Plastics

IN THE ENVIRONMENT

Te Ao Hurihuri – The Changing World

ROYAL SOCIETY
TE APĀRANGI

EVIDENCE SUMMARY


Packed On
20/05/2019

There is growing concern about the use of plastics and their effects on the environment and human health. This document sets out how plastics are made, used and disposed of. It also covers how plastics enter the environment and the risks plastics pose to wildlife and humans.

It has taken less than 100 years for plastics to become foundational to nearly every aspect of our modern life. They became an excellent substitute for many materials including ivory, horn, silk, cotton, and natural rubber. Plastics are everywhere and ubiquitous. We use them for building and construction, agriculture and primary production, textile production, healthcare, food distribution, transport, communications and much more.

The desirable properties of plastics include being strong, lightweight, easy to shape, hypoallergenic, easy to sterilise and cost-effective to produce. These properties contribute to reducing transportation costs, protecting food from damage and microbial contamination, and making plastics useful in healthcare, to name just a few uses. However, these same properties encourage single or light-use and we have discarded three quarters of the volume of plastics ever produced. This amounts to hundreds of millions of tonnes of plastics being disposed of as waste every year. Only a small proportion of this waste is recycled.

Unfortunately, plastics continue to break down over decades or even centuries. Most do not fully degrade, but split into tiny fragments. Disposal and waste management practices have resulted in widespread pollution from plastics. Researchers have detected plastic in almost every imaginable place on Earth including the air, mountaintops, the deepest parts of the ocean, and Arctic sea ice.

Plastic pollution can harm animals that get caught in it, and it also poses a biosecurity risk by transporting invasive species and disease over vast distances. Plastic pollution damages the intrinsic beauty and cultural value of our landscape. Plastics enter the food chain because organisms are ingesting waste plastics, with the potential to harm all life on Earth, including potential risks for human health.

New Zealand has a very high per capita use of plastics and, like the rest of the world, we are witnessing plastic pollution and impacts on our wildlife. We have long relied on other countries to process the majority of our plastic recycling. However, these countries no longer accept our plastic waste and we are being forced to rethink how we deal with it. The March 2019 environmental contamination from flooding and erosion of the historic landfill site at Fox River has further highlighted the urgent need for better waste management in New Zealand.

By changing how we use and dispose of plastics we can start to turn the plastic pollution problem around. Strategies include reducing, reusing and recycling the plastics that we use, removing excess plastics from products where possible, recovering energy from plastic waste where appropriate, and redesigning products to create more sustainable alternatives.

Rārangi upoko

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Te hanganga me te whakamahi i te kirihou

Creation and use of plastics

Plastics are versatile, durable and lightweight materials. As a result, many everyday products incorporate plastics.[1,2] There are a wide variety of applications for plastics such as packaging, construction, textiles, and as components in electronics and transportation, to name a few.[1,3]

Plastics were first created in the late 19th and early 20th centuries.[1–3] Celluloid was one of the first plastics obtained from chemically modifying a natural material.[3] Celluloid and other plastics could be used to replace items made from scarce natural resources such as horn, ivory and tortoiseshell.[3,4] Prior to plastics, the widespread use of ivory for many products including billiard balls, boxes, combs and piano keys was placing a huge demand on the elephant trade.[4] The invention of Bakelite in 1907, the first mass-produced and truly synthetic plastic, was revolutionary with its strength, heat and water resistance, and low electrical conductivity. It could be easily moulded and was quickly incorporated into new products such as casings for communication technologies including radio and telephone.[3,5]

Plastics were not widely used until the late 1930s. They began to be used extensively in the Second World War, often as a substitute for natural resources that were in short supply.[3,5] Mass production of plastics started around 1950; the industry has grown rapidly with demand still continuing to this day.[6] During the second half of the 20th century, plastics replaced components of many household products traditionally made from metal, cotton, glass and cardboard. Furthermore, plastics were increasingly incorporated into sophisticated industrial and technological applications, such as components for cars, aircraft and electronics.[3,5] Synthetic textiles and fibres, including nylon, acrylic and polyester, were developed from plastics.[1,3] Within a short time, plastics have become foundational to nearly every aspect of our modern everyday life, including in our homes and workplaces, transport, sports and leisure.[3,7]

What are plastics?

The term plastic originates from the Greek word 'plastikos,' meaning capable of being shaped or moulded.[2] Plastic has become a catch-all term referring to the large variety of materials made from polymers and additives that can be moulded and cast into various shapes.[8,9] Polymers can be natural or synthetic; natural polymers include materials such as cellulose, protein fibre (silk, wool) and starch.[6,10] The polymers that make up plastics are long molecular chains made from joining short repeating subunits in a chemical process known as polymerisation (Figure 1). The physical properties of these extremely long, flexible and interlinked chains of molecules give many plastics their strength and flexibility.[10]

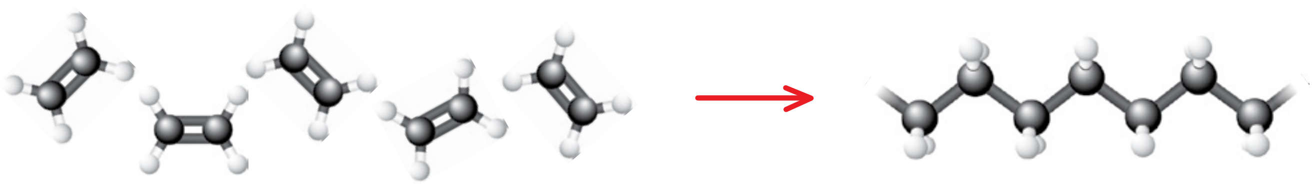


FIGURE 1 | The chemical process of polymerisation is used to make plastics. For example, many ethylene molecules (monomers) combine to form long chains of polyethylene (a polymer).

How do we use plastics?

Almost all aspects of our modern life involve plastics in various forms with diverse applications ranging from cling film to bullet-proof fibres such as Kevlar®.[4] We use plastics in many products across every industry including construction, transportation, electronics, healthcare, and agriculture.[1,3,7]

Plastics are lightweight, strong, cheap to produce, and easily adapted into different shapes and colours. Therefore, plastics are commonly used for single-use items, such as straws, food and beverage packaging, cigarette filters, disposable cups, plates and cutlery. Unfortunately, because these are designed as low-cost items, they are often quickly discarded as trash.[2,11]

Plastic packaging is widely used to transport, protect and preserve products from manufacturer to the customer in a convenient and safe manner, preventing food contamination and increasing shelf life.[1,5] Plastics are also used in many durable products and applications, such as furniture, pipes, textiles, electronic goods and vehicles (Table 1).

Although a diverse range of plastics are commercially available, only a few dominate the market because they can be produced in high volumes at relatively low cost.[1] The plastics that account for the majority of the world's total plastics produced are polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), polyurethane (PUR) and polyvinylchloride (PVC).[6,7,12]

Transporting goods that are packaged using plastics can reduce fuel consumption because plastic packaging is generally much lighter than glass, wood, metal, paper or cardboard alternatives.[3,5] Plastics are widely used in aviation, marine and land transportation to build lighter, and therefore more fuel efficient, vehicle components from hubcaps to parts of spaceships.[7] Vehicle tyres are commonly made of a mixture of natural and synthetic rubber (styrene-butadiene rubber).[14]

The Boeing 787 Dreamliner is constructed of 50% advanced plastic composites, allowing for significant weight reductions and fuel savings.[16]

In medicine, plastics have revolutionised healthcare through improving sterility by the use of disposable syringes, surgical gloves, IV tubes and catheters; enhancing safety with tamper-proof caps on medical packaging, blister packs, and non-permeable biohazard bags; and increased comfort with hypoallergenic medical devices and heart valves, and flexible prosthetics.[1,3,7]

In agriculture and horticulture, plastics are used in many applications including as protective mesh, sheets and films to combat crop damage and wrap hay; as pipes to support irrigation, water conservation and drainage; and as containers for storing and transporting produce.[15]

Recent estimates suggest that the world's population is using up to 600 million plastic bags and 60 million bottles each hour. If all of these bags were tied together, the bags could be wrapped around the planet seven times.[11]

TABLE 1 | Examples of how the most common plastics are used (ordered by quantity produced).[1,3,7,12,13]

PLASTIC		EXAMPLE OF USE	
Polypropylene	5 PP	**Packaging, transportation, building and construction, agriculture, and household items:**	Food packaging and containers including bottle caps, margarine tubs, yoghurt pottles, food trays, microwave containers, film for sweet and snack wrappers; stackable crates for transport and storage; water or sewage pipes; geomembrane liners used in building applications; insulation, household items including bowls, trays, combs, hairdryers; automotive parts; bank notes.
Low density polyethylene	4 LDPE	**Packaging, building and construction and agriculture:**	Films for carrier bags, sandwich and freezer bags, cling wrap and agricultural film; electrical wire and cable insulation.
High density polyethylene	2 HDPE	**Packaging, building and construction, and household items:**	Bottles and containers including milk bottles, water bottles, bottles for cleaning (e.g. detergents, bleach) and personal care products (e.g. shampoo and conditioner); irrigation and drainage pipes.
Polyvinyl chloride	3 PVC	**Packaging, building and construction, and household items:**	Building and furniture applications including floor and wall coverings, upholstery, window shutters, plumbing pipes, cable insulation and fittings; garden hoses; inflatable pools; packaging as cling films for household and industrial applications; shoe soles; traffic cones.
Polyethylene terephtalate	1 PET	**Packaging and textiles:**	Bottles for water, soft drinks and other beverages, food jars and containers, textiles including polycotton and fleece.
Polyurethane (a thermoset plastic)		**Building and construction, transportation, and household items:**	Vehicle parts (tyres, gaskets, bumpers), building insulation, pipes, pillows and mattresses, insulating foams for refrigerators, shoes, life jackets.
Polystyrene	6 PS	**Packaging, building and construction, household items, and electronic/electrical products:**	Building insulation; packaging material for electronic goods; cups and trays. Expanded polystyrene foams are used in large volumes for packaging and building insulation.
Other	7 OTHER	**Transportation, building and construction, electrical/electronic products and household items:**	There are many type of plastics in this category including: Polycarbonate (PC) used in eyeglasses lenses, roofing sheets, light casings for cars, drinking bottles and containers; polymethyl methacrylate (PMMA) used in touch screens; and acrylonitrile butadiene styrene resin (ABS) used in hubcaps, furniture and dashboards.

How do we make plastics?

The raw materials for plastics are most commonly obtained from non-renewable resources including products of the fossil fuel industry such as styrene and ethylene (Figure 1).[1,3] Plastics manufacturing uses an estimated 4% to 8% of global oil production, accounting for both raw materials and the energy required for manufacturing.[17,18] These levels are similar to those used by the aviation sector.[17]

If the plastics industry continues to grow as expected, manufacturing plastics is predicted to consume 20% of total oil production by 2050.[17]

Alternative bio-based plastics are increasing in popularity.[6] These are generated from agricultural or forestry waste or specifically grown crops such as sugarcane, corn and trees.[18–21]

The term 'bioplastics' usually refers to plastics sourced from renewable resources (bio-based), but sometimes it is used to refer to plastics that are biodegradable. Some bio-based plastics such as polylactides (PLA) are also biodegradable (Figure 2). The chemical structure of the plastic will determine how it degrades – it is not dependent on whether it is sourced from plant, animal or fossil fuel-based raw material. Many biodegradable plastics (see Composting and biodegradation, page 18) require specific conditions such as high temperatures reached in commercial compost facilities to fully degrade.[19]

During the production of both conventional plastics and bioplastics, a variety of 'additives' may be added to the polymer to change its character. Additives allow plastics to take on many forms with varying appearances, durability and performance, and make them behave differently in the environment. Common additives include plasticisers (used to enhance flexibility and durability), ultraviolet blockers, thermal stabilisers, dyes and pigments, and flame retardants.[22,23] Some of these additives are toxic at low doses (see Toxic chemicals associated with plastics, page 32), and can leach out of the plastic where they can affect our health and the environment.[24–26]

PLASTIC TYPES AND BIODEGRADATION

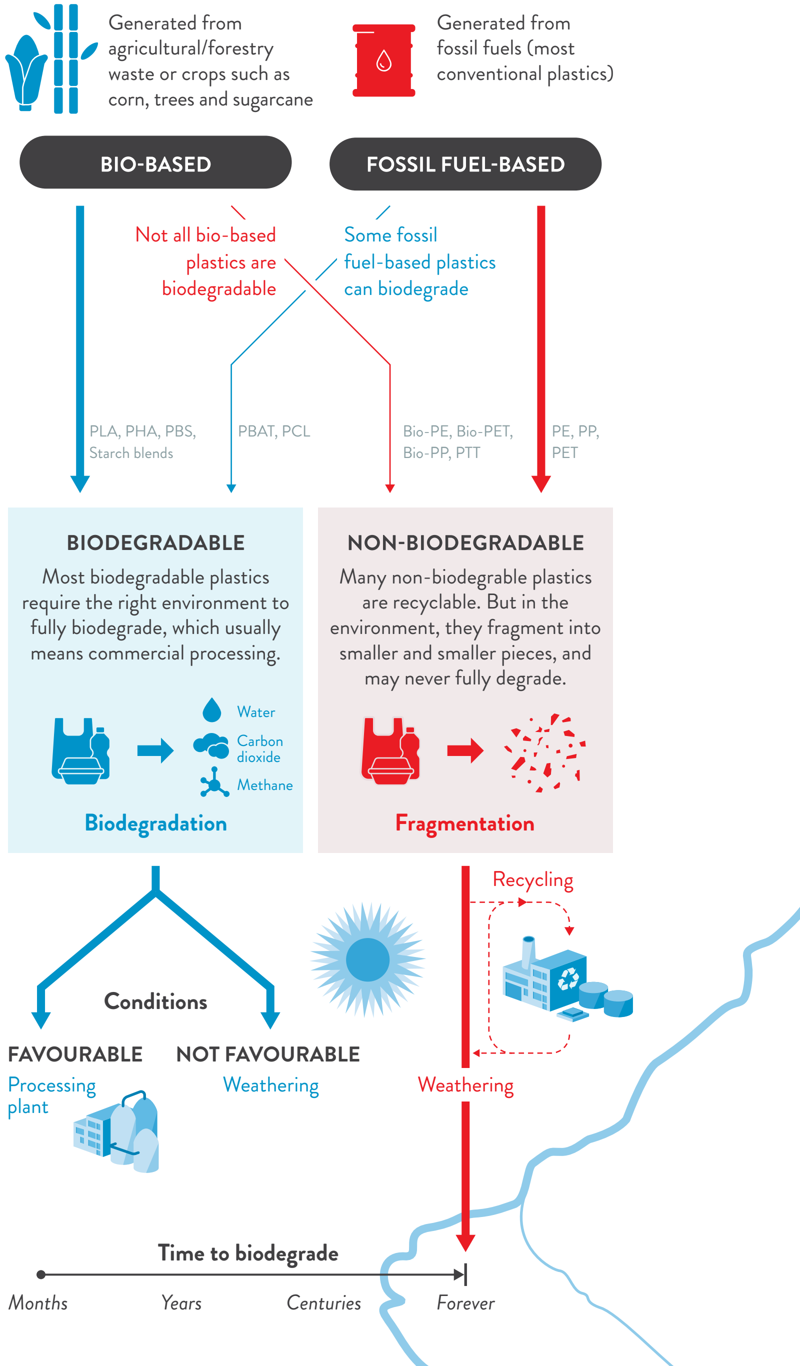
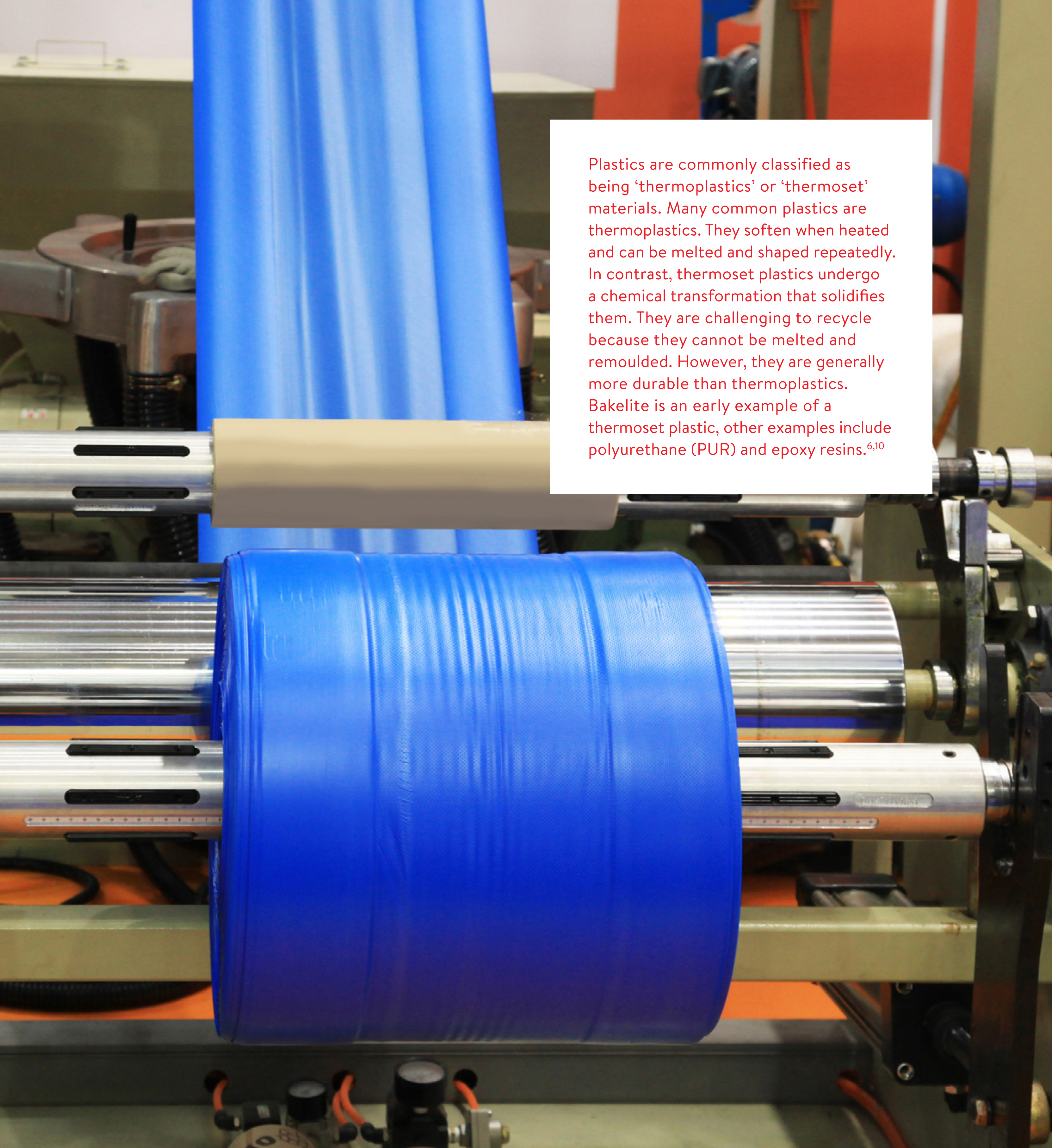
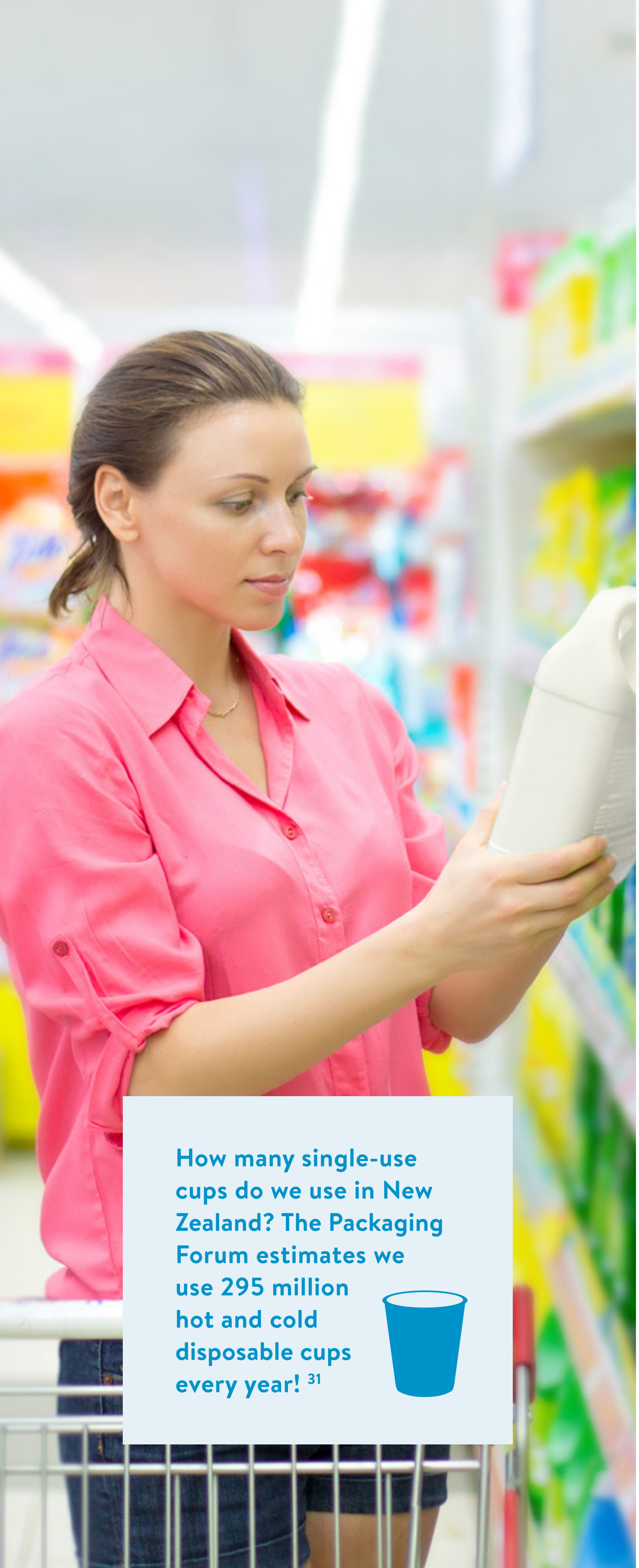


FIGURE 2 | Some plastics produced from biomass (bio-based) or fossil fuels can biodegrade under favourable conditions.



Plastics are commonly classified as being ‘thermoplastics’ or ‘thermoset’ materials. Many common plastics are thermoplastics. They soften when heated and can be melted and shaped repeatedly. In contrast, thermoset plastics undergo a chemical transformation that solidifies them. They are challenging to recycle because they cannot be melted and remoulded. However, they are generally more durable than thermoplastics. Bakelite is an early example of a thermoset plastic, other examples include polyurethane (PUR) and epoxy resins.[6,10]



How much plastic do we use?

The boom in global plastics production (Figure 3) has outpaced that of almost every other material in history, owing to the massive growth of plastics used in everyday applications. In 2015, 407 million tonnes of plastics were produced worldwide (Figure 4), and 302 million tonnes of plastics were discarded as waste.[12] If this growth in the plastics industry continues, global production could produce about 1124 million tonnes of plastics annually by 2050.[17] While bioplastics contribute only a small fraction of the overall plastics industry, the global bioplastics industry is growing steadily, and is predicted to increase to about 2.6 million tonnes by 2023.[27]

In 2017, New Zealand imported over 300 thousand tonnes of plastic resin to be used in manufacturing products.[29] Plastics were also a key component in 49% (by value) of textile and textile article imports (including clothing), 85% of footwear imports, and 27% of fishing rods imports.[29] In the same year, New Zealand exported 41.5 thousand tonnes of plastics as waste[30] (see Recycling, page 16).

How many single-use cups do we use in New Zealand? The Packaging Forum estimates we use 295 million hot and cold disposable cups every year! [31]

GLOBAL PLASTIC PRODUCTION OVER TIME

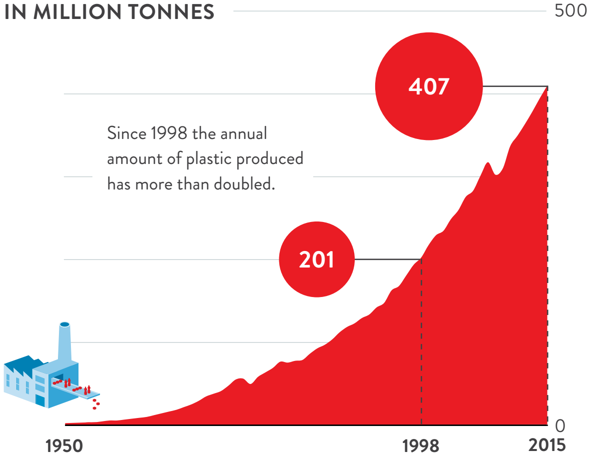
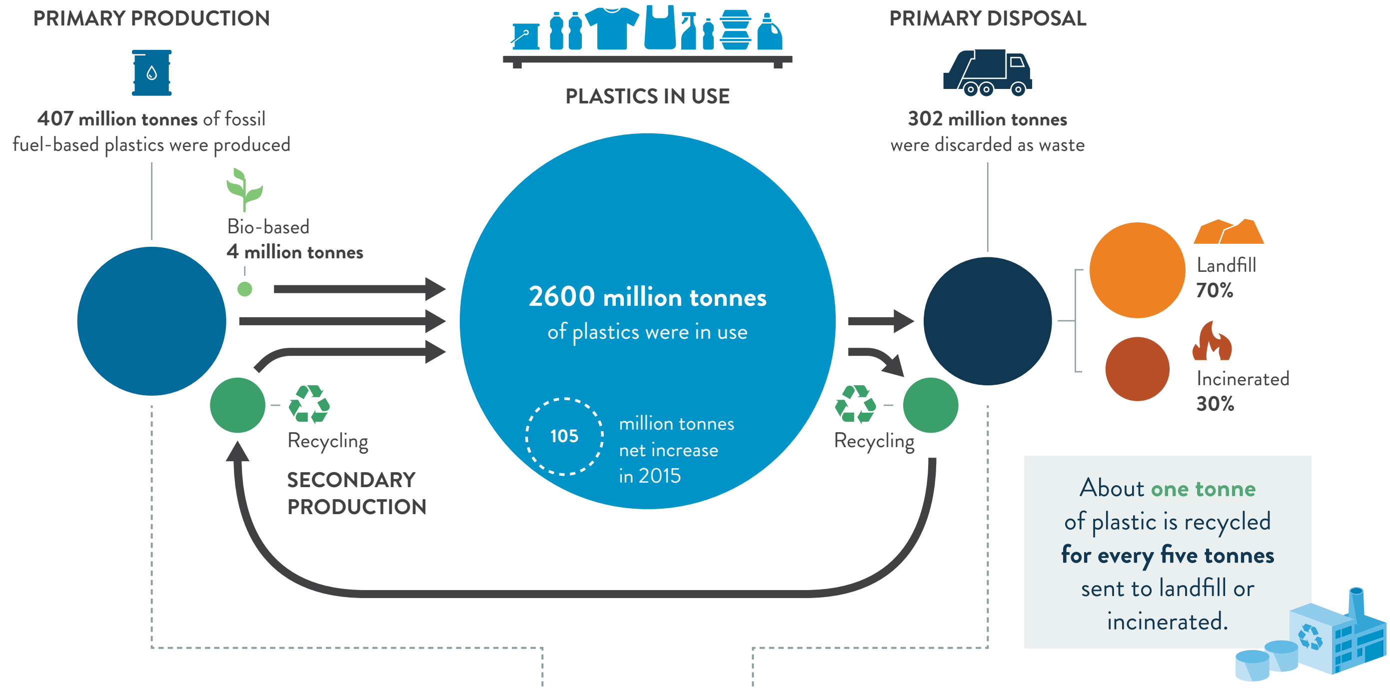


FIGURE 3 | Global production of plastics has grown exponentially and the industry is still expanding.[12,17]

GLOBAL PLASTIC PRODUCTION, USE AND DISPOSAL IN 2015



BREAKDOWN BY SECTOR

IN MILLION TONNES

Sector	Primary Production	Primary Disposal
Packaging	146	141
Building & Construction	65	13
Textiles	59	42
Consumer & Institutional Products	42	37
Transportation	27	17
Electrical/Electronics	18	13
Industrial Machinery	3	1
Other	47	38

While plastics produced for packaging are usually disposed of within a year, plastics produced for building and construction can stay in use for 20 years and longer, resulting in the different sector breakdowns for production and disposal.

FIGURE 4 | The production, use and disposal of plastics, based on data from Geyer 2017.[12] Examples of consumer and institutional products include cups and cutlery, medical devices, sporting equipment and toys.[28]

Te porowhiu i te kirihou

Disposal of waste plastics

By 2015, plastics represented a quarter of all types of packaging (by volume) and it is expected that plastic packaging volumes could double within 15 years.[17]

Plastics account for hundreds of millions of tonnes of waste every year. Over three hundred million tonnes of plastic were discarded in 2015, with packaging accounting for almost half of this waste.[12] Globally, plastics disposed of through managed waste streams are generally sent to landfill, recycled or incinerated.[12]

Scientists estimate that 8.3 billion tonnes of plastics had been produced globally by 2015, over a tonne of plastics for every person on the planet at the time.[12] Of this, 6.3 billion tonnes (76%) had been discarded as waste. Between 1950 and 2015, 9% of plastic waste was recycled, 12% was incinerated, and the remaining 79% has accumulated in landfills and the environment.[12]

The total amount of waste generated per person varies significantly between countries (Table 2 and Figure 5).

PLASTIC WASTE GENERATION

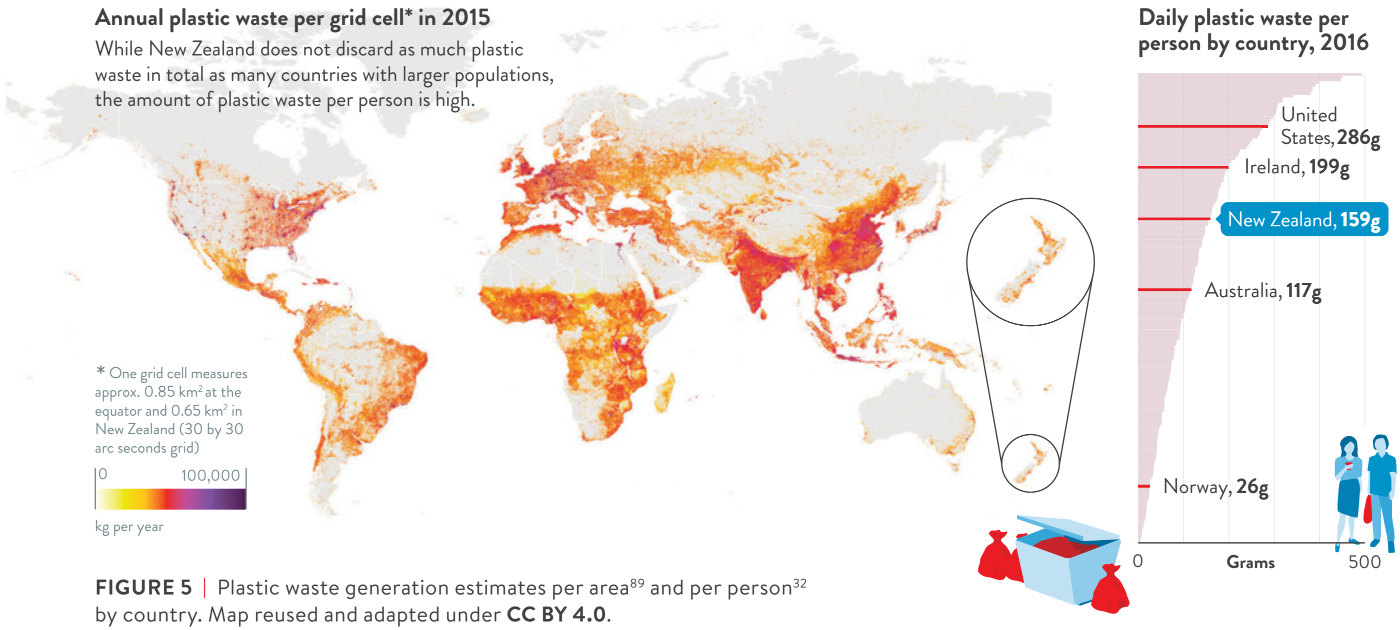


FIGURE 5 | Plastic waste generation estimates per area[89] and per person[32] by country. Map reused and adapted under **CC BY 4.0**.

TABLE 2 | Total solid municipal waste and plastic waste estimates as calculated in the World Bank report *What a Waste 2.0* using their data adjusted to 2016 for cross-comparability.[32]
Note: data collection varies between countries, see World Bank report for more information.

COUNTRY	WASTE GENERATION RATE (g/person/day)	PLASTIC IN WASTE STREAM (%)	PLASTIC WASTE PER CAPITA (g/person/day)
Norway	1160	2.25	26
Denmark	2160	1.6	35
Canada	1940	3	58
Japan	950	11	104
Spain	1190	9	107
Australia	1540	7.6	117
France	1370	9	124
New Zealand	1990	8	159
Ireland	1610	12.4	199
Germany	1720	13	224
United Kingdom	1330	20	266
United States	2220	12.9	286

Landfill

In many developed nations, such as New Zealand, the final destination for the majority of our waste is the landfill, where it is typically crushed and buried.[12,33–35] Landfill waste generated in New Zealand has steadily increased in recent years.[35–37] We do not know exactly how much and what is in our landfill waste, as reporting is only required from 45 of the 426 facilities currently operating under a resource consent.[36] These 45 facilities account for over 3.3 million tonnes of waste in the year ending 30 June 2016.[37] Plastics represent approximately 12% of landfill waste as estimated by regional council surveys conducted between 2011 and 2017.[35]

Many plastics will remain in a landfill for decades or even centuries, due to their resistance to microbial degradation and requirements for oxygen and ultraviolet light to aid degradation.[13,33] How long this process takes is highly dependent on environmental conditions and the type of plastic.[13] Chemicals released from degrading plastic contribute to the leachate from landfills.[24,25,38,39]

Unregulated or poorly managed landfills are a source of plastics entering the wider environment.[6,40] Flooding from severe rainfall on 26 and 27 March 2019 exposed and dislodged waste from the historic landfill close to the banks of the Fox River.[41] Historic landfills situated in valleys, or adjacent to rivers and

PHOTO | Dislodged waste from a historic landfill scattered across the banks of the Fox River and nearby coastline following severe rain in March 2019.[41] **Photo credit:** Kelsey Porter

waterways, can also contribute to this problem and are likely to be increasingly vulnerable to extreme weather events and flooding as a result of climate change. In New Zealand, plastic agricultural waste has been burnt or buried on farms, a practice that is now banned by some regional councils and recycling is encouraged through waste deposit schemes.[37,42,43]

Incineration

Plastic waste may also be incinerated by burning the material at extremely high temperatures. New Zealand regulations place some restrictions on the incineration of waste.[44–47] Some countries, including France and Germany, recover energy from this process to use for heating or the generation of power.[34,48] Incinerating plastics releases toxic fumes, including dioxins and other persistent organic pollutants known to cause cancer and birth defects. Under optimum conditions, technologies can reduce the amount of toxins in these emissions to very low levels (<0.1 to 10 ng/m^3).[49] Ash generated from incineration can also be hazardous to human health and the environment.[50,51]

Recycling

Recycling recovers waste plastics to manufacture into new products. Recycling can reduce the loss of plastics into the environment[52] and keep the material in the economy.[17] However, it is not economically feasible to recycle some plastics, particularly when the cost of manufacturing new plastics from fossil fuels is low.[52,53]

Globally, an estimated 14% to 18% of plastic waste is currently recycled.[54] In developed countries, recycling has increased steadily since the 1980s.[12,54] The volume and composition of waste, including plastics, collected nationally across New Zealand's recycling schemes is unknown.[36] While the United States and Europe routinely report data on recycling (Table 3), data from other countries, including New Zealand, are sparse.[12,54] Sweden and Norway now recycle over 40% of waste plastics, whereas the United Kingdom and France recycle 32% and 23% of their waste plastics, respectively.[7]

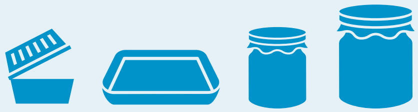
New Zealand has very few facilities for recycling plastics and must export most plastics recovered for recycling, relying on other countries to process this waste. Until recently, the majority of these plastics were shipped to China,[56] which imported over 50% of the world's recyclables for processing.[57] However, China, and some other countries importing recycling, have recently tightened their import criteria for waste. These restrictions have resulted in the widespread accumulation of plastic material for recycling.[58] Stockpiles of plastics collected for recycling pose a fire hazard as the piles continue to grow while we seek alternative options for processing plastics within New Zealand or overseas.

The fickle markets for different plastics, the volumes required for recycling, and the cost of collecting and sorting are barriers that can make some plastics uneconomical to recycle.[53] Clear polyethylene terephthalate (PET) and opaque or 'natural' (uncoloured) high density polyethylene (HDPE) have a high recycling value (Figure 6),

TABLE 3 | Treatment of plastics from municipal waste in Europe (2016) and the United States (2015).[7,55]

COUNTRY	RECYCLING	INCINERATION	LANDFILL
Germany	38.6%	60.6%	0.8%
Spain	36.5%	17.1%	46.4%
United Kingdom	32.1%	38.3%	29.6%
Italy	29%	33.8%	37.2%
Poland	26.8%	29.1%	44.1%
France	22.8%	44.2%	32.5%
United States	9.1%	15.5%	75.4%

Flight Plastics Ltd in Lower Hutt can recycle 8000 tonnes of clear PET annually back into new packaging.[56]



making it more economical to collect and recycle than other plastics.[56] Polyvinyl chloride (PVC), polystyrene (PS) and polyurethane (PUR) are particularly difficult to recycle.[59] Plastics that do get recycled are typically made into lower value items in a process known as ‘down-cycling’. Ultimately, each time a piece of plastic is recycled, the quality of the plastic declines, until it is no longer useful as a source of raw material for new plastic products.[53]

Contamination causes issues for recycling, including from waste residue such as food[11] and from items composed of multiple materials that are difficult to separate.[53] The latter requires deconstruction into each type of plastic. Processing multiple plastics together will reduce the integrity and value of the recovered material.[53] Additives from the original plastics may increase the toxicity of recovered plastics, making it more difficult to reuse plastics in certain products due to safety concerns. Recycled plastics used for food packaging require a thin layer of virgin plastic coating to achieve food contact grade standards.[56] There are also risks in recycling plastics contaminated with other chemicals, such as brominated flame retardants, into new products such as children’s toys, grooming and hair accessories.[60]

FIGURE 6 | Recyclable plastics and ease of recycling.

Composting and biodegradation

Biodegradable and compostable plastics are designed to be easily broken down by microorganisms under certain environmental conditions. Common biodegradable plastics include thermoplastic starch (TPS), polycaprolactone (PCL), polyhydroxyalkanoates (PHAs), and polybutylene adipate terephthalate (PBAT), a modification of polyethylene terephthalate (PET).[13,61] These are used currently in medical applications, agricultural products, adhesives, bottles, bags, disposable cutlery, cups, food packaging and paper coatings.[13,61] Polylactide (PLA) is the most commonly used compostable plastic globally.

Biodegradable plastics can be made from either bio-based or fossil fuel-based resources (see How do we make plastics? and Figure 2, page 8). Bio-based biodegradable plastics use a variety of plant and animal-based raw materials. Cellulose, sugar and starch (e.g. from potatoes) are the most common raw materials, but fats and proteins can also be used to produce biodegradable plastics.[62] Biodegradable fossil fuel-based plastics include PBAT and PCL.[61]

The term 'compostable plastic' can be confusing; consumers may assume that these items are suitable for their home compost system when they rarely are suitable. Commercial facilities are generally required to generate high temperatures (50–60 °C) and other conditions needed for microorganisms to break down compostable plastics, such as PLA, completely into small molecules such as carbon dioxide, methane and water.[61–64] A few plastic products are certified to break down under home composting conditions, according to Australian, US or EU standards.[65] However, there are currently no New Zealand government standards or guidelines about how best to compost these plastics at home.[61]

Oxo-degradable plastics are not a good solution. These plastics contain additives that accelerate oxidative degradation to easily 'weather' plastic into small fragments. This process quickly creates microplastics that can cause issues in the environment.[17,61]

He para kirihou ki te taiao

Plastic debris in the environment

Factors that can affect loss of plastics to the environment include waste collection and management infrastructure; population density; regulations that apply to commercial and industrial sectors using plastics; import and export policies; and the social practices, priorities and values of the population.[6,40,66] These in turn may depend on a variety of factors including national, regional and global policies and legislation,[6] as well as the financial, human, and technical capital of the country.[40]

The lightweight and durable properties that make plastics so useful also mean that plastics discarded into the environment are persistent, highly-mobile pollutants that are easily transported around the globe.[67–69] Wind patterns and ocean currents can result in floating plastic debris travelling thousands of kilometres, where they may accumulate in areas far from their source.[6,33,70] Researchers have detected plastic pieces in almost every imaginable place on Earth including air,[9,71] soil,[26,72–75] mountaintops, shoreline, freshwater, estuarine and marine environments.[9,76] These extend to the deepest parts of the ocean,[77–79] waters surrounding Antarctica[80] and frozen into Arctic sea ice.[81,82]

How do plastics enter the natural environment?

Plastics can enter the environment at any stage of product manufacturing, use and disposal, creating plastic pollution (Figure 7). Poor waste management, deliberate littering, illegal dumping, and accidental loss of plastics during use and transportation are the main contributors to plastic debris.[33,83]

It is estimated that in 2010, up to 12.7 million tonnes of plastics leaked into the ocean – which is equivalent to dumping the contents of one garbage truck into the ocean every 38 seconds.[17,40]

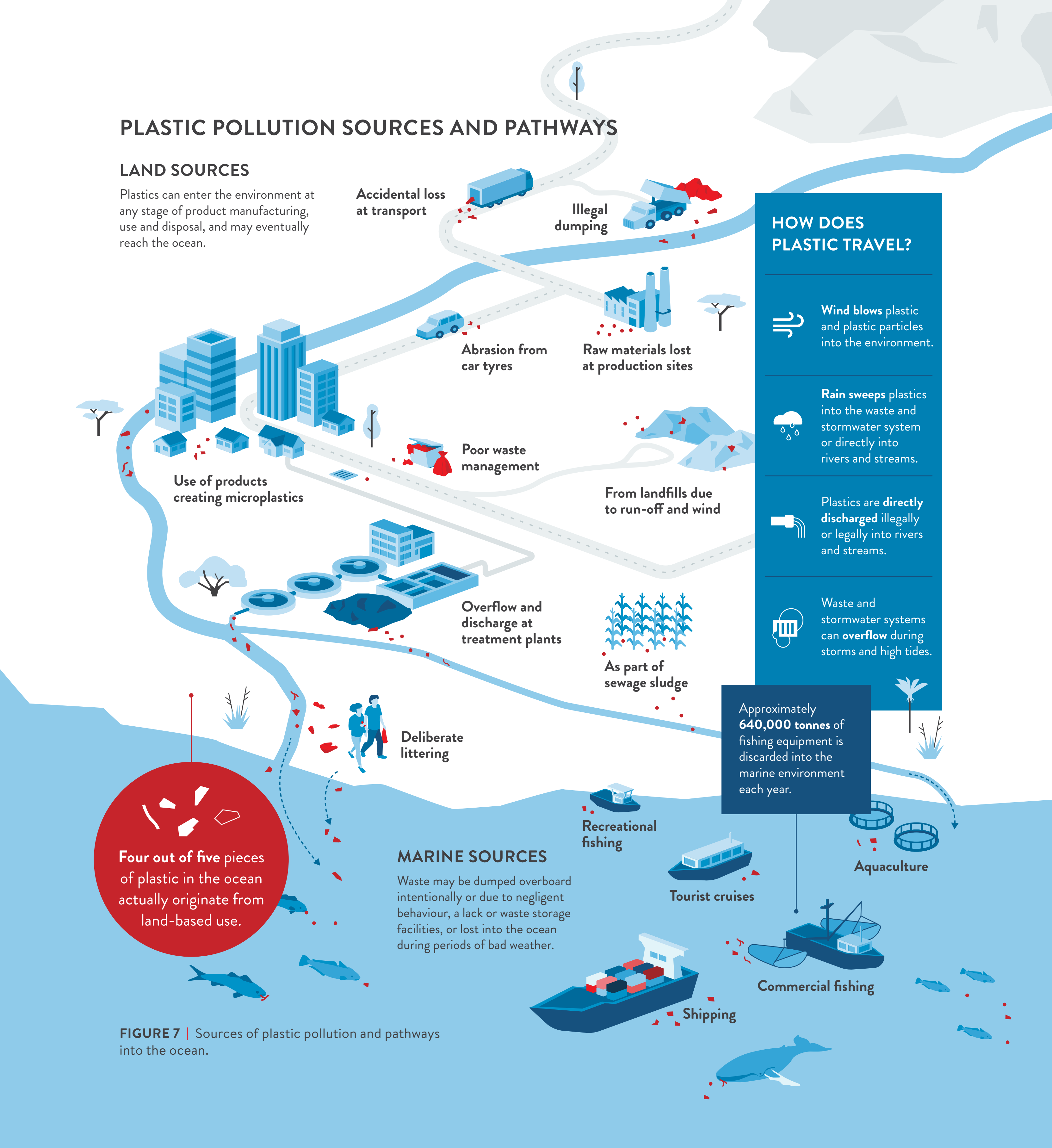
Four out of five pieces of plastics in the ocean actually originates from land-based use[67,84] and the rest from marine-based activities. Approximately half of the world's population lives close to the ocean or near rivers and streams which connect to the ocean.[6] Marine sources of plastic pollution include commercial and recreational fishing, aquaculture, shipping, tourist cruises and other recreational users.[6]

Waste generated on ships is a major source of marine-based plastics. Waste may be dumped overboard intentionally or due to negligent behaviour, a lack of waste storage facilities, or lost into the ocean during periods of bad weather.[2,6,85] It has been estimated that five million plastic items are lost or thrown overboard from ships daily.[86] Abandoned, lost and discarded fishing and aquaculture equipment are other significant sources of plastic pollution.[6,87,88] Approximately 640,000 tonnes of fishing equipment is discarded into the marine environment each year.[84,86]

PLASTIC POLLUTION SOURCES AND PATHWAYS

LAND SOURCES

Plastics can enter the environment at any stage of product manufacturing, use and disposal, and may eventually reach the ocean.



MARINE SOURCES

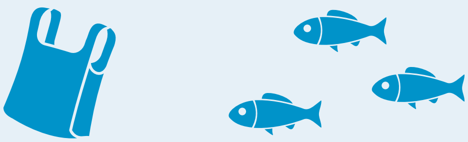
Waste may be dumped overboard intentionally or due to negligent behaviour, a lack or waste storage facilities, or lost into the ocean during periods of bad weather.

FIGURE 7 | Sources of plastic pollution and pathways into the ocean.

Practices contributing to plastic pollution

Mismanagement of plastic waste contributes to the release of plastics into the environment, which in turn is influenced by a range of socio-economic factors. Proximity to services and charges for waste disposal can influence local practices, especially in areas of geographic isolation and socio-economic deprivation. In 2015, 16 of the top 20 countries contributing to marine plastic pollution were middle-income countries,[40] where economic growth often outpaces the development of effective waste management infrastructure.[40] However, other countries, including New Zealand, add to these countries' burden by sending waste for processing overseas.[56]

> "In a business-as-usual scenario, the ocean is expected to contain 1 tonne of plastic for every 3 tonnes of fish by 2025, and by 2050, more plastics than fish (by weight)".[17]



The marine environment: plastics final destination?

Many plastics, whether lost on land or at sea, ultimately enter the ocean. Wind, rivers, storm and wastewater pipes, and ocean currents transport plastics to destinations far from their original source. Plastics disposed of in landfills may still enter the marine environment if they are inadequately managed, particularly from windblown plastics or uncontrolled landfills near the coast.[6,40] Within the marine environment, plastic items accumulate on sandy beaches and the seabed, as well as in salt marshes, mangrove forests, deep sea trenches, sea ice, and coral reefs.[90]

Oceans in the Northern Hemisphere have the highest concentrations of plastics, which have been attributed to large populations surrounding them.[91] The North Pacific Gyre, also known as the "Great Pacific Garbage Patch", is the region that accumulates plastics along with other waste and debris.[87,92] Investigations have found that there are also high concentrations of plastics in the South Pacific Ocean,[91,93] Atlantic Ocean,[94] Indian Ocean[91] and Mediterranean Sea.[95]

The quantities of floating plastics that have been observed in the open ocean are thought to be just a fraction of the total input into the ocean.[6] Many common plastics, including polyethylene (PE) and polypropylene (PP) commonly used in packaging, will float[88] and can be easily transported by wind, waves and currents. Foamed polystyrene is the most frequently identified plastic in visual surveys of surface ocean and coastal waters.[91] Other plastics that are denser than seawater, such as polyethylene terephthalate (PET), are commonly found on the seafloor.[33,78] Plastics that normally float can eventually sink due to fouling by living organisms and other organic material making the plastic debris heavier.[69] Hydrodynamic processes, including down-welling where different water bodies meet, may also distribute small pieces of plastic vertically within the water column.[91]

Plastic debris found on beaches and coastlines originates from local sources as well as wind and wave transported plastics that may have travelled for thousands of kilometres.[6] The most common plastic items found in international beach clean-ups are single-use items, including cigarette butts, food wrappers, bottles, bottle caps and lids, single-use bags, straws and stirrers, take-away containers, and polystyrene foam containers.[96] Many of these items are also commonly found on New Zealand beaches.[97]

In New Zealand, our storm water pipes are discharged into streams, rivers or directly into the sea,[98,99] and even New Zealand's most remote beaches contain plastic debris. Mason Bay, on the West Coast of Stewart Island, has long been known as an accumulation zone for plastic pollution. Much of this debris is related to lost equipment from the local fishing industry. However, debris from Australia, Asia, South America and Europe has been identified in New Zealand, demonstrating the ability for plastic pollution to travel extremely long distances.[100,101]

PHOTO | Plastics frequently wash up at Mason Bay Stewart Island. **Photo credit:** Phil Clunies-Ross

How do plastics degrade?

Traditional plastics were designed to be long lasting, resilient materials and often contained stabilisers to improve their resilience to environmental conditions such as sunlight.[102] These plastics may take decades or even centuries to degrade[6] via physical (abrasive/mechanical), chemical (thermal and UV/photochemical) and biological (microbial degradation/animal digestion) processes.[69,88,103,104] Biodegradable plastics (see Composting and biodegradation, page 18) will not persist in the environment for as long as conventional plastics, however they may still cause issues if they end up in the wrong environment, such as the ocean.[56,61]

Progressive weathering will eventually make plastics brittle and vulnerable to fragmentation.[33] As plastics break down, the ratio of surface area to volume increases, revealing more sites for potential degradation (via weathering or biodegradation). When plastics break down, toxic chemicals can leach from the plastics into the environment.[6] In addition, the increased surface area provides a larger number of sites that can adsorb other toxins (see Toxic chemicals, page 32).[6] Eventually most non-biodegradable plastics will disintegrate and form microplastics.

Microplastics

Microplastics are very small plastic particles generally less than 5 mm in size.[6,8,69,85] Some people also distinguish microplastics from even smaller plastics, termed nanoplastics, that are less than one thousandth of a millimetre wide.[8] In 2014, it was estimated that the ocean contained between 15–51 trillion microplastic particles, not counting those that have sunk to the seabed or have been deposited on shorelines worldwide.[76]

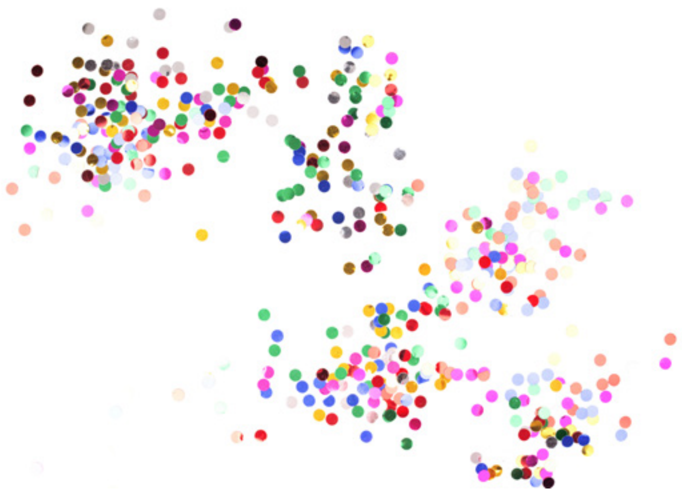
It can be extremely difficult to remove microplastics that are lost into the environment.[33] It is likely that these microplastics have been accumulating in the environment since the origin of plastic materials.[69,105]

Microplastics are found across many environments, including on New Zealand's coastlines,[112,113] particularly in the urban centres of Auckland, Wellington and Christchurch.[112] Globally, secondary microplastics, especially wear from tyre abrasion and fibres released from synthetic clothing, are found to be the greatest type of microplastics in sediments, soils, marine and freshwater samples.[105,109,110,114]

Both primary and secondary microplastics can be transported to freshwater and marine environments when they are washed into storm and wastewater systems.[69,111] Synthetic fibres and fragments (Figure 8) account for the majority of the microplastics found in discharge from wastewater treatment plants.[109,115] Garments made of synthetic materials, such as polyester and nylon fleece, can release up to 1900 fibres per wash.[116] An American study of 17 wastewater treatment plants found on average 4 million microplastic particles were being discharged daily from each wastewater treatment plant,[115] while a Scottish study found 65 million microplastic particles were being released daily from a single wastewater treatment plant.[117]

Primary microplastics are small plastic particles manufactured for specific uses, for example 'microbeads' used in personal care products, such as facial cleansers, toothpaste and cosmetics. Microplastics are sometimes added to these products to replace traditional natural ingredients such as pumice, oatmeal and almonds.[106–108] Tiny particles of abrasive plastic are also commonly used in industrial cleaning products.

Secondary microplastics are plastics originating from the fragmentation of larger plastic items. Examples include fibres from synthetic clothing, and fragments of items such as plastic bags and bottles.[109] Transportation also contributes to the production of microplastics, including the wear and tear of vehicle tyres[14] and brakes[110], and the chipping of paints and coatings, especially from road markings.[111]



MICROPLASTICS IN THE WASTEWATER TREATMENT SYSTEM

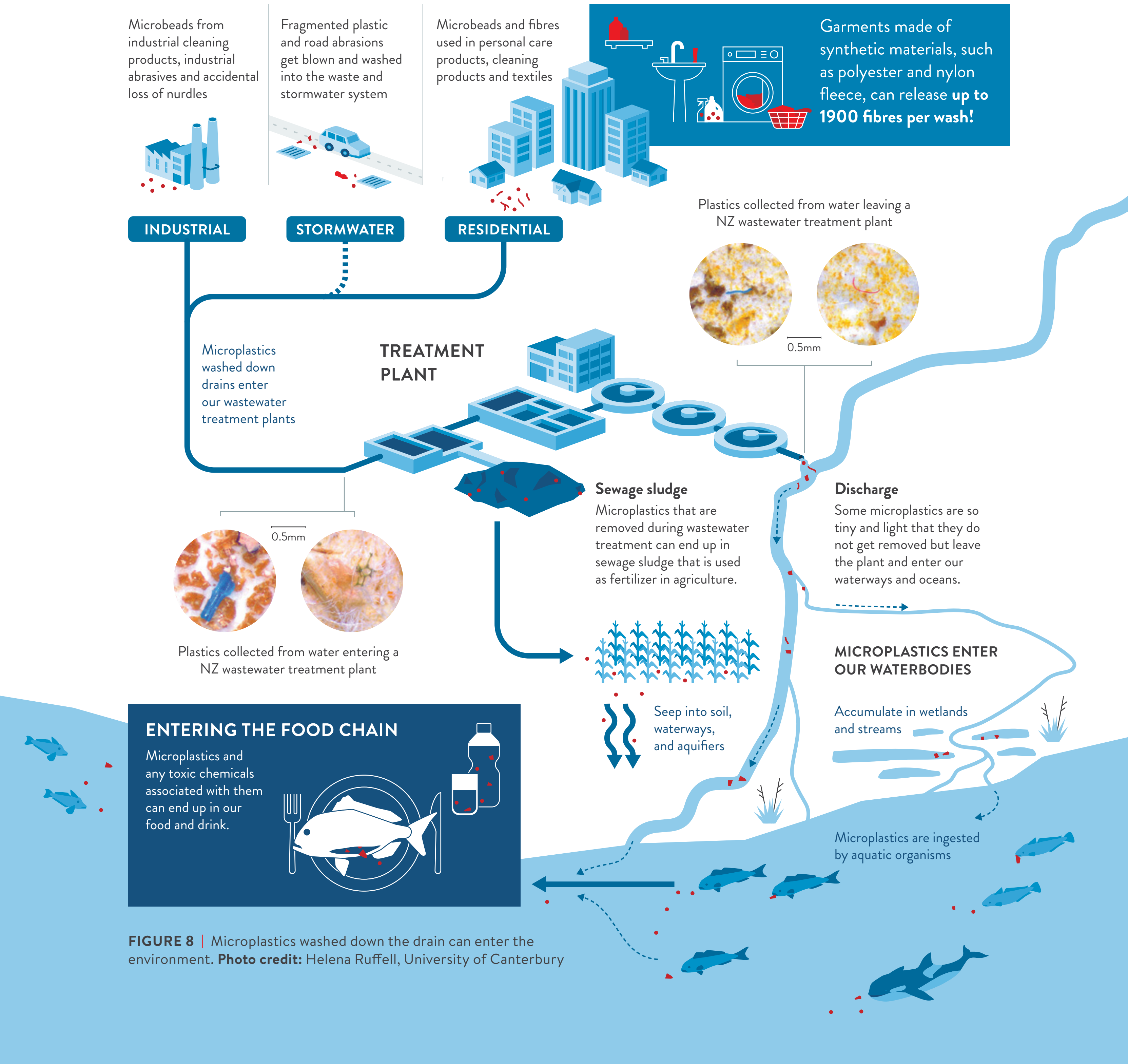


FIGURE 8 | Microplastics washed down the drain can enter the environment. **Photo credit:** Helena Ruffell, University of Canterbury

An investigation by Scion found significant levels of microplastics in Auckland's waterways and coastlines, especially polyethylene, polyethylene terephthalate and polypropylene. Concentrations were higher on the west coast than the east. A large proportion of the microplastics were fibres, consistent with international studies suggesting that wear and washing from textiles is a significant source of microplastics in the environment.[122]

Modern wastewater treatment plants are designed to capture and remove large pieces of plastics and other debris from water during treatment processes. However, they are generally not designed to remove microplastics, which can pass through the treatment process (Figure 8) and into the environment.[117,118] Any microplastics that are removed during wastewater treatment can end up in sewage sludge and enter the environment if this sludge is used on land including as fertilizer in agriculture.[109]

To reduce the amount of primary microplastics entering the environment, some countries, including New Zealand, ban the use of microbeads in some consumer products such as those designed to be washed down the drain.[119]

Plastic resin pellets or 'nurdles', used as the raw materials in the production of plastics products, are another significant source of primary microplastics. They are typically cylindrical and a few millimetres in diameter, generated in massive quantities and transported to production facilities around the globe.[88,112] Nurdles are commonly lost if they are poorly stored or mishandled during transportation and processing. As a result, nurdles are now commonly found in the marine environment, particularly near cities and industrial areas.[6] Nurdles were first seen in New Zealand waters in the 1970s.[112]

The fate of microplastics on land is not well studied, but research is demonstrating that these particles are accumulating in dust and soils,[26,72–75] and have been detected in air.[9,71] Microplastics on land may be retained in the soil or washed into rivers and streams during periods of rain.[38] On land, known problem areas include farms where plastic rope, silo wrap, sheeting, packaging and netting is left to accumulate and fragment into agricultural soil.[38]

PHOTO | Mangrove plants on the edge of Whangamata Harbour. **Photo credit:** Dave Allen, NIWA

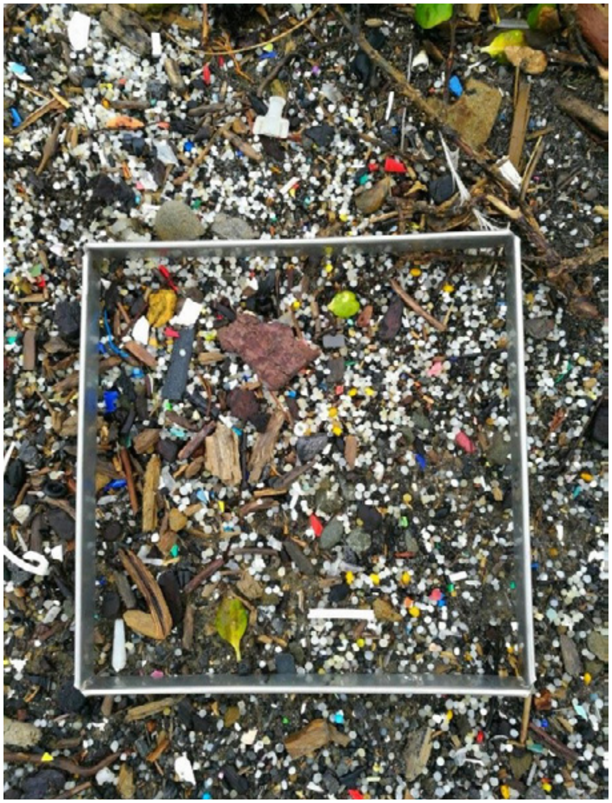
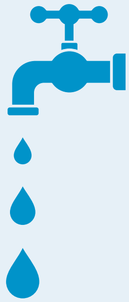


PHOTO | Nurdles washed ashore at Evans Bay, Wellington. The transect sampling grid (25 cm^2) contains hundreds of nurdles. **Photo credit:** Phil Clunies-Ross

Plastic-based glitters are primary microplastics – they are frequently found entering and leaving municipal wastewater plants, and are therefore being discharged into the environment.[120,121]



Te hauora, te waiora me te taiao

How plastics affect human and animal health, and the environment

The majority of plastics produced are still in existence in some shape or form[33] and it is only in the past 15 years that researchers have begun to understand the complexity and scale of this issue.[6] For example, plastics lost to the environment can have ecological effects by changing soil structure and affecting the microbes and plant life growing there.[26,67,123]

Plastic pollution may damage habitats, reduce biodiversity, and pose a threat to health and welfare. This threat will continue, and worsen, if the input of plastics into the environment continues to increase. The impacts on seabirds and marine animals are best understood.[23,124] Many of the species affected are already rare and endangered, including some of New Zealand's marine birds and mammals.[98,124–126]

For Māori, understanding and connecting with the natural environment is integral to identity, whakapapa and culture. Plastic waste and debris can affect the mauri, or life force, of the environment, which can therefore affect cultural health and wellbeing.[127] Customary harvesting practices that may involve higher levels of consumption of raw fish, shellfish, and whole fish also give greater exposure to potential health risks. These factors, and the depth of cultural connection with the natural environment, mean that Māori will experience a disproportionate burden of risk from plastic waste in Aotearoa New Zealand.

Animal entanglement

Plastic pollution can cause harm to animals through entanglement, often affecting an animal's ability to move, eat, escape predators and successfully reproduce. Often, they will die if they cannot escape entanglement.[6,101] This global issue affects numerous species, including birds, marine mammals, turtles and fish.[23,124]

Abandoned, lost or discarded fishing equipment is especially harmful to animals in the marine environment. Fishing nets, line, rope and pots are designed for long-term use.[6] These plastics do not degrade easily in the marine environment and one piece of discarded fishing equipment can entangle, capture and kill many marine species. Animals caught in these lost or abandoned nets and traps will often attract other species, which can also become trapped. This cyclical process may continue for years or even decades, depleting commercial fish and shellfish stocks.[85,86,101]

In terrestrial environments, plastics incorporated into bird nests also pose an entanglement threat. A crow hatchling study in California showed that entanglements, particularly from long pieces of plastic including synthetic twine, string and rope, were more common in agricultural areas than in urban environments.[128]

Plastics as a vehicle for invasive species and disease

Plastic debris can provide an artificial environment for foreign and invasive species to travel around the world's oceans, colonising new locations when the conditions are favourable. This process, known as 'rafting,' naturally occurs on materials such as wood and pumice[101] which are colonised with lifeforms including bacteria, algae and barnacles.[129] Compared to natural substrates, plastics can be more resilient and can travel vast distances, posing a risk for global biosecurity.

Large concentrations of plastics in our oceans increase the opportunity for invasive species to colonise sensitive environments or spread disease.[2] The threat from plastic debris to New Zealand's biosecurity is not yet known. However, over 150 marine species have been identified attached to plastic debris stranded on coastlines in the North Island of New Zealand, many of which may have travelled from overseas by rafting on plastics.[101]

Plastic debris from aquaculture provides a potential biosecurity risk. A New Zealand study identified both native and non-indigenous species were associated with plastic rope debris originating from aquaculture facilities.[131] The potential biosecurity threat increases for beaches with built structures such as jetties and boat ramps close to shore, that facilitate debris accumulation.[131]

In the Asia-Pacific region, corals with plastic snagged on them are much more likely to be diseased (89%) than corals without any plastic debris (4% diseased).[130]

Scientists have started a five-year research project investigating how microplastic contamination affects our native species, environment, tāonga and health in Aotearoa New Zealand.[132] As part of this project, scientists from the Cawthron Institute are investigating plastics as a biosecurity threat.[133]

Ingestion of plastics by animals

Many animals, including reptiles, birds, mammals and fish can eat/ingest plastic debris by mistaking it for natural prey and food.[124,134–136] As an example, plastic bags can resemble jellyfish in water and are commonly eaten by toothed whales, dolphins and turtles.[11,101] The effects can be devastating with large plastic items interfering with the ability of an animal to breathe, eat or digest food potentially resulting in its death.[137] When plastics are mistaken for food and ingested they can starve the animal, retard development and hinder the animal's capacity to escape from predators and to reproduce.[138]

In New Zealand, there have been reports of sharks, seals, turtles, fish and mussels ingesting plastics, often resulting in injury or death.[98,101,139] New Zealand's seabirds are also vulnerable to ingesting plastic, with the earliest observations dating back to 1958,[140] with implications for customary practices of tītī or muttonbird harvesting.[141]

Are microplastics harming animals?

Microplastics can be ingested by various animals, ranging in size from tiny creatures known as zooplankton,[134] to sharks and whales.[142,143] The likelihood of microplastics being eaten is influenced by their abundance in the environment and how closely they resemble food.[138] Laboratory studies indicate that microplastics can potentially transfer through the food web when marine, terrestrial and freshwater species that have previously ingested microplastics are preyed on by other animals.[38,138,144,145]

Microplastics eaten by larger marine animals will generally pass through their bodies. However, research does show that microplastics can be retained in the gut for extended periods, where they may cause abrasion and damage to internal tissues.[138,146] Nanoplastics can pass through the gut wall and travel to different parts of the body, such as the lungs and liver, where they can cause damage.[138,147] Further research is required to understand the potential health implications from ingesting microplastics.[104]

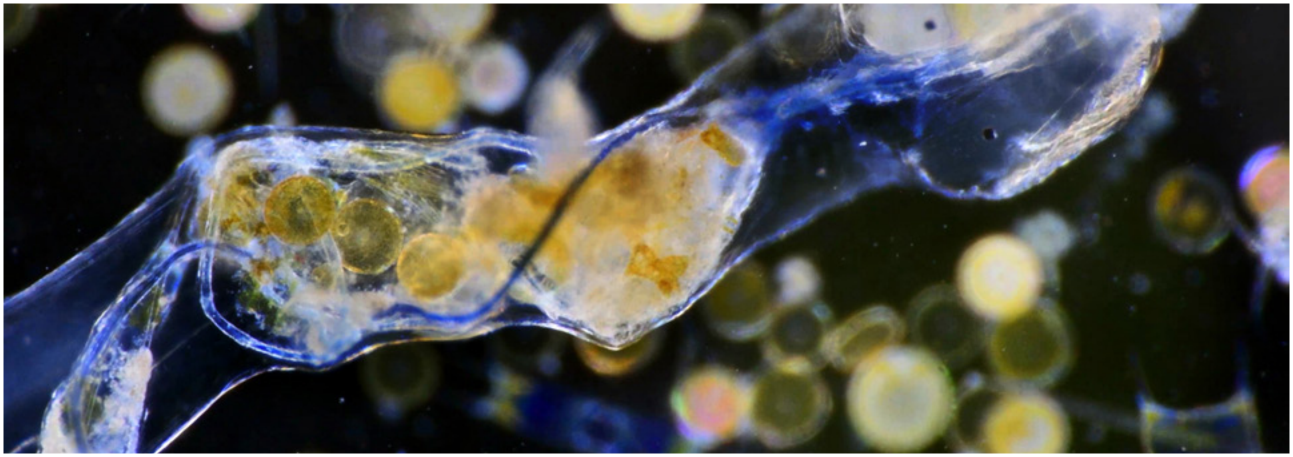
Smaller animals, including marine and freshwater invertebrates, can suffer a range of effects from ingesting microplastics including reduced reproduction and growth.[38,148] These effects are generally caused by physical damage including lacerations and inflammatory responses as well as reduced feeding behaviour when microplastics are consumed instead of digestible food.[38] Filter feeders such as mussels and oysters are particularly vulnerable to ingesting microplastics as they filter high volumes of water while feeding.[149] Effects vary between species and by the types of plastic, and the concentration of microplastics.[38,148] Some invertebrate species can survive at the microplastic concentrations likely to be found in the environment.[148]

Toxic chemicals associated with plastics

Various chemicals incorporated into plastics as raw materials or additives during manufacture can leach from plastics into the environment. Humans and other animals are also exposed to these chemicals when they ingest plastics, when these chemicals leach into food, or are released into the atmosphere when plastics are burnt.[22,39,150] Some chemicals directly associated with plastics have been detected in humans[24,151] and wildlife including birds and various marine species.[152]

These raw materials or additives may pose a health hazard as potential carcinogens and/or endocrine disrupting chemicals.[24,150,152] The endocrine system is an important chemical messaging system that regulates animal and human mood, development, metabolism and reproduction. Heavy metals such as lead, cadmium and tin are used during the manufacturing process including as catalysts, fillers, and colouring agents, and can pose a health risk.[152] Some additives, particularly persistent organic pollutants (POPs), including some brominated flame retardants and polychlorinated biphenyls (PCBs), can accumulate in the tissue of these animals and may transfer through the food web.[39,104,153,154] Plastics are not the only source of these substances in the environment, but contribute a possible pathway for exposure.

PHOTO | Marine arrow worm, *Parasagitta setosa*, having eaten a blue plastic fibre about 3 mm long.



Endocrine disrupting compounds interfere with hormone biology. These compounds have been associated with abnormal growth, changes in reproductive, neurological and immune function, and may lead to obesity, diabetes and some types of cancer.[24,155] Some additives with the potential to disrupt the endocrine system are well studied and regulated, while most require further research to understand their potential effects on human and animal health. Phthalates and bisphenol A are well studied and regulated, particularly in food packaging, due to concerns about their potential to be carcinogenic at very low doses.[24,25,156,157] A report for the Ministry of Primary Industries in 2017 on the migration of packaging chemicals in New Zealand foods found phthalates and printing inks in the sampled foods, but at levels that did not pose a health risk.[158]

Adsorbed pollutants

Some pollutants including many persistent organic pollutants (POPs)[161] and heavy metals[152] can also adsorb or 'stick' to plastic surfaces. As a result, plastics can act like 'sponges' in the environment, passively collecting chemicals onto their surfaces. Microplastics have a high surface area, providing many potential sites for chemicals to bind, making them very good at concentrating chemical contaminants.[69]

While plastics can remove some POPs from the surrounding water, there is concern about what happens when plastics containing these adsorbed pollutants are ingested by animals. The ability of some POPs, such as polychlorinated biphenyls (PCBs), to bind to plastics is particularly concerning due to their toxicity at low doses.[104,162] These toxic and persistent chemicals are widely distributed in the marine environment[163] and are readily concentrated onto plastic surfaces, at up to one million times the concentration than in the surrounding water.[39,161,164] Studies have shown that these chemicals can transfer from ingested plastics to animal tissue where they can become concentrated within the animal and transfer through the food chain.[147,165,166]

Bisphenol A (BPA) is most commonly used in the production of polycarbonate plastic, a rigid material that is used in some food and beverage containers and the epoxy lining of food storage cans. BPA can leach into our food and drink from these materials, particularly when heated. Almost all individuals in developed countries now have detectable levels of BPA in their tissues.[24,151] Research into whether or not the trace levels of BPA leached from plastic food containers result in health problems is ongoing.

A major research programme by the US Department of Health into BPA should report later in 2019.[159] Regulations around food grade plastics sets out maximum allowable levels of certain contaminants that may be present in food after contact with packaging to ensure food is safe for consumption.[160]

Environmental scientists can use plastics samplers at testing stations within aquatic environments to absorb and calculate the concentration of contaminants in the water.[152]

Do plastics affect human health?

Plastics are beneficial to human health through their use in medical applications (see How do we use plastics, page 6) and for protecting our food and beverages. Plastic bottles and containers provide a way of distributing water that is safe to drink in locations where there are major issues of water contamination. Plastic packaging limits food and beverage spoilage through microbial contamination.

It is likely that we are ingesting some level of plastics in our diet. A rapidly growing body of research is showing that ongoing accumulation of toxins associated with plastics poses a risk to our food safety and public health.[6,150,167,168] However, the levels of plastics and associated chemicals we are exposed to in our diet compared with other everyday activities has not been assessed.[169]

Microplastics have been found in many seafood species, including various kinds of fish and shellfish.[149,170,171] Research into commercial fish species in the South Pacific identified microplastics in up to 25% of fish collected from Auckland, Samoa, Tahiti and Rapa Nui, Easter Island.[172] These plastics are often in the gut, which is removed before eating; however, they may still pose a dietary risk through plastic-associated contaminants transferring to other tissues. Microplastics in shellfish are likely to contribute less than 0.2% of dietary exposure of bisphenol A, polyaromatic hydrocarbons (PAHs) or PCBs.[9]

Microplastics have also been detected in common table salt,[173–175] tap water [176] and up to 90% of bottled water.[177] Recently, microplastics have even been found to be present in the air,[9,71,178] and in household dust.[169] Most of us are likely to breathe in microplastics on a day-to-day basis. However, it is not yet known what degree of harm this exposure could be causing us or what happens to such microplastics within the human body.[39,178]

Scientists found on average 325 microplastic particles per litre of bottled water.[177] Most of these particles were very small in size (6.5 to 100 µm), and only about 10 particles per litre were larger than 100 µm.

Plastic pollution and its impacts on society

Plastic pollution puts pressure on our recreational, cultural and spiritual values. New Zealanders take pride in their environment and the opportunities and values it provides to its people and its visitors.

The Māori concept of kaitiakitanga, the guardianship and management of the environment, recognises that there is a responsibility for caring for nature and maintaining its resources for future generations.[179] Plastic waste and debris can impact the mauri of the environment, and therefore impact the people.[127]

Plastic pollution harms communities and industries that rely on the environment to support their livelihoods through contaminating food and water; damaging a location's beauty and intrinsic cultural value; and reducing recreational opportunities for residents and visitors.[66] This harm results in losses of revenue and jobs to these regions, many of which are reliant on tourists for their primary source of income.[66] Marine plastic pollution also causes issues for the shipping and fishing industries by damaging propulsion and cooling systems on ships.[6,8,85]

There are social, economic, and environmental costs of manufacturing and disposal of plastics including greenhouse gas emissions, water depletion during production, and environmental pollution from discarded plastics.[53,180] The environmental costs of replacing plastics in consumer products and packaging with alternative materials such as paper, glass and aluminium, may be even greater due to increased energy needed for production and transportation.[180]

Me pēwhea te whakaeke iho te para kirihou?

How can we reduce plastic pollution?

Policy makers, organisations, manufacturers and consumers can take action to improve the management of plastic waste and reduce the effects on the environment. Social attitudes to plastics are evolving, with a gradual switch to practices that reduce plastic pollution.[6] Plastic pollution is now not just seen as a nuisance or an eyesore, but a problem that causes extensive harm to our environment and poses potential risks to human health.[53] Waste plastics that are not reused and recycled also represent a wasted resource from loss of material in the economy.[17]

International and regional action

Governments around the globe have begun to take action to mitigate plastic pollution.[19] Regional and international initiatives involving governments and industry are seeking to reduce reliance on unsustainable plastics and encouraging the innovation of new solutions to prevent plastics entering the environment. The prevention and reduction of marine pollution, including plastics, is one of the United Nation's targets in the Sustainable Development Goals. The United Nations Environmental Programmes' *#CleanSeas Campaign* and the *Commonwealth Clean Oceans Alliance* are two examples of the many initiatives that target marine plastic pollution.[19,181,182] Reports from the United Nations Environmental Programme have assessed global, national and regional governance strategies for addressing plastic pollution, noting many of these have limited scope and application and much more still needs to be done to tackle the issue.[19,183]

New Zealand's Waste Minimisation Act 2008 aims to reduce waste generation through imposing levies on waste disposed in landfills, and help to fund waste minimisation initiatives. The Act can be used to ban certain products, for example the ban on the manufacture and sale of wash-off products that contain plastic microbeads.[119] The Act also contains provisions to encourage, or in certain circumstances require, stewardship schemes where businesses and organisations take responsibility for managing the environmental impacts of their products. Accredited stewardship schemes under this Act include recycling schemes for certain agricultural and horticultural plastics.[37]

What actions can we take?

Business and the manufacturing industry

The current global economy revolves around the manufacture of products designed to break or be discarded after they are used or become outdated, encouraging the purchase of new products.[6] We are not able to effectively process and manage the quantities of plastic waste we currently generate. With a growing global population and an escalating demand for material goods and safe transportable food, it is expected that the production of plastic could double in the next 20 years.[5]

Businesses can help tackle this issue by reducing or phasing out plastic materials in their products and packaging, or ensuring plastics in their products are reusable or recyclable.[19,53] Businesses are also signing up to new initiatives, such as the 'New Zealand Plastic Packaging Declaration', the 'New Plastics

The 'three R's' concept to reduce, reuse and recycle plastics has been in use for nearly half a century, encouraging people to think about their consumer choices and reduce the quantity of plastic in their lives. A fourth and fifth 'R' have been conceived as additional ways to address the generation of plastic waste; remove excess plastics from products where possible; and recover energy from plastic waste when appropriate.[6] A further 'R' is for manufacturers to redesign their products to reduce plastic waste and allow for the reuse of plastics.[6,53]

Economy Global Commitment' and the 'Circular Economy Accelerator'.[56] The Consumer Goods Forum acknowledges the need for industry to help reduce plastic waste through optimising packaging design and making it easier to recycle and reuse waste plastics.[184]

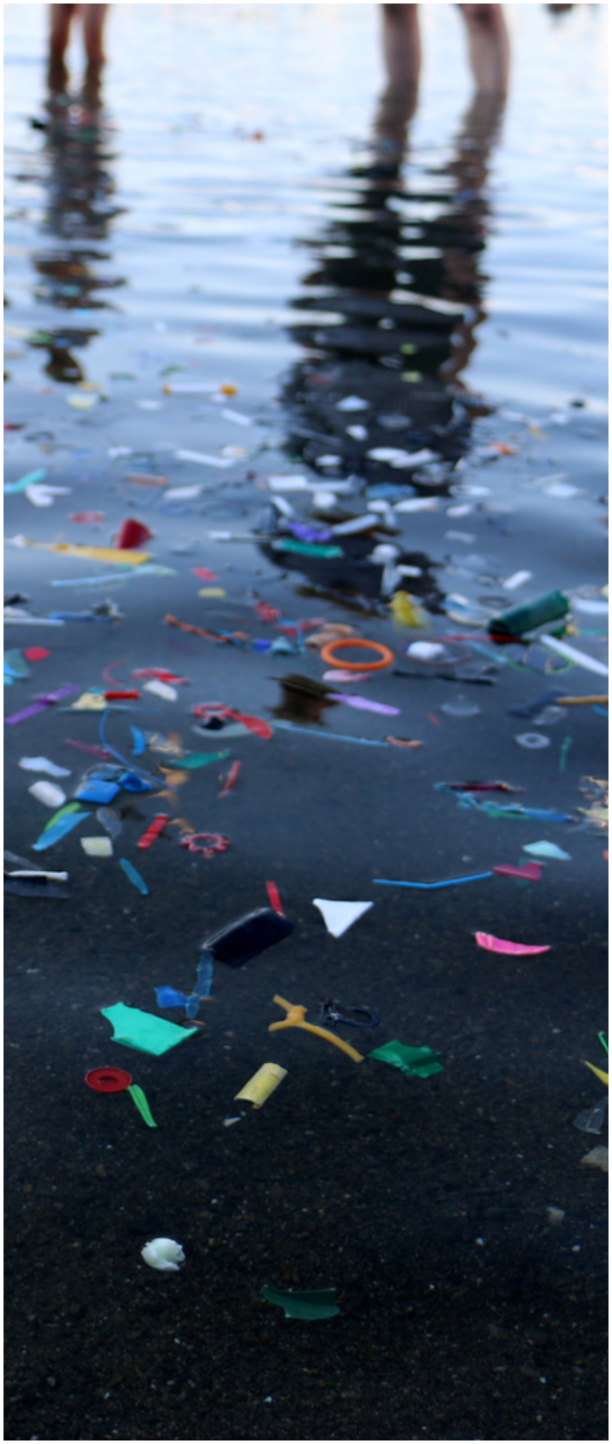
Technologists can design new products in such a way that plastic components can be disposed of responsibly with preference for recovery, regeneration and reuse of plastics.[53] Products can also be designed to reduce waste including specific design for extended use or low wear and tear during use. Products designed with end-of-life in mind would avoid mixed plastics, dyes and other additives that complicate recycling or make the recycled product less desirable.[53] There is a need for consistent and clearly identifiable labelling of plastics so that they can be diverted to the correct waste-stream.[56] Waste infrastructure for collecting, storing, and processing (sorting and recycling or composting) are required to support these initiatives.[53]

Biodegradable plastics can be an effective alternative to traditional plastics provided they are sourced from sustainable materials, and there are suitable collection and processing systems for disposal. Oxo-degradable plastics that break down when exposed to air are not a viable solution as these plastics merely fragment into small pieces more rapidly than other plastics, rather than biodegrade.[17,61] Researchers are developing innovative plastics that are home compostable, edible or water-soluble and would be easier to degrade in various environmental conditions.[17]

Consumers

Two out of three New Zealanders are now concerned about the build-up of plastic in the environment.[185] However, we can all help to prevent it occurring in the first place. One way to reduce plastic pollution is to minimise the amount of plastics that we use in our daily lives.[11,19] Consumer pressure has been effective at encouraging businesses to consider more sustainable alternatives to disposable plastic products, including reducing the use of plastic bags, straws and packaging.[19] This pressure resulted in New Zealand banning single-use plastic shopping bags from July 2019, stopping millions of these bags entering the environment every year.[186]

However, relying on consumer behaviour change approaches is problematic for many reasons, including that plastics are ubiquitous and embedded in all aspects of our daily life – in food production, transport, communications, hygiene, medical and personal care. Whilst consumer choice can contribute to sustainable change, avoiding excess plastics and reducing material demand requires significant change in regulation, infrastructure, technologies and social practices in order to influence household consumption.[187–189]



Managing plastic waste in New Zealand

For more information about what can be done to reduce the impact of plastic in New Zealand, see the "Rethinking Plastics in Aotearoa, New Zealand" project of the Office of the Prime Minister's Chief Science Advisor.[190]

Knowledge gaps

A better understanding about the use, disposal and effects of plastics in the environment is required to help mitigate harmful effects of plastics debris and better manage disposal of plastics and plastic pollution. Some knowledge gaps include:

- What is the amount of plastics collected nationally across New Zealand's recycling schemes compared with landfill waste?[36]
- Where, how, how much, and what types of plastic, particularly microplastic, enters the environment including into air, freshwater and terrestrial systems?[9,109,191]
- Where does plastic debris on New Zealand shores originate from and how much of these plastics are carried here from other countries?[6,8,23]
- How much leaching takes place from plastics (particularly absorbed chemicals) into animals[6] and humans[178] compared with other routes of chemical exposure?
- What level of microplastics do we encounter daily through our diet or airborne sources, and what are the potential health risks associated with these exposure rates?[9,39,178]
- To what extent does the ingestion of microplastics actually harm individuals and populations in the real environment?[6,104,109]
- How do we best deal with plastic waste and plastic pollution, drawing on interdisciplinary knowledge across science, technology, social sciences and the humanities?[9]

Ngā mātanga pūtaiao
Our experts

Royal Society Te Apārangi staff prepared this paper with assistance from Dr Phil Clunies-Ross and guidance from the following experts:

Dr Stewart Collie, Dr Trisia Farrelly, Associate Professor Sally Gaw, Dr Julie Hope, Dr Elspeth MacRae, Professor Indrawati Oey and Associate Professor Kevin Simon.

The Society would like to thank the following experts and organisations for their valuable input in contributing to and commenting on the paper:

Ms Virginia Baker, Distinguished Professor Debes Bhattacharyya (FRSNZ), Dr Erik Behrens, Dr Stephanie Borrelle, Dr Kirsten Edgar, Mr Stephen Harris, Dr John McKinnon (FRSNZ), Dr. Velram Mohan, Professor Andreas Neef, Dr Olga Panthos, Professor Kim Pickering, Ms Helena Ruffell, Professor Mary Sewell, Dr Dawn Smith, Professor Jadranka Travas-Sejdic (FRSNZ), Associate Professor Johan Verbeek, Auckland Council, Ministry for the Environment, Ministry for Primary Industries, New Zealand Product Stewardship Council, Office of the Parliamentary Commissioner for the Environment, Office of the Prime Minister's Chief Science Advisor and WasteMINZ.

Professor Michelle Coote and Associate Professor Mark Hamann provided independent international review of this paper.

He mihi
Acknowledgment

This work was made possible by a bequest from the Baumgart estate.

Ian Baumgart had a distinguished career as a soil scientist in the Department of Scientific and Industrial Research (DSIR). Ian was awarded a Harkness Fellowship in 1962 and became New Zealand's first Commissioner for the Environment in 1973. Ian was also a recipient of Royal Society Te Apārangi Thomson Medal for service to New Zealand science, the Queen's Jubilee Medal and the Queen's Service Order. He passed away in September 2013.

He rārangi pukapuka

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Version 1.0
Print ISBN: 978-1-877264-38-2
Online ISBN: 978-1-877264-39-9

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Published July 2019