown:



Source: PETCO (2018)

Opportunities and barriers

Opportunities	Barriers
• Replacing new virgin polymer with recycled plastic polymer can directly reduce oil consumption and greenhouse gas emissions. Recycling a single metric ton of plastic bottles avoids emissions of 1.5-2.3 metric tons of carbon and reduces natural resource consumption. • In the PETCO example, about 2.7 million m^3 of landfill space is saved.	• Recycling needs a clear financing stream to enable equipment support and sponsorship for waste collectors. • It is financially more advantageous to process large volumes of waste. • High purity sorting of plastic is necessary to ensure high quality output. • Degradation of plastic polymers is observed as a result of the mechanical process and exposure to natural light, oxygen or moisture. For example, after six cycles of PET recycling the quality is greatly reduced.

3. Chemical recycling

Objective: Recycling of unsorted plastics

Costs for pyrolysis

<table>
<tr><td>Investment costs
• USD 260 million plant in Ashley, Indiana (United States) for a plant with:
- Capacity: 91,000 tons per year of plastic waste
- Output per year: 68 million litres of diesel and naphtha, and 22 million litres of industrial wax</td><td colspan="2">Annual operation and maintenance
For a pyrolysis plant with capacity of:
• 15,000 metric tons per year:
- USD 800 per metric ton in North America
- USD 1,000 per metric ton in Europe
• 55,000 metric tons per year
- USD 500 per metric ton in North America
- USD 600 per metric ton in Europe</td></tr>
<tr><td>USD 857,000 to process 1 ton/day capacity</td><td colspan="2">USD 500-1,000 to process 1 ton/day capacity</td></tr>
<tr><td>Profitability
This type of recycling will not be attractive when oil prices are low, e.g. less than USD 100 per barrel. It is only profitable when large volumes can be processed (50,000-100,000 metric tons/year).</td><td>Maturity
4</td><td>Policy support need
4
• Policy support to ensure large volumes are collected is essential.
• High landfill tipping fees or gate fees[2] are also an incentive.</td></tr>
</table>

Costs for gasification

<table>
<tr><td>Investment costs:[3]
• USD 106 million plant in California (United States):
- Capacity: 99,000 tons/year of plastic waste
- Typically USD 108/ton or USD 260,000-550,000 to process 1 ton/day capacity</td><td colspan="2">Annual operation and maintenance
• Labour: USD 15/ton or USD 4,250 to process 1 ton/day capacity
• Maintenance: USD 64/ton or USD 18,100 to process 1 ton/day capacity</td></tr>
<tr><td>Profitability
• If energy recovery is carried out, yield is 43.5 megajoules per kilogram (MJ/kg) of plastic (estimated revenue USD 286 per ton of plastic).
• If hydrogen is purified and marketed, the revenue is USD 197/ton of plastic.
• Though the plant can break even, profitability is reduced and net present value (NPV) remains negative even after 15 years of operation.</td><td>Maturity
3</td><td>Policy support need
4
• It is essential to ensure large volumes are collected.
• High landfill tipping fee is also an incentive.</td></tr>
</table>

Description

Feedstock (or chemical) recycling is a tertiary recycling method. It uses processes such as gasification and pyrolysis, through which plastic waste breaks down to produce synthesis gas (syngas) and oil (fuel), among others. Depolymerisation is a variant of catalytic pyrolysis that converts selectively a plastic polymer into its monomer(s) (e.g. polystyrene will yield styrene).

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[2] The tipping fee or gate fee is the charge levied to deposit waste at a treatment plant or landfill. It is usually expected to offset the cost of setting up, operating and maintaining the treatment site.

[3] Based on a theoretical/pre-feasibility study.

Implementation

The chemical structure of plastic waste is transformed through thermo-induced chemical or biochemical reactions into shorter molecules which are readily usable to manufacture new products such as fuels, chemicals or virgin plastics. The key operating parameters include the process temperature (or energy consumption), the type of plastic feedstock and its level of contamination (in particular how it affects the proposed technical process), and the level of polymer breakdown desired.

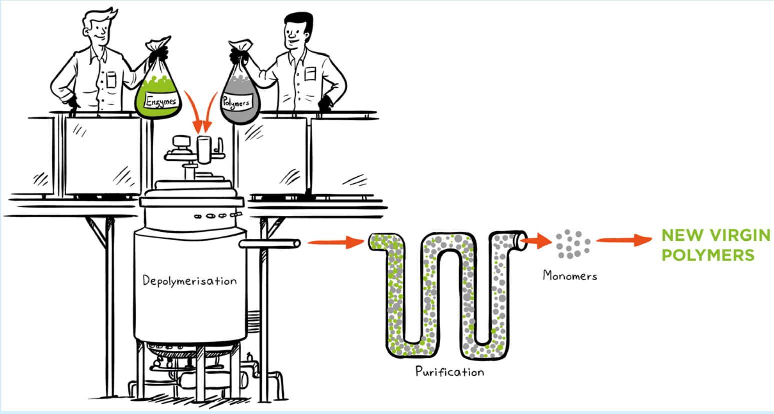
Variants and examples

Technology	Process outputs	Feedstock impact on process	Example of commercial application
Pyrolysis*	Oil, gas and char (unreacted solid carbon and ash)	High	Mogami-Kiko, Japan: 3,000 metric tons processed per year
Catalytic pyrolysis	Oil, gas and char	Medium to high	Sapporo/Toshiba, Japan: 14,800 metric tons of mixed plastic waste processed per year
Depolymerisation	Plastic monomer(s)	High	CARBIOS technology
Gasification	Mix of hydrocarbons and syngas, tar (dark thick flammable liquid) and char (the last two are less desirable)	Low to medium	Enerkem, Edmonton, Canada: 100,00 metric tons of mixed plastic waste processed per year

*Research and development activities at the International Atomic Energy Agency (IAEA) show that combining pyrolysis with irradiation technologies to lower the process energy demand and decrease unreacted solids and by-products shows promise.

CARBIOS technology

The CARBIOS technology targets polyesters such as PET. Sorted and cleaned plastics are mixed with water and enzymes, heated and churned. The enzymes decompose the plastic into molecules that serve as basic building blocks, which can then be separated, purified, and used to make virgin plastic. With this process there is no loss in quality for the recycled product.



Source: CARBIOS (2020)

Opportunities and barriers

Opportunities	Barriers
This technology recovers more waste types than mechanical recycling because it recycles the plastic waste usually sent to landfill or incinerated, such as grocery and trash bags, bubble wrap, other retail packaging, food wraps and carpet fibres. Mixtures of plastic materials can also be processed for some technologies. The process saves typically 1.5 metric tons of carbon dioxide (CO_2) per metric ton of plastic (compared with 2.3 metric tons in the case of mechanical recycling).	In Europe gasification demands high investment costs, high energy consumption and high input levels, so that only very large plants (i.e. those able to process over 60,000 metric tons of waste per year) are economically viable. However, pyrolysis could be implemented to process lower waste volumes, as shown above.

There are important gendered impacts on human health during chemical recycling process, arising from gases and other by-products. Noxious gases and particulate matter generated have gendered impacts on workers, communities and the environment in general. Biological gender differences such as body size, amount of adipose tissue, reproductive organs, hormones, and other biological and physiological differences impact the effects and elimination of toxic chemicals and substances. Hence, women and men are exposed differently to hazards in the workplace. As an illustration, a Canadian study found that women working in the plastics industry had a five-fold elevated risk of breast cancer and reproductive disorders (Brophy *et al.* 2012). Gender-disaggregated health effects during specific processes of plastic waste management (i.e. recycling, incineration) are currently unavailable.

4. Incineration

Objective: Burn unsorted solid waste, including plastics for energy production

Costs

Investment Typically: USD 741 per metric ton of municipal solid waste input. Typical electricity generation: 0.40-0.77 megawatt hour (MWh) per metric ton of input.	**Annual operation and maintenance** Typically: USD 31 per ton processed, including 56 per cent for maintenance and management, 11 per cent for personnel and 25 per cent for utilities.
USD 260,000-550,000 to process 1 ton/day capacity	USD 10,800-40,000 to process 1 ton/day capacity

Profitability An incineration plant in a developing country, in particular, might not be profitable (e.g. in Myanmar it would require five to nine times higher tipping fees, which cannot be implemented in the local context). However, profitable plants are operated in Europe, especially in France, which has over 100 incinerators. A minimum capacity of 60,000 MT per year is usually necessary for profitability to be achieved.	**Maturity** 5	**Policy support need** 1-2 • Policy support is essential to ensure that large volumes are collected. • High landfill tipping fees are also an incentive. Similarly, high rates for electricity and hot water help the financial model to be sustainable.

Description

Plastics and other municipal solid waste are incinerated together. Energy is released from plastics following incineration. The presence of plastic usually increases the calorific value of the waste mixture being incinerated.

Implementation

Plastic has a notable potential for energy generation, as its calorific value is similar to that of hydrocarbon-based fuel. Nevertheless, the risks of air contamination following combustion of plastic waste remain critically important.

Example: Comparing recycling and incineration of plastics in the Netherlands

Benefits, limits and drivers towards recycling and incineration in the Netherlands

Solutions	Expected benefits	Foreseen limits	Drivers
Mechanical recycling of plastics to produce new plastics for high quality industrial purposes	• Avoidance of CO_2 that would otherwise be emitted during incineration • Production of (new) material	High collection and recycling costs	• Environmental awareness • Local policy promotes incineration and recycling
Incineration of plastics for energy recovery	• Heat and electricity production leading to fewer emissions in the regular energy production sector • No sorting required	Requires a waste-to-energy plant with the associated capital investments	• Lack of space • Local policy promotes incineration and recycling

In the Netherlands the cost difference is EUR 199 per metric ton of plastic in favour of incineration, while the difference in CO_2 emissions is 1.16 ton per ton of plastic in favour of recycling.

Net costs of recycling and incineration in euros/metric ton of plastic and CO_2 emissions from recycling and incineration in metric tons of CO_2 per metric ton of plastic

Item	Recycling		Incineration	
	Cost (euros)	CO_2 emissions	Cost (euros)	CO_2 emissions
Collection and transport	408	0.02	60	0.01
Net – treatment	262	0.85	6	2.6
Opportunity energy production[a]	90	0.78	0	0
Opportunity plastic recycling[a]	0	0	495	0.20
Total	760	1.66	561	2.82

a The opportunity cost is the cost associated with loss of other alternatives when one alternative is chosen.

Opportunities and barriers

Opportunities	Barriers
• Incineration can be applied to a waste mixture that cannot be recycled mechanically or chemically. • Does not require selective collection for waste (compared to recycling), which reduces costs. • Typically, 70-80% of the energy from waste incineration can be recovered to produce hot water. If there is interest in electricity only, energy recovery is 20-25%. In the case of co-generation, energy recovery totals 50-60% of the original energy released by waste combustion.	• Incineration is often viewed as an unsustainable solution which is not fully aligned with the transformation principles of the circular economy. • Some microplastics (typically 1.9-565 particles per kg of ash formed) are found in the ashes resulting from the process. These ashes represent 10-25% of the input mass. • Noxious gases may be released during incineration.
In addition, there is a financial trade-off between incineration and recycling. In the Netherlands incineration is preferable to recycling when the market value of CO_2 is below EUR 68-172 per metric ton, which is the case at the moment.	

5. Household washing machine filters

Objective: Reduce microfibres and microbeads in washing machine wastewater effluents

Costs

Investment None	**Annual operation and maintenance** USD 131 per year and per household	
Profitability Not available	**Maturity** 1	**Policy support need** 3-4

Description

Over 840 million domestic washing machines are operated worldwide, using 55 million m^3 per day of water. With the projected number of washing machines continuously rising, it is essential to explore solutions to treat contaminated wastewater effluents from these units. For example, washing a single garment can release up to 1,900-1 million fibres, with typical average dimensions of 5.0-7.8 mm (11.9-17.7 μm in diameter). The extent of releases is related to the type of fabric (e.g. polyethylene fabrics release 8.6 times more microplastics than acrylic fibres) and its weathering, but also to washing conditions (temperature, friction, velocity, washing time, detergent used, presence or not of softener).

One interesting way forward would be to develop household-based systems to treat wastewater and retain microplastics. Adoption of adequate treatment technologies for grey wastewater[4] at the household level, or for washing machine effluents, would help prevent microplastics reaching wastewater treatment plants and, in countries where WWTPs do not exist, the environment.

Implementation

The use of filters to retain fibres in domestic wastewater effluents could become a solution to prevent releases of plastic fibres and microfibres provided they are used extensively. Approaches such as providing filters when washing machines are purchased could support wide adoption.

Currently household-based treatment systems are struggling to be adopted at scale for various reasons, including the immaturity of existing technologies. In addition, it is not clear how to manage filter waste residue.

A European private company markets filters for household washing machines. Typically, access to service costs EUR 9.95 per month and per household. Each filter retains 90 per cent of the microfibres generated during washing, according to the manufacturers. Filters must be replaced monthly.

Other solutions

Among additional measures that could be explored for households are:

- Better control of household washing equipment to encourage design which would reduce releases of microfibres or be effective in microplastics pollution control;
- Better control of cleaning and washing products (e.g. detergents and softeners) to define acceptable ranges of microbead concentrations or microfibres release;
- Improved control of fabric quality, to exclude certain types of products which are prone to release microfibres during washing.

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[4] Grey wastewater is a mixture of all wastewater streams generated in households or office buildings excluding toilet waste.

The use of levies on fabrics and products that result in high microfibres release, in order to help finance higher treatment costs, could be explored.

Opportunities and barriers

Opportunities	Barriers
• There is a need for effective consumer education and legislation to guide and ensure adequate management of contaminated domestic waste(water). This would involve creating gender-sensitive knowledge products highlighting linkages between waste management and household involvement/consumer choices. Involving both consumers and the private sector is crucial, bearing in mind gendered roles. • The focus of most governments with respect to microplastics management has been limited to microbeads control, and then only in the case of selected personal care and cosmetic products (i.e. rinse-off types). This means microfibres, which appear to be of greater concern than microbeads, are so far completely neglected by regulatory actions.	• Enforcing treatment solutions for microplastics at household level is viewed as expensive when end-of-pipe wastewater treatment systems can be envisaged. • This solution could help prevent environmental contamination in developing countries, which often lack sewer systems or effective wastewater treatment plants for collected sewage. However, enforcing these measures requires strong policies and monitoring capacity, which are often lacking. In addition, there is no use for the retained filter waste, whose mismanagement will lead to recontamination of the environment.

6. Design of new textiles

Objective: Reduce microfibres generation during textile washing and use

Costs

Investment Not available	**Annual operation and maintenance** Not available

Profitability Not available	**Maturity** 1	**Policy support need** 2-3

The cost of enforcing measures and practices to reduce the generation of microfibres during textile washing and use is ultimately borne mainly by consumers. There is a need to accompany implementation of these technologically advanced solutions with supporting policies and awareness-raising campaigns which do not promote the status quo.

Description

Around 35 per cent of microplastics in the oceans are believed to originate from washing of synthetic textiles which release fibres to the water. The extent of microfibre releases into the aquatic environment is related to the type of textile. For example, thicker fabrics tend to shed more than nylon, filamentous yarns and woven textiles. Similarly, polyethylene fabrics release 8.6 times more microfibres than acrylic fibres. Microfibre releases are also determined by washing conditions (e.g. temperature, friction, velocity, washing time, detergent used, presence or not of softener).

Implementation

Some manufacturing processes are known to affect releases of microfibres during textile washing. Increased control of production techniques and of fabric quality could help in this regard. Safeguarding heath in the process is rather important, as studies have reported that women who work in textile factories and are exposed to synthetic fibres and petroleum products at work before their mid-thirties appear to be most at risk of developing breast cancer later in life. Many modern synthetic fibres are basically plastic resin treated with additives such as plasticizers, many of which are recognized mammary gland carcinogens and endocrine disrupting chemicals.

Example

Textile manufacturing processes that affect release of microfibres during textile washing are:

• Improved knitting techniques Tight knitting increases the concentration of fibres per area and the amounts of microfibres released during fabric washing. • Ultrasonic welding of fabrics This technique is better than conventional cutting techniques: reduction of fibre loss is 70 per cent for particles larger than 5 μm in diameter.	• Innovative and quality formulations of textiles Techniques such as effectively combining synthetic and natural textiles and eliminating loose (poor quality) fibres could help reduce fibre loss during washing by up to 80 per cent. • Textile coating Use of silicon emulsion to coat textile fibres reduces fibre loss during washing. However, this could have important health impacts, especially on women who could become more vulnerable to breast cancers.

Opportunities and barriers

Opportunities	Barriers
• By optimizing textile design the generation of microfibres can be addressed at source in a cost-effective way.	• The solutions in this section have mostly been explored at a laboratory or pilot scale. This means actual marketing of newly designed products with the clear aim of reducing releases of microfibres is not yet happening.

There is no information about the impact of manual washing, which is common in developing countries, on releases of microfibres compared to use of conventional washing machines. In addition, research in this field should consider human (gender-disaggregated) health impacts.

7. Treatment of effluent from commercial and industrial laundries

Objective: Reduce microfibres in wastewater effluents

Costs

Investment
Low-cost units made in India exist at a cost of USD 5,000 or more for a plant treating 1-1,000 m^3 per day. The cost could be USD 40,000 and more in Europe.

Annual operation and maintenance
Can be high due to energy demand and use of chemicals in the process.

Typically, USD 706 per m^3 of wastewater treated, for both capital cost and one-year operation and maintenance cost. The process is a simple sedimentation and filtration combination. The cost should be higher for conventional treatment based on physical-chemical processes.

Profitability
Water can be recycled, leading to some cost savings.

Maturity
4

Policy support need
3

The costs of these treatment systems are not available in the literature. However, they are borne by the private sector and implemented when required by policies.

Description

During cleaning of laundry, water becomes polluted to the point that it may not be suitable for discharge into municipal sewers. The composition of wastewater effluents depends mostly on the washing machine and its use.

	Laundromat (commercial laundry)	Industrial laundry
Water consumption (litre/kg cloth)	15	20-30
pH	7-8	10
Temperature	38°C	45°C
Chemical oxygen demand (COD) (mg/litre)	5,000-10,000	8,000-12,000
Biochemical oxygen demand (BOD) (mg/litre)	250-500	5,000-7,000
Suspended solids (SS) (mg/litre)	400-1,200	1,500-2,000
Grease (mg/litre)	400-600	1,500-32,000
Surfactants (mg/litre)	50-80	100-600
Phosphate (mg PO_4/litre)	250-300	300-2,000

Implementation

Commercial laundries often work in self-service mode, while industrial laundries usually specialize in providing services to users such as hotels, restaurants, hospitals and nursing homes.

Some technologies exist for treating industrial laundries' effluents. In the past the focus of treatment was not the removal of microplastics, but rather the removal of, for example, oils and suspended solids. Typical technologies for treating the wastewater mostly use physical-chemical processes such as precipitation/coagulation and flocculation, adsorption on granular-activated carbon (GAC), and possibly also membrane filtration (e.g. ultrafiltration and reverse osmosis). These systems have been proven to achieve microfibre removal of 65-97 per cent, typically.

Concentrations and releases of microplastics and microfibres 100-1,000 µm in size in effluents from laundries in Sweden

Laundry	Main type of fabric	Share of microfibres compared with other microplastics (per cent)	Microplastics concentration in effluent (number per litre)	Total microplastics released (number per kg of textile)
Hotel	Cotton Polycotton (50 per cent polyester + 50 per cent cotton)	17-50	1,000-3,000	5,000-15,000
Hospital 1	Polycotton	30-68	103,000-235,000	711,000-1,620,000
Hospital 2	Polycotton	28-65	11,500-26,500	106,000-249,000
Mats	Cotton, nylon, rubber	49-83	151,500-254,500	318,000-534,500
Work clothes	Polyester, cotton, polycotton	81-95	385,000-455,500	4,550,000-5,375,000

Opportunities and barriers

Opportunities	Barriers
With enhanced awareness of the possible impacts of microplastics, technologies for the treatment of laundromat effluents need to be optimized for microplastics removal. Research in this area is still in its early stages.	There is no information on the impact of manual washing, which is common in developing countries, on releases of microfibres compared to use of washing machines.

B

Technologies to Treat Wastewater and Run-off Before the Treatment Plant

1. Booms

Objective: Remove floating waste particles (including plastics) from run-off in canals/creeks/drains

Costs

Investment The costs of booms depend mostly on type of material used and size. Items manufactured in the United States may cost USD 1,214 for a 2.5 metre boom and USD 725 for one that is 1.3 metres.	**Annual operation and maintenance** Annual maintenance fees for a boom in the United States are USD 533 per metre of boom. To reduce O&M costs, a boom can be strategically placed only during wet seasons, and downstream to avoid capturing the bulk of surface vegetation.	
Large booms (typically 30 metres) can cost up to USD 36,000.		
Overall cost is USD 485-1,200 per metre for a long boom.		
Durability Booms can last three to five years in turbulent water, or 10 years and more in calmer locations such as urban drains and creeks.	**Maturity** 3-4	**Policy support need** 3

Booms do not require installation of permanent structures in the run-off water bed.

Description

Booms are logs or timbers that float on the surface of the run-off water to collect floating debris, including plastic waste. They are anchored close to drainage banks (left or right) to allow traffic on the water to pass and are cleared using clean-up boats equipped with a conveyor belt, a coarse shredder and several garbage dumpsters.

Implementation

Booms generally consist of a floating construction designed to direct surface plastic. Booms and collection devices can be designed to account for drainage size and to be climate-specific, e.g. to take into account extreme weather conditions such as storms which result in large fluxes of water and hence plastic pollution.

Examples

A boom system captures floating trash as it travels.

In this example the bin attached to the boom system captures floating trash.

Source: Elastec (2020)

Opportunities and barriers

Opportunities	Barriers
• Booms are designed to be climate-specific, e.g. to take account of extreme weather conditions such as storms that result in large fluxes of water and therefore plastic pollution. • Booms do not require the installation of permanent structures in the run-off water bed (aside from possibly the anchoring system).	• Booms are unable to remove waste travelling sub-surface. • They require operating a separate system to collect the trapped waste (e.g. a clean-up boat).

2. Debris fins and deflectors

Objective: Redirect, remove and reduce waste particles (including plastics) in run-off water

Costs

<table>
<tr><td colspan="2">Investment
Construction costs for these structures are part of the bridge construction budget.</td><td colspan="2">Annual operation and maintenance
Installed debris fin and deflector structures do not require much maintenance.</td></tr>
<tr><td colspan="2">Durability
Structures have comparatively low environmental impact when properly designed and installed. They last as long as bridges, depending on material use. Concrete can last a lifetime.</td><td>Maturity
5</td><td>Policy support need
2-3</td></tr>
</table>

Description

Debris fins (also commonly referred to as pier nose extensions) are barriers built in the stream or drainage channel immediately upstream of a bridge. They allow debris (including plastics) to continue travelling in the flow in a directed manner. The fin walls are intended to position large plastics in run-off water to pass through the culvert[5] entrance of a bridge without accumulating at the inlet.

Example

The vertical walls must spread from the internal culvert/ bridge walls. The length of the fins is recommended to be 1.5 to two times the height of the culvert and the culvert must have an opening of four feet or wider.

Source: Tyler (2011)

Debris deflectors are triangular-shaped frames placed upstream of the bridge piers to deflect and guide plastics (and debris in general) through the bridge opening and away from the culvert entrance. Deflectors are placed immediately upstream of drainage structures in order to direct plastics from run-off water.

Example

For a debris deflector the apex angle should be between 15° and 25°, while the combined area of the two sides should be at least 10 times the area of the culvert opening. Storage capacity above the waste rack or the size of the accumulation area must be considered.

Source: Tyler (2011)

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[5] A culvert is a tunnel that carries a stream or run-off water under a road or railway. A culvert may act as a bridge for traffic.

Design and implementation

The debris fin is designed to align debris to pass unimpeded through a bridge opening. The deflector is designed to guide plastics away from and through the bridge entrance/culvert, based on the plastic size and how it compares to the deflector's openings. It should be carefully aligned with the upstream flow and constructed with a downward sloping upstream face, to limit impact force and the probability of debris accumulation. Cylindrical pile debris deflectors have been widely used throughout the United States.

Opportunities and barriers

Opportunities	Barriers
• The installed debris fin structure requires little maintenance and its environmental impact is comparatively low when properly designed and installed.	• Most plastics are deflected by the debris deflecetor. The subsequent accumulation of plastics can be a problem. • The design of this type of device is complicated. Physical model tests may be necessary.

3. Trash racks/meshes

Objective: Remove and reduce waste particles (including plastics) upstream of run-off water

Costs

Investment Rack structures made of heavyweight rail or steel cost USD 3,000-30,000 or more, depending on the size and materials required. A heavy rail or steel structure may be worth the investment, depending on e.g. the values at risk.	**Annual operation and maintenance** For systems with manual clean-up, O&M costs are USD 1,800-9,000 (1,460-7,000 pounds sterling [£]). For systems with mechanical clean-up, O&M costs are USD 2,100-9,700 (£1,700-7,600).	
Durability Racks will last 10+ years when proper maintenance is adopted by cleaning clog debris off the rack when required.	**Maturity** 5	**Policy support need** 1

Description

The most common technique for dealing with plastic waste in traditional facilities is to use a trash rack to keep plastics from entering the wastewater drainages. Debris racks are similar to debris deflectors in that they trap the plastics but do not necessarily redirect them. They can be placed at the culvert entrance (as seen on the right).

Design and Implementation

Racks consist of slightly inclined vertical bars that stretch nearly the entire height of the culvert, typically from the bottom of the intake to above the water surface. They are generally made of mild carbon steel, but wrought iron, alloy steel and stainless steel are also used in certain parts of the device structure. At the top of the rack the bars are often attached to the culvert by horizontal supports which can be designed so that removal for maintenance is possible. Accumulated plastics are usually removed from a rack by raking, which can be done by hand or with mechanized rakes. Mechanical rakes are preferable for large facilities; the rake sinks into the water and is pulled up along the rack face.

Source: Bradley, Richards and Bahner (2005)

Design spacing should allow smaller plastics to pass through, but catch larger plastics that might plug the culvert. However, in urban areas the maximum spacing is about six inches to prevent children entering the culvert.

Opportunities and barriers

Opportunities	Barriers
- Plastics accumulation is initially addressed by the slope of the rack's incline (15° to 45°).	- Severe accumulation of plastics can cause head loss as well as structural fatigue, which is a severe design concern. Proper maintenance is essential.

4. Microplastics removal from stormwater run-off

Objective: Reduce and better manage microplastics carried with stormwater run-off

Costs

Investment
Not available. A gully pot is quick and easy to install, reusable and cost-effective. Retention ponds construction costs vary considerably with hydrogeology.

Annual operation and maintenance
Not available.
Adequate O&M is essential for these systems to remain effective in microplastic, sediment and other pollutants' control.

Durability
Retention pond and infiltration basins can last forever when well maintained by removing clog debris occasionally. A concrete gully pot can last 20+ years.

Maturity
- Retention pond: 5
- Infiltration basin: 5
- Gully pot: 4

Policy support need
- Retention pond: 3
- Infiltration basin: 3
- Gully pot: 5

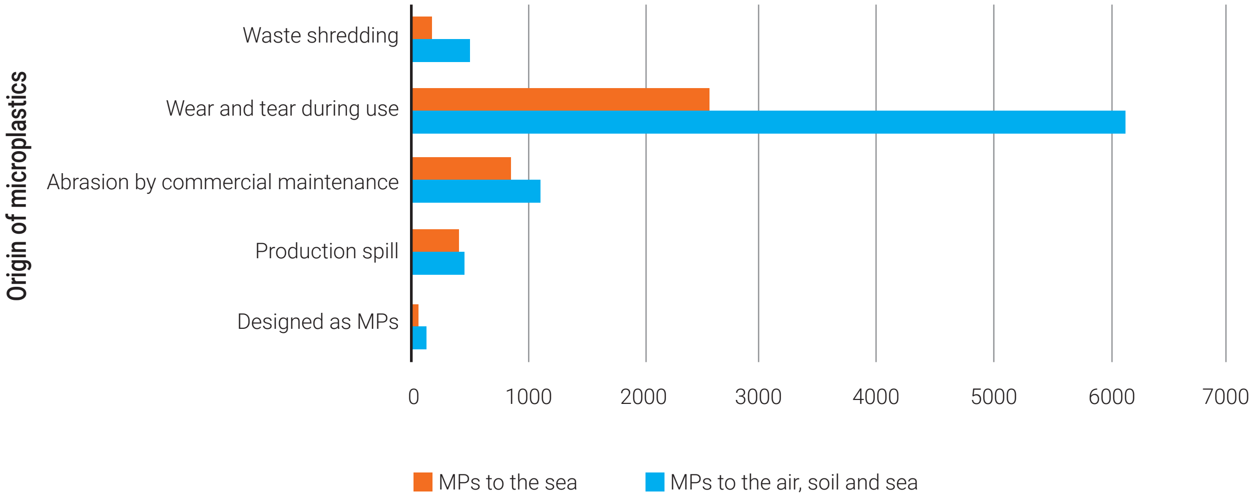
Description

Earlier studies have shown that soils contribute up to 80 per cent of microplastics entering water bodies. This is because microplastics present in soils and drains contaminate run-off water. A key source of microplastics in run-off water is the abrasion of tyres and road surfaces. Improving the design of tyre treads and road paving methods can reduce microplastic emissions (Boucher and Friot 2017; Norwegian Water Institute 2019).

Wear on tyres

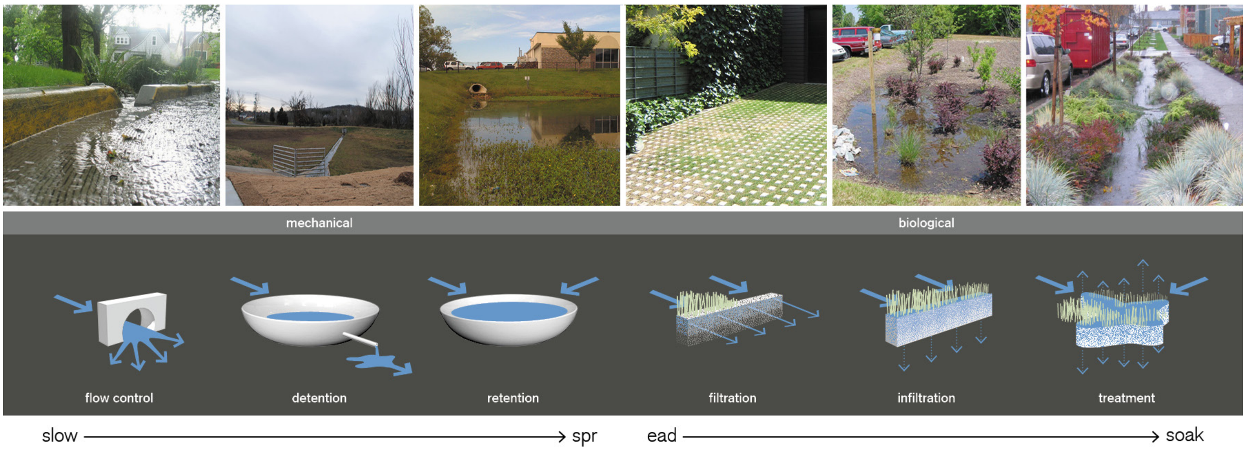
Type of vehicle	Wear intensity (gram/km)	Wear intensity (kg/year)
Passenger	0.033	0.23-4.7 (average: 0.81)
Light commercial	0.051	
Commercial	0.178	

Quantity of microplastics released to air, soil and water in Norway (metric tons)



Sources: Sundt, Schulze and Syversen (2014); Herbort, Sturm, Fiedler *et al.* (2018); Herbort, Sturm and Schuhen (2018)

In urban areas run-off is sent via drains or sewers to water bodies or it may arrive at a wastewater treatment plant (WWTP), increasing microplastic loading rates.



flow control: The regulation of stormwater runoff flow rates.

detention: The temporary storage of stormwater runoff in underground vaults, ponds, or depressed areas to allow for metered discharge that reduce peak flow rates.

retention: The storage of stormwater runoff on site to allow for sedimentation of suspended solids.

filtration: The sequestration of sediment from stormwater runoff through a porous media such as sand, a fibrous root system, or a man-made filter.

infiltration: The vertical movement of stormwater runoff through soil, recharging groundwater.

treatment: Processes that utilize phytoremediation or bacterial colonies to metabolize contaminants in stormwater runoff.

Source: University of Arkansas Community Design Center (2020)

Retention ponds

Stormwater in treatment ponds in Denmark contained 0.5-22.9 items/litre (about 0.085-1.143 µg/litre; particle size 10-2,000 µm). The lowest microplastics concentrations were measured in ponds collecting stormwater from highways and residential areas. The highest concentrations were associated with industrial and commercial areas. Key plastic polymers included polyvinyl chloride (larger microplastics), polypropylene, polyethylene, polyethylene terephthalate and polystyrene.

Infiltration basins

The infiltration basin is another commonly used sedimentation technique which receives stormwater run-off and contains it until the water infiltrates the soils. Accumulated sediments (containing microplastics) must be removed frequently from the basin bottom to avoid clogging of the surface soils, which will make basin cease to operate as designed.

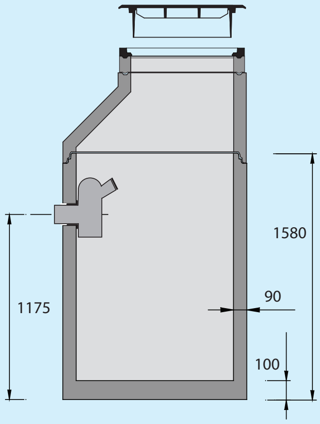
Gully pots

These sustainable urban drainage systems are used extensively to remove from road run-off water microdebris, i.e. sediments such as microplastics that would otherwise enter drains and sewer systems. In the city of Oslo, Norway, there are about 30,000 gully pots.

Other solutions

Additional measures to reduce contamination of run-off with microplastics include:

- Improving urban cleaning services to avoid accumulation of plastic waste in drains;
- Installing meshes, booms or separators on drains to retain and remove microplastics and plastic waste separately.



Source: Norwegian Water Institute (2020)

Typical design of a Norwegian roadside gully pot. The minimum inner diameter is 1,000 mm.

Opportunities and barriers

Opportunities	Barriers
• It is not clear how effective currently employed run-off treatment technologies are in retaining/removing microplastics. • A gully pot is a quick, easy to install and reusable structure used to reduce or remove microplastics from road run-off.	• There is a need to define relevant standards for tyre quality, as well as guidelines to evaluate and approve tyre design and products before marketing.

C

Domestic and Industrial Wastewater, Sewage Sludge, and Landfill Leachate Treatment Technologies

Refer to the Annex for diagrams showing microplastics removal during typical treatment in western countries, China and Canada.

1. Preliminary treatment for plastics removal

Objective: Reduce waste particles (including plastics) in incoming wastewater before further treatment

Costs

Investment		**Annual operation and maintenance**
Acquisition costs per m^2 for total screen area are typically between USD 1,500 (£1,200) for the larger screen and USD 1,980-2,240 (£1,550-£1,750) for the smaller one. Full construction costs (design, fabrication and installation) are USD 44,000-190,000 (£35,000-150,000) in the United Kingdom.		For manual clean-up, annual O&M costs are USD 1,860-8,930 (£1,460-£7,000). For mechanical cleaning, annual O&M costs are USD 2,170-9,700 (£1,700-£7,600).
Durability	**Maturity**	**Policy support need**
Screens will last 10+ years when proper maintenance is adopted by cleaning clog debris off the screen regularly.	5	3

The costs of screen units used for plastics removal in the WWTP vary depending on the type of technology used and its applicability in diverse situations.

Description

Before wastewater enters any plant for treatment, it must flow through a debris removal structure which removes large floating debris, sticks or rags in order to protect the WWTP (including mechanical equipment and piping) from blockage and/or damage. Screens are a structural unit made of parallel bars or rods that can have a circular or rectangular opening. The screening process separates debris in and/or on water, which may include plastics, from entering the WWTP. Screens are generally placed so they incline towards the flow of the wastewater in inflow channels. Screening units are categorized, based on the opening size, as coarse screens (bar screens) or fine screens.

Implementation

The size of a screening unit refers to the size range of the particles it removes. Coarse screens remove large plastics from wastewater and are typically made of woven wire cloth with openings of 6-20 mm or larger. Bar racks (or bar screens) and coarse woven-wire screens are common types of coarse screens. Some modern wastewater treatment plants use both coarse screens and fine screens. Fine screens with as low as 0.2-1.5 mm openings are placed after coarse screens to remove smaller particles. Design considerations for screens include the depth and width of the channel; the approach velocity of the wastewater; the discharge height and screen angle; wind; aesthetic considerations; redundancy; and head loss.

Example

Source: Bradley, Richards and Bahner (2005)

Opportunities and barriers

Opportunities	Barriers
• Preliminary treatment is very well known and well mastered in many countries. • Cleaning of accumulated waste on screens can be carried out both manually and mechanically. • Mechanically cleaned screens tend to have lower labour costs than manually cleaned ones. A major advantage of using manually cleaned screens is that they require little or no equipment maintenance, although they do require frequent raking to avoid clogging and high backwater levels in order to avoid build-up of waste. The greater raking frequency increases labour costs.	• Removal of the screen mat during manual cleaning may cause flow surges. This can reduce the solids capture efficiency of downstream units, whereas mechanically cleaned screens are not subject to these problems but have high equipment maintenance costs. • WWTPs that utilize mechanically cleaned screens should have a standby screen to put in operation when the primary screening device is out of service. This is standard design practice for most newly designed plants. • Note that plastic waste is not totally removed during preliminary treatment, leaving materials such as cotton swabs in the wastewater treated subsequently.

2. Primary treatment, for plastics and microplastics removal

Objective: Remove grit (sand, silt and other heavy particles), suspended solids (including microplastics), oils, volatile organic compounds (VOCs), heavy metals and phosphorus in wastewater

Costs

Investment	**Annual operation and maintenance**
USD 3-40 per capita in developing countries. Investment costs include engineering (10-15 per cent of the total). They are also determined by the level of automation needed for the treating system.	USD 0.1-2 per capita in developing countries. Note: Primary treatment alone is not sufficient to meet quality standards for treated wastewater effluents.

Reduction of microplastics	**Maturity**	**Policy support need**
-42 to -82 per cent in general. It may be higher in northern plants. For example, in plants in the United States it reaches -78 to -95 per cent. This higher treatment performance is due to the advanced and effective treatment units implemented in these countries.	5	1 Wastewater treatment standards have been defined globally, and conventional systems are able to remove a large percentage of microplastics.

Description of the primary treatment

Influent wastewater concentration: 1 to 18,285 particles per litre

Sequence of processes and objectives (relevance)	1. Fine screening with metal grids to remove fine debris, i.e. less than 6-10 mm in size 2. Grit removal to remove sand, silt and other heavy particles 3. Skimming tank for grease, oil and fat removal 4. Coagulation and flocculation to create large flocs of heavy metals and phosphorus 5. Primary sedimentation to remove particulate matter and flocs 6. Flotation to remove floating materials and volatile organic compounds (VOCs) (e.g. those which are strong smelling) and grease
Performance achieved	• Microplastics: 42-82 per cent (higher in plants in the United States, for example, where it reaches 78 to 95 per cent) • BOD: typically 20-30 per cent • SS: typically 60-98 per cent • Phosphorus: typically 60-95 per cent • Other pollutants, including heavy metals (based on design target)
Microplastics during the process	The major part of microplastics removal occurs during this step through: • Skimming of grease for floating microplastics • Filtration and gravity settling processes for heavier microplastics or those trapped in flocs.

Examples

Process in use	Country	Microplastics removal[6] (per cent)	Inlet concentrations (particles per litre)	Outlet concentrations (particles per litre)
Screening, grit removal, skimming and primary sedimentation	Various	78	-	-
Screening, grit removal, pre-aeration and sedimentation	Finland	82^{m}	567.8	11.7
		~ 55-60^{n}	430.0	290.7
		99^{n}	57.6	0.6 per litre
Screening, aerated grit removal chamber	China	21-30^{n}, 3^{m}	0.28 (or 5.60 mg/litre)	0.22 (or 5.43 mg/litre)
Screening, rotary grit removal chamber		-371,^{n} 1^{m}	0.28 (or 5.6 mg/litre)	1.32 (or 5.54 mg/litre)
Screening, grit removal and primary sedimentation		41.7^{n}	2.06	1.2
Screening, flocculation and sedimentation		78.2^{n}	1.01	0.22

Opportunities and barriers

Opportunities	Barriers
• This process stage removes the largest amounts of microplastics from wastewater. Overall removal of microplastics during treatment is mainly determined by the performance achieved during this stage. • It is easier to maximize microplastics removal during this stage than during subsequent ones (i.e. secondary or tertiary treatments).	• Advanced primary treatment which removes more microplastics is adopted in developed countries. It involves use of chemicals for coagulation and flocculation, making it expensive to adopt by developing countries.

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[6] Removal efficiency can be obtained on a percent mass basis or a percent number basis. To differentiate the two cases, ^{m} is for removal efficiency basis based on the mass concentration and ^{n} is for removal efficiency based on the item number concentration.

3. Secondary treatment, for microplastics removal

Objective: Remove biologically and physically suspended particles, dissolved nutrients (mainly nitrogen, possibly phosphorous), and suspended, colloidal and dissolved organic material as well as microplastics in wastewater

Costs

Investment	**Annual operation and maintenance:**
Complete chain (sewer + primary + secondary treatments):	
Costs including engineering, design, installation and start-up, per m^3/day in capacity in the United States are USD 399-9,246, with an average of USD 3,308 (or USD 1,324 per capita) (2017). Other costs reported earlier were USD 1,300-11,900 (2014).	O&M costs per m^3/day: USD 29-1,321, with an average of USD 437 (2017) in the United States (or USD 175 per capita) Between 4 per cent (percentage lower for larger plants) and 25 per cent of investment costs (13 per cent on average) O&M costs in Jaén, Spain are USD 124 per m^3/day treated
Secondary treatment process only:	
USD 10-150 per capita in developing countries (excluding sewer cost)	USD 0.2-8 per capita in developing countries
Secondary treatment plant only (no sewer; primary + secondary treatments): Costs depend on various parameters such as the type of process implemented, the treatment level required, the level of automation of the plant, etc. Typically: • In the United States, averaged total costs (capital + O&M): USD 1,295 per m^3/day treated, or USD 518 per capita. • Another source reports costs between USD 880-2,650 per m^3/day treated (or USD 352-1,060 per capita) for the United States. • Investment in the United States: USD 4,400 per m^3/day treated for an aerobic fixed-bed bioreactor wastewater treatment system; similar for membrane bioreactors; -20 per cent in the case of a moving bed bioreactor. Respectively, annual O&M costs per m^3/day treated are: USD 485, +25 per cent, +100 per cent. • Investment in the United States: USD 5,300-7,100 per m^3/day treated for an anaerobic wastewater treatment system; annual O&M per m^3/day treated: USD 288-387 per m^3. • In Iran, investment is USD 2,600-3,000 (or USD 484-550 per capita) for a wastewater treatment system using either activated sludge, extended aeration activated sludge, or sequencing batch reactor. Annual O&M costs are USD 111-147 per m^3/day capacity.	

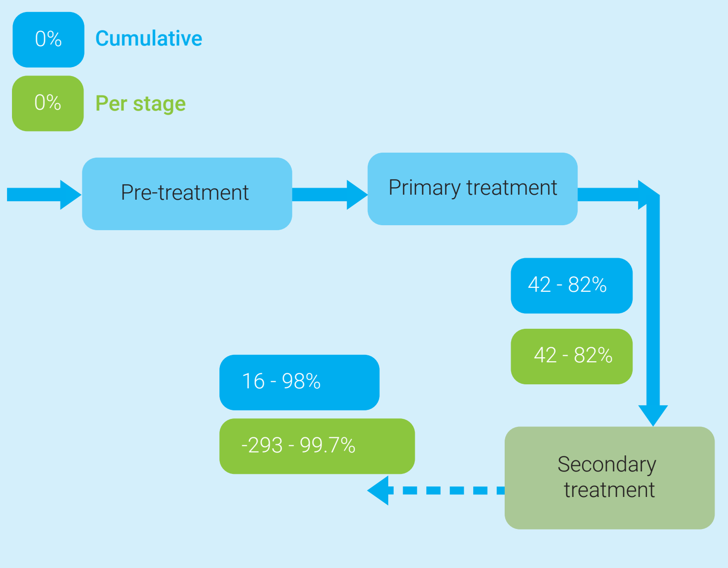
Note: The costs include those of sludge management.

Land requirement	**Reduction of microplastics**	**Maturity**	**Policy support need**
0.2 m^2 per m^3 for conventional activated sludge	-5 to -20 per cent	5	2-3 Wastewater treatment standards have been defined globally, and conventional systems must treat at least up to secondary level. However, enforcement of policies remains weak in many countries.

Description of the secondary treatment

Sequence of processes and objectives	Secondary treatment is preceded by primary treatment. Its main objective is to achieve biological and physical treatment by removing, in aerobic, anoxic or anaerobic bioreactors, dissolved nutrients (mainly nitrogen [N], possibly phosphorous [P]), suspended and dissolved organic material and colloidal material. Processes involved at this stage are: • Suspended growth biological treatment (including activated sludge and its variants such as oxidation ditch or A2O) • Attached growth biological treatment (including, for example, trickling filters, rotating biological contactors) • Combined growth biological treatment • Membrane bioreactors Secondary treatment is followed by secondary sedimentation (except in the case of membrane bioreactors).
Performance achieved	• Typically, 85-95 per cent removal for BOD and total suspended solids (TSS) • Removal efficiencies for microplastics in WWTPs: - in Europe and North America: 86 per cent and 99.8 per cent[n] - in other countries such as China: typically 64 per cent
Microplastics during treatment	Exact removal mechanisms are mostly unknown. Sludge flocs and microbial secretions could help with the accumulation and removal of microplastics in sludge, especially when contact time is high. Microplastics may also be ingested by protozoans and metazoans.

- In the United States the secondary treatment process adds typically 5-20 per cent extra removal compared with primary treatment only.
- When removal of microplastics is poor during secondary treatment, it is often because it is not coupled with an effective biomass separation process. In these cases, notable microplastics removal is achieved during the tertiary filtration.
- After most secondary treatments, plastic particles more than 0.5 mm in diameter are removed almost totally.
- Secondary treatment is similar to or better than tertiary treatment in removing microplastics.
- Subsequent disinfection does not much affect microplastics removal.



Key parameters impacting treatment performance during implementation

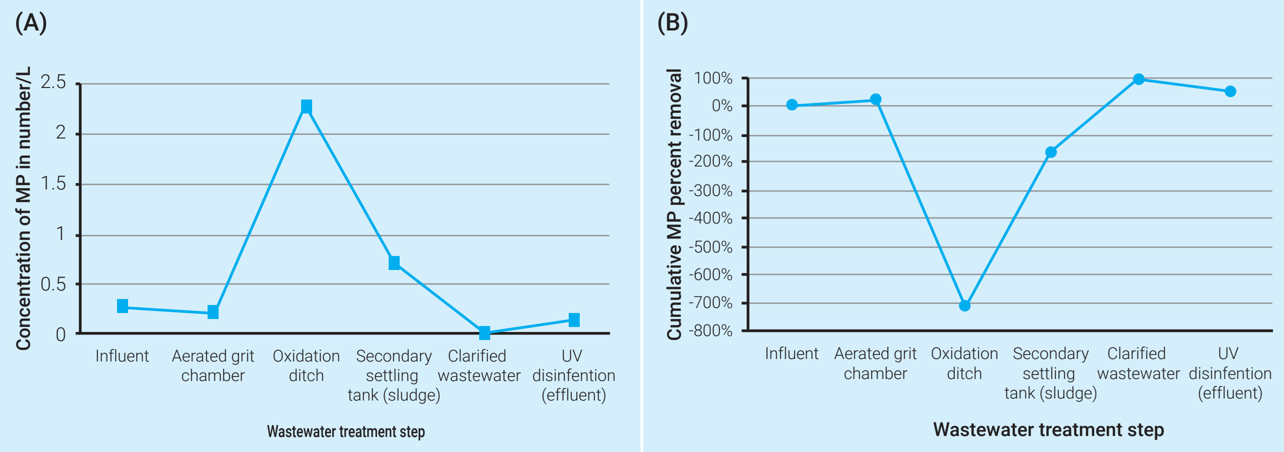
1. Population size and preferences
2. Sewers combined with run-off or not
3. Climate
4. Type of treatment process
5. Microplastics shape and size

Examples

Secondary treatment variant	Country	Microplastics removal[8] during process [cumulated with primary treatment]	Inlet concentrations (microplastics/litre)	Outlet concentrations (microplastics/ litre)
Membrane bioreactor	Finland	99.4 or 99.7 per cent	0.6	0.004
Activated sludge		88 per cent of microlitter (ML)[a] [99.98 per cent][m]	11.7	1.4
		~ 75 per cent [90.2-92.4 per cent][m]	290.7	68.6
		around -66 per cent [n] [98 per cent]	0.6	1.0
	Turkey	[74 per cent][n]	26,555	6,999
		[79 per cent][n]	23,444	4,111
	China	77.5 per cent [86.9 per cent][n]	1.2	0.27
Oxidation ditch		95 per cent [96 per cent]n or 76.5 per cent [96 per cent][m]	0.22 (or 5.43 mg/litre)	0.01 (or 0.22 mg/ litre)
A2O process		17 per cent [-293 per cent]n or 15 per cent [16 per cent][m]	1.32 (or 5.54 mg/litre)	1.1 (or 4.70 mg/ litre)
7 WWTPs		[90.5 per cent][n]	[6.55]	0.59

a Microlitter (ML) is a mix of microparticles, mainly plastics, but could also include glass, metals, rubber, wood, paper, textile, such as cotton fabric.

Profile of microplastic concentrations (A) and cumulative microplastics removal efficiency (B) during treatment in a typical WWTP in China



Source: Lv *et al.* (2019)

Remark: In this case, the aerated grit chamber is the primary treatment; the oxidation ditch and secondary settling tank constitute the secondary treatment; and finally disinfection is achieved using ultraviolet (UV) radiation.

Conclusion: Microplastics removal within a wastewater treatment plant is a complex process which is not determined by one single process step. Each stage of the wastewater treatment process targets different contaminants, and therefore interactions could be noted.

Opportunities and barriers

Opportunities	Barriers
• All secondary wastewater treatment plants are able to achieve notable removal of microplastics. Among those currently studied in North America and Europe, estimated daily discharges through treated wastewater for a conventional WWTP remain about 10-60 grams of microplastics per day, depending mostly on the total volume of treated wastewater. • During the treatment process microfibres are removed well from the wastewater. However, microbeads and small microfibres could still be released in the treated effluent.	• In many countries sewers may not exist or may provide limited coverage. • Current wastewater treatment plants are not designed with optimization of microplastics removal during the process in mind.

Gaps

- Microplastics removal performance remains uncertain for several wastewater treatment processes, such as waste stabilization ponds and up-flow anaerobic sludge blanket (UASB).
- It is unclear which secondary processes are most effective.
- Possible effects of microplastics on human health and possible gender dimensions remain to be investigated. This will be essential to define the optimal treatment targets.

4. Tertiary filtration, for microplastics removal

Objective: Ensure final effluent meets the required quality standard, and potentially remove microplastics in wastewater.

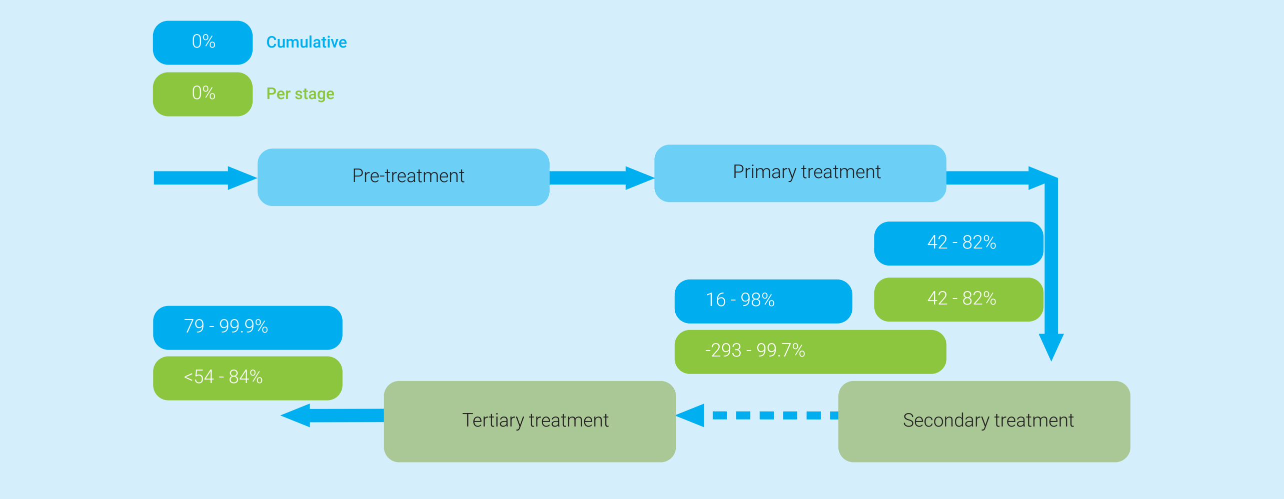
Costs

Investment Not available for developing countries	**Annual operation and maintenance:** 1-33 per cent of investment costs (10 per cent on average) In the United States, O&M costs per m^3/day are USD 76-21,804 with an average of USD 6,168 (2017) (or USD 2,768 per capita).
Complete chain (sewer + primary + secondary + tertiary). Costs per m^3/d in the United States: • USD 984-144,224 with an average of USD 57,534 (2017) in the case of conventional tertiary treatment processes • USD 379-11,016 with an average of USD 3,441 (2017) in the case of wetlands	
Single tertiary treatment process: • Average total costs (capital + O&M): USD 1,717 per m^3/day treated, or USD 687 per capita. • In the case of wetlands as tertiary treatment, capital + O&M costs average USD 159 per m^3/day, or USD 64 per capita.	

Reduction of microplastics	**Maturity**	**Policy support need**
Usually, -1 to -5 per cent The incremental benefit achieved with tertiary treatment is not financially justified when considering microplastics only. However, tertiary treatment aids in removing other pollutants and therefore may still be essential for adequate treatment of some wastewaters.	4-5	4

Description of tertiary treatment

Sequence of processes and objectives	Tertiary treatment processes are selected to ensure the final effluent meats the required quality standards. It is not always absolutely essential. However, tertiary treatment is used to ensure adequate nutrient removal as well as removal of heavy metals (if not removed earlier). • Wetland (low-cost) • Membrane bioreactor (carries out secondary and tertiary treatment simultaneously) • Membrane filtration • Slow sand filtration • Adsorption • Gas stripping • Ion exchange • Advanced oxidation
Performance achieved	Typically, 90 per cent N removal
Fate of microplastics during the treatment process	The concentration of microplastics in item number per litre may increase during the process while the concentration in mass per litre may be reduced.



Examples

Process variant	Country	Microplastics removal [7] [cumulated with preceding treatments]	Inlet concentrations (microplastics per litre)	Outlet concentrations (microplastics per litre)	Impact on microplastics removal
Biological aerated filter (BAF)[a]	Finland	Up to 53.8 per cent [99.9 per cent]	1.4 (range: 1-2)	2.5 (range: 0.7-3.5)	Removal is occasionally negative, leading to an increase in microlitter release. This could in part be due to a buffer effect in the filter.
		85 per cent[a] [98.6-98.9 per cent]	13.8 (microfibres) 68.6 (other microplastics)	4.9 (microfibres) 8.6 (other microplastics)	Microfibre removal rate is less than removal rate of other types of microplastics.
Membrane filtration	China	95 per cent [79 per cent][n] 83.5 per cent [99.5 per cent][m]	1.1 (or 4.70 mg/litre)	0.06 (or 0.03 mg/litre)	Concentration in the membrane sludge is 4/litre (or 4.54 mg/litre).

[a] Assuming that up to 85 per cent of the inflow goes out after the primary treatment.

Opportunities and barriers

Opportunities	Barriers
• Wastewater treatment plants which provide tertiary treatment are able to remove 95-99.9 per cent of the microplastics in raw wastewater. However, this does not indicate that the tertiary treatment stage itself is beneficial with respect to the removal of microplastics in wastewater. In fact, the impact of tertiary treatment seems to be inconsistent from one study to another. • Tertiary treatment my contribute to better quality of treated water and enable water reuse.	• While in some cases WWTPs with tertiary treatment performed better than those ending after secondary treatment, it was noted in other cases that tertiary treatment led to an increase in the concentration of microplastics, expressed as number per litre. As many authors do not report the concentration of microplastics in mass, it is difficult to confirm whether the same trend will be maintained on a mass basis. • Tertiary treatment is usually expensive to implement.

Possible effects of microplastics on human health and possible gender dimensions remain to be investigated. This will be essential to define the optimal treatment targets and to define when implementing tertiary treatment might or not be essential to treat microplastics.

5. Incineration or co-incineration of sludge

Objective: Prevent recontamination of land with microplastics in sewage sludge

Costs

Investment Costs are part of wastewater treatment costs.		**Annual operation and maintenance** Costs are part of wastewater treatment costs.
Profitability Not applicable	**Maturity** 4-5	**Policy support need** 3-4

Costs of sludge incineration are hardly accounted for separately from those of the rest of the wastewater treatment plant.

Description

In Europe and North America, 110,000-730,000 metric tons of microplastics are added on an annual basis to agricultural soils via land application. This means the current burden of microplastics in soils is greater than the current burden of microplastics in oceans.

Implementation

Land application is the main post-treatment process applied to stabilized sludge. However, it increases the microplastics content of soils. Microplastics can be found in soils even five to 15 years after the last land application of sludge. Incineration of sludge totally removes the microplastics. However, the process is often not cost-effective, especially when volumes generated are "low". Whenever applicable, co-incineration with other wastes or within cement kilns can be a cost-effective way to manage sewage sludge. Microplastics may still be found in the ash of incinerators.

Concentrations of microplastics in sludge from various origins

Sludge volume and content in microplastics vary widely with the biological wastewater treatment processes used. For example, anaerobic/aerobic (A/O) processes and their variants yield higher microplastic concentrations in sludge than oxidation ditch and sequencing batch reactor (due to retention time or settling efficiencies). The average size of microplastics in sludge is larger than in the initial wastewater, showing that the sludge mainly concentrates large microplastics.

Origin of sludge within a WWTP	Concentrations of microplastics (wet or dry weight [DW])	Description
Primary sludge (from primary clarifier)	14.9 microplastics/gram	Sludge includes 65 per cent microfibres and 34 per cent microplastic fragments. Foam and pellets are present in negligible proportions.
Activated sludge (from secondary clarifier)	23.0 microplastics /gram DW	-
	113 microplastics/gram DW	Sludge generation is 0.075 gram DW/litre of treated wastewater. It contains 47 per cent as microfibres.
	4.4 microplastics/gram	Sludge includes 82 per cent microfibres and 10 per cent microplastic fragments.
A2O sludge (from secondary clarifier)	14.9 microplastics/gram	Sludge generation is 0.99 grams/litre of treated wastewater.
	240.3 microplastics/gram DW	Average microplastics size in sludge is 223 µm. Microfibres (33-57 per cent) and fragments (30-46 per cent) dominate in the sludge.
Sequential batch reactor sludge	9.7 microplastics/gram	Sludge generation is 0.76 g/litre of treated wastewater.
Media-based process	13,2 microplastics/gram	Sludge generation is 0.51 gram/litre of treated wastewater.
Digested sludge	170.9 microplastics/gram DW	-
Membrane bioreactor (MBR) sludge	27.3 microplastics/gram DW	-
Lagoon sediments	3.4-18.0 (average: 8.0 ± 6.8) microplastics/gram DW	Microfibres make up 82, 89 and 91 per cent of microplastics in the sludge at the three processing sites.

Examples in sludge treatment

Traditionally, the main aim of sludge treatment is to stabilize the sludge to enable its disposal.

A key step in sludge treatment is dewatering to reduce the water level in the sludge. The dewatering method selected affects the concentration of microplastics found in the final sludge. During centrifugation part of the low-density microplastics remains in the liquid, leading to moderate concentrations of microplastics in dewatered sludge. However, filter pressure and belt-type dewatering produce dewatered sludge with a high concentration of microplastics (energy consumption: 10-60 kWh per metric ton of total solids).

Mechanical erosion and sedimentation contribute to lowering the average particle size of microplastics in sludge. Typically, following sludge treatment, 95 per cent of microplastics in raw sludge are retained in the final sludge. The impact of drying beds, which are common in hot countries, is uncertain. How drying beds affect content of microplastics in dewatered sludge is still unknown.

Main characteristics of the sludge dewatering process

Characteristics	Drying bed	Belt press	Centrifuge
Land requirements	+++	+	+
Energy requirements	-	++	++
Implementation cost	+	++	+++
Operational complexity	+	++	+++
Maintenance requirements	+	+++	++
Complexity of installation	+	++	++
Influence of climate	+++	+	+
Sensitivity to sludge quality	+	++	+++
Sensitivity to type of sludge	++	++	+
Chemical product requirement	+	+++	+++
Dewatered sludge removal complexity	++	++	+
Level of dryness	+++	++	++
Odours and vectors	++	+	+
Noise and vibration	-	++	+++

Opportunities and barriers

Opportunities	Barriers
• Overall, removal of microplastics from wastewater can attain 99 per cent within a wastewater treatment plant. Typically, microfibres typically represent 63-80 per cent of microplastics in sludge.	• The removal of microplastics in wastewater is simply a phase transfer of the microplastics from the liquid to the sludge. Inadequate management of the sludge could therefore lead to recontamination of soils and water.

Incineration plants result in health and environmental impacts, which can be serious especially to communities surrounding them. Therefore, wider gendered societal impacts should be considered in the decision of implementing this process. Key questions to be addressed include:

- How far should the incineration plant be built from communities?
- What are the gendered impacts on the populace and what safeguards might be put in place so as to "do no harm"?
- How much air pollution arises from these plants affecting workers, and what are the differentiated impacts on women, men, girls and boys in communities in the area?

6. Industrial wastewater treatment

Objective: Remove microplastics and other contaminants from industrial wastewater effluent

Costs

Investment Variable	**Annual operation and maintenance** Variable. Depending on how their treated wastewater is disposed of, the required treatment level required may vary.	
Profitability Not applicable	**Maturity** 4	**Policy support need** 3-4

Description

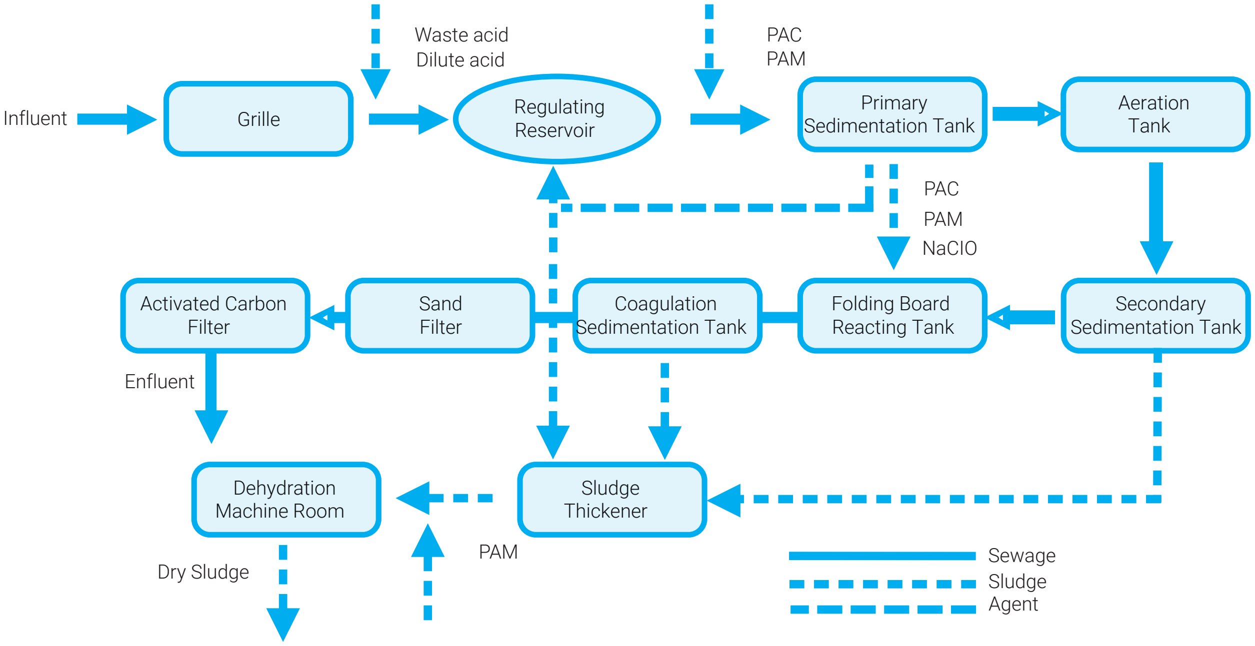
The water requirement for textile manufacturing is 0.1-0.2 m^3 of water per kg of textile product. Most of the water will become contaminated by microfibres as a result of the processes involved in textile manufacturing.

To date, the treatment objective for this type of industrial wastewater effluent remains to remove organic pollution and chromaticity, in order to meet quality standards for release into the environment or municipal sewers. Nevertheless, the efficiency of microfibre removal could exceed 95 per cent The treatment is affected by the type of filaments present in the wastewater being treated.

Example: Details of a typical treatment process in China

Influent concentration: 300 particles per litre

This wastewater treatment plant treats 30,000 metric tons/day of wastewater, with 95 per cent in volume coming from 33 printing and dyeing enterprises while the remaining 5 per cent is domestic wastewater from residential areas.



Source: Xu *et al.* (2018)

Poly-aluminium chloride (PAC) and Polyacrylamide (PAM)

Note: investment, operation and maintenance costs are borne by the private industry operating the plant and are not publicly available.

How removal of microfibres is achieved

	Influent quality	Removal efficiency for each step	Screening + grit separation + primary sedimentation (per cent)	Aeration + secondary sedimentation (per cent)	Coagulation + sand filter + activated carbon filter (per cent)
Microfibres	10.0 10^9 per day [a]	Cumulative	76^n	84^n	95^n
		Individual process	76^n	32^n	70^n
Chroma	342.0	Cumulative	-82	46	85
		Individual process	-82	70	72
COD	283.4 mg/litre	Cumulative	36	73	91
		Individual process	36	58	68
NH_3-N	3.9 mg/litre	Cumulative	28	43	68
		Individual process	28	20	44
SS	207.8 mg/litre	Cumulative	74	93	99
		Individual process	74	73	84
TP	0.3 mg/litre	Cumulative	24	49	77
		Individual process	24	33	56

[a] More than 80 per cent of microfibres were larger than 0.03 mm in diameter, with the majority between 0.1 and 1 mm; 60 per cent of the microfibres were microplastics while the remainder were composed of natural fibres.

Note: in this particular case sludge quality was not analysed.

Opportunities and barriers

Opportunities	Barriers
• Industrial wastewater treatment is usually considered a must. However, contaminants targeted for removal during the treatment do not yet include microplastics, which are treated and removed as suspended solids. • Removal of microfibres is mostly achieved in membrane-based processes such as membrane bioreactors or reverse osmosis technologies. Air flotation appears to be suitable for removal of low-density microfibres.	• There is some uncertainty about how the plant's treatment performance is affected by the various pigmented microfibres. • The human dimension comes in because of the differentiated health impacts arising for women and men, thus calling for the introduction of safeguards which so far remain inexistent.

7. Landfill leachate treatment

Objective: Remove microplastics and other pollutants from leachate

Costs

Investment • India: USD 10,000-73,000 per m^3/day of treatment capacity	**Annual operation and maintenance** • United States: USD 9.3 per m^3 of leachate or USD 3,240 per m^3/day • India: - USD 4.0 per m^3 of leachate or USD 1,460 per m^3/day - 2-7 per cent of the capital cost.	
Profitability Not applicable	**Maturity** 4-5	**Policy support need** 4-5

Description

It has been estimated that 79 per cent of the plastic waste ever produced has been stored in landfills. The decomposition rates of various plastics in landfills are not fully known. However, it is understood that plastics in landfills are exposed to severe environmental conditions (e.g. in terms of temperature and pressure), which are likely to influence their behaviour and fragmentation rates.

Some authors state that most microplastics will remain trapped in the landfill under normal conditions. However, practices such as landfill mining would enable the microplastics to be reintroduced to the environment. In addition, microplastics (fragmented plastics) could contaminate the landfill leachate.

Influent concentration: 0.42-24.58 particles per litre.

Example: Composition of landfill leachate in China

Landfill leachate generation in China is estimated at 1.3-3.2 m^3 per metric ton of waste, occurring over a 100-year period. In Finland, by comparison, landfill leachate generation is 1.4 m^3 per metric ton of waste. Leachate volume generation depends on various factors, such as the design of the landfill and the climate. The typical composition of landfill leachate is presented in the following table:

Six landfills in China	Operation time	Storage capacity in million metric tons (MT)	pH	COD (mg/litre)	Five-day biological oxygen demand (BOD_5) (mg/litre)	Dissolved N (mg/litre)	Average microplastic concentrations (items per litre)
Shanghai 1	2013 to date	6.9	7.8	3,052	132	1,760	11.8
Shanghai 2	2010-2016	3.8	8.0	1,905	295	1,757	1.3
Shanghai 3	1989-2014	0.23	7.7	880	36	1,217	1.0
Wuxi	2008 to date	4.23	7.9	12,220	2,371	3,711	0.7
Suzhou	1993 to date	13	7.9	3,960	1,520	2,199	3.0
Changzhou	2003 to date	3	8.0	9,815	2,493	4,106	2.9

In the leachate, 17 different types of plastic materials were identified. Polyethylene and polypropylene represented 99 per cent of the plastics. In terms of their shapes, the authors identified pellets (59 per cent), fragments (23 per cent) and fibres (15 per cent); in terms of size, 77.5 per cent of microplastics were 0.1 to 1 mm of size.

Opportunities and barriers

In some countries poor communities' livelihoods depend upon landfills, where gender differentiated roles are found among landfill pickers. There is also a certain level of discontent between landfill operators (largely men) and informal pickers, for example, over illegal fires the pickers start on landfills to keep warm, which pose safety hazards. On the other hand, with respect to microplastics capture during the treatment process, the performance of currently used treatment systems for landfill leachate is not yet available. However, it is likely that they are able to remove microplastics given the types of processes typically involved.

D

Technologies to Treat Receiving Waters Downstream of Discharging Points

1. Wetlands

Objective: Reduce plastics and microplastics in run-off or secondary treated wastewater

Costs

Investment	**Annual operation and maintenance**
Wetlands (including upstream systems) cost: USD 379-11,016 with an average of USD 3,441 (2017) (or USD 1,377 per capita). Costs can vary greatly, depending upon initial site conditions. Earthworks costs are USD 2.5-15 per m^2 (the higher the wetland surface, the lower the rate) while planting costs USD 3.00-5.00 per transplant. These parameters typically represent 35-50 per cent and 11-17 per cent of total construction costs, respectively.	Typically, USD 0.35-0.99 per m^2 each year. This is equivalent to up to USD 40-400 per m^3/day treated for the entire system.
Capital + O&M costs average USD 159 per m^3/day of treatment capacity in the United States. Normally, wetlands have indefinite lifespans and are expected to be permanent landscape.	

Stormwater treatment – wetlands only

Description	Cost (USD/m^2)
Total	6.2-12.4
Design, engineering	2.0-3.7
Retrofit grading	1.2-3.7
Aquatic plants	2.5-4.9
Spillway/drawdown structure	2.5-3.7

Land requirement	**Profitability**	**Maturity**	**Policy support need**
10-40 m^2 per m^3/day	The opportunity cost of any land removed from agricultural production is not negligible. It could represent 50-70 per cent of total implementation costs. Other expensive components of constructed wetlands are site planning and design, excavation activities, and the control structures required.	4	3

Wetlands are generally classified as low-cost technologies, which could satisfy constraints in developing countries. However, as in the case of all extensive processes, the land requirement is high.

Description

Wetlands are widely used around the world as treatment systems for bioremediation to capture and remove a wide range of pollutants and nutrients. However, their capacity to reduce microplastics has not been much studied.

Wetlands are known for their ability to improve water quality through natural processes involving wetland vegetation, soils, and their associated microbial assemblages to filter water as it passes through the system. For conventional contaminants, the removal mechanism is primarily through transformation and uptake by microbes and plants, as well as assimilation and absorption into organic and inorganic sediments. The plants and microbes absorb nutrients and break down contaminants through biological processes (biodegradation).

Treatment wetlands (both natural and constructed wetlands) can be considered an end-of-pipe solution to reduce the volume of microplastics entering streams, rivers and oceans, while floating wetlands provide an ongoing treatment process for freshwater systems.

Implementation

There are different types of wetlands.

Floating treatment wetlands (FWs) are small, artificial platforms that allow plants to grow on floating mats in open waters where their roots spread through the mats and down into the water, creating dense columns of roots with lots of surface area. By reducing turbulence and mixing by wind and waves, the mats also allow sediment to settle.

Similarly to a constructed wetland, nutrients and other pollutants are gradually incorporated into the biomass and thus withdrawn from the aquatic ecosystem. While the plants take up nutrients and contaminants, the plant roots and the FW's materials provide extensive surface area for microbes to grow, forming a slimy layer of biofilm. The biofilm is where the majority of nutrient uptake and contaminants degradation occurs in a FW system. The shelter provided by the floating mat also allows sediment and elements to settle by reducing turbulence and mixing by wind and waves.

Constructed wetlands (CWs) are engineered and managed wetland systems designed to mimic natural wetlands. A constructed wetland is scaled according to its treatment drainage area. The wetland/watershed area ratio typically ranges between 0.5 and 2 per cent. In addition, maximum wetland depth is typically less than 3 metres while depth at the edge will vary throughout the year with water level.

Compared with conventional treatment plants, CWs are a cost-effective and technically feasible approach for treating polluted water. They are easily operated and maintained, with the potential to become a good alternative to conventional treatment technologies.

Examples

Wetlands appear able to remove high levels of microplastics, as reported by one study.

Facility	Örsundsbro wetland, Sweden	Alhagen wetland, Sweden
Area (ha)	0.8	28
Mean flow (m^3/day)	667	5,100
Theoretical residence time (day)	3.5	86
Reduction efficiency: microplastics 20-30 µm (per cent)	99.7	99.8
Reduction efficiency: microplastics > 300 µm (per cent)	100	100

To treat stormwater, 90th percentile stormwater must be allowed at least two days' residence time. A sediment removal structure may be implemented before the wetland to better control sediment and prevent excessive accumulation.

Opportunities and barriers

Opportunities	Barriers
• Current findings highlight that CWs can remove small and rather large microplastics. • The long-term effectiveness of CWs is not well known. Effects of wetland aging may jeopardize treatment performance. • Temperature and flow fluctuations can cause a wetland to display inconsistent contaminant removal rates.	• Only a few studies attempted to assess the performance of wetlands regarding microplastics removal. • Sediment in wetlands may have higher microplastics concentrations than water being treated. Occasionally, water may be enriched in microplastics as it passes through the wetland.

2. Treatment of drinking water

Objective: Remove pollutants, including microplastics, to reduce human exposure

Costs

Investment Variable, depending on source of water used		**Annual operation and maintenance** In the United States, USD 548 per m^3/d (or 1.5 per m^3 of water treated)
Profitability Usually operated on a cost-recovery basis.	**Maturity** 5	**Policy support need** 1-2

Description

To mitigate health risks associated with human consumption of water contaminated with high levels of microplastics, it is essential to ensure that currently adopted treatment plants are able to remove the microplastics in freshwater to a satisfactory level before it is consumed.

Implementation

Microplastics have been detected in bottled water in several countries. It should be noted that packaging materials are often plastic and are thus a possible origin of microplastics other than the water itself. However, significant amounts of microplastics have been reported in samples from glass bottles or beverage cartons.

Drinking water treatment appears to be able to remove smaller particles better than larger ones. Therefore, when this treatment is combined with wastewater treatment plant, it is possible to prevent humans being exposed to contamination. However, the rest of the environment remains exposed to this contamination.

Drinking water treatment in the Czech Republic

Treatment process	Concentration of microplastics in freshwater (per litre)	Removal of microplastics with size (μm) (per cent)			Overall removal (per cent)
		<10	10–100	>100	
Coagulation + sand filtration	1,473	86	13	1	70
Coagulation + sedimentation, sand filtration and granular activated carbon (GAC) filtration	1,812	92	8	0	81
Coagulation + flotation, sand filtration and GAC filtration	3,605	81	17	1	83

Opportunities and barriers

Opportunities	Barriers
In developing countries drinking water treatment is carried out using simple processes such as, for example, slow sand filtration. Performance with respect to microplastics removal when such treatment systems are used has not yet been investigated. They could also be able to achieve some removal of microplastics.	During drinking water treatment there could be a risk of interaction with other pollutants or with the chemicals used for treatment.

There are a number of gendered health concerns that must be tackled to ensure safe water access to women, youth and children, who are at a higher risk. Beyond microplastics, other plastic-based chemicals such as bisphenol A, potentially found in drinking water, require attention and monitoring.

3. Clean-up boats and sweepers

Objective: Remove waste particles, including plastics, from freshwater (rivers) and downstream

Costs

Investment A typical clean-up boat could have a trash collection capacity between 1.6 and 2.8 m^3. Investment cost not available. Costs of sweepers are variable, depending on structure material. Where applicable, their costs could part of bridge construction costs.	**Annual operation and maintenance** Operational costs of the debris-collector boat could be high due to fuel consumption, while O&M costs of a sweeper are less. Exact figures could not be obtained.

Durability Not available	**Maturity** Boats: 4 Sweepers: 2	**Policy support need** Boats: 3 Sweepers: 4

Description

Freshwater systems are a common pathway by which land-based plastic waste reaches the marine environment, as they connect coastal and inland urban communities to the oceans. Plastics from freshwater compartments all originate from land-based sources, which contribute approximately 80 per cent of plastics in marine environments.

Removal of plastics with a clean-up boat is a technology which is simple and flexible to operate and maintain. Several types of boat are designed to collect plastic pollution from river surfaces. They are positioned in locations ranging from nuclear waste facilities to major municipalities. Clean-up boats function with skimmers or conveyor belts that skim plastics as they move along the water surface.

A sweeper is a cylinder located in front of a pier that rotates with the flow and "sweeps" the plastics away from the pier and into the flow between piers (figure, left). Sweepers are usually polyethylene and float up and down so they can move with the water surface. They are intended to buffer structures from impact and to steer plastics around downstream structures. Sweepers shed plastics, greatly reducing the likelihood of accumulation.

Implementation

Clean-up boats have been successfully deployed in several rivers in the United States. An example is the skimmer baskets boat that cruises the Chicago River collecting plastics from the municipal sewer system. The Interceptor is The Ocean Clean-up's answer to the problem of plastic waste in rivers.

The American Association of State Highway and Transportation Officials (AASHTO) has expressed disparate opinions on the merits of sweepers.

Examples

Garbage collection boat on the Pearl River in Guangzhou, China 	Sweepers attached to a river bridge  Sources: Tyler (2011); Elastec (2020)

Opportunities and barriers

A clean-up boat for removal of plastics is a simple, flexible technology to operate and maintain.

Sweepers may be subject to failures due to clogging. They could be crushed by large plastic objects or dislodged from their mounts. A factor that may contribute to clogging failure is water flow speed; it has been observed that sweepers are not generally effective when flow speeds are low.

4. Seabins

Objective: Removal of waste particles (including plastics) from seawater

Costs

Investment	Annual operation and maintenance
A typical Seabin, with a 20 kg trash load capacity, costs USD 4,000 in the United States.	O&M costs are USD 1,200 per year for an operational mode in which one bin bag is used per day. It includes energy consumption (500 watts).

Profitability and durability	Maturity	Policy support
Recyclable components. The structure is mobile. Typically, the Seabin can be used for five or more years.	2	5

Description

A Seabin has the possibility to intercept mismanaged waste such as macroplastic debris in freshwater bodies before they reach the ocean. Seabins look like floating trash cans but are powered by pumps that pull water from their open tops through a filter bag at the bottom to collect plastic particles. They are designed to be placed in calm waters near a power source (e.g. dock or marina).

Implementation

The Seabin design was piloted and tested at Tutukaka Marina in New Zealand for a 11-month period. It gradually removed human-generated debris that found its way into the marina. Data sheets were used to document the amount of debris collected in a range of different categories (e.g. cigarette butts, plastic food wrappers, clear plastic packaging, foam pieces, fishing gear, plastic bottles). Based on the result analysis, the most notable items removed within this period were 1,468 pieces of unidentified plastic and 517 cigarette butts within.

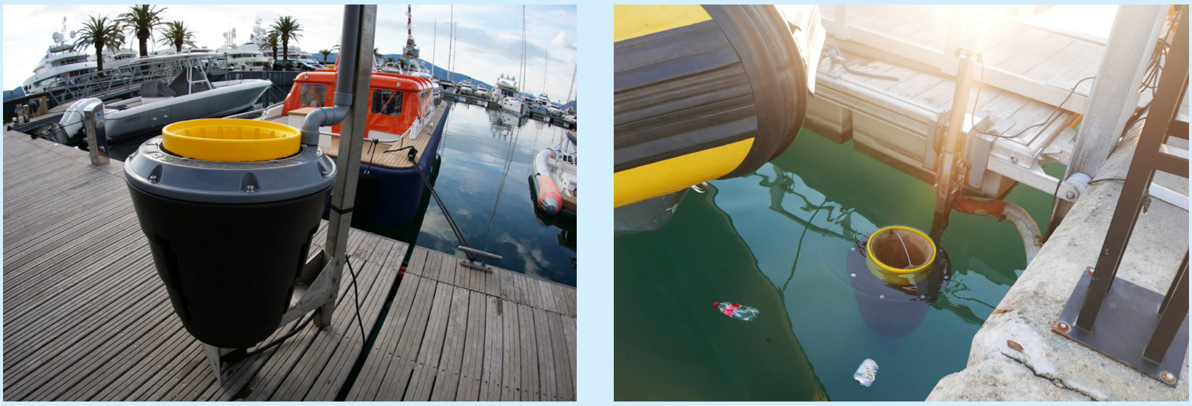
In the United States the Seabin has been highly successful in California, Hawaii Oregon and Texas, demonstrating its potential for deployment along rivers. More Seabins have also recently been implemented at marinas in Perth, Australia, to remove litter within marinas.

Examples

The Seabin Project has developed a floating debris bin device called Seabin V5 (shown in the two figures below). The Seabin V5 acts as a trash skimmer and debris interceptor. It is used to tackle ocean plastic pollution in the water of marinas, ports and yacht clubs.

- Each Seabin is projected to clean about 1.4 tons per year of floating debris (depending on weather and debris volumes).
- The device catch bag has a capacity of 20 kg and can be replaced several times per day.

The Seabin's effectiveness relies on strategic positioning to allow wind and current to bring the debris to where it is located. Specifically, Seabin V5 requires AC power of either 110 or 220 volts. Its power intake is 2.5 amps at 500 watts.



Source: Seabin Project (2020)

Opportunities and barriers

Opportunities	Barriers
• A typical Seabin is estimated to collect up to 1.4 tons per year of floating plastics, from large to small plastic particles.	• It is important to acknowledge the significant cost barrier for this technology. A successful strategic solution will eventually combine methods and tools that are logistically and financially feasible in a given location.

Conclusion

Table 2 provides a preliminary prioritization of technical solutions proposed in this study. Some solutions are mature (i.e. they have been tested and utilized repeatedly with some success to mitigate negative impacts associated with plastics and microplastics). They could represent good starting point solutions to address the issue of environmental contamination by microplastics from primary and secondary sources. High maturity solutions have proven effective and knowledge with respect to their operation and maintenance is easily available.

There could be some gaps concerning the effectiveness of these solutions in particular cases. On the other hand, developing countries often struggle to enforce effective and sound policies. Some solutions have failed in the past due to lack of strong policy support to back an initiative. It is therefore essential to consider the ability and need to enforce policies in selecting the appropriate solution for a given context or country. Some solutions with higher potential for success, even in countries traditionally struggling with policy enforcement, are presented in Table 2.

Implementation of solutions to mitigate impacts of microplastics will demand financial contributions from various stakeholders. Indeed, while some initiatives place the financial burden on the municipality, others require retailers, consumers or manufacturers to bear the financial costs. In the table solutions are shown that require minimal funds for operation or as investments from the public sector. In addition, inclusive stakeholder engagement is necessary to ensure that gender, diversity and inclusion are given the prominent importance they deserve. To that effect, it appears essential to acquire more insight into the gendered impacts of waste management and the associated impacts, as articulated in comments in this study. It is crucial to encourage collection of sex-disaggregated data and analysis of these data to support policy formulation. Disaggregated data reveal important gender dynamics and are crucial for gender-sensitive policy formulation. Data enhance understanding of life cycle and intergenerational links in regard to deprivations and support the alignment of actions with needs, leading to better designed policies according to specific regional and national contexts.

Table 2. Prioritization of available technologies

Mature technologies	**Technologies requiring less policy-support**
Mechanical recycling of sorted clean plastics Incineration of plastics for energy production Trash racks/meshes Enhancing plastic waste management Preliminary treatment Treatment of stormwater run-off Primary treatment Secondary treatment Landfill leachate treatment Incineration of sludge Treatment of drinking water	Mechanical recycling of sorted clean plastics Trash racks/meshes Primary treatment Secondary treatment Treatment of drinking water
Low investment cost technologies (for the public sector)	Technologies with low operation and maintenance costs
Mechanical recycling of sorted clean plastics Booms Trash racks/meshes Preliminary treatment Household washing machine filters Design of new textiles Treatment of stormwater run-off Primary treatment Secondary treatment Wetlands	Mechanical recycling of sorted clean plastics Trash racks/meshes Preliminary treatment Treatment of stormwater run-off Primary treatment Secondary treatment Wetlands

- ● For management of macroplastics only
- ● For management of both macroplastics and microplastics
- ● For management of microplastics only

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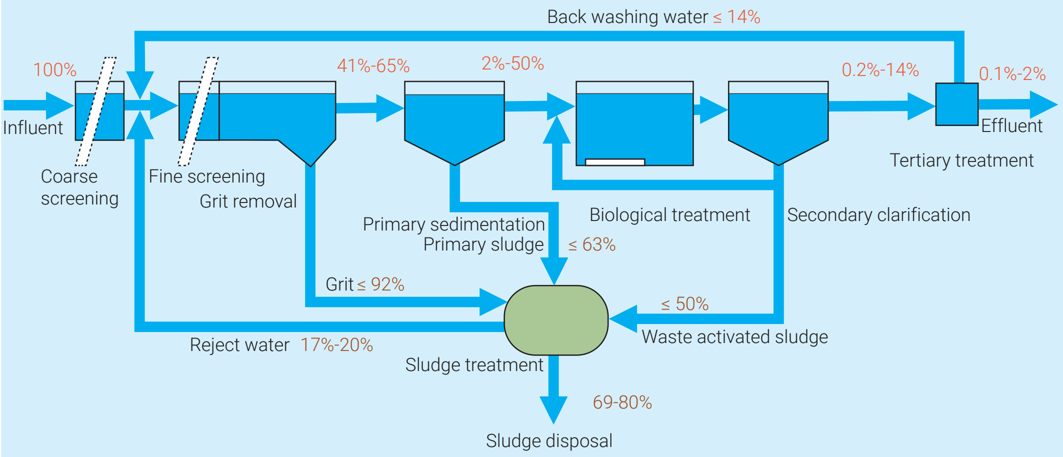
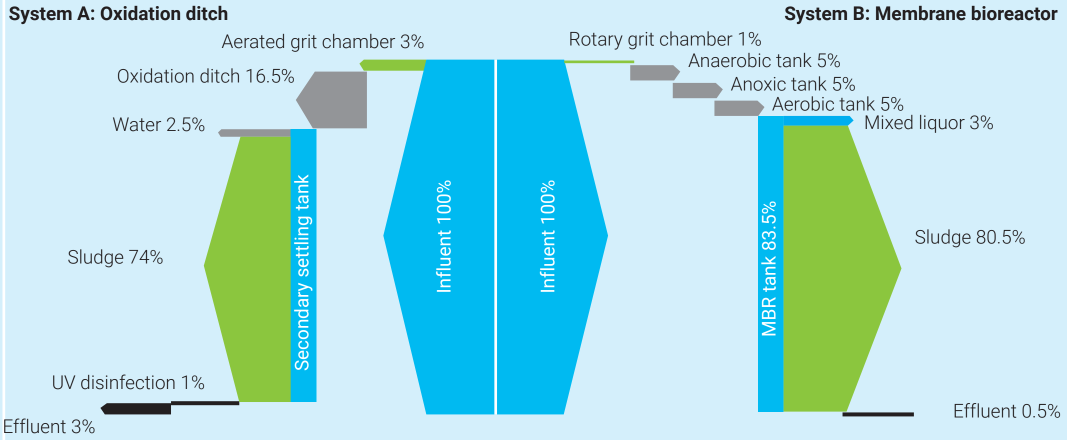
Annex: Processes for Removing Microplastics from Water Effluent During Typical Treatment in Western Countries, China and Canada

Removal of microplastics during typical treatment in western countries



Source: Sun *et al.* (2019)

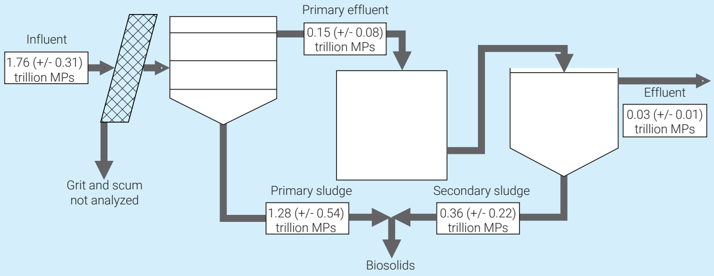
Removal of microplastics during typical treatment in China



Left: System A (Oxidation ditch).

Right: System B (Membrane bioreactor).
Source: Lv *et al.* (2019)

Description	Key findings for A (%)	Key findings for B (%)
• Microplastics leave the plant through the secondary sludge • Microplastics remain in the treated effluent after treatment • Microplastics removed through primary treatment	• 74 • 3 • 3 (aerated grit chamber)	• 80.5 • 0.5 • 1 (rotary grit chamber)

Removal of microplastics during typical treatment in Canada	 Source: Gies *et al.* (2018)	Key findings • Preliminary + primary treatment achieve 91.5 per cent of removal efficiency for microplastics • After secondary treatment, microplastics removal efficiency attains 98.3 per cent • 72.7 per cent of the microplastics end up in the primary sludge and 20.5 per cent in the secondary sludge. This means 93 per cent accumulate in the biosolids. From the number balance, it is likely that 5 per cent of the microplastics are removed with the grit/scum.