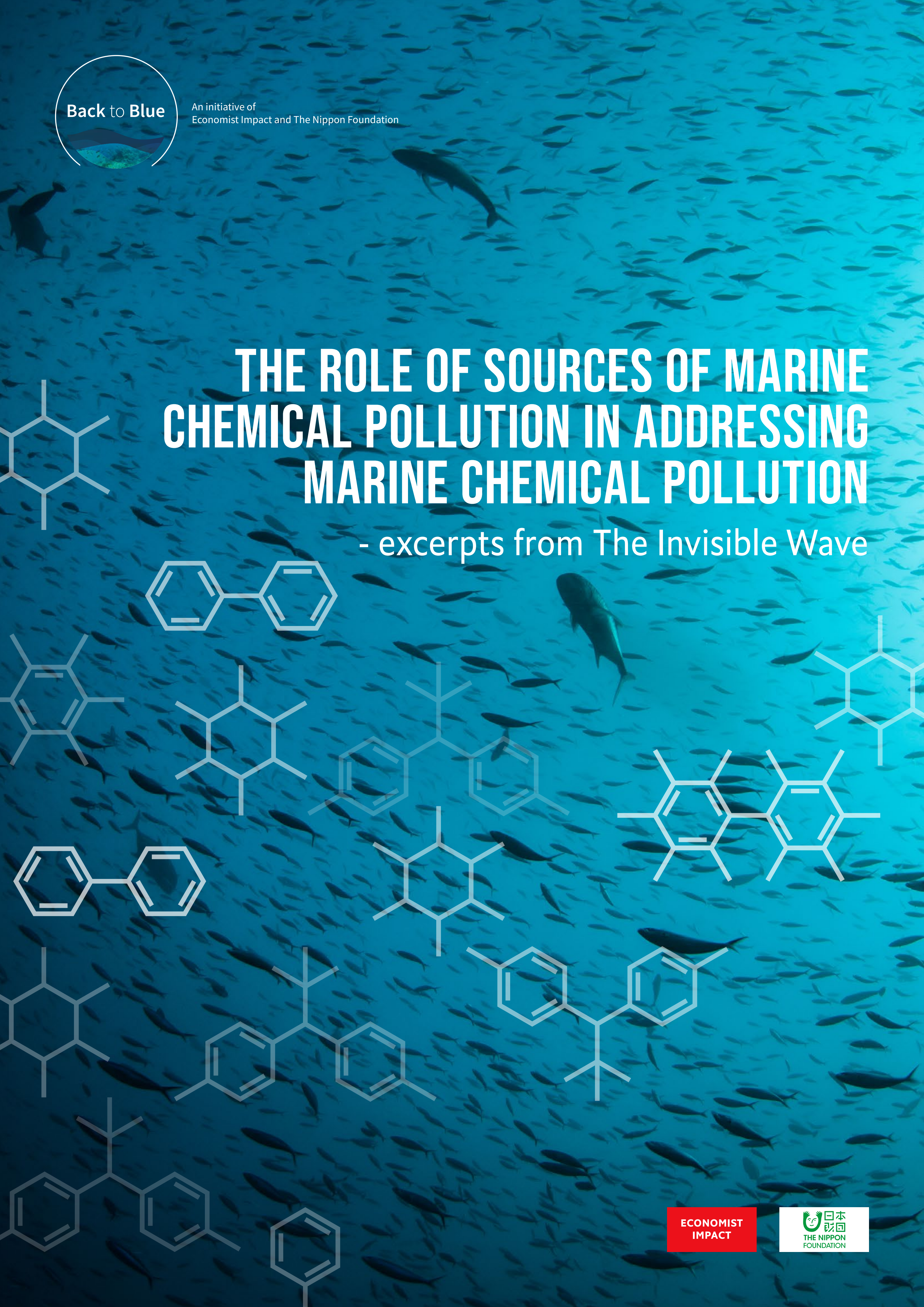
Back to Blue

An initiative of
Economist Impact and The Nippon Foundation

THE ROLE OF SOURCES OF MARINE CHEMICAL POLLUTION IN ADDRESSING MARINE CHEMICAL POLLUTION

- excerpts from The Invisible Wave



ECONOMIST IMPACT

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About The Invisible Wave

Chemical pollution—of land, air, rivers, watersheds—has been a festering issue for decades, occasionally prompting resolute action. But only recently has the scale of chemical pollution become more apparent. Chemicals in the form of nutrients, heavy metals, persistent organic pollutants, sewage and many others are being uncovered almost everywhere—in soils, aquifers, food chains, remote ecosystems such as the Antarctic, in the highest and lowest places on Earth, and in humans. As evidence accumulates of its impact on nature and human health, there is a gathering consensus that chemical pollution is a first-order global threat, alongside climate change and biodiversity loss, and often compounding the impacts of these other issues.

This awakening to the systemic nature of chemical pollution understandably focuses on where humans live, on land. This report seeks to raise awareness of marine chemical pollution, as its scale and potential impact—and thus urgency—are not widely appreciated, and to focus minds on delivering solutions that prevent, reduce and minimise chemical pollution in the marine environment. An aspiration towards zero pollution is gaining currency. The hope is not so much that the ocean can be free of pollution, which may be impossible, but rather that more will be accomplished if the goal is seen to be ambitious. Back to Blue shares this aspiration.

The Back to Blue initiative grew out of the findings of our 2021 global survey, which showed that plastic and chemical pollution are the two greatest concerns that people have about ocean health, with climate change ranked third. As this report will show, the three are profoundly connected.

The ocean is fundamentally important to all life on Earth. It covers 70% of the planet's surface and comprises 99% of its habitable space.[1] It is therefore remarkable that there has not yet been a serious scientific assessment at scale of marine chemical pollution and its impact on life in the ocean, marine biodiversity and how ocean ecosystems function, and ultimately on the ocean's overall health. The Invisible Wave seeks to set out clearly what is known about its impact and where our knowledge gaps sit, prompting the urgent need for more research.

This urgency is underscored by a further point that this report seeks to demonstrate: that despite lacking a complete picture of the dangers posed by marine chemical pollution, failing to act now is a risk too far. The report therefore suggests solutions for various groups of stakeholders that, if taken, would ameliorate chemical pollution in the marine environment. It is a starting point: mapping out the paths to those solutions is the function and aim of a research and engagement programme that the Back to Blue initiative will undertake following the launch of the report.

Despite lacking a complete picture of the dangers posed by marine chemical pollution, failing to act now is a risk too far

The marine environment

This report concerns itself with the impact of chemicals on the marine environment. In other words, we are looking at the saltwater part of the hydrosphere: from the deep ocean to coastal seas, bays and estuaries, and including the array of ecosystems found there, including coral reefs, seagrass beds, mangroves, mudflats, sediments and water columns. The freshwater part of the hydrosphere—rivers, land run-off and groundwater—is a key transport mechanism for chemical pollution reaching the ocean and coastal areas, but otherwise is not a focus of this report.

The importance of the saltwater hydrosphere to life on Earth is greatly underestimated. Not only is the ocean a crucial food source for billions of people, but it also provides more than half the planet's atmospheric oxygen, acts as a massive carbon sink (without which global warming would be far worse), regulates the weather and climate, and provides countless formal and informal jobs in economically crucial activities that include fishing, shipping, tourism, recreation and offshore hydrocarbon exploration. The ocean provides services estimated to be worth trillions of dollars—services that are at risk from marine chemical pollution.

Despite the ocean's centrality to all life on Earth, humanity's view has been that the seas have an infinite capacity to absorb waste. That is wrong. While there is patently a need for more research on the harm that chemicals inflict on the marine environment, the existing evidence is clear: chemical pollution has damaged marine biota, from polar bears to plankton to large-scale ecosystems such as the seas and beyond. As the production and use of chemicals rises, so inevitably will their impact escalate too.

There are many reasons why this matters. Science has already shown that climate change is in large part due to human activities, and this anthropogenic cause is true too for marine chemical pollution. Importantly, the two are linked: science is learning that synthetic chemicals in the seas can increase climate change's negative effects, while the effects of climate change (including warming water temperatures, increased acidification due to higher carbon levels, and greater salinity) can heighten the negative effects that chemicals have in the marine environment. In other words, climate change and marine chemical pollution are deeply interlinked. Consequently, it is crucial to tackle both.

Failing to do so will lead to accelerated damage to marine life and biodiversity—"the variety of life ... and the natural patterns it forms"[2] —and would come even as the number of species on Earth is declining at perhaps its most rapid rate due to factors like climate change, pollution and activities like overfishing. And while biodiversity loss is common to the terrestrial environment and ocean, one key difference is that we know very little about countless marine creatures. Consequently, when it comes to the ocean, we often do not even know what we are losing.[3]

This damage to marine biodiversity, and the complex interactions that underpin it, has important knock-on effects on the functioning and resilience of ocean ecosystems. Exactly how such ecosystems are affected by complex and multiple stresses such as warming waters, acidification, chemical pollution and the growing industrialisation of the seas, including overfishing, is still not well understood. The science is in its infancy. Yet rising levels of marine chemical pollution are an important factor in undermining, even potentially imperilling, the capacity of marine ecosystems to provide the services on which all of humanity relies, and that are crucial to the stability of wider systems, including climate and the carbon cycle.

Why marine chemical pollution?

Marine pollution as a broad topic has deservedly gained greater attention in recent years, with plastic taking centre stage. As many of our interviewees pointed out, this is because plastic pollution is highly visible and emotive: who can forget the video of a turtle with a plastic straw in its nostril, or media coverage of whales and seabirds found dead with plastic waste in their stomachs?

Plastic is a challenge of epic proportions and complexity, and is also important to the chemicals story. Marine chemical pollution, however, is of a different order:

- For a start, it is invisible and, in a world where awareness-raising is often most effective when it is visual, as the turtle video shows, this hinders understanding its scope and significance.

- Second, synthetic chemicals production is increasing rapidly and set to grow fastest in the coming years and decades, with many new chemicals being created and circulated. The green transition is an important driver of these trends.

- Third, production is shifting to middle- and lower-income countries where regulations to manage chemicals and combat chemical pollution are typically limited and less effective. At the same time, higher-income countries that have addressed conventional chemical contaminants to some degree face new challenges with the relentless pace of chemicals' innovation and associated pollution risks.

- Fourth, scientists are open about the need for more research to better determine how marine chemical pollution will damage the ocean, which is not surprising given that there are tens of thousands of chemicals with, in most cases, completely unknown effects on human health and the environment.

- And fifth, while marine chemical pollution continues to be a threat in wealthier countries, much of the new and incremental damage taking place globally is in poorer countries where people and ecosystems are at a great remove from the markets ultimately driving the increased use of chemicals. This further decreases its visibility.

For these reasons and more, as we explore in detail in this report, marine chemical pollution is an under-appreciated and underestimated danger. It must not be.

Key chemicals and their sources

A recent study found that there are at least 350,000 synthetic chemicals and mixtures of chemicals, with thousands being added each year.[4] Yet, worryingly, we know almost nothing about most of their health and environmental consequences. Additionally, even when chemicals are deemed so harmful that they must be replaced, their replacements are also often found to be toxic (known as regrettable substitution).

In recent years, hundreds of chemicals have been placed on lists for banning, restriction or substitution. Of particular concern are persistent organic pollutants (POPs), which, as the name indicates, linger in the environment, can travel long distances, and have serious effects on the environment and biota. Although hundreds of chemicals have been recognised as POPs, some researchers believe thousands of other unrestricted chemicals meet the requirements to be classified that way.

The sheer volume of chemicals makes drafting a list of the worst of them a significant challenge, and inevitably this report does not provide a comprehensive list of all chemicals of concern. For that reason, our expert panelists have suggested a list of classes or groups of chemicals that they feel are the most severe or that could have the greatest impact in terms of:

- Environmental health, particularly the health of the ocean.
- Human health.
- Economics (quantifying this is a long-term goal of the Back to Blue initiative).

Given their effects, POPs are an obvious category for inclusion, and feature heavily in this report. The others include heavy metals, nutrients, pesticides, plastics, pharmaceuticals, radioactive materials, oil products, household chemicals and pseudo-persistent chemicals. While some of these chemicals are banned or restricted, most are not.

By default, these are the chemicals or chemical groups that we know most about. However, future research will surely identify others that constitute a greater threat or that inflict increased harm to marine ecosystems. It is entirely possible, then, that the potential impact of marine chemical pollution will prove to be wider and more serious than currently estimated.

That raises two important questions:

- What effects do these chemicals have in the marine environment?
- How do they enter the marine environment?

Answering the first with accuracy requires more research, particularly when it comes to determining how chemicals react individually and collectively in the real world. The answer to the second question begins by identifying the various parties involved in the chemicals value chain: the chemicals industry (which to date has externalised its costs), its clients (more than 95% of manufactured goods contain chemicals) and financiers. It also includes regulators and governments (with public sector sources of pollution including dredging and defence), end-of-life operators and civil society.

Consumers are also of note. Sources of marine chemical pollution here include pesticides, fertilisers and plastics, with pharmaceuticals and personal care products—sometimes referred to as chemicals of emerging concern—becoming increasingly important due in part to the growth in the number and size of coastal cities and towns in recent decades, and with the background rise in population numbers and incomes globally.

Our efforts to map accountability across the value chain of the chemicals' lifecycle also includes the pre-production phase: extracting and processing the fossil fuels, minerals and metals used to manufacture chemicals, with oil and gas majors like ExxonMobil, Shell and BP involved in both extraction and chemicals manufacturing. Given the projected growth of the chemicals industry and its role at the heart of marine chemical pollution, as well as often-lax industry oversight, accountability will become more important going forward.

The end-of-life phase of the chemicals value chain is another important source of marine chemical pollution, with municipal waste, e-waste and untreated sewage growing in importance. Plastics, for instance, are laced not only with chemicals from the manufacturing process, but they also break down into micro- and nano-sized particles that can adsorb chemicals in the water and transport them vast distances.

Overseeing, in theory at least, this vast value chain from extraction to disposal are regulators.

The success of any strategy to combat marine chemical pollution hinges on regulators enacting and enforcing stricter rules on pollution, and working in concert with peers elsewhere to combat regulatory arbitrage, where firms move to jurisdictions with less oversight. Encouragingly, research by the European Commission shows that regulations bring numerous benefits, cutting the costs of marine chemical pollution on the environment and human health, and lowering water pollution levels.

The success of any strategy to combat marine chemical pollution hinges on regulators enacting and enforcing stricter rules

Regulations, properly enforced, also require that producers adhere to common standards, and should be employed to ensure that product designers factor in end-of-life aspects, particularly impacts on the marine environment.

The dangers of inaction

Most marine chemical pollution is caused by humans, and most of that has taken place in the past 100 years. Given that the pace of chemical production and innovation is predicted to rise rapidly in the coming years and decades, and that much of the production growth will happen in countries with less regulation, it is likely that marine chemical pollution will get significantly worse unless action is taken.

Assessing the scope, extent and impact of marine chemical pollution, now and in the future, is a pressing task for scientists and environmentalists, as is evaluating the cost of such pollution. Armed with a clearer picture, action is more likely to succeed. And while inaction remains a possible response, it is no longer necessarily the likely response. The past few years have seen a broad awakening to the problem of pollution. The UN Environment Programme (UNEP) has elevated pollution (chemicals, plastics and waste) alongside climate change and biodiversity loss as one of three interconnected anthropogenic crises. Pollution is one of the key stresses that led the UN to state that ocean sustainability is "under severe threat", and that addressing pollution was vital to achieve the UN Sustainable Development Goals (SDGs). Meanwhile, *New Scientist* rang the alarm in mid-2021 with the headline: "Why chemical pollution is turning into a third great planetary crisis".[5] The Stockholm Resilience Center has, for the past decade, included pollution as one of several planetary boundaries within which humans need to operate to ensure stable Earth systems.

The language of crisis and emergency is nothing if not a call to action. While more research (and funding) is needed to close some significant knowledge gaps, it makes no sense to refrain from acting until every gap is filled. After all, it will be decades before we understand the effects that the tens of thousands of synthetic chemicals might have on health and the environment, whether individually or collectively, and the world does not have that much time. Additionally, intervening is in line with the precautionary principle, which demands that we act now on the grounds that we know enough about the effects of marine chemical pollution to be concerned about its potential effects.

A large part of this burden to act must fall on the chemicals industry and on its clients in the broader business world. In part, this will require that the business community factor in its impact on marine chemical pollution in the way that it has started to do on climate change.

If the world does not act, it is reasonable to assume that the problem of marine chemical pollution will worsen. Rising production volumes is one reason, but there are others like weak regulation and enforcement, poor product design, the lack of domestic and industrial wastewater treatment in much of the world, and insufficient waste management.

Yet perhaps the biggest problem, our experts said, is assuming that we can keep dumping waste into the ocean because it is vast enough to absorb and dilute the array of toxic substances that we produce. As this report shows, we cannot.

A global problem that lacks local research

The transboundary nature of marine chemical pollution means it affects everyone, no matter how far they are from its production. Toxins have been found in islanders in the Pacific and the Faroes, as well as in people living in the Arctic Circle—and, notably, in women and children in poorer countries who rely on seafood.

Marine chemical pollution, in other words, is a global problem. That said, much of our understanding of its economic costs is derived from a few high-income countries, which means that research is lacking that would be most relevant to billions of people for whom the seas are crucial to lives and livelihoods. This needs to be remedied. Funding should be targeted at the chemicals with the greatest potential to harm ocean biota and, in turn, human health and local economies.

It is also clear that much more research is needed on chemicals and their impact—particularly in conjunction with other chemicals in the marine environment. This needs to factor in climate change variables like temperature, acidity and salinity, as each can affect how chemicals react.

One result of the research bias favouring wealthier nations is that the studies cited often examine marine chemical pollution in the rich world. While this is an unavoidable consequence, we have kept this imbalance in our minds and endeavoured where possible to incorporate research that covers poorer nations. Clearly, a key task for the future is tipping the scales back.

A final point on research is that what is known needs to be brought to the wider community. As UNEP notes, this includes improving the flow of communication between researchers and policymakers. This could help to motivate change by quantifying the costs of inaction and the rewards of intervention. Our bespoke case study on marine chemical pollution in the US Gulf of Mexico, for instance, found that dead zones worsening—where the sea has been starved of oxygen owing to pollution—would cost the US about US$838m a year in fisheries revenue. Taking measures to reduce dead zones, on the other hand, would boost marine biodiversity and therefore increase revenue by more than US$117m.

Industry

As the ultimate source of chemical pollution, the chemicals industry has the primary responsibility to act. It could hugely influence resolving the issue. However, if it fails to act, it could face an existential crisis for two reasons. First, this industry is dependent on fossil fuels to manufacture feedstocks, with the likely regulatory and financial pressures this carbon-heavy operational base will bring. Second, owing to the growing understanding of the impacts of chemical pollution on environmental and human health, there is increasing consumer and investor pressure on this issue, which could ultimately prove as critical as climate change.

Additional pressure on laggards in the sector will come as more innovative firms step up in areas like green chemistry, which could hold the key to sustainable change for the sector, even as clients come under pressure from customers to better manage the chemicals in their product portfolios, and as public awareness compels governments to enforce stricter regulations.

Surprisingly, though, industry efforts have been piecemeal at best, even though the momentum for a circular economy is growing—as with plastics. Accelerating change will require a shift at the corporate culture and systems levels.

Conclusion

Although marine chemical pollution remains a largely invisible problem, this is starting to change. There is now enough evidence to show that the problem is extensive and worsening. Moreover, given the crucial role that the ocean plays in regulating climate and weather, generating oxygen, absorbing carbon, and providing food for billions of people, we also know that inflicting further harm risks too much.

Action, then, is vital. It requires that all stakeholders play their part. Although marine chemical pollution is a huge challenge to solve, it is not impossible. In mapping the sources of marine chemical pollution, the consequences (as we know them) and a series of paths that can resolve one of the defining issues of our times, this report and the Back to Blue initiative aim to raise awareness and galvanise action from all of those involved.

2: Sources of marine chemical pollution

This excerpt of The Invisible Wave seeks to map accountability for marine chemical pollution across the chemicals lifecycle, from those involved in the pre-production phase—including extractors of the fossil fuels, minerals and metals that are used to manufacture industrial chemicals—to those who make and use chemicals, and the public- and private-sector operators that manage the end-of-life waste process.

2.1 Principal findings and recommendations

- **Marine chemical pollution is present along the industry's value chain—beginning with fossil fuel inputs. And the industry is set to grow, with laxer oversight.**
  The chemicals value chain sees fossil fuels, minerals, metals and air converted into a huge array of products—with pollution at every stage of the production processes and beyond. This is of major concern since the chemicals industry, one of the world's largest, is growing fast—and much of its growth will come from countries where regulatory standards are often lower than in the 20th century's chemicals-manufacturing heartlands of the US, Europe and Japan.

- **Manufacturers, consumers and the public sector are notable sources of marine chemical pollution.**
  Chemicals are present in nearly all manufactured products, which means most of the industry's clients also bear some responsibility for marine chemical pollution.

  - On the **consumer** side, pesticides, fertilisers and plastics are key points of marine chemical pollution, with pharmaceuticals and personal care products growing in importance.

  - In the **public sector**, areas of concern include dredging, defence—including legacy munitions that have been stockpiled or dumped—and fire-retardant chemicals.

  - Other underappreciated sources of marine chemical pollution include **e-waste**, of which just 20% was properly recycled in 2016; **untreated sewage**; and **plastics**, which can break down into micro- and nanoplastics that transport chemical pollution around the ocean.

- **Regulators need to enact and enforce stricter rules on pollution; producers need to adhere to common standards.** Given that most future chemicals production growth will come from Asia-Pacific, the Middle East and Africa, and that two-thirds of sales of industrial chemicals (excluding pharmaceuticals) will be in Asia by 2030, countries in these regions should take regulatory steps to protect their citizens and environments—underpinned by stronger global action, as some countries in these regions lack sufficient national capacity. To minimise chemical pollution and be seen as responsible, industry players need to ensure their facilities in Asia and other regions operate at a minimum to the standards required in their home countries.

- **Product designers must factor in end-of-life considerations.** Too few manufacturers take end-of-life factors into account when designing and making products, thereby contributing to marine chemical pollution. Given that more than 95% of manufactured products rely on chemicals to some degree, manufacturers must factor in end-of-life considerations.

- **Climate change events and the growth of coastal cities need greater consideration.** Storm surges and the impact of sea-level rise on industrial facilities remain largely underappreciated risks. Industry should do more to take these risks into account, thereby minimising the risks of marine chemical pollution. The number of coastal cities has grown fast in recent decades, with negative effects on the marine environment. City authorities should act to minimise the impacts of marine chemical pollution, particularly by improving wastewater treatment.

Although it is the chemicals industry that manufactures the vast array of marine chemical pollutants, the chain that constitutes the chemicals lifecycle has numerous links and players, all of which play a role in the route to the seas.

This route often varies by chemical: mercury from coal-fired power stations, for instance, is typically carried vast distances in the atmosphere to be deposited in the high seas or polar regions; some PFAS chemicals, on the other hand, are washed into rivers after being used on land, and move from there to the seas.

Other pathways by which chemicals reach the seas include:

- Direct discharge of industrial effluent and mine tailings into the sea or the rivers that lead into them.
- Application of chemicals directly on to the land (such as fertilisers or wastewater sludge), which then is washed by rains into rivers and from there to the seas.
- Untreated or under-treated wastewater from domestic, industrial and business sources like hotels, restaurants and hospitals.
- Stormwater runoff into rivers or freshwater ecosystems.
- Seepage from, for instance, septic tanks into groundwater, which then leaches into rivers and seas.
- Air-dispersed chemicals (including pesticides) settling on the ground, and being washed by rain into rivers and seas.
- Direct discharge of contaminants at sea by vessels.

- Accidents, the dumping of contaminated materials (including chemical weapons) and the effects of extreme weather events or natural disasters on land-based infrastructure.

Most marine chemical pollution begins on land—about 80% versus 20% thought to originate at sea—with freshwater environments such as rivers and lakes providing direct or indirect routes to the ocean

Most marine chemical pollution, then, begins on land—about 80%, according to a commonly cited statistic, versus 20% that is thought to originate in the seas—with, in many cases, freshwater environments like rivers and lakes providing a direct or indirect route to the seas.

For a number of reasons, though, this 80:20 proportion is not as helpful as it might appear, says Dr Peter Kershaw, an independent consultant on marine environmental protection. For one thing, he says, you cannot apply it to every substance of concern, as they are released in different quantities in different regions and have different effects.

Another factor is the impact that chemicals have. While the global quantity of a particular chemical entering the ocean could be large, more damage might be done in a particular area by a sea-based source of pollution—for example, the case in 2021 of a tanker carrying 25 tons of nitric acid, other chemicals and plastic pellets that caught fire and sank off Sri Lanka.[6]

"A complex mixture of chemicals entered the ocean and had a big impact on the delicate ecology of that region," says Dr Kershaw. "So, in that case the proportion going into the sea was small, but in this particular instance had a large impact."

In other words, he says, it is important to understand both where the contamination begins and the impact that it has, "because then you can start to put in place measures to mitigate that—for instance, how you store containers on a ship, or what regulations to implement in factories".

And while most marine chemical pollution does begin on land, Dr Kershaw says applying the 80:20 formula could allow people "to dismiss what's happening at sea as 'less important' when there are cases there that you can do something about that will have a positive impact—whereas other cases of contamination [emanating from land] are much harder to resolve, like the widespread use of biocides in countries like China, India and the US".

Where 80:20 does make more sense, he adds, is when applied to categories of chemicals like POPs or metals, "because in most circumstances the majority of those substances of concern will originate from land".

"However, the route by which these get into the ocean will differ depending on what they are—so, it might be via the atmosphere, as is often the case with mercury, or, in the case of nitrogen fertilisers and some biocides, for example, it might be via rivers; for other industrial pollutants it could be down wastewater pipes," he says.

The sources of marine chemical pollution, then, are varied and often complex. To try to make sense of them, this report breaks them down into six broad categories (which inevitably overlap to some degree):

- The chemicals industry.
- Other industries that use chemicals for their products and processes.
- Consumers.

- Public use and legacy chemicals.
- Accidents.
- Waste management and disposal.

2.2 Overview: Major sources and the chain of accountability

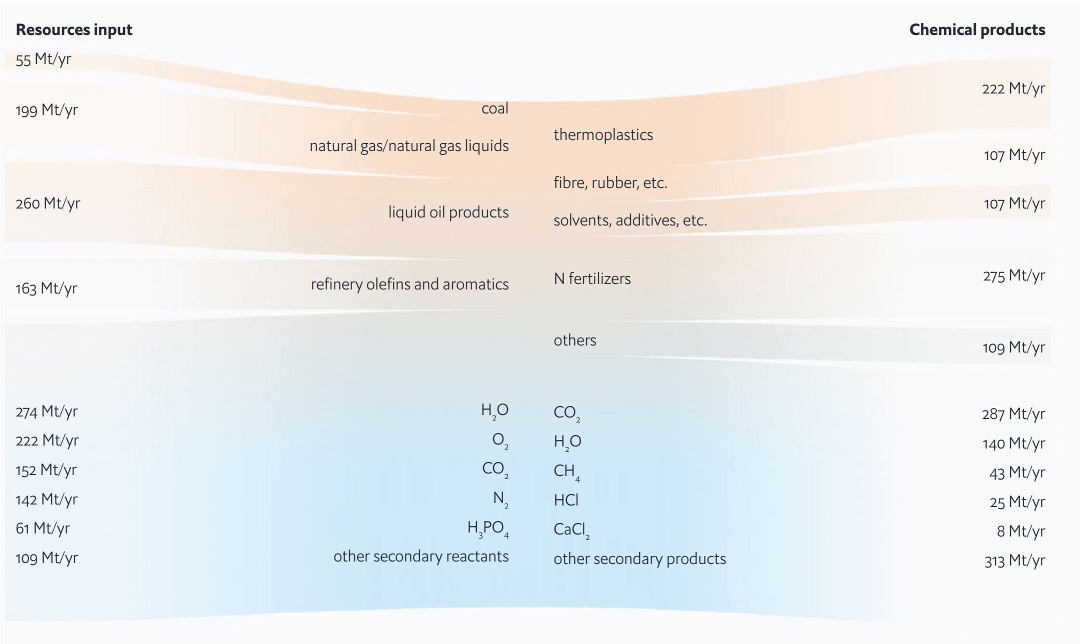
The companies that comprise the global industry vary from multinationals, of which there are several hundred, to the many thousands of smaller firms. And while some segments of the industry (pharmaceuticals and basic chemicals, for example) are dominated by a handful of very large companies, others, like specialty chemicals, have numerous sub-segments in which thousands of firms operate.

In addition, the industry itself—the largest industrial consumer of energy,[7] accounting for about 10% of global energy demand and 7% of global greenhouse gas (GHG) emissions[8]—is neither the start nor the end of a process that for decades has added huge amounts of toxic chemicals to the marine environment.

Further up the supply chain are the firms that extract the key raw materials or feedstocks—like oil, gas, metals and minerals—and that are themselves major polluters of the ocean. These feedstocks (see chart) are processed into so-called bulk chemicals by chemical industry majors (some of which, like ExxonMobil Chemical, are owned by extractive industry firms), with intermediate and specialty chemicals produced in subsequent steps and often by smaller players.

Chemicals sector transformation

A 2018 study found fossil fuels and their derivatives are the largest single resource input (around 677 million tonnes) for the chemicals industry, with water, oxygen, carbon dioxide, nitrogen, phosphoric acid and secondary reactants comprising the remaining 960 million tonnes. The main outputs are carbon dioxide, nitrogen-based fertilisers, thermoplastics and secondary products, which together total about 1.1 billion tonnes.



Source: Global Chemicals Outlook II, UNEP (2019)

Down the chain (see chart) are the users of these chemicals—the firms that incorporate them as inputs for their industrial and consumer products. Next are the industrial, public sector and consumer users of those products, while the process ends with the public and private operators that dispose of the waste products.

A deeper analysis of the value chain of the chemical manufacturing sector (see diagram) shows fossil fuels, minerals, plants and air converted into a huge array of products—including plastics, paints, petrochemicals, explosives, agricultural chemicals, industrial gases, and diversified chemicals and specialty chemicals like advanced polymers and intermediates for food, pharmaceuticals and other industries.

The chemicals lifecycle: From raw material to disposal

Chemical pollution takes place at every stage of the process. According to UNEP, the industries responsible for the largest releases of hazardous chemicals include mining, agriculture, wastewater treatment, energy generation, chemical production, and product-manufacturing use and disposal

Extraction of raw material	Chemical manufacture, processing or refining	Downstream chemical products manufacture	Industrial and consumer products manufacture	Industrial and consumer products use and reuse	Industrial and consumer product disposal and waste

Source: Global Chemicals Outlook II, UNEP (2019)

The chemicals sector value chain

Raw materials	Basic chemicals	Chemical intermediaries	Formulated products and product materials	Customers of the chemical sector
	Olefins (ethylene, propylene, butylene)	Commodities	Plastics and engineering resins	Automotive/transport
	Aromatics (benzene, toluene, xylenes)	Differentiated commodities	Extruded films, pipes, profiles, coatings, sheets, foams	Consumer products
	Chlor-Alkali (chlorine, caustic soda)	Technical specialities	Blow-molded parts	Packaging
	Methanol		Injection molded parts	Building and construction
	Bio-based materials (eg, sugars, starches, natural oils and acids)		Composites	Recreation/sport
	Others (eg, ammonia, phosphorous)		Synthetic Fibres	Industrial
			Rubber products	Medical
			Paints and coatings	Pharmaceuticals
			Adhesives and sealants	Personal care
			Lubricants	Textiles
			Water treatment products	Electrical/electronics
			Cleaning products	Aircraft/aerospace
			Industrial chemicals	Food
			Flame retardants	Bio-based materials
			Many others...	

Source: Chemical Sector SDG Roadmap, World Business Council for Sustainable Development (WBCSD) (2018)

Bio-based chemical feedstocks

One trend to watch for its potential effects on marine chemical pollution is the move towards bio-based chemical feedstocks.

That is because the growing pressure to move away from fossil fuels due to sustainability worries has seen increased interest in using crops and wood pulp as substitutes—with the market share of bio-based chemicals predicted to climb 11-fold to reach 22% of the entire chemical market by 2025.[9]

Using crops, though, will likely require using fertilisers and pesticides, which have known marine pollution consequences. Consequently, this shift will need careful management to ensure that the benefits are not undone.

In addition, many bio-based chemicals have the same end-of-life issues as existing chemicals. That means simply changing feedstocks might have only limited benefits, and with those benefits felt mainly in the area of climate change.

For much of the 20th century chemical production was centred in Europe, the US and Japan. More recently, the big players have boosted capacity in non-OECD countries. Firms in China and the Middle East have been growing their market share too

It is a sprawling, complex chain. Importantly, though, each link is responsible for areas of chemical pollution into the ocean, either directly (the consequence of extracting fossil fuels, metals and minerals from undersea operations or from sites close to the ocean, for example) or indirectly (for instance, firms pumping untreated or partially treated effluent into rivers or the sea). Accidents are also points of risk for marine chemical pollution, with events like storm surges and hurricanes likely to become more prominent as the effects of climate change worsen.

Background on the chemicals industry

With global sales in 2020 of nearly €3.5trn (almost US$4trn)—which excludes pharmaceuticals sales—chemicals is the world's second-largest manufacturing industry.[10] Factoring in pharmaceuticals brings that total to just under €5trn for 2020, up from about €2trn in total at the turn of the century, according to European industry body Cefic.[11]

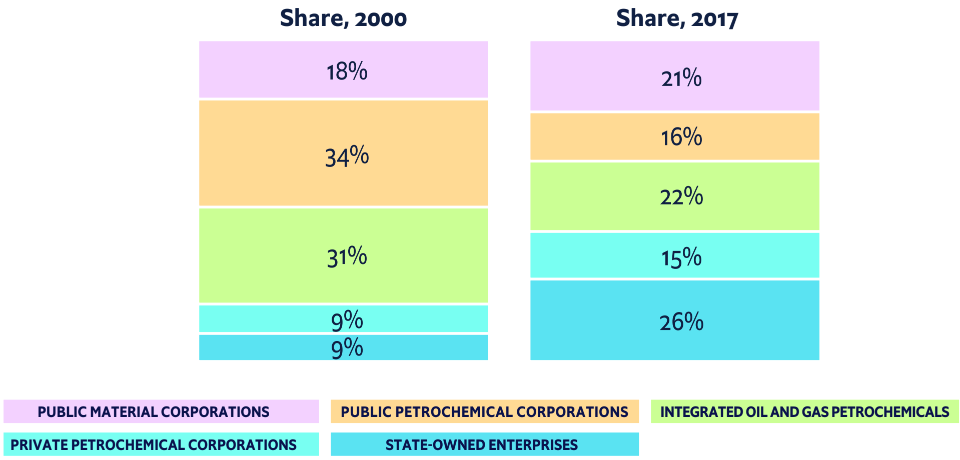
By 2030 Cefic predicts global sales of chemicals (excluding pharmaceuticals) will climb to €6.2trn, with China accounting for just under half of that total.[12] And by 2060, the OECD predicts, the value of chemicals produced globally will reach nearly US$22trn.[13] As sales increase, so too, logically, do production volumes: chemicals' production capacity doubled to 2.3bn tonnes between 2000 and 2017, and will keep climbing.[14]

Chapter 6 looks at the chemicals industry's future in more detail, but it is worth noting here that the industry has undergone important changes in recent decades, and that these go to the heart of the current situation. First, for much of the 20th century production was concentrated in the OECD nations in Europe, North America and Japan. However, the multinationals that dominate the industry have looked to boost capacity by growing operations in non-OECD countries.

Second, around the same time domestic firms in China and the Middle East started growing their market share. Third, and linked to this, state-owned enterprises (SOEs) have become far more prominent players in chemicals, with the result that, by 2017, SOEs took 26% of the industry's global revenue, nearly threefold the proportion they had in 2000.[15]

Revenue share: How the global chemicals industry has changed, 2000-17

From having the smallest share of revenue in 2000, SOEs now enjoy the largest, at 26%. Other notable changes include a smaller slice for integrated oil and gas petrochemical companies and for listed petrochemical firms—their combined share dropped from 65% to 38%. Some of that share has been taken by private petrochemical corporations, which saw their take climb to 15%.



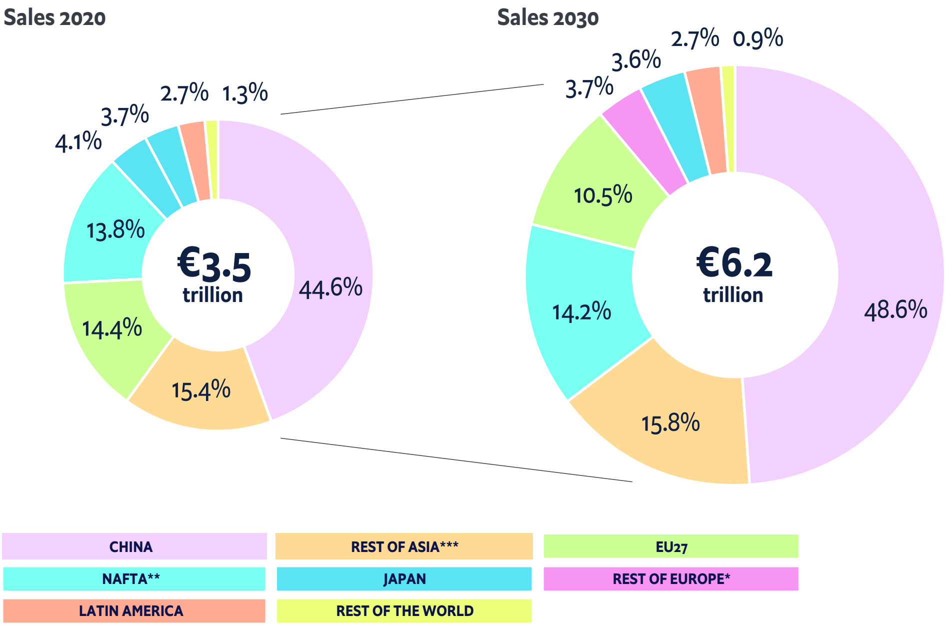
Source: Global Chemicals Outlook II, UNEP (2019)

Another crucial development is a slew of emerging synthetic chemicals (including those that have endocrine-disrupting properties, as well as nanomaterials, herbicides and insecticides—many of which have not been assessed for their effects on health and the environment). This development, The Lancet Commission on pollution and health noted in its 2017 report, is "of great concern … and this concern is heightened by the increasing movement of chemical production to low-income and middle-income countries where public health and environmental protections are often scant".[16]

When it comes to manufacturing, China is by far the world's biggest player, recording about 45% of global sales in 2020, followed by Asia (excluding China, Japan and South Korea), the NAFTA bloc and the EU.[17] Since 2000 most global growth has come from China, the Middle East and India, with the bulk of future growth expected to come in Asia-Pacific, the Middle East and Africa.[18] By 2030 it is estimated that about two-thirds industrial chemicals sales (excluding pharmaceuticals) will be in Asia (see graphic).[19]

Projected growth in global chemical sales, 2020-30

The graphic, which excludes pharmaceutical sales, shows that Asia will continue to dominate global sales of industrial chemicals.



* Rest of Europe covers UK, Switzerland, Norway, Turkey, Russia and Ukraine
** North American Free Trade Agreement
***Asia excluding China, Japan, and South Korea

Source: 2022 Facts and Figures of the European Chemical Industry, Cefic (2022)

Each of these developments has implications for the actions needed to combat marine chemical pollution.

2.3 Industry—chemical producers

The increase in production in non-OECD nations in recent decades has been a major development for the multi-trillion-dollar chemicals industry. The UN's flagship publication on the ocean—The Second World Ocean Assessment (WOA II)—highlights this shift from the Atlantic to the Pacific, noting that 70% of the industry is expected to be operating in the Pacific Ocean region by 2030.[20] At the same time, WOA II points out, the ocean will be exposed to a greater mix of chemicals as new products are developed.

In addition to finished products, a huge array of chemicals is also emitted during the manufacturing process. As production of fertilisers, pesticides, pharmaceuticals, flame retardants, PFAS and other chemicals climbs in many parts of the world, the scale of addressing this challenge will increase.

Another key aspect is that different segments of the chemicals industry have vastly varying degrees of efficiency. Pharmaceuticals is by far the worst-performer: it generates 25-100 kg of waste for every kilogram of finished product versus 1-5 kg for basic chemicals production and 5-50 kg for fine chemicals (see chart).[21]

The e-factor: Resource efficiency in the chemical industry

The e-factor shows how much waste is generated for every unit of product manufactured. An e-factor measure of 10, for example, means that 1 kg of product generates 10 kg of waste.

Industry segment	Tonnes per year	e-factor (kg waste per kg product)
Oil refining	10^6-10^8	<0.1
Bulk chemicals	10^4-10^6	<1-5
Fine chemicals	10^2-10^4	5-50
Pharmaceuticals	10-10^3	25- >100

Source: Global Chemicals Outlook II, UNEP (2019)

In other words, the further up the chemicals value chain one goes, the greater the volume of waste per unit of finished product. (Bulk chemicals manufacturers produce far more volume than pharmaceutical firms, of course, but the comparison remains a useful one in terms of determining relative waste amounts generated.)

Although the measurement of hazardous waste is absent in many countries, it is recorded in, for example, the US, the EU and China, and that can provide some indication of the chemical industry's proportional contribution.

In the US, for instance, basic chemical manufacturing was responsible for 56% of hazardous waste in 2011, much of which was treated on site; petroleum and coal products manufacturing added a further 19% while agricultural chemicals and fertilisers contributed 5%.[22] For its part, the EU's chemicals and pharmaceuticals sector was the source of a combined 13% of hazardous waste generation in 2015, with petroleum comprising 8%.[23] (At 51%, waste and wastewater management were the EU's largest source of hazardous waste.)

There are several routes through which chemicals manufacturing can pollute the ocean. The first is from land-based point sources—for example, direct discharge of effluent into rivers or the sea, or to wastewater treatment plants, which are unable to filter many of the chemicals involved before they discharge the water back into the environment. Indeed, more than 80% of municipal and industrial effluent globally is thought to be pumped into the environment without being adequately treated.[24]

Atmospheric deposition is another key route for marine chemical pollution. Creating petrochemicals that are used to manufacture plastics, for instance, is done by converting natural gas; this process sees significant amounts of CO2 and nitrogen oxide released into the air, both of which drive acidification of the ocean.[25] Other sources of marine chemical pollution include: chemical run-off from the land; from contaminated groundwater seeping directly into the seas;[26] from illegal or historical cases of direct dumping[27] (for example, of an estimated half a million barrels of DDT-laden sludge off the California coast[28] and of two million car tyres in Florida's waters[29]); and from chemically laden sludge at industrial landfills.

The location of plants for chemicals manufacturing also contributes to marine chemicals pollution.

"A lot of the chemical manufacturing sites are close to water, because they need water," says Dr Zhanyun Wang of the Technology & Society Laboratory, Swiss Federal Laboratories for Materials Science and Technology (EMPA). "In some regions they discharge the wastewater via wastewater treatment plants—and in other regions there aren't any [facilities]."

In the latter case, he says, chemical pollutants often have a route to the ocean—whether they are pumped directly into the sea or whether they get there after being pumped into rivers or dumped in landfills where they can eventually leach into groundwater or the atmosphere.

While some wastewater treatment plants can remove some chemical compounds, the most persistent chemicals such as PFAS will not all be removed

"Just using one compound as one example: perfluorooctanoic acid, or PFOA, which we have identified in the ocean. That's mainly coming from these manufacturing sites," he says. "And because of its high persistence and environmental mobility, basically [all the PFOA] we've emitted will at some point get into the ocean."

Additionally, says Dr Wang, while some wastewater treatment plants can remove some chemical compounds, "today we have a lot of very persistent chemicals, and they will not all be removed".

"Removal is really compound-specific," he says. "For some compounds, like many PFAS, they don't remove much—it's very limited."

Most developing countries have no suitable treatment plants. In richer countries that may have them, upgrading them to cope with new pollution threats—one example being Switzerland's €1bn investment over 20 years with the goal to halve organic pollutant loads in wastewater streams[30]—is not necessarily a panacea. Installing costly solutions like a combination of ozonation and activated carbon, which are energy-intensive, might still not remove persistent and mobile pollutants, whether those stem from chemicals manufacturers themselves or any of the users along the value chain.[31]

2.4 Industry—other parties

Industrial users of chemicals cover nearly every sector imaginable, and they overlap significantly. For the purposes of identifying the sources of marine chemical pollution, key manufacturers of industrial products for land-based use include agriculture, mining, fossil-fuel extraction, transport, construction, defence and tourism, while sea-based industries include fishing, shipping and deep-sea mining.

In addition, there is the consumer market, with a vast array of electronics, vehicles, clothing, household items and toys, to name a few, along with the largely plastics-based packaging that goes with them.

Regardless of the sector, chemicals are typically used in one of four ways:

- On their own—for example, as a cleaning solvent during industrial processes.

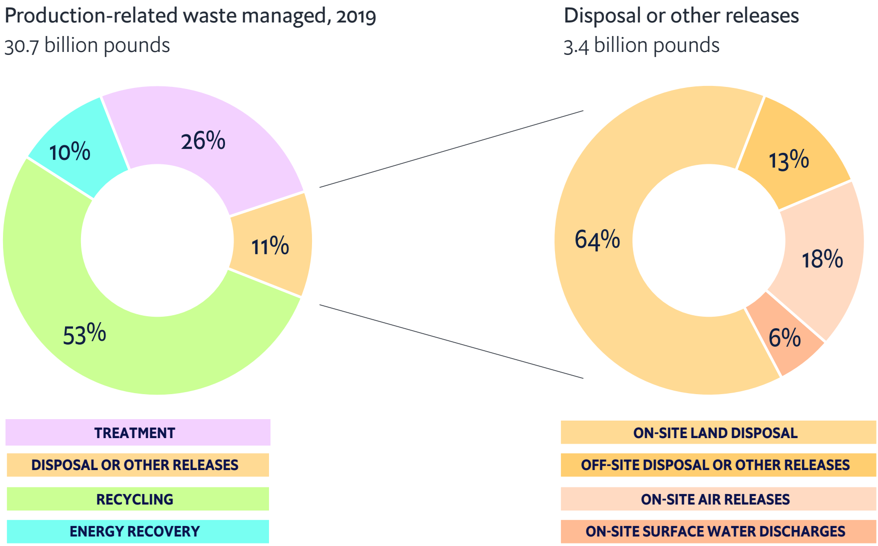
- Combined with other chemicals in mixtures—as with pesticides, detergents and consumer-care products.
- In materials—for example, adding phthalates to plastic compounds to make them more flexible for end-use as toys.
- Directly in products—for example, battery electrolytes.[32]

Although the globalised nature of chemicals usage means it is impossible to know the true extent of chemical pollution, some countries do measure emissions. One example is the OECD's Pollutant Release and Transfer Register (PRTR), which compiles emissions data from about 40 countries across a range of industries for several hundred chemicals. (However, the global PRTR system has some drawbacks, and would benefit from an internationally harmonised system that saw, for example, a "common list of chemicals, thresholds for reporting [and] units by which the data can be aggregated or made available to the public".)[33]

Another is the US EPA's Toxics Release Inventory (TRI) that compiles emissions data of 770 chemicals and 33 chemical categories as reported by 21,000 US-based facilities operating in certain industries.[34] It shows that production-related waste in those sectors totalled 30.7 billion pounds (about 14 million tonnes) in 2019. While nearly 90% was recycled, burned for energy or treated, the remaining 3.4 billion pounds (about 1.5 million tonnes) was dumped in landfill, released into the air or into water sources (see chart).

How US facilities deal with chemical waste—and how much is released into the environment (2019)

The TRI compiles emissions data—as reported by 21,000 US-based facilities—of 770 chemicals and 33 chemical categories. The facilities operate in sectors like mining, manufacturing and hazardous waste management. While most waste is recycled, treated or recovered (all processes in which chemicals can be released), about 10% is dumped.



Note: To avoid double counting, the Disposal or Other Releases pie on the right excludes quantities of TRI chemicals that are transferred off site from a TRI-reporting facility and subsequently released on site by a receiving facility that also reports to TRI. Percentages do not sum to 100% due to rounding.

Source: Introduction to the 2019 TRI National Analysis, EPA

According to the EPA, about one million tonnes was released on-site at the facilities—typically into landfills or injected underground. The remaining half a million tonnes of chemical waste was pumped into the air, shipped to off-site landfills or released into water.[35]

Many countries have little regulatory oversight, monitoring and infrastructure to deal with hazardous waste. Whatever chemical pollution is taking place is thus largely unknown

Many countries, however, have little regulatory oversight, less monitoring and minimal infrastructure to deal with hazardous waste, and even the definition of the term "varies greatly from one country to another, and sometimes also over time".[36] Additionally, whatever chemical pollution does take place is often not monitored either in terms of its generation or its management, so its extent is largely unknown.[37]

Three notable areas within this admittedly very broad category are:

- **Mining:** a particular cause for concern is the deep-sea disposal of land-based waste tailings, which are comprised of a range of pollutants including sulphides, metals like arsenic, cadmium, mercury and lead, as well as process chemicals and silt particulates.[38] A related and increasingly important area (albeit one that is still at an early stage) is deep-sea mining, in which companies tap the seabed for deposits of minerals (like phosphate and sulphides), metals (including nickel, copper, cobalt and manganese) as well as rare earth elements and other materials critical to green technology and a low-carbon, sustainable future.[39] The contaminants that are released vary depending on what is being mined.[40] Looking ahead, deep-sea mining will become a more important part of marine chemical pollution as companies and governments look to exploit underwater reserves as what is commercially available on land decreases. However, as Dr Kershaw notes, the credibility of green technology solutions will be harmed if critical deep-sea habitats are destroyed in the process, which highlights the importance of ensuring that such programmes are sustainable.

- **Shipping:** Nitrogen oxide (NOx) and sulphur oxide (SOx) emissions are significant sources of marine chemical pollution, and stem from fuel combustion. However, the introduction of emission control areas is expected to see SOx-driven acidification decrease in those zones, while a similar scheme for the Baltic Sea is forecast to cut nitrogen deposition there by 40%.[41] Additionally, the introduction of low-sulphur fuels and scrubbers that clean exhaust gases will cut SOx emissions globally, although the UN notes that "the discharge of water from [scrubbers] is an emerging source of metals and polycyclic aromatic hydrocarbons", as well as of sulphur oxides.[42] Concerns about the effect scrubbers have on the marine environment have seen numerous ports in Europe, the US and China ban ships from discharging scrubber wash water locally. The IMO's MARPOL Convention is an example of how international co-operation can tackle a range of ship-sourced marine pollution issues.[43]

- **Oil and gas:** on average, 120 oil platforms are decommissioned each year, with an estimated 2,500-3,000 to follow. The UN describes this as "an increasing area of concern" from a marine environment perspective.[44] While regulations applying to the North Sea require that topsides and sub-structures must be removed from platforms, this is not the case elsewhere. In the US and South-east Asia, for instance, parts of the subsea structures can be left as artificial reefs—which has been the fate of more than 500 structures in the Gulf of Mexico alone.[45] Two other pollution aspects related to offshore drilling are the production of chemically contaminated produced water, with as much as 39.5 million cubic metres generated each day, and disposing of drilling waste.[46] Produced water, for instance, contains levels of metals like cadmium, lead, mercury and chromium that are between 100 and 10,000 times their background concentrations, as well as hydrocarbons and naturally occurring radioactive material.[47]

There are numerous other industry-linked areas that this report could examine, but space constraints preclude doing so. That said, a crucial—and increasingly challenging—area is the rapid growth in the manufacture of electronic items in the digital era, in which the three biggest producing regions (Asia [73%], Europe [14%] and the Americas [12%]) account for 99% of global output.

The use of chemicals is central to almost all electronics manufacturing, with lead, mercury, flame retardants and phthalates among the hazardous substances employed.[48] Failure to dispose of these chemicals or the by-products generated during manufacturing risks further contaminating the ocean either through air pollution, leaching from landfills or discharge into rivers and from there to the seas. And, as the report will examine later, failure to factor in end-of-life disposal is poisoning the seas—including in less-developed nations where wealthy countries have long dumped their e-waste.

2.5 Consumers

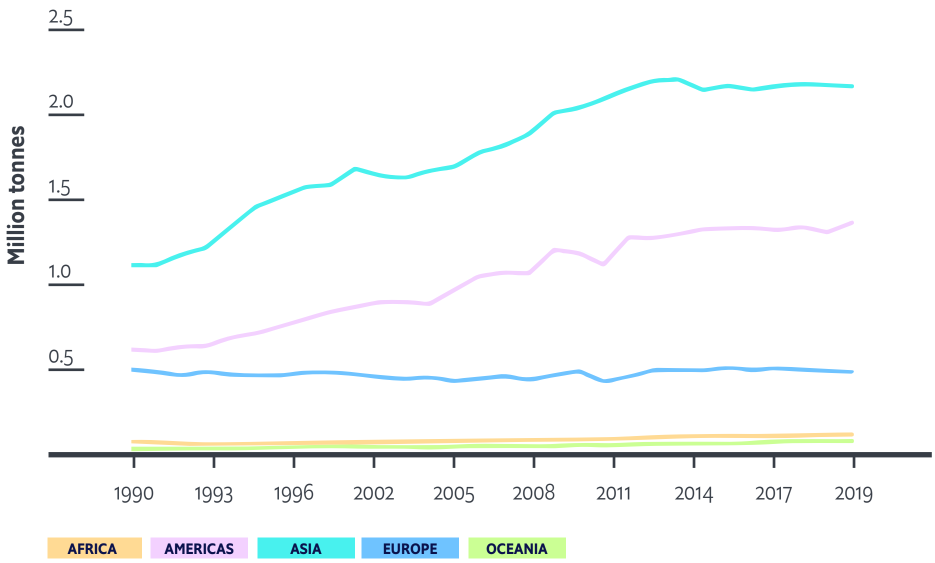
This category covers a vast array of the items manufactured by many of the players in the previous two sections—from mobile phones to TVs, personal care products to pharmaceuticals, and from household cleaning products to transport-related purchases like fuel and tyres.

In much of the world, where people grow crops or raise animals on a subsistence or small-business basis, this category also includes animal pharmaceuticals and agricultural chemicals like fertilisers and pesticides that are used to boost yields. According to the FAO, about 90% of 570 million farms globally fall into the "small" category, with the majority of those run by poor families in the rural parts of developing nations.[49]

When it comes to pesticides, Asia (and China in particular) uses more than any other region (2.2 million tonnes), which is about twofold what the continent used in 1990 (see chart). Asia also uses the most pesticide per hectare of cropland at 3.7 kg/ha, or 1 kg/ha more than the global average. Most of the rest of the pesticides are used in the Americas. (Note that these figures include the use of pesticides on a commercial basis as well as by individuals.)

Pesticides use by region, 1990-2019

The chart shows that the bulk of pesticides are used in Asia, which has also seen significant growth in their use since 1990—as have the Americas. Europe's use of pesticides has stayed flat, while Africa and Oceania use the lowest quantities. However, in Africa's case, with the population set to rise rapidly this century, this will probably change.



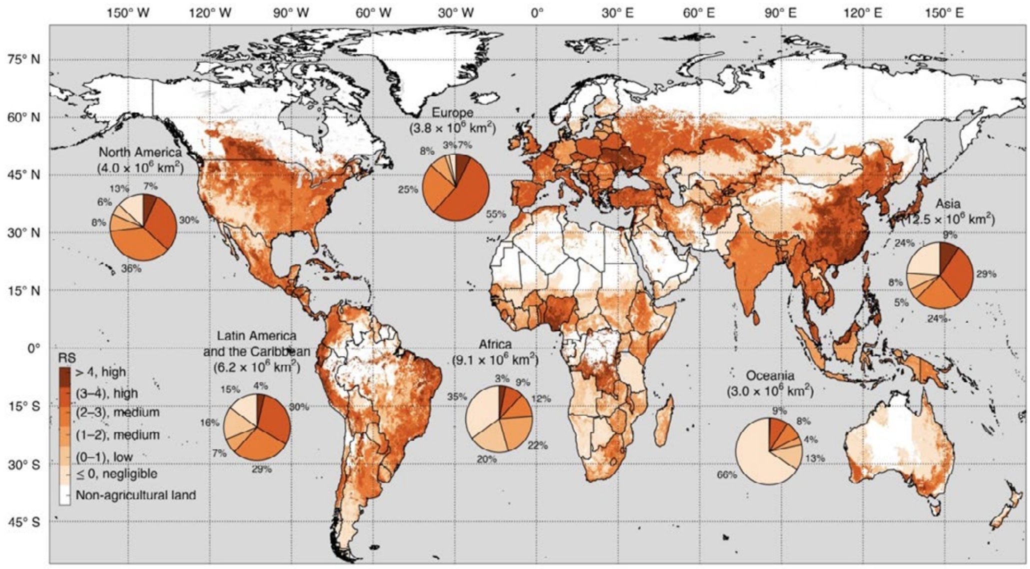
Source: Pesticides use, pesticides trade and pesticides indicators 1990-2019, FAO (2021)

China uses more pesticides—1.8 million tonnes—than the rest of the top ten countries combined,[50] with the country's land and migration policies leading to small-scale farmers using agricultural chemicals, including pesticides, extremely inefficiently.[51] Removing the distortions, a study concluded, would as much as halve the use of pesticides and fertilisers and their environmental impact, while doubling farmer incomes.[52]

China's heavy reliance on pesticides is clear from the map (below), which is taken from another study on the use of pesticides globally.[53] The report does not measure pesticide levels in the seas; however, because pesticide run-off via waterways into the ocean is a crucial route for ocean pollution, the map does indicate areas of concern. The authors highlight watersheds "in South Africa, China, India, Australia and Argentina as high-concern regions because they have high pesticide pollution risk, bear high biodiversity and suffer from water scarcity".

Global pesticides risk

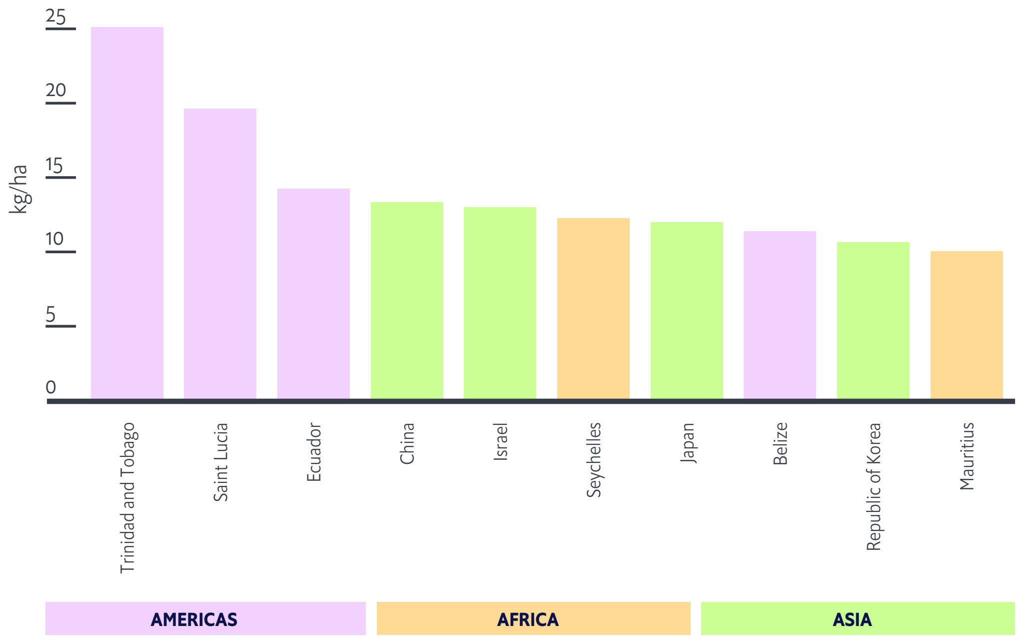
The study assessed the environmental pollution risk from 92 active ingredients in pesticides in 168 countries. Regions were scored as at risk of pollution if pesticide residues in the environment exceeded the level below which they would likely have no toxic effect. High-risk areas were where residues exceeded this level by three orders of magnitude. The pie charts show the fraction of agricultural land falling into each risk score category for that region, while the values above the pie charts show the region's total agricultural land. The darker the colour, the higher the risk.



Source: Risk of pesticide pollution at the global scale, Tang HM et al, Nature Geoscience (2021)

Yet while China uses far more pesticides than any other nation, it ranks only fourth in terms of use per hectare (see chart) with Trinidad and Tobago (25 kg/ha), Saint Lucia (20 kg/ha) and Ecuador (14 kg/ha) applying more.[54] Additionally, every top-ten user of pesticides has a coastline (with five of them classed as small island developing states), which makes it likelier that more of the pesticides they use will enter the marine environment. Indeed, as the World Bank notes in its report on marine pollution in the Caribbean, "pesticides and insecticides used for agriculture are the primary chemical wastes".[55]

Top ten countries for pesticides use per cropland area, 2019



Source: Pesticides use, pesticides trade and pesticides indicators 1990-2019, FAO (2021)

Additionally, it is important to note that in many developing countries, where levels of literacy are typically lower, farmers often create mixtures of different pesticides—including pesticides that are banned for use in the developed world.[56] Inevitably some of these pesticides will run off into rivers, and from there into the seas.

Aside from consumer users of pesticides, another important category in many developing nations is artisanal gold mining. This trade is a major user of mercury, which the small-scale miners heat to separate gold from ore, with the mercury vapours entering the atmosphere (see box). Artisanal gold-mining is the leading human-based source of mercury emissions, totalling 38%, followed by coal-burning for power (21%).[57]

Mercury—the 21st century's toxic winged messenger

The Romans believed that one important role of the god Mercury was to traverse the skies as the winged messenger of the gods. In a toxic 21st century echo, the element that was named after the Roman god often circulates across the planet in the atmosphere.

Despite mercury's proven harm—and despite the efforts of the signatories to the Minamata Convention, a global treaty that came into force in 2017, "to control the mercury supply and trade, reduce the use, emission and release of mercury", among other aims[58]—mercury continues to enter the environment, and at an increasing rate, UNEP says.

Mercury deposited into the ocean from the atmosphere and rivers totalled an estimated 4,100 tonnes in 2015 (see graphic).

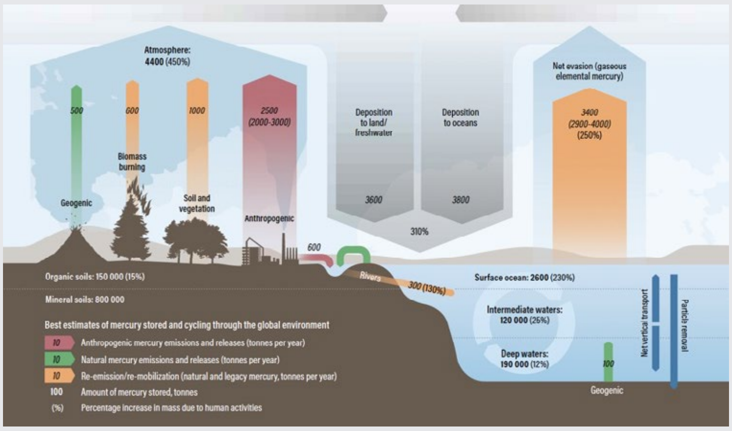
While artisanal gold-mining is the main human-based source of mercury emissions, it is not the only one. Burning coal to generate power ranks second (21%), while non-ferrous metal production and cement production together contribute 26%.[59]

In water, bacteria convert inorganic metallic mercury to methylmercury, which is highly toxic and accumulates in top-order predators. As a result, mercury remains a significant health risk, particularly for communities dependent on the sea for their food.

A study of more than 200 women in six countries, for example, found that nearly all of those living on Pacific islands exceeded the reference level of one part per million (1ppm) of total mercury in their hair. By comparison, just one in five of the participants in the other countries exceeded that level.[60]

The mercury cycle

The image shows the impact of human activities on the mercury cycle and the resulting increase in mercury accumulated in soils and ocean



Source: Global Mercury Assessment 2018, UNEP

Mercury atmospheric emissions

Anthropogenic mercury emissions into the atmosphere by region and sector (2015 estimates)

Quantities of mercury emitted to air from anthropogenic sources in 2015, by different sectors in different regions

	Sector group (emissions, tonnes)				Regional total (range), tonnes	% of global total
	Fuel combustion	Industry sectors	Intentional-use (including product waste)	Artisanal and small-scale gold mining		
Australia, New Zealand & Oceania	3.57	4.07	1.15	0.0	8.79(6.93-13.7)	0.4
Central America and the Caribbean	5.69	19.1	6.71	14.3	45.8 (37.2-61.4)	2.1
CIS & other European countries	26.4	64.7	20.7	12.7	124 (105-170)	5.6
East and Southeast Asia	229	307	109	214	859 (685-1430)	38.6
EU28	46.5	22.0	8.64	0.0	77.2 (67.2-107)	3.5
Middle Eastern States	11.4	29.0	12.1	0.225	52.8 (40.7-93.8)	2.4
North Africa	1.36	12.6	6.89	0.0	20.9 (13.5-45.8)	0.9
North America	27.0	7.63	5.77	0.0	40.4 (33.8-59.6)	1.8
South America	8.25	47.3	13.5	340	409 (308-522)	18.4
South Asia	125	59.1	37.2	4.50	225 (190-296)	10.1
Sub-Saharan Africa	48.9	41.9	17.1	252	360 (276-445)	16.2
Global inventory	**533**	**614**	**239**	**838**	**2220 (2000-2820)**	**100.0**

Source: Global Mercury Assessment 2018, UNEP

Another aspect of this category is chemical releases from recreational activities. One that came to prominence in recent decades (and that overlaps with the prior section on industry, as it applies to large vessels as well as recreational boats) was tributyltin (TBT), an antifouling paint and biocide that is used on hulls to stop the growth of shellfish and waterweeds. The WWF has described TBT as "the most toxic chemical ever deliberately released into the seas".[61]

TBT, a type of organotin, is highly toxic to fish, and to shellfish in particular—research showed that even low concentrations caused a phenomenon known as imposex, in which female molluscs' endocrine systems were so disrupted that they developed male sex characteristics. That meant they could not release eggs; affected commercial shellfish populations consequently collapsed.

As populations grow, particularly in coastal regions, the pressure on coastal and marine ecosystems will climb as more people use more cosmetic, personal-care and cleaning products, and pharmaceuticals

TBT was forbidden for use on ships in 2008, while the Rotterdam Convention regulates the trade of TBT. However, TBT remains available, with the authors of a 2021 study stating that "the situation does not seem to have significantly changed since 2014 when TBT-based paints were shown to be still being manufactured in the United States and offered for sale in stores throughout the Caribbean and Central America. In fact, this study shows that seven years later the same situation not only persists, but may have an even more global distribution than previously thought."[62]

As Dr Kershaw says, the debate about replacements for TBT has not abated. As he points out, "anything you paint on a surface to stop things growing is a biocide, and these coatings tend to flake". The effect that replacements might have will depend in part on where those craft are used—whether in harbours or marinas, to visit protected areas or coral reefs, or transiting the ocean.

A final aspect to consider in the consumer category is the use of pharmaceuticals and personal care products, which are known collectively as PPCPs. The quantity of pharmaceuticals produced annually for humans and animals totals about 100,000 tonnes, and for various reasons will keep climbing over the coming decades. At least 3,000 PPCPs are currently on the market, with more entering each year.[63]

As populations grow, particularly and particularly relevant to this paper, in cities in coastal regions—by 2012, there were more than 2,100 coastal cities globally with more than 100,000 residents versus just 472 in 1950[64]—the pressure on coastal and marine ecosystems will climb as more people use more cosmetic products, personal care products, cleaning products and pharmaceuticals. A further consideration is the increased use of pharmaceuticals by a burgeoning ageing population.

In short, a growing global population with more money to spend on healthcare means greater demand for PPCPs. At the same time, higher demand for meat, including farmed seafood, means more pharmaceutical products will be used on animals. As a result, greater volumes of PPCPs will enter municipal wastewater treatment systems, which are mostly unable to deal with the chemical contaminants in wastewater streams. The result will be yet more pressure on marine ecosystems.

2.6 Public use and legacy chemicals

The fourth category is the use by governments and other public authorities of products that contain chemicals, actions taken for, say, public works or defence, as well as the storage and disposal of so-called legacy chemicals—the banned, restricted or expired chemicals that have not yet been dealt with.

When it comes to products, many of these chemicals overlap with those used in products by consumers (wearable devices and displays, for instance), and for which improper disposal can cause marine chemical pollution. Others are more specific to this category: military weapons and supplies, for instance, or the use of fire-retardant chemicals to fight wildfires or for fire-training at military bases with the constituent PFAS chemicals contaminating water supplies.[65]

One little-known aspect is the dumping of chemical munitions at sea during the 20th century. A 2015 meta-study showed that hundreds of thousands of tons of chemical munitions were offloaded into the ocean last century, with the coasts off Japan, Russia and the US most affected, along with Europe, where the Baltic Sea and the North Sea are the most extensively researched.[66]

The most common chemical warfare agents dumped at sea are sulphur mustard, Lewisite and nerve agents, while others include choking agents and compounds containing arsenic. The rate of leakage is hard to determine, and varies according to local conditions. Studies of marine organisms have shown levels of chronic toxicity, while laboratory analyses of microbiota taken from dumpsites showed significant alteration, "which may imply unseen but significant changes to ecosystems of dumpsites".[67]

HELCOM, which is an inter-governmental organisation that monitors the Baltic Sea area,[68] stated in a 2013 report that 40,000 tonnes of chemical warfare materials were dumped in the Baltic Sea, including compounds like sulphur mustard, arsenic-containing substances and Tabun, a nerve agent (which, it pointed out, is extremely toxic in very small doses).[69] However, HELCOM's report also stated that measurable quantities of chemical weapons or their degradation compounds had not been detected in the water columns, although it concluded, too, that "little is known about the magnitude of the effect of different chemical warfare degradation products on the marine environment". The risks to fishing fleets are noteworthy, too: Danish fishing trawlers operating in the Baltic Sea reported hauling in chemical weapons on more than 200 occasions between 1968 and 1984, for instance, most of which was sulphur mustard.[70]

While the 2015 meta-study noted that the risks chemical weapons pose to humans from eating seafood constituted a minimal risk, it also concluded that "the long-term threat to the benthic habitat via increased arsenic concentrations, shifts in microbiota speciation, and chronic toxicity to vertebrates and invertebrates is not currently understood".[71] And, it noted, as better technology makes the sea-bed more accessible, the risks of disturbing chemical weapons through activities like cable-burying, pipe-laying, drilling and trawling for fish will increase. "The risk to the environment of massive release via disturbance remains a distinct possibility," the meta-study concludes.[72]

Another risk to the marine environment is the dredging of ports, harbours, marinas and near-shore areas, which can release contaminants trapped in the sediments like heavy metals, POPs, hydrocarbons and pesticides,[73] all of which are toxic to marine life.[74] A project to build a road tunnel under Sydney Harbour in Australia, for example, involved dredging, with known contaminants in the harbour sludge including dioxins, TBT, PCBs, pesticides, hydrocarbons, PFAS and heavy metals.[75]

Stockpiles of banned, obsolete or expired pesticides are a further issue in many countries where there are limited or no facilities to dispose of them safely. And sometimes the stockpiles have long been forgotten

Stockpiles of banned, obsolete or expired pesticides are a further issue in many countries, particularly where there are limited or no facilities to dispose of them safely. Just to identify them is "a very tricky area", says Dr Zhanyun Wang of EMPA.

"And then there is how to identify those stockpiles—sometimes those stockpiles have been long forgotten," he says. "And then when you do identify them, how do you treat them? Do you incinerate them? Because when you incinerate these chlorinated chemicals, you may also generate dioxins. Everyone knows this issue is very important, but it's very difficult to do it well."

In addition, says Dr Wang, another form of legacy chemicals are PCBs, with an estimated 80% still in existence—including in transformers around the world—and that leak unnoticed into the environment. (As noted in Chapter 1, PCBs are still in use in some countries, with the requirement to end their use not until 2025—a deadline that some governments have already said will be missed.)

The effects on marine life can be catastrophic, as scientists studying orcas have found.[76] By modelling data on PCB concentrations in the tissues of killer whales, as the mammals are also known, the researchers showed that the effects of PCBs on their reproduction and immune systems would put the survival of more than half of the global population in doubt. Populations of orcas off the coasts of the UK, California, Japan, Brazil and in the Straits of Gibraltar were thought highly unlikely to survive.[77]

"PCB-mediated effects over the coming 100 years predicted that killer whale populations near industrialised regions, and those feeding at high trophic levels regardless of location, are at high risk of population collapse," they wrote. "Despite a near-global ban [on the production] of PCBs more than 30 years ago, the world's killer whales illustrate the troubling persistence of this chemical class."[78]

2.7 Accidents

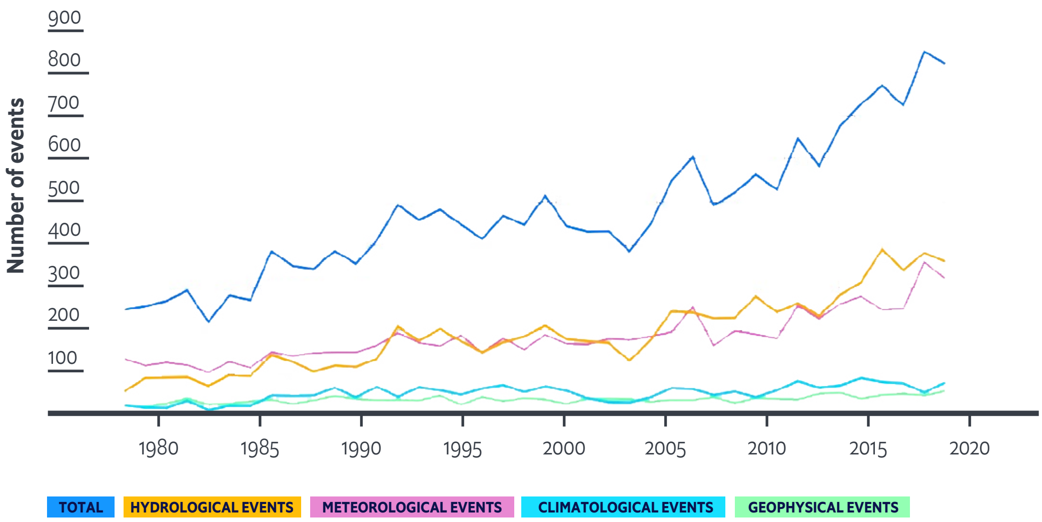
For many people, the subject of marine chemical pollution stemming from accidents suggests listing oil tankers, vast oil slicks spread across sea, sand and rocks, and sea-life and birds coated in a toxic black sheen.

Natural events are a major source of marine chemical pollution, and will likely become more prevalent as the effects of climate change bring rising sea levels and intense storms with storm surges

While shipping accidents remain a major source of oil spills, large spills are less common. The number of oil spills greater than seven tonnes declined from an annual average of 35.8 in the decade to 1999 to 6.4 in 2009-18—in part due to better safety measures after single-hull tankers was phased out.[79]

Natural events are a major source of marine chemical pollution, and these will likely become more prevalent as the effects of climate change bring rising sea levels, more intense storms with storm surges, and greater rainfall and flooding—and that is on the back of a steadily increasing number of natural catastrophes since 1980, according to reinsurance giant Munich Re (see chart).[80]

Natural catastrophes—the number of relevant loss events by peril category, 1980-2019



Source: Risks posed by natural disasters, Munich Re

The nature of the chemicals industry, with shipping of feedstocks and finished products a key method of transport, means it is often located on or near the coastline. When Hurricane Ida made landfall in the US Gulf state of Louisiana in mid-2021, for example, the predicted route of the Category 4 hurricane—the second-highest classification for hurricanes—contained nearly 600 sites that either produce toxic chemicals or store them. Two-thirds of these were within 80 km of the coast, "putting them at particular risk from storm surge, strong winds and heavy rain".[81]

2.8 Waste management and disposal

Last but by no means least is the crucial end-of-life element that is typically lacking from the design phase of manufactured products, of which more than 95% "rely on some form of industrial chemical process" when being made.[82] Those end-of-life considerations are often ignored, which is why numerous products—not least those containing plastics—can contribute to marine chemical pollution.

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In addition, even when products *are* designed with end-of-life in mind, there are still safety factors that come into play. Disposal of batteries, for instance, is well catered for in some richer countries but largely absent in many poorer ones, with expired batteries often dumped in landfill where their chemical components can leach into the ground, and from there travel into the atmosphere or water sources. In many poorer countries, vehicle lead-acid batteries are manually recycled, which releases large amounts of the toxic element into the environment.[83]

The rapid increase in electrical and electronic items produced over the past 50 years has had a huge impact on global waste generation both the volume of e-waste that is generated and the chemicals it contains. Global e-waste totalled nearly 45 million tonnes in 2016, and was expected to reach more than 52 million tonnes by 2021. Much of it contains toxic chemicals including mercury, lead and brominated flame retardants, while the many types of plastic used are also highly problematic as they are typically laced with chemical additives.[84]

When it comes to e-waste, Asia generated the largest amount in 2016 (18.2 million tonnes), with Europe and the Americas not far behind (12.3 million tonnes and 11.3 million tonnes respectively). Africa and Oceania together generated 2.9 million tonnes.

Significantly in terms of marine chemical pollution, just 20% of e-waste from 2016 was documented as being recycled. Much of the rest was dumped in landfill or relabelled as second-hand and shipped to poor countries to be broken apart and often burned to extract value. Ghana's infamous Agbogbloshie dump in Accra, for example, lies just a few kilometres from the sea and is home to a huge informal e-waste industry involving tens of thousands of people who process large quantities of e-waste shipped from rich nations.

As the computers, TVs, mobile phones, white goods and other items are taken apart, and their plastic casings and cables burned to access the metals, toxic chemicals in those plastics are released—including brominated flame retardants as well as by-products like brominated and chlorinated dioxins and furans.[85] Other chemicals detected at the dump include PCBs, PBDEs and short-chain chlorinated paraffins (SCCPs),[86] which are harmful to aquatic organisms, highly persistent and do not break down in the natural environment.[87]

E-waste has proven to be a significant problem, with as much as 80% of the world's e-waste going to China, India, Pakistan, Vietnam and the Philippines in the past decade, where it is recycled in a similarly informal manner, with shredding and burning common.[88] Although the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal has some measures to tackle e-waste,[89] much is still sent across borders illegally for dumping.

It is not just e-waste that is improperly disposed of into landfill or burned—both of which can see chemical contaminants leach into groundwater or rise into the atmosphere and end up in the seas. Vast quantities of other consumer and business purchases end up in landfill each year, with many containing levels of toxic chemicals (see chart) that, if not treated or disposed of properly, can end up contaminating the ocean.

Study-based list showing unintended chemical contaminants in products

Product/article	**Chemical(s)**	**Example study**
Thermo cups and kitchen utensils	brominated flame retardants, eg, decabromodiphenyl ether (decaBDE), tetrabromobisphenol A (TBBPA)	Samsonek and Puype 2013
Electrical articles	lead	KEMI 2014
Waste paper and board from households	mineral oil hydrocarbons, phthalates, phenols, polychlorinated biphenyls, and selected toxic metals	Pivnenko *et al.* 2016
Children's toys	polybrominated diphenyl ethers (PBDEs) and phosphate flame retardants (PFRs); plasticizers such as phthalate esters	Ionas *et al.* 2014
Packaging material	hexabromocyclododecane (HBCDD)	Bodar *et al.* 2018
Rubber on playgrounds and football fields	polycyclic aromatic hydrocarbons (PAHs), phthalates, antioxidants (eg, BHT, phenols), benzothiazole and derivatives	Llompart *et al.* 2013, Bodar *et al.* 2018
Pizza board package	phthalates and synthetic biocides	Pieke, Smedsgaard and Granby 2018
Various food samples	bisphenols	Liao and Kannan 2013
Commercial salt	microplastics (polypropylene, polyethylene and others)	Karami *et al.* 2017
Honey	neonicotinoids (acetamiprid, clothianidin, imidacloprid, thiacloprid and thiamethoxam)	Mitchell *et al.* 2017
Lettuce	various pesticides	Skovgaard *et al.* 2017
Various food samples	DDE (a DDT metabolite), PCB congeners, PFOA and others	Schecter *et al.* 2010
Wine	lead (584 ug/kg, sample taken in 2015)	WHO 2018
Cooked crabs	dioxins (WHO TEF; 740 pg/kg; sample taken in 2010)	WHO 2018

Source: Global Chemicals Outlook II, UNEP (2019).

A further difficulty is that even where regulations exist to prohibit the use of toxic chemicals in products, unscrupulous or unaware manufacturers add them regardless. In 2016, for example, the Swedish Chemicals Agency determined that nearly 40% of 154 randomly selected low-priced electrical products—including headphones, bicycle lights and USB contacts—that it checked contained levels of prohibited substances higher than permitted including lead, SCCPs and phthalates.[90]

Tackling the sources of marine chemical pollution unquestionably remains a challenge for wealthier nations, but is far more difficult for poorer nations, which often lack the resources and expertise, and typically have weaker regulations

Finally, and as noted earlier in this report, untreated sewage is a major source of chemical contamination in the ocean. The proportion of untreated sewage entering the ocean from many lower-income countries, for example, is 80-90%, with toxins typically including heavy metals like lead, cadmium and mercury.[91] And even where wastewater plants do operate, their effluent contains compounds from pharmaceuticals and personal care products because they are not designed to filter out the complex chemicals involved—whether those are used in the manufacturing process[92] or contained in the finished product.[93]

This dive into the sources of marine chemical pollution contains an important truth: while it is unquestionably a challenge for rich nations, says Dr Peter Kershaw, tackling it is a far more difficult prospect for poorer nations. Not only do they often lack the resources and expertise in what can be a highly specialised area, he says; they typically have weaker regulations and are less able to influence corporate behaviour. (That said, Dr Kershaw adds, the UNEP-hosted Global Chemical Regulations database would be of use to such nations, as it holds 16,000 regulations in searchable format from more than 120 countries.)[94]

Linked to that, and looking to the coming decades, population growth for this century will be concentrated in these poorer regions—Africa, for example, is expected to see its population triple from 2020 levels to more than four billion people by 2100.[95] That could have profound implications for marine chemical pollution, which is at heart an anthropogenic challenge.

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