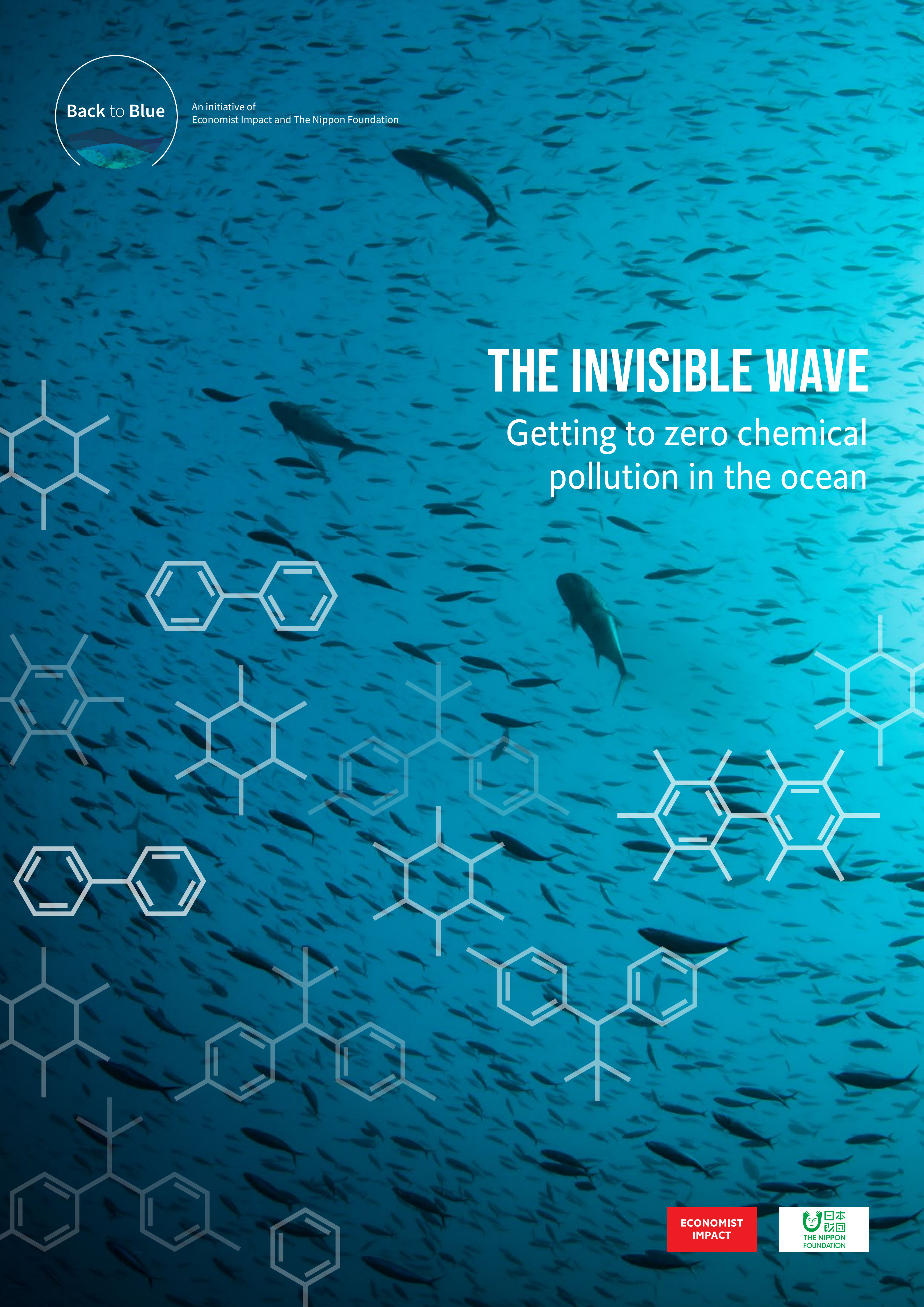

Back to Blue

An initiative of
Economist Impact and The Nippon Foundation

THE INVISIBLE WAVE

Getting to zero chemical pollution in the ocean

ECONOMIST IMPACT

THE NIPPON FOUNDATION

About the report

The Invisible Wave: Getting to zero chemical pollution in the ocean is a report from Back to Blue, an initiative of Economist Impact and The Nippon Foundation. The report was written by Economist Impact. The overall aim of *The Invisible Wave* is to bring the issue of marine chemical pollution to a wider audience, one that includes policymakers, governments, the chemicals industry itself, the broader business community, the finance sector, civil society and consumers.

The authors of the report were Robert Carmichael and Jessica Brown. The lead editor was David Line, while editorial management was provided by Naka Kondo. The case study of the economic impact of dead zones was conducted by Pratima Singh, Shreya Mukarji, Divya Sharma Nag and Aayushi Idda Sharma. The initiative lead for Economist Impact is Charles Goddard.

In preparing for this report, and to inform the wider Back to Blue initiative, we have spoken with many people from businesses, financial institutions, governments, NGOs and scientific research institutes. Not all are mentioned here, yet we nevertheless thank them for their time and insights. We would like to offer particular thanks to the following people (listed alphabetically by institution) who are either quoted in this report or joined our expert panel:

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The Back To Blue initiative marries Economist Impact's global audience and its reputation for objective, independent analysis with The Nippon Foundation's global reputation for supporting ocean science, data and evidence. This unique initiative aims to have a measurable impact on ocean health. To find out more, visit https://backtoblueinitiative.com/

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What if the world wakes up to the threat of marine chemical pollution?

How Asia's approach to marine chemical pollution restored the region's seas to health—while other parts of the world struggled. An imagined scenario from 2045, grounded in historical facts, current speculation and science-backed evidence.

It was the return in significant numbers of larger marine animals—dolphins and turtles, for instance—in 2033 to the coastal seas off Hong Kong that gave Dr Hai Mei[1] hope that the measures that had been imposed five years earlier to counter marine chemical pollution were starting to pay off.

"That was encouraging, of course—it made me think we might be turning a corner in our efforts to conserve the oceans and seas from manmade pollution," the marine biologist said. "But what clinched it for me was when we found not one but three breeding pairs of dugongs near the mouth of the Pearl River in 2036. That was when I knew something profound was under way."

Dugongs had not been seen in the area for decades, which was hardly surprising given that their diet of seagrass was impossible to find due to decades of pollution, particularly nitrogen from agricultural runoff. Their return was a vindication of the world's most ambitious environmental programme, one that started in China and that then spread throughout South-east Asia and beyond.

That this programme was brought about by necessity makes its success no less remarkable. The Pearl River Delta is one of the most populous parts of the world and, in the early 2020s, was one of the most polluted. But the success of China's 2013 Air Pollution Prevention and Control Action Plan to cut concentrations of fine particulate matter (PM2.5)[2]—one of a swathe of environment-focused measures brought in nationwide—culminated in a massive project focused on reversing decades of ever-higher marine chemical pollution.

A notable success in China's rolling five-year plans for pollution control, says Dr Hai, was that by 2035 the country had met its goal of cleaning up nearly all of its waterways, making coastal waters healthier and paving the way for the return of a variety of once-abundant marine species.

Renminbi, regulations, restoration

With access to central government funds, municipalities along the coast of southern China embarked on a huge infrastructure programme in 2028 that tackled key sources of marine chemical pollution, including industrial emissions to air and water, agricultural run-off, domestic wastewater, and municipal waste.

The programme did not stop there. Regulatory measures targeted China's chemicals industry, which is the world's largest and mostly state owned, to ensure that its sourcing, production and use of chemicals followed green chemistry principles: being environmentally safe, recyclable and having a low-carbon footprint.

The industry was also ordered to adopt the precautionary principle, which meant it had to prove that the chemicals it made did not harm the environment or human health. (This approach was timely: China's chemicals industry grabbed market share as manufacturers and customer-facing firms globally could source non-toxic and sustainable products from outside the EU, which had long led in green chemistry.)

Success came fast. By 2038, the seas off China were the cleanest they had been in decades

Also vital, said Dr Hai, were efforts by coastal municipalities to restore important ecological habitats as part of China's rolling five-year plans to combat pollution. Steps included planting thousands of square kilometres of seagrass beds and mangroves along China's coast, introducing hundreds of millions of shellfish to filter toxins from the water, and efforts to restore coral communities and wetlands.

Success came fast. By 2038, ten years after the programme began, the seas off China were the cleanest they had been in decades—as clean, even, as those in the EU, which had already improved markedly since the bloc introduced increasingly onerous regulation through the 2010s and 2020s.

A muddier global picture

Elsewhere, though, the story is mixed. In the US, for instance, efforts to counter marine chemical pollution stalled as federal efforts ran up against states' powers to write their own environmental rules, which often favoured business interests. In addition, the so-called lost decade of the 2020s, when successive US administrations were hamstrung through a lack of control of both legislatures, hampered the battle. As a result, the marine environment in the US has continued to deteriorate and is at the worst in its history.

And while South America, which has had some success, still has far to go before its seas are free of chemical pollutants, it is Africa that remains the outlier and the key worry, with its fast-growing and wealthier population boosting demand for goods. That said, money from China's Belt and Road Initiative and the EU's €300bn infrastructure fund has financed important infrastructure projects in municipal waste and wastewater management in populous countries like Nigeria, Kenya and Mozambique.

Indeed, the unexpected success of projects in fields like wastewater treatment and municipal waste in the continent's two largest cities, Lagos and Kinshasa, have shown what is possible even in places with huge populations and near-zero infrastructure. Though their combined population is nearly 70 million, their state-of-the-art facilities mean they now produce less pollution from wastewater and municipal waste than London.

Leading by example

It is Asia, though, that has most impressed. In the first three decades of the century, the continent's booming population and growing levels of waste made it an unlikely poster child for success in the battle against marine chemical pollution. But the outcomes seen in places like the Pearl River Delta saw those lessons applied elsewhere in Asia, from Thailand and Vietnam to Indonesia and the Philippines, and to many of the small island nations in the Pacific.

Another motivator was the UN Decade of Ocean Science, which ran to 2030 and saw collaboration around the world to reverse the decline in ocean health

In part, this was due to China's revamp in 2030 of its Belt and Road Initiative to factor in environmental goals. It was also because marine chemical pollution knows no national boundaries, so success required co-ordinated action across the region. As a result, many countries in Asia-Pacific and elsewhere have for over a decade been able to source cheap finance for infrastructure and waste projects. They have also been able to tap funding and expertise from the EU, Japan and Canada, and from the innovative G20 Marine Infrastructure Fund, which sees rich governments underwrite blue loans to poorer nations from private sector providers.

Consequently, hundreds of state-of-the-art plants to treat wastewater and municipal waste have been built across Asia-Pacific, while a range of simultaneous measures have resulted in far lower runoffs of agricultural chemicals like pesticides and fertilisers. Studies show that the runoff of all chemical pollutants into the region's hydrosphere has halved in a decade, and is expected to reach net zero by 2060.

Action in Asia and elsewhere was also helped by the signing of global treaties that shored up a weak and ineffective global regulatory regime. In this context, two stand out: the 2028 Tokyo Protocol on Marine Chemical Pollution and the 2033 Port Moresby Declaration on Mining Waste, which regulates deep-sea mining and mining waste dumped into the seas.

Another motivator was the UN Decade of Ocean Science for Sustainable Development, which ran to 2030 and saw collaboration around the world on generating science-based solutions to reverse the decline of ocean health. Among its successes was the reduction in coastal pollution in many major estuaries worldwide, including of the Hudson-Raritan Estuary south of New York, which at the turn of the century was ranked as one of the world's most polluted.

Perhaps most surprising, says Professor Cordelia Marino,[3] an expert on international environmental law at South Africa's University of the Witwatersrand, was the success in the 2020s of court action against major chemicals companies in the EU and other wealthy nations. In many ways that started in 2021 when a Dutch court ordered oil and gas major Royal Dutch Shell to accelerate its targets to reduce its carbon emissions.[4]

Buoyed by this success, which was built on environmental and human rights arguments, pro-environment lawyers filed cases in numerous countries against other oil and gas majors, vehicle manufacturers (back then, almost all cars used combustion engines that burned petrol or diesel), banks and financial regulators.

Given that many of the biggest chemical producers were also oil and gas majors, it was not long before they appeared as defendants. After losing a string of cases, the industry was forced to transition far faster to a sustainable future.

Inevitably, not all were successful. Among the corporate casualties were some manufacturers of the particularly toxic PFAS , known as “forever chemicals”, which were driven to the wall by huge clean-up costs and legal liabilities that far exceeded those levied on Big Tobacco decades earlier. As pension funds and other asset managers belatedly adjusted their portfolios to factor in marine chemical pollution, the chemicals industry’s financiers were compelled to do the same.

Although the global battle against marine chemical pollution has not been won yet, the world is clearly on the right track. The approach of funding, regulation and knowledge-sharing, underpinned by the political realisation that action was vital for the planet, has reversed what looked to some in the 2020s to be an impending catastrophe.

For marine biologist Dr Hai (who won this year’s “Nobel for the Environment”, the Gore-Thunberg Medal), the outcome is more than she could have dreamed of when she graduated in 2025. Back then, a world free of marine chemical pollution seemed impossible. Now it is within sight. For proof of that, you need look only as far as the Pearl River Delta: today there are 42 breeding pairs of dugongs, says Dr Hai, with that number expected to reach more than 100 by 2050.

Please see Notes for references

Introduction and summary

The overall aim of this report—written by Economist Impact for Back to Blue, an initiative of Economist Impact and The Nippon Foundation—is to bring the issue of marine chemical pollution to a wider audience. And with that, bringing it to policymakers, governments, the chemicals industry itself, the broader business community, the finance sector, civil society and consumers.

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. This report 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.

Roadmaps for key stakeholders

While intervening makes sense on every level—including in terms of human health and wellbeing, and on the environment, economy and culture—it requires co-ordinated action from all stakeholders: government, industry, finance and civil society. It also requires a sense of urgency. This is a concern because previous crises like mercury, which saw the adoption of the Minamata Convention, require consensus-building, which can take decades.

International and national legislation

The extent of marine chemical pollution, and the fact that it is getting worse, shows that the existing (and complex) legal and regulatory landscape does not work as it needs to. An international treaty could serve to oversee action yet would require that countries overcome the risks of excessive caution, mis-framing and time lags that characterise co-ordinated global efforts.

Improving regulation would also require overcoming vested interests, increasing awareness of marine chemical pollution, and implementing monitoring and assessment programmes, with the resulting evidence driving further policy actions. Countries should also improve their treatment of wastewater and solid waste (and enforce existing regulations, where those exist), with wealthier countries helping poorer nations to improve or build such systems.

This report would like to see a range of interventions, including: raising awareness of the causes and remedies for marine chemical pollution (particularly better communication between scientists and policymakers, and also to the public); using the precautionary principle to prevent further damage to the marine environment; improving the regulation of harmful chemicals (and enforcing rules globally); establishing a global science-policy body with a remit that covers chemicals and waste; creating a comprehensive chemicals database at the global and national levels; and mandating disclosure of all chemicals in products and their potential effects.

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.

Among the interventions this report would like to see are more innovative approaches from the chemicals industry, where it seeks to develop new and more sustainable products and processes, and in that way shift from a risk-based approach to one avoiding hazard. This will also create a commercial incentive to change, creating a "coalition of the willing" that would help to offset first-mover disadvantage. Increased transparency and collaboration across the supply chain will also be key.

Finance

Banks and other financial players like asset managers remain largely unaware of marine chemical pollution and its associated risks. This mirrors the situation in the mid-2000s on climate change and, as with climate change, our view is that the finance sector will one day be compelled to factor marine chemical pollution into its environmental, social and governance (ESG) considerations.

Better information can help the finance sector to see this picture more clearly and would help to clarify the risks and rewards of transitioning to a more sustainable future for chemicals. Equally, failing to transition to net zero will bring risks for the chemicals sector, and therefore finance, as seen in other sectors. These include litigation, reputational risk and changed downstream market conditions.

On the other hand, progressive players should reap rewards in a more ESG-focused world, with firms more likely to require access to funds to finance such transitions. To that end, eliminating marine chemical pollution needs to be an investable proposition, with room for novel solutions like blue bonds and impact investing—and with opportunities for deep-pocketed investors like private equity to fund the necessary long-term, capital-intensive projects.

Improved ESG-related guidance, more and better published data on companies' impacts on marine chemical pollution and their exposure to transition risks, and improved sources of and access to transition financing solutions are other actions that should be implemented.

Civil society and consumers

The final group could be classed as motivators of change with a track record of putting pressure on policymakers, governments and companies on important issues. Popular awareness of the dangers of marine chemical pollution is low compared with other urgent environmental problems, and rectifying this would require emotive and visual storytelling that is grounded in science.

The next step would be to ensure that people can take achievable actions by exerting their power as voters and consumers. Solutions include better labelling, citizen science projects and efforts to promote behavioural change such as replacing or cutting down on using products with toxic chemical ingredients like sunscreens that kill coral.

For their part, civil society groups can co-ordinate action and focus it on the other key stakeholders, and can also convene these disparate groups in an effort to find solutions to marine chemical pollution.

Among the interventions this report would like to see are awareness-raising to make the invisible visible, developing campaigns that are grounded in science yet emotionally appealing, and offering individuals solutions that are realistic and achievable—in part by providing them with the tools and information needed to be proactive.

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.

Outline of the report

This report has two parts:

- **Part 1: Sources and impacts** examines the scale of the problem of marine chemical pollution and its sources.
- **Part 2: Mitigation, resolution and prevention** outlines the roles that each of the various stakeholders—regulators, the producers and users of chemicals, the finance industry, and civil society and consumers—must play if the world is to resolve marine chemical pollution.

PART 1: SOURCES AND IMPACTS

Chapter 1: Ocean chemical pollutants of major concern

The report begins by listing the key categories of chemicals that our panel of experts believe are at the heart of marine chemical pollution, providing examples and explaining the repercussions. Among the categories are POPs, plastics, fertilisers, pesticides and heavy metals.

Chapter 2: Sources of marine chemical pollution

The second chapter focuses on chemical lifecycles and the sector's value chain: from pre-production (oil, gas, minerals and metals are key feedstocks) to chemicals manufacturers, then to the businesses that use those products and the end-users—with each stage culminating in marine chemical pollution. It also examines other ways that chemicals pollute the seas, including accidents, public sector use, and waste management and disposal, and notes the growing problem of e-waste.

Chapter 3: Towards an anthropogenic crisis?

This chapter asks whether marine chemical pollution is moving the world towards a serious anthropogenic crisis, with a recent study concluding that Earth has already crossed the levels of chemical pollution that it can sustain. Positively, it explains how tackling marine chemical pollution would help to meet many of the SDGs and how combating climate change, like cutting fossil fuel use, would also benefit the ocean. However, it also warns that steps being taken to "green" economies must not worsen marine chemical pollution, and notes that the urgency to act is heightened by: growing volumes of chemicals production, particularly in less-developed nations where regulations are often weaker; and burgeoning population growth, which will drive demand.

Chapter 4: Measuring the impact and risks of marine chemical pollution

This chapter looks at the value of the ocean, which easily measures trillions of dollars annually, and the impact of marine chemical pollution on the services it provides: economic (fishing, for instance); tangible ecosystems services (producing oxygen and regulating climate); and intangible ecosystems services (its cultural value). Given the ocean's fundamental importance to life on Earth, it is imperative that all stakeholders act urgently to counter marine chemical pollution. Central to this is the fact that regulations are proven to work in this context and therefore must be employed to ensure producers and users of chemicals no longer externalise their costs. Chapter 4 concludes with a case study that assesses the impact of marine chemical pollution on US fisheries in the Gulf of Mexico, calculating that the difference between acting and not acting would be worth nearly US$1bn for the US fisheries sector alone.

PART 2: MITIGATION, RESOLUTION AND PREVENTION

Part 2 has four chapters, each of which outlines a stakeholder's role in mitigating, resolving and preventing marine chemical pollution. In so doing, it lists barriers to progress and concludes with a wish list of actions that each should take.

Chapter 5: Regulations

This chapter looks at the role of regulators and policymakers. It outlines the legal landscape and explains why existing regulatory processes are inadequate—in part due to excessive caution in acting, but also because it is far easier (and quicker) for industry to place chemicals on the market than it is for regulators to remove them. The chapter highlights one key area for action, which is better global treatment of domestic and industrial wastewater and effluent, most of which goes into the rivers and seas untreated or under-treated.

Chapter 6: Industry

This section puts the role of the chemicals industry, as well as the companies further along the value chain, in the spotlight. The chapter notes that the sector faces an existential crisis should it fail to address upcoming climate-related and financial pressures, while pointing out that it has seen far too little change—despite the valuable opportunities that exist for first-movers in sustainable and green chemistry. Unless the sector changes its culture, it risks having change foisted upon it. This could come either directly from regulators, but also indirectly via consumers, who are growing increasingly aware of the dangers of chemical pollution, and who are pressuring the consumer-facing companies that are the sector's clients to take action.

Chapter 7: Finance

The role of finance in marine chemical pollution is the subject of this chapter, which notes that—despite limited investor awareness of the drivers of and solutions to marine chemical pollution—new regulatory taxonomies will compel improved understanding of the issue and the need to act. This, in turn, will shape the extent to which ESG-focused investors and the broader finance sector are prepared to fund those responsible for marine chemical pollution. One crucial factor will be how to clarify the transition risks and potential rewards for investors; another will be how best to fund the transition, with private equity and M&A among the mechanisms that have the potential to drive innovation in the chemicals sector.

Chapter 8: Consumers and civil society

The final chapter looks at the roles that civil society and consumers can have in curbing marine chemical pollution. It notes that, although public awareness of this largely invisible issue is low, this can be turned around with compelling, science-based storytelling. It also points out that while civil society has a long history of focusing and co-ordinating popular action, it must ensure its campaigns provide consumers with measurable, achievable actions, particularly when it comes to making informed purchasing choices.

Principal findings and recommendations

Detailed summaries of principal findings and recommendations are included at the start of each chapter. What follows is a simplified and condensed summary of the research's most important findings.

- **Marine chemical pollution is a profound and growing global problem that requires urgent and co-ordinated action.**
  Synthetic chemicals are present in the deepest parts of the ocean and in all manner of marine biota, and concentrations of many of the most dangerous chemicals in the marine environment continue to rise. Worryingly, a 2022 study concluded that the world has already crossed the planetary boundary where chemicals threaten the very ecosystems—including the marine environment, which provides services worth trillions of dollars every year—upon which humans and most other species depend. Ocean services range from economic benefits like fishing and tourism to Earth-critical functions like generating oxygen, storing carbon and regulating the climate.

- **Marine chemical pollution is a human-made problem that will get worse.**
  Since humans are producing far more chemicals and in ever-greater volumes, and will continue doing so for decades, the impact on the marine environment will get more severe. Exacerbating factors include the so-called greening of economies (not least the push for deep-sea mining to meet resource needs); the expansion of production by the chemicals industry, particularly in Asia and to countries with limited oversight; and growing populations—predominantly in poorer countries with a limited capacity to deal with chemical pollution. Among the urgent solutions suggested by the 2022 planetary boundaries study is to cap chemicals' emissions, as with greenhouse gases, to ensure they do not exceed the planet's ability to cope.

- **Marine chemical pollution is linked to tackling both climate change and plastic waste.**
  The way chemicals interact with environmental factors like temperature, acidity and salinity—all of which are affected by climate change—and the way they react to other chemicals has a big influence on their effects in the marine environment. Modelling projections show climate change could cause chemical concentrations in marine environments to rise as much as three-fold, with that increase driven largely by higher water temperatures. At the same time, plastics constitute a central challenge to marine chemical pollution: not only do they contain numerous toxic chemicals, but they also absorb chemicals and transport them in the marine environment. Microplastics have known negative effects on marine life, including weight loss, lower growth and reduced fecundity, while nanoplastics have been shown to affect reproduction, and can be bioaccumulated and biomagnified in the marine food chain. Sunlight can chemically alter certain plastics as they break down, producing a range of thousands of new, water-soluble products that do not resemble the original material.

- **More research is needed, but this must not hamper taking steps to combat marine chemical pollution.**
  There are tens of thousands of synthetic chemicals, yet in most cases we know nothing about their potential impact on the ocean environment—or on humans. Much more research is needed to determine the damage that many chemicals inflict on the marine environment, including how their interactions increase or lessen that harm. This will require far greater levels of funding, which should be targeted towards the chemicals of greatest concern in terms of their harm to ocean ecosystems and biota and, via those, to human health and local economies. Yet the fact that we cannot fully quantify the damage done by chemicals to the marine environment must not preclude action: we do know enough to be concerned about the *potential* impact. It is already clear that certain chemicals inflict significant harm. Additionally, a large number of chemicals still need to be assessed and managed. For these reasons and more, the need to act is urgent.

- **Regulators need to enact and enforce stricter rules on pollution; producers need to adhere to common standards.**
  Central to marine chemical pollution is the fact that industry has been able to externalise its costs—passing these on to society, and often to the poorest and most vulnerable. Given that most future chemicals production growth will originate in Asia-Pacific, the Middle East and Africa, 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. Industry players need to ensure their facilities in Asia and other regions operate at a minimum to the standards required in their home countries. In addition, too few manufacturers take end-of-life factors into account when designing and making products. Given that more than 95% of manufactured products rely on chemicals to some degree, manufacturers must factor in end-of-life considerations.

- **The chemicals industry and companies along the chemicals value chain can have a massive impact on resolving marine chemical pollution.**
  Actions by the chemicals sector, encompassing fossil fuel-based commodity chemicals, specialty chemicals, pharmaceuticals and agricultural chemicals, present perhaps the most compelling opportunity to address marine chemical pollution. Yet the industry is sprawling, diverse, intertwined in long and complex global supply chains, and dependent on capital-intensive infrastructure and processes that operate at low margins and demand huge scale. Change will be a complex, expensive and fraught process. Failure to change may lead to an existential crisis for chemicals companies.

- **Momentum is growing for a circular economy; innovation in green chemistry may be a route to reducing pollution.**
  There are viable pathways for change. Growing segments of the industry have pledged to tackle plastic pollution. While some companies and industry groups still insist that recycling while producing ever-larger quantities is a solution, others have begun to acknowledge that a genuinely circular economy will require radical product redesign and may result in reduced sales. Green chemistry offers an opportunity to design high-performance products that are less toxic and less polluting.

- **Investors are not sufficiently aware of the problem of marine chemical pollution: better information is needed.**
  A lack of awareness among the finance community about the profoundly damaging effects of marine chemical pollution is a barrier to change: the current level of awareness mirrors the sector's understanding of climate change in the mid-2000s. While demand for sustainability-linked investments is strong, data about marine chemical pollution, the role that industry plays and the possible impact of regulation are patchy. Better information about the material risks that the chemical sector will face transitioning to a zero-pollution ocean will be an important first step for any finance sector-led solution—in tandem with an appreciation of the potential rewards for early movers.

- **Quantifying the costs of inaction and the rewards of intervention may help motivate change.**
  Although putting a dollar value on everything at risk is impossible, combating marine chemical pollution has been shown to bring sizeable economic benefits in areas it has been measured. In a case study in this paper on the costs of hypoxic "dead zones" in the Gulf of Mexico, The Economist Intelligence Unit found that should the issue worsen and contribute to a greatly reduced landing weight of fish catch, the US stands to lose nearly US$838m in annual fisheries revenue. Conversely, if measures were taken to reduce the dead zone, contributing to increased marine biodiversity and fisheries landing weight, the best-case scenario (a 15% increase in landing weight) could see an increase in revenue of over US$117m.

- **Popular awareness of the danger of marine chemical pollution is low: consumers need better information.**
  Community awareness about marine chemical pollution is low relative to other environmental issues such as plastic pollution or climate change. Knowledge-building is a critical first step. The most effective way to do this is by using emotive and visual storytelling. And while industry and government are the stakeholders that can have the most direct impact on marine chemical pollution, civil society groups have had some notable success in influencing decision-makers to act on marine chemical pollution. Ultimately, the most potent way for individuals to influence marine chemical pollution is through purchasing decisions. Unfortunately, consumers do not always have access to the necessary information to make these decisions. A key goal is to establish consumers' right-to-know about hazardous chemicals in the products they buy.

- **Non-government organisations (NGOs) can act as focuses of citizen power and convenors of stakeholder groups with divergent interests.**
  NGOs play a crucial role in focusing and co-ordinating popular action: there are some illustrative examples of multinational businesses and governments responding directly to NGO campaigns or community pressure to address marine pollution. NGOs can also act as convenors, bringing together disparate stakeholder groups that might not otherwise act in concert.

As this report makes clear, marine chemical pollution is a global and systemic problem for which we are all responsible. To that end, tackling marine chemical pollution requires the co-ordinated action of everyone in the chemicals value chain—from the chemicals industry itself through to the broader business community, governments, regulators, investors and financiers, as well as civil society and consumers. Failure to address marine chemical pollution in a systematic manner risks inflicting irreparable harm on the ocean, its biota and functions, risks exacerbating a threat that humanity simply cannot afford to ignore.

Please see Notes for references

1: Ocean chemical pollutants of major concern

This chapter outlines the key chemicals and chemical groups of greatest concern when it comes to marine chemical pollution, looking at the known causes and impacts of each group.

1.1 Principal findings and recommendations

- **There are huge numbers of chemicals, but there is limited knowledge of the potential impact of most. Regrettable substitution is often the result.**
  There are tens of thousands of synthetic chemicals, yet in most cases we know nothing about their potential impact on the ocean environment—or on humans. In some cases, however, the toxic effects are understood. In recent years, scores of chemicals have been put on lists for banning, restriction or substitution. Yet a lack of knowledge has led to regrettable substitution, in which replacement chemicals are not properly tested and are later found to be toxic too.

- **The list of chemicals of concern for the marine environment is long.**
  The list of the chemicals of greatest concern, some of which overlap, includes the following: persistent organic pollutants (POPs); heavy metals; nutrients; pesticides; plastics; pharmaceuticals; radioactivity; oil products; household and consumer chemicals; and pseudo-persistent chemicals. While some of these are banned or restricted, most are not. And even where some are banned, there are still large stockpiles that require disposal or treatment. POPs are of particular concern: although a few dozen chemicals are listed in the Stockholm Convention and in other international regulations for banning, restriction or substitution, thousands more chemicals likely meet the definition of POPs (and of other chemicals of concern). Acting on these is essential.

- **More research is needed to overcome knowledge gaps...**
  Much more research is needed to determine the damage that many chemicals inflict on the marine environment, including how their interactions increase or lessen that harm. This will require far greater levels of funding, which should be targeted towards the chemicals of greatest concern in terms of their harm to ocean ecosystems and biota and, via those, to human health and local economies. This will also require a much greater focus on research on the effects of marine chemical pollution on poorer nations. To date, research has been centred on wealthier nations,

despite the fact that marine chemical pollution disproportionately affects poor and marginalised populations.

- **... but this must not hamper taking steps to combat marine chemical pollution.** The fact that there is a lack of sufficient research to fully quantify the damage done by chemicals to the marine environment must not preclude action. It is already clear that certain chemicals inflict significant harm on the marine environment; additionally, a large number of chemicals still need to be assessed and managed. For these reasons and more, the need to act is urgent.

A comprehensive 2020 study found more than 350,000 chemicals and mixtures of chemicals have been registered for production and use – three times a previous estimate—and that the identities of about 120,000 of these are publicly unknown because industry claims they are confidential or because they are described ambiguously.

We know so little, and in many cases nothing whatsoever, about the vast majority of chemicals, very few of which have been tested for their potential to do harm on humans or the environment

Consequently, there is significant concern among experts that the toll that chemicals exact on the marine environment and the wildlife that inhabits it is far higher than is currently known, to say nothing of the impact on humans—either directly through the seafood we eat or indirectly through the effects that chemicals can have on climate change, for instance, or on ecosystem services like fisheries and the protection from storm surges provided by mangroves and coral reefs.[1]

The need to fill the array of global knowledge gaps is one that UNEP highlighted in its 2019 Global Chemicals Outlook report—one of ten key areas it identified as important for the world to tackle in order to minimise the adverse effects of chemicals and waste. Success requires "taking steps to harmonise research protocols, considering health or environmental impact information and harm caused to set and address priorities (e.g., emerging issues), and strengthening the science-policy interface through enhanced collaboration of scientists and decision-makers".[2] Linked to that, UNEP noted that more attention is needed to determine how mixtures of chemicals affect the environment—including the marine environment.

"The cumulative exposure of ecosystems to the mixture of chemicals entering the environment has been identified [by the Secretariat of the Convention on Biological Diversity 2010] as one of the five main pressures negatively affecting biodiversity," UNEP's report notes. "How this chemical 'cocktail' interferes with human health, and how it interacts with organisms and the environment, is still largely unknown."[3]

This makes drafting a list of the ocean chemical pollutants of greatest concern a significant challenge. We know so little (and in many cases nothing whatsoever) about the vast majority of chemicals, very few of which have been tested for their potential to do harm on humans, to say nothing of the damage they do to the environment.[4] Consider this: A recent 20-year study that examined more than 3,500 chemicals in 130,000 scientific papers found just 65 chemicals constituted half of all occurrences, and that "for some chemicals the scientific knowledge is dominated by publications associated with the industry".[5] In short, only a limited number of chemicals have been tested for their ecotoxicity, with the objectivity of at least some of that research questionable.

Much of what we do know is based around chemicals' impact on human health, and that alone is worrying enough: the WHO calculated that exposure to a limited range of chemicals contributed in 2019 to 2 million premature deaths, with lead alone responsible for nearly half.[6] And, the global health body warned, the data covered only "a small number of chemical exposures, and people are exposed to many more chemicals every day".[7]

1.2 Defining the problem: A work in progress

For reasons we will examine in more detail shortly, our knowledge about the impacts that the majority of chemicals might have on the marine environment remains woefully inadequate. While this makes it impossible to draft a list that is both comprehensive and definitive, some national and supranational bodies have made a start. The EU's European Chemicals Agency (ECHA), for instance, has several such lists. One is its Candidate List of 223 chemicals or groups of chemicals that it describes as "substances of very high concern [that are manufactured in Europe or imported to it] that may have serious effects on our health or the environment".[8]

Another, the ECHA's Authorisation List, has the names of 54 chemicals or groups of chemicals whose use in the EU bloc has been or will be largely phased out,[9] while its Restricted List contains a further 69 substances or groups of substances whose manufacture or use in the EU is limited or banned.[10]

Logically enough, these lists are a work-in-progress. European nations can propose that the ECHA consider adding other worrisome chemicals to them. Eight of the chemicals on the ECHA's Candidate List, for example, were added in July 2021, with the ECHA noting that they have been included because "they are hazardous to human health as they are toxic for reproduction, carcinogenic, respiratory sensitisers or endocrine disruptors".[11]

Inclusion on the Candidate List, though, does not mean that companies are barred from using these chemicals. Under the bloc's REACH Regulation (Registration, Evaluation, Authorisation and Restriction of Chemicals, which entered into force on June 1, 2007), it simply means that a supplier of products that contain a Candidate List substance whose concentration is above 0.1 percent weight-by-weight "has to give sufficient information to their customers and consumers to allow safe use".[12]

Other national and supranational bodies have their own lists of chemicals of concern, as do interested parties like ChemSec, a Europe-based non-profit. It has created the SIN List (in which SIN stands for Substitute It Now) of 1,027 hazardous chemicals and groups of chemicals that it wants to see replaced by businesses with safer alternatives—far more than those listed in the three ECHA lists, for instance.

That raises a further key point: how best to determine whether a particular chemical is so dangerous that it should be banned or its use restricted. Establishing the knowledge base for a clear, swift and globally applicable process for this is one of the core aims of the ongoing Back to Blue programme. In part this means identifying those chemicals that are doing the most harm to marine environments (or that are likely to do so), and in that way are also harming people and local economies. This process will also point the way to where research is most urgently needed.

As mentioned, determining which chemicals are of concern is far from easy. At the heart of this is deciding which characteristics should be considered. Some assess a chemical's persistence, its bioaccumulation and its toxicity (known as its PBT). For its part, the Stockholm Convention on Persistent Organic Pollutants—a global treaty designed to prevent harm to human health and the environment from a range of chemicals known collectively as POPs—also incorporates the ability of a chemical to travel long distances (which is one reason no individual country can successfully deal with POPs' toxic impacts).[13] On top of this, assessment bodies often vary in terms of the threshold values used to measure a chemical's impact, and sometimes use different data sources—all of which can result in different outcomes.[14]

Not surprisingly, the lists of chemicals of concern (including whether or not they qualify as POPs) differ depending on the body concerned. To some experts, existing lists of chemicals of concern fall far short of what is needed. Independent assessments have concluded that the number of chemicals that should be considered as POPs, for instance, is far higher than the 29 that are currently listed in the Stockholm Convention. One study of 95,000 industrial chemicals identified as many as 5,000 as potential POPs.[15]

Regrettable substitution

A sensible solution for chemicals that are known to be toxic is to phase them out. However, this does not necessarily solve the problem; what they are replaced with is also crucial. Take polybrominated diphenyl ethers, or PBDEs. This class of synthetic fire-retardant chemicals replaced another synthetic fire-retardant class of chemicals devised about a century ago called polychlorinated biphenyls, better known as PCBs. PCBs, which were found to have hugely toxic effects on humans and animals, leach into the environment and build up in sediment in seas, rivers and on land, where they enter the food chain.

Although using PBDEs in products like furniture, mattresses, carpets and plastic cabinets is meant to make them less likely to catch fire (a questionable conclusion, some scientists say, though one that has for years been promoted by US manufacturers of fire retardant chemicals,)[16] it subsequently transpired that PBDEs, which are structurally similar to PCBs,[17] are also extremely toxic and disrupt the delicate hormone systems (the endocrine systems) of humans and animals.[18] This consequence, in which a substitute for a banned chemical has not been sufficiently tested and is later found to be as dangerous or even worse, is known as "regrettable substitution".

While there are restrictions on the use of the three types of commercially available PBDEs (pentaBDE, octaBDE and decaBDE—the last of which was brought to market as a substitute for pentaBDE and octaBDE, and which is therefore another example of regrettable substitution), they are still present in countless products around the world, including in the EU, for example, where their use is subject to certain limits.

PBDEs are only one of the five main classes of so-called brominated fire retardants,[19] and—as with PCBs—their regrettable substitution is not the end of the matter. One of the replacements for PBDEs is a class of fire-retardant chemicals called organophosphate esters (OPEs),[20] which at least one study has associated with hyperthyroidism in household cats.[21] Concerns about OPEs are on the rise: they are listed as Chemicals of Emerging Arctic Concern (CEAC) by the Arctic Monitoring & Assessment Programme,[22] a working group of the Arctic Council, an intergovernmental forum;[23] and a 2019 study concluded OPEs "are now often found at higher levels compared to PBDE peak exposure levels", with data suggesting health concerns for humans at current exposure levels.[24]

As it turns out, regrettable substitution is not unusual, with its effects seen more recently in the shipping sector. In January 2020, the International Maritime Organization (IMO) made it mandatory for ships to start using a new type of marine fuel called Very Low Sulphur Fuel Oil (VLSO), replacing the standard heavy fuel that was rich in sulphurs, and whose sulphur oxide emissions contribute to ocean acidification and harm aquatic species.[25]

In July 2020, the *MV Wakashio*—a bulk carrier—ran aground near Mauritius and eventually broke up. Although most of the fuel was pumped out, about 1,000 metric tons leaked into the ocean. The good news was that researchers found that the version of this new class of fuel oil as used in the *MV Wakashio* had lower quantities of components known to be toxic to marine life than those found in typical heavy fuel oils.[26]

However, they also found that other Low Sulphur Fuel Oils that they tested "contained higher concentrations of toxic components than the oil discharged in the Mauritius spill," said Dr Alan Scarlett of the Australia's WA Organic and Isotope Geochemistry Centre in Curtin's School of Earth and Planetary Sciences, and lead author of the study.

"So, more research will be needed before we can conclude that all the oil types within this new class pose less of a threat to marine ecosystems than heavy fuel oils," he said.[27]

Combinatory effects

How to replace pollutants, therefore, is one challenge in drafting a list of chemicals of greatest concern, because we simply do not know enough about the chemicals that are in use.

It gets more complicated still. Chemicals in the ocean do not exist in isolation, and nor are they immune to what is happening around them. Consequently, some have additive toxicological effects (the damage done accumulates as other chemicals are added to the mix) and some have synergistic effects (the damage done is multiplied). Some chemicals worsen the impact of other chemicals, while some can inflict greater or lesser damage on organisms depending on the order in which those chemicals are encountered.

All of this is without considering other factors that seem to affect chemicals' mobility and toxicity like sea temperature, acidity levels and deoxygenation, all of which the report examines in more detail in Chapter 3. Some experts fear these factors could mean that the ways that chemicals interact in the future might change—which means that the relative importance of different contaminants might also alter (an issue that Chapter 3 also looks at). In short, there is much that we do not know.

Toxic mix: Spoiled for choice

For the purposes of this report, determining the most worrisome chemicals starts by drafting the below list. And although this must be prefaced with an acknowledgement that it will by definition be incomplete, it is important to have such a list as a baseline.

As noted in the Summary, the categories are those that our expert panel believes constitute the most significant risk to the marine environment (to the best of our current knowledge). They also believe that tackling these will be crucial to efforts to reverse the damage to the ocean and restore ocean health.

To that end, this report categorises marine chemical pollutants as follows (though many chemicals fall into more than one category):

- **Persistent organic pollutants (POPs):** these chemicals include the PCBs and PBDEs outlined earlier, as well as organochlorine pesticides, dioxins, furans and certain fluorinated chemicals in the PFAS group like perfluorooctane sulfonic acid" (PFOS) and perfluorooctanoic acid (PFOA).

- **Heavy metals:** mercury, lead and cadmium are among the key constituents in this group.

- **Nutrients:** this includes fertilisers as well as organic matter, including human and animal waste, that leads to eutrophication[28]—the process in which algal blooms consume so much oxygen from the water that other sea life dies off en masse.

CHEMICAL POLLUTION AND THE OCEAN: PATHWAYS AND POLLUTANTS

Over 350,000 chemicals have been registered for production and use, and they play a fundamental role in many of the technologies and products of our everyday life, from smartphones to food preservation. Most marine chemical pollution, then, begins on land – about 80 percent, according to a commonly cited statistic, versus 20 percent that is thought to originate in the seas. The below illustrates some chemicals of key concern to ocean health.

HEAVY METALS

Hg

Mercury
Enters environment through channels including artisanal gold mining, burning coal, and non-ferrous metal and cement production

Cd

Cadmium
A grade 1 human carcinogen used in products including batteries, solar panels and plastics, with major effluent sources including marble, steel, and metal-plating industries

Pb

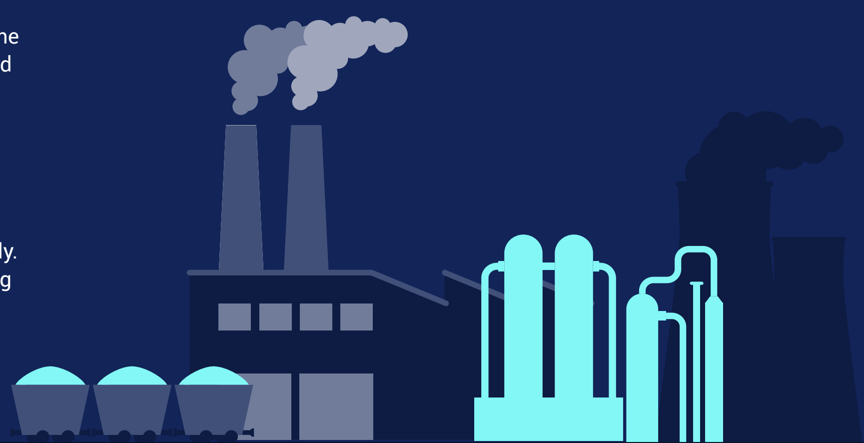
Lead
Produced by industries including mining, oil and gas exploration, infrastructure-building and dredging, and electronics. Lead accumulation is linked to heart disease, strokes and cancer

MANUFACTURED CHEMICALS

Persistent organic pollutants (POPs)
Carbon-based chemicals found in everyday products like furniture and electronics which can harm human health

Hydrocarbons
Oil includes around 10,000 components, some of which are linked to cancers, mutations and birth defects

Pesticides
More than 1,000 pesticides — insecticides, herbicides and fungicides — are used globally. They are causing coral die-offs and bleaching events and damaging aquatic vegetation



- **Pesticides:** an important category given that, for example, more than half of the chemicals targeted for elimination under the Stockholm Convention are pesticides.
- **Plastics:** this covers macro-, micro- and nanoplastics, all of which are themselves pollutants, and which can pick up and transport POPs and other chemicals long distances.
- **Pharmaceuticals:** this covers medications for humans and animals, with antibiotics a central concern given that their overuse or misuse can give rise to antibiotic resistance.
- **Radioactivity:** this covers recent contamination (for example, the 2011 Fukushima disaster in Japan), the historical dumping of radioactive waste, as well radiation emanating from natural sources.
- **Oil:** this also includes the toxic chemicals that are used to clean up spills.
- **Household and consumer chemicals:** many cleaning products contain toxic chemicals, as do numerous cosmetics, shower gels and sunscreens.
- **Pseudo-persistent chemicals:** these are chemicals that would dissipate relatively quickly in the aquatic environment, but whose concentrations keep rising because they are so prevalent in products—for example, some pharmaceuticals.
- **Other chemicals:** this includes a wide variety of the approximately 300,000 chemicals in use, most of whose effects are unknown.

1.3 Persistent organic pollutants (POPs)

Persistent organic pollutants, or POPs, is the collective name for a range of carbon-based chemical substances whose properties make them toxic to humans and animals, ensure that they can be widely distributed via soil, water and the air—including to the Arctic, far from any sources of POPs—and remain in the environment for years (or, in the case of PFOA, potentially forever). POPs enter the food chain and often accumulate in fatty tissue, where their concentrations build up over time—as high as 70,000 times the background levels for those high up the food chain like humans, fish, predatory birds and mammals.[29]

Many POPs present in the environment were used in agriculture and manufacturing, including in consumer products like furniture, electronics and toys; others, like dioxins and furans, spew into the environment from incineration or are the by-products of industrial processes.[30] Although there is less production today of some of the 29 POPs listed in the Stockholm Convention, large stockpiles exist and need to be disposed of or treated properly to avoid further contaminating the environment. Additionally, it is likely that far more chemicals than those 29 meet the criteria for classification as POPs.

POPs are problematic because they can trigger a wide array of ailments in humans and animals, including cancers, allergies, reproductive disorders, birth defects and developmental disorders. Many are endocrine disruptors, while others damage the immune system or the nervous system. Most of the 29 POPs listed in the Stockholm Convention are targeted for elimination,[31] with a further six being considered for inclusion as of early 2022.[32]

Perhaps the best-known POPs are the dioxins associated with Agent Orange, which was a defoliant used in the Vietnam War and that has had appalling health consequences, and DDT, an insecticide that disrupts the endocrine system. The latter is still used in some countries for mosquito control, though is banned from use in agriculture.

PCBs

Less well-known, but described as "one of the world's worst toxic legacies",[33] are a group of synthetic chemicals known as polychlorinated biphenyls, or PCBs, with an estimated 680,000 metric tons manufactured in the US alone until production was banned in 1979.[34] With 1.3 million metric tons thought to have been produced worldwide,[35] PCBs were used in electrical transformers, as flame retardants, in paint, in electronic items and in plastics—and even sprayed on roads to keep down dust. About one-third of the total produced is believed to be in coastal sediments and the ocean, with the rest in landfill or still in use, and so will likely continue to contaminate the ocean for decades.[36]

POPs, many of them endocrine disruptors, can trigger a wide array of ailments in humans and animals, including cancers, reproductive disorders and birth defects, and can damage the immune and nervous systems

There are 209 PCB congeners, or unique chemical compounds, in the PCB category. All are listed for elimination under the Stockholm Convention, and have a range of toxic effects in humans and animals. In humans, transmission is often through food, and causes developmental delays and behavioural problems as well as harming short-term memory. PCBs suppress the immune system in humans and some animals, such as seals, and are likely carcinogenic.[37] They are also toxic to fish: high doses kill them, while lower doses result in failure to spawn.

A major study of PCBs in the 1980s found that atmospheric deposition was central to contamination of the ocean; subsequent research indicates that PCB concentrations are higher in the marine environment of the Northern Hemisphere, particularly the Mediterranean and the Baltic.[38]

There are indications that PCB levels in at least some parts of the ocean are dropping. Although a study by the OSPAR Commission, a regional body that works to protect the marine environment of the North-East Atlantic, showed no appreciable decline up to 2015 in PCB concentrations in sediment in the Irish and Scottish West Coast and in the Irish Sea, it did reveal significant statistical declines in the other three areas surveyed (the Northern North Sea, Southern North Sea and the Gulf of Cadiz).[39]

That said, a 2017 study found extremely high levels of numerous types of PCBs (along with PBDEs) in crustaceans in two of the deepest parts of the ocean, far higher than surface levels, and with the most contaminated crustaceans exhibiting levels 50 times higher than those found in crabs in a very polluted river in China.[40] And a study from 2016 found that concentrations of PCBs and other POPs in fish in the remote Antarctic Ocean in the southern hemisphere had risen over the past two decades.[41]

In addition, countries may continue to use PCBs in certain equipment until 2025, with the obligation by 2028 to dispose of and destroy all such waste. In some, though, it is clear the 2025 deadline will be missed, which means PCBs will continue to contaminate the ocean despite the decades-old ban on production.

Other POPs

Largely unknown to the public yet also included for elimination under the Stockholm Convention's Annex A are a further two dozen or so POPs. These include chlordane, dieldrin and lindane (all of which are insecticides), dicofol (a pesticide), endosulfan (an insecticide that is still used in many countries, including on coffee and rice) and mirex (an insecticide and fire-retardant in plastics, rubber and electrical goods). Others are decabromodiphenyl ether (known as decaBDE, a bromine-based flame retardant still widely used in, for instance, electrical goods, vehicles, airplanes and carpets) and hexabromobiphenyl (another bromine-based flame retardant).

However, as noted earlier, there are likely far more chemicals that should be categorised as POPs than are listed in the Stockholm Convention. A 2012 study reckoned that between 190 and 1,200 chemicals of about 93,000 that it assessed could exceed the criteria for inclusion as POPs—with those criteria being persistence, bioaccumulation, toxicity and long-range transport.[42] Ten of those, the authors wrote, are "high-production volume chemicals".[43]

One group that has for now been dealt with only minimally under the Stockholm Convention are the perfluoroalkyl and polyfluoroalkyl substances, known as PFAS, with the US Environmental Protection Agency (EPA) calculating there are more than 9,200 of these synthetic compounds.[44] Within the PFAS group, only PFOS and PFOA are currently listed as POPs under the Stockholm Convention, although the convention's expert committee has recommended that PFHxS be listed as a POP. Other PFAS chemicals are also in line for inclusion. In mid-2021, Canada nominated long-chain PFCAs, their salts and related compounds for addition to the Stockholm Convention,[45] with the convention's POPs Review Committee agreeing in early 2022 that they met the criteria for POPs and should move forward to the second stage in the three-stage listing process that in several years might well see them banned globally.[46] (The committee also agreed action was needed on toxic plastic additives UV-328 and Dechlorane Plus, as well as on medium-chain chlorinated paraffins (MCCPs), which are produced in huge quantities and are used as flame retardants in plastics and in a number of industrial applications.)[47]

The resistance of many PFAS to heat, oil, water stains and grease have seen them used for decades in an array of household and industrial products, including firefighting foam, waterproofing for clothing, and grease- and water-resistant food packaging, as well as in non-stick cookware, cosmetics, sunscreens, artificial grass (for properties like low-friction) and electronics (for properties like flame retardance).

The two most notorious PFAS are PFOA (once used to make Teflon non-stick cookware coatings) and PFOS (precursors of which were used in 3M's Scotchgard coatings, and which is now used mostly in industrial processes like metal-plating), both of which have been phased out for domestic manufacture in the US.[48] In the body, many PFAS bind to proteins; many are carcinogenic, harmful to the immune system and damaging to the hormone systems of humans and animals. Both PFOS and PFOA are among the PFAS that have been found in measurable levels in ocean-based plankton[49] and in ocean waters.[50] A study, for instance, of 30 surface seawater samples taken from the North Pacific to the Arctic Ocean found PFCAs (which are a subset of PFAS that includes PFOA[51]) in more than 80 percent of them.[52]

"If that doesn't ring an alarm bell, then I don't know what will—because we know that the PFAS are endocrine disruptors, we know they are reproductive toxins and, most importantly, we know they are immune toxins," says Dr Mariann Lloyd-Smith, Senior Adviser to the International Pollutants Elimination Network (IPEN), a global network of non-profits. "If you have something that adversely affects the immune system of living things, then that inevitably impacts all health issues."

Some PFAS dissolve in water, and many of those that end up in the ocean stay in a layer 50-200 metres deep.[53] Studies have also shown high concentrations of PFAS at the sea's surface, whose microlayer (which is less than 50 μm, or 0.005 cm, thick) is "where exchange happens between the atmosphere and the ocean, [and which] provides [a] vital habitat for biota, including the fish eggs and larvae of many commercial fishery species and their phytoplankton food resources".[54]

Some PFAS are consumed, some sink to the sediment, while others in the depths rise to the surface from where they enter the atmosphere as tiny droplets that can be carried vast distances. These sea-spray aerosols are reckoned to be the largest secondary source of many atmospheric PFAS, with effects, too, on climate.[55] While much research is still needed on their prevalence and impact on the ocean, studies show PFAS levels in the rainfall of the Great Lakes region of North America are 10-1,000 times higher than those of traditional legacy chemicals like mercury, PCBs and pesticides.[56]

In the meantime, PFAS continue to pollute the ocean, with firefighting foams an important source. Many defence sites, which regularly practise firefighting exercises, are known to be contaminated by PFAS. The US Defense Department, for example, is investigating nearly 700 military sites for potential PFAS contamination,[57] with the Environmental Working Group, a US NGO, stating that "tests have confirmed that PFAS chemicals have contaminated drinking water or groundwater on or near" 385 bases to date. Similar contamination of defence bases in other countries, including Australia, is also evident.[58]

With half-lives measured in years or even decades, not for nothing are PFAS known as "forever chemicals"

Many PFAS are not only ubiquitous; they are also nearly impossible for water treatment plants to remove.[59] Additionally, their carbon-fluorine bonds ("the strongest chemical bond in nature"[60]) ensure they are extremely stable, making many of them highly resistant to degradation once they are in the environment. Even those PFAS that do degrade often culminate in end-products that are still highly persistent PFAS. Many of the PFAS that have been studied—and most have not been tested for their potentially harmful effects—are known to stay in human tissue for years, with half-lives measured in years or even decades.[61] Not for nothing are PFAS known as "forever chemicals".

Despite this litany of toxic effects, most PFAS are legal to use—though that could start to change. In the US, the EPA has created a body that will work "to better understand and ultimately reduce the potential risks caused by these chemicals".[62] That work included removing and updating a "politically compromised" assessment of the toxicity of one type of PFAS—an indication that improper influence of chemical toxicity can be found even in the world's richest nation.[63]

Also in mid-2021, five European countries announced their proposal to restrict the "manufacture, placing on the market and use of PFAS" in the EU. In their announcement, the countries stated that failure to act would see the concentration of PFAS in the environment continue to rise, making their harmful effects hard to reverse.[64]

"Due to their water solubility and mobility, contamination of surface, ground-, and drinking water and soil has occurred in the EU as well as globally and will continue," Germany, Denmark, Netherlands, Norway and Sweden wrote. "It has been proven very difficult and extremely costly to remove PFAS when released to the environment. In addition, some PFAS have been documented as toxic and/or bioaccumulative substances, both with respect to human health as well as the environment."[65]

1.4 Heavy metals

Although the world has seen regulatory action at the country and international level in recent years to counter the damage done by some heavy metals, "the market for most heavy metals (including lead and mercury) is stable or increasing", the UN Environment Programme (UNEP) notes in its Global Chemicals Outlook II report.[66]

In the public consciousness, lead and mercury rank far higher than many chemicals that pollute the ocean, including their metal peers like cadmium (used, for instance, in batteries and solar panels, as well as in plastics as a stabiliser and pigment), copper, chromium and manganese.

For lead, 2021 was a landmark of a sort as it saw this contaminant phased out of petrol for trucks and cars when Algeria announced that it had used up its stock of leaded petrol.[67] In the century in which lead was added to petrol, UNEP said, it had "contaminated air, dust, soil, drinking water and food crops" and caused heart disease, strokes and cancer, damaged human development and cut IQ by 5-10 points.[68] Banning leaded petrol, UNEP said, had prevented an estimated 1.2 million premature deaths annually, and saved the global economy nearly US$2.5 trillion.[69]

Lead, however, still enters the ocean each year, along with other heavy metals like arsenic, cadmium and mercury. Deep-sea mining is one source of heavy metal contamination in the ocean, as the next chapter will show, and one that will become more critical as companies and governments look to exploit underwater reserves as land-based mineral reserves decrease.

Another source is the dredging of harbours and near-shore areas, which can release heavy metals that have been trapped in sediments.[70] Untreated sewage is a third—the proportion of untreated sewage that enters the ocean from many lower-income countries, for example, is between 80-90 percent, and it "often contains heavy metals such as lead, cadmium and mercury".[71] Industrial sectors, including land-based mining as well as oil and gas, are also key sources of heavy metals contamination, as is the burning of fossil fuels.

One key pathway for exposure to mercury is from eating fish and shellfish that have accumulated the metal through their diet, with studies showing that as many as 1.7 percent of children living in subsistence fishing populations in Brazil, Canada, China and Columbia suffered cognitive impairment from eating tainted fish.[72]

Mercury has highly toxic effects on the nervous system, the immune system, the lungs and kidneys, and is especially dangerous for babies in utero and for young children.[73] Mercury's effects are so devastating that the WHO classes it as one of its ten chemicals of major public health concern.[74]

1.5 Nutrients

This category includes fertiliser nutrients—nitrogen, phosphorus and potassium—as well as human waste and animal waste. Runoff of these nutrients into the seas causes eutrophication, the rise of algal blooms that bring so-called red tides and the smothering of seagrasses by algae. The algae pull the oxygen out of the water, causing marine life, including fish, to die en masse, and resulting in deoxygenated dead zones.

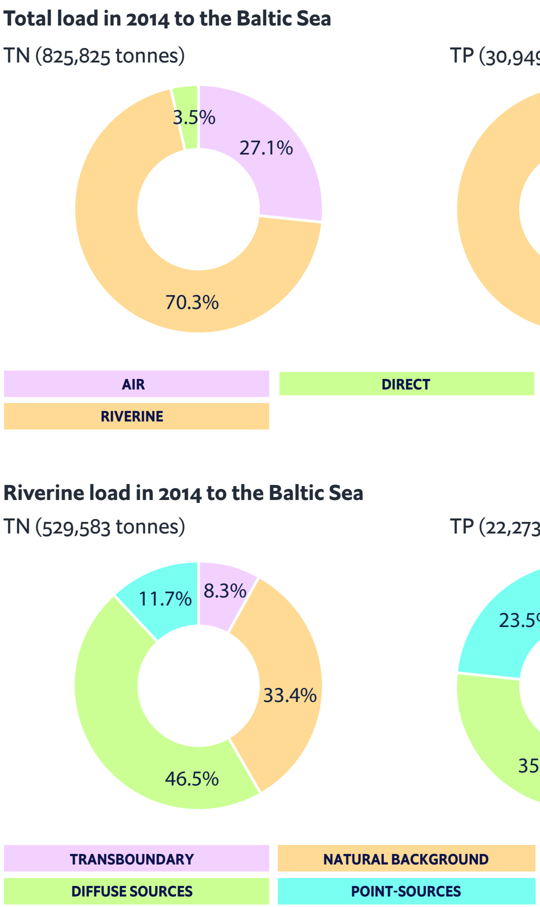
This brings an environmental cost as well as an economic one, as there are fewer fish and other marine stocks (like oysters and crabs) available to catch. While eutrophication can occur naturally, most is caused by human activity—in part from wastewater treatment plants but also from the runoff from agricultural and urban land after rainfall.[75]

One of the most affected marine areas is the Baltic Sea, where a recent study found that "at least 97 percent of the region was assessed as eutrophied in 2011-2016"—mainly from the agricultural run-off of nitrogen and phosphorus fertilisers. While inputs of nitrogen and phosphorus have decreased in recent decades, large amounts of both still enter the Baltic Sea (in 2014 alone, 825,825 metric tons and 30,949 metric tons respectively). Most flowed in from the region's rivers (see chart), with the economic cost estimated at €3.8bn-4.4bn annually.[76]

We examine the broader cost of dead zones, as a case study in quantifying the economic impact of ocean chemical pollution, in Chapter 4.

Baltic Sea—nitrogen and phosphorus flows

The sources for the Baltic Sea's nitrogen and phosphorus loads in 2014



Source: State of the Baltic Sea—Second HELCOM holistic assessment 2011-2016

1.6 Pesticides

The rise of industrial farming has seen demand for problem-solving chemicals—insecticides, herbicides and fungicides—climb fast. More than 1,000 pesticides are used globally,[77] helping to grow sufficient food for the planet's increasing population. Without pesticides, it has been estimated that the number of people at risk of malnutrition or starvation would rise from 0.8 billion to 3 billion[78]—although, as the UN's Food & Agriculture Organization (FAO) points out, the use of organic methods for food production in non-industrialised nations has the potential to increase yields or at least to ensure that yields do not drop.[79]

The need for pesticides, then, is something that experts debate. What is not in question is that their very function as toxins means many are also highly damaging to human and animal health and to the environment. The fact that more than half of the chemicals scheduled for elimination as POPs under the Stockholm Convention are pesticides shows that at least some of this harm is understood.

While much of that harm takes place on land, run-off and atmospheric deposition mean pesticides affect the marine environment too. In the Caribbean, for example, their use has resulted in fish die-offs, coral mortality and the thinning of eggshells, according to UNEP.[80] In Jamaica, UNEP noted that "an increase in fish mortality in coastal areas coincides with the period of the year when pesticides are applied on coffee plantations". Herbicides, in particular, damage seagrass beds and other aquatic vegetation.[81]

A healthier marine environment requires better management of pesticides, and elimination of the worst of them. Progress is slow. The Stockholm Convention lists fewer than 20 pesticides for elimination; the Pesticides Action Network lists 338 as highly hazardous

Australia's Great Barrier Reef, the world's largest coral reef system and one of its most important sanctuaries, is arguably the best-known example of a marine environment that has been damaged in recent years with large-scale coral die-offs and bleaching events. While pesticides and agricultural run-off are by no means only to blame (climate change is a key reason), some experts fear that large-scale pesticide run-off from sugarcane plantations and other crops are damaging the reefs, with studies showing pesticides and their associated degradation products are present in the river sources that flow into the sea,[82] and in the sea itself.[83]

What is clear is that a healthier marine environment requires better management and use of pesticides, and elimination of the worst of them. But progress is slow. While the Stockholm Convention lists fewer than 20 pesticides for elimination, the latest report from the Pesticides Action Network (PAN), a global network of more than 600 NGOs in 90 countries, lists 338 pesticides that it has concluded are highly hazardous (based on information from, for instance, the WHO, the EU and national agencies in the US and Japan).[84]

And, as PAN points out, the list is incomplete—in part because so little is known about the potential endocrine-disrupting properties of many pesticides. That holds true for their effects on ocean ecosystems too: a 2021 study that assessed the use of nearly 400 pesticides over the past 25 years, for instance, concluded that "despite decreasing total amounts applied and decreased impacts on vertebrates, toxicity—in particular to insects and aquatic invertebrates—has increased substantially". The authors added that their findings challenged claims that pesticide use was having decreased impacts on the environment.[85]

Meantime, pesticide use continues to climb in both absolute terms and in terms of amount used per hectare. In the three decades to 2019, according to the FAO, the world used 4.2 million metric tons of pesticides for agriculture in 2019—an increase of about 50 percent. By then, the amount used equated to 0.6kg for every person on the planet.[86] Herbicides account for just over half of the total used, while fungicides and insecticides account for most of the rest.

For its part, PAN, which is supported by hundreds of environmental health NGOs, wants the use of the 338 highly hazardous pesticides phased out globally by 2030.[87] Pesticides, PAN says, should be used only as a last resort, with studies from around the world showing that an agroecological approach—like using leguminous cover crops, compost, integrating livestock into cropping farms, and better timing of planting and weeding—are better for human health, yields and the environment.[88] They would also be far better for ocean health.

1.7 Plastics

The amount of plastic the world has manufactured since mass production started around 1950 is staggering: by 2015, that number was estimated at 8.3 billion metric tons, of which 2 billion metric tons was still in use.[89] The remainder was waste, with nearly 80 percent of that sent to landfills or polluting the environment, including the ocean, where it will take centuries to degrade. Even there, though, it will not disappear, but will break down into smaller and smaller particles, whose effects on the environment are unknown.

It is perhaps not surprising, then, that public concern about plastics is high. In a recent survey about ocean health, 60 percent of people said tackling plastic pollution was the top priority for restoring ocean health, ahead of dealing with chemical pollution and addressing climate change.[90] This concern is timely: in 2020, the world manufactured 367 million metric tons[91]—most of which was used in packaging and construction[92]—and production is forecast to double again by 2040.[93]

With such volumes, vast quantities of plastic have ended up in the environment. Between 1950 and 2015, an estimated 80 percent of the 8.3 billion metric tons manufactured went to landfills or was dumped, with some going into the ocean.[94] In 2016, the marine environment was estimated to hold about 150 million metric tons of all types of plastics, with eight million metric tons being added to that sink annually. That equates to a garbage truck's-worth of plastic being dumped in the marine environment every minute; unless action is taken, that volume is likely to triple by 2050.[95]

One reason plastics are such a problem is because most of what is made has zero-value (or close to it). Other contributing factors are that plastics are cheap to make, and are therefore disposable, and that too few countries have sufficient ability to recycle or reuse what is generated.

However, the issue runs deeper. While the public perception of the damage that ocean-based plastics do often revolves around seals entangled in plastic fishing nets, whales choked with plastic debris, or turtles dying from ingesting plastic bags, much of the harm is done out of sight.

This is because people typically consider the problem to involve bags, containers, fishing gear, straws, cup lids and single-use packaging. However, these visible plastics—known as macroplastics—are just one element. Smaller still are microplastics, which measure between 5mm and 1 micrometre (one thousandth of a millimetre), while nanoplastics, which are less than 1 micrometre, comprise the third group.

Some of these micro- and nanoplastics are added to products during manufacture (think microbeads for cosmetics, for example), while others come from the wear and tear of car tyres or from clothing that is made from synthetic materials, with all of these known as primary microplastics. The other category is secondary microplastics, which refers to macroplastics that have broken down in the natural environment from abrasion, wave action or sunlight.

Crucially for ocean health, though, this process is not the same as the decomposition that happens with, say, an apple. Instead, plastics become smaller and smaller plastic particles, with the resultant microplastics and nanoplastics ending up in the food chain. The fish and crustaceans that eat these microplastics become malnourished, and the plastics and the chemicals attached to them then accumulate up the food chain as those animals are eaten by other predators.[96]

Also central to ocean health is that plastics pick up pollutants, including POPs, and can transport them vast distances on ocean currents. That is one reason POPs have been found in the deepest parts of the ocean and at the polar extremes, far from any POP sources.

But perhaps the biggest concern is that plastics—which are largely derived from oil—contain not only those oil compounds that break down, but in almost every case contain added chemicals (like BPA, phthalates or colourants) that leach into the environment, and that not only have toxic effects on their own but whose effects can worsen when, for example, the ambient temperature heats up or cools down, or when they encounter other chemicals. More work needs to be done to understand many of these interactions—with the working assumption that our overuse of plastics is likely to have become highly dangerous for the ocean.

There is evidence that certain pharmaceutical products adversely affect marine organisms, and growing evidence that these chemicals are entering the food chain

1.8 Pharmaceuticals

A growing global population with more money to spend on healthcare means more pharmaceuticals being sold. At the same time, the growing demand for meat, including farmed seafood, means more pharmaceutical products being used on animals too.

While this is good news for pharmaceutical companies, it is clearly not the case for ocean health. There is evidence that certain pharmaceutical products in marine ecosystems adversely affect organisms, not least algae, which could have knock-on effects further up the food chain.[97] According to UNEP, evidence is also growing that these chemicals are entering the food chain, and that they are changing the sex functions of fish.[98] And at least one study has found that antidepressants affect how fish interact and hunt for food.[99] Beyond that, however, much about these effects is not known.

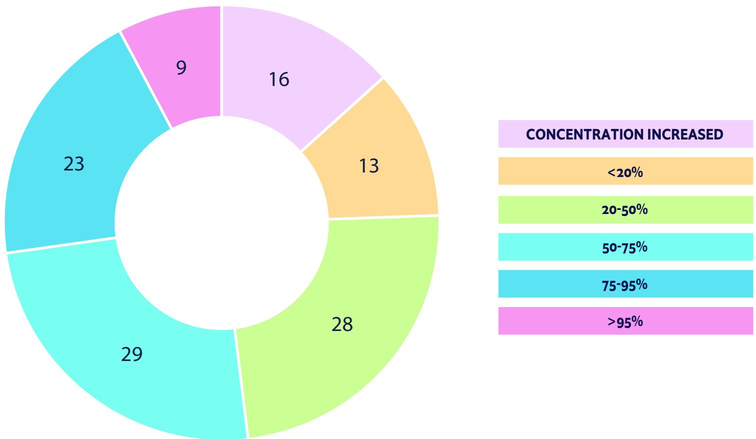
What we do know are the main routes by which pharmaceuticals enter the environment: during the manufacturing process; when used and excreted by humans or animals; and through the improper disposal of unused products that have, say, expired.

Wastewater treatment plants are central to the first two routes, but are largely unable to cope. As UNEP notes, these plants "mostly reduce solids and bacteria by oxidizing the water. They were not designed to deal with complex chemical compounds."[100] And because wastewater treatment plants cannot filter out the chemical compounds used for pharmaceuticals, "these chemicals seep into freshwater systems and into the ocean".[101]

Those consequences have been seen in studies across the world. A 2017 study of pharmaceutical levels in the Baltic Sea, for example, concluded that most entered the marine environment from municipal wastewater treatment plants (MWWTPs).[102] It determined that the removal rate for most of the 188 pharmaceutical compounds it assessed was low: nearly half saw removal rates below 50 percent, with 16 of those compounds increasing in concentration.

Proportion of pharmaceutical products removed in MWWTPs

Of the 118 pharmaceutical products assessed, just nine recorded removal rates greater than 95 percent, while 16 of them were more concentrated after treatment—an outcome that the researchers could not conclusively explain



Source: Pharmaceuticals in the aquatic environment of the Black Sea region: A status report, UNESCO and HELCOM

Beyond the effects on marine life, many of which remain unclear, there are significant concerns that leakage of antibiotics into the environment—including into the ocean—will lead to greater rates of antimicrobial resistance (AMR), which the WHO has identified as one of the 10 key threats to global health.[103]

Triclosan, for example, is an antimicrobial agent with antibacterial, antifungal and antiviral properties, and is used in hand sanitisers and a range of other personal consumer products. Evidence is growing that it and other biocides (along with heavy metals like cadmium and mercury) "contribute to the spread of AMR because they increase the selection for antibiotic resistance genes among bacteria".[104] In short, killing off weaker bacteria leaves room for more dangerous bacteria to flourish.

That could have catastrophic effects. A 2014 UK government report, for instance, forecast that superbugs would by 2050 kill 10 million people worldwide annually, with an economic cost by that date of US$60-100 trillion.

1.9 Radioactivity

According to the International Atomic Energy Agency (IAEA), the first dumping of radioactive waste at sea took place in 1946 some 80 kilometres off the Californian coast.[105] Since then, radioactive waste has entered the marine environment in a range of forms—encased within nuclear reactor pressure vessels, as solid radioactive waste and as liquid radioactive waste, with 14 countries dumping it into more than 80 sites. The last dumping took place in 1993.

In addition, accidents and losses at sea—including military vessels, nuclear weapons and cargoes of nuclear materials in transit—have added to the burden. On top of that are releases from accidents on land, the fallout from nuclear tests (both above ground and underwater), and the discharge of radioactive liquid effluent from nuclear power stations.

According to the IAEA, most radioactive waste dumped at sea was either low-level solid waste (54 percent) or reactors with spent nuclear fuel (43 percent), with nearly 95 percent of the 8.5×10^4 TBq of deliberately dumped radioactive waste ending up in either the Northeast Atlantic or in the Arctic Sea off northern Russia (in roughly equal volumes). The remainder was dumped in the Northwest Atlantic or the Pacific.

Activities of different types of waste dumped in the Atlantic and Pacific oceans and the Arctic Sea

The data covers the period from 1946, when the first dumping took place, to 1993, when dumping at sea ceased. The unit of measurement is a terabecquerel

Waste type	Atlantic	Pacific	Arctic	Totals	Percent of total activity
Reactors with spent nuclear fuel	0	0	3.7×10^4	3.7×10^4	43
Reactors without spent nuclear fuel	1.2×10^3	1.7×10^2	1.4×10^2	1.5×10^3	2
Low level solid waste	4.4×10^4	8.2×10^2	5.9×10^2	4.6×10^4	54
Low level liquid waste	$<1 \times 10^{-3}$	4.6×10^2	7.6×10^2	1.2×10^3	1
Total	4.5×10^4	1.4×10^3	3.8×10^4	8.5×10^4	-
Percent of total activity	**53**	**2**	**45**	**-**	**100**

Source: Inventory of Radioactive Material Resulting from Historical Dumping, Accidents and Losses at Sea, IAEA (2015)

Radioactive decay means the inventory of radioactive material dumped at sea declined to about 2×10^4 TBq, and will further halve by 2050.

Aside from the deliberate dumping of radioactive waste, the marine environment is also contaminated by so-called enhanced naturally occurring radionuclides (NORM), like uranium, radium and radon, and which can also stem from offshore oil and gas processes and from discharges from the processing of phosphate, as well as from accidental releases—like the Fukushima disaster in 2011, when thousands of tons of contaminated water entered the ocean (see box).

Fukushima—an ongoing challenge for the marine environment

Quite apart from the terrible human toll, the catastrophic events of 2011 when a tsunami hit the Fukushima Dai-ichi nuclear power plant on Japan's east coast had a significant impact on the nearby sea. Radiation reached levels millions of times higher than before,[106] with iodine-131, caesium-134 and caesium-137 the most abundant radionuclides.[107]

The first two, however, have relatively short half-lives, and radiation levels dropped rapidly after a matter of weeks. Most of the iodine-131 decayed in a few weeks, and by 2021 scientists reckoned 97 percent of the caesium-134 had decayed. Caesium-137, however, with a half-life of 30 years, will take far longer to break down.[108] The high levels of caesium-137 and caesium-134 found in fish saw the government close local fisheries.[109]

In terms of the marine environment, there have been some positive developments since then. First, after 2015 only two fish out of thousands tested had levels higher than Japan's strict limits.[110] Second, although the facility still leaks radioactive materials into the sea, the current release rate "would take 5,000 years to equal the amount of caesium that entered the ocean in the first month of the accident". And third, radioactivity in the sea off Fukushima remains well within safe limits—since 2016, those levels have measured around 100 Becquerels per cubic metre. Although that is well above the pre-disaster level of 2 Becquerels per cubic metre, it is a vast improvement on the 50 million level seen in the days after the disaster.[111]

However, that looks set to change. In 2021, the government said it would by 2023 release into the sea over 1 million metric tons of radioactive water that has been stored in about 1,000 tanks on the facility's site, angering China and South Korea. Filtering of the water would in theory see the release only of tritium—a radioactive isotope of hydrogen considered relatively low risk.[112]

However, the tanks still contain high amounts of other isotopes. Dr Ken Buesseler, a senior scientist and marine radiochemist at the Woods Hole Oceanographic Institution, was reported as saying these were a concern, as they "are all of [a] greater health risk than tritium and accumulate more readily in seafood and sea floor sediments".[113]

Among the known contaminants are cobalt-60 and strontium-90, "which are much more likely to end up on the seafloor or be incorporated into sea life". And, Dr Buesseler said, the lack of information provided to experts like himself by TEPCO, the plant's operator, and the government of Japan mean other contaminants could be present too, including plutonium.[114]

The government and TEPCO, he says, must be open about what is in the water, and "demonstrate that they have cleaned up the non-tritium contaminants before they propose to release the water into the ocean".[115]

Oil and gas activities discharge NORMs from so-called produced water. That is the water emitted from the oil and gas reservoir, and which has low levels of radionuclides like lead-210, polonium-210 and radium.[116] However, there is limited data available outside the Northeast Atlantic making it impossible to determine trends.[117]

The risks to marine life of radioactive materials are significant, whether those elements are short-lived (like iodine-131, which has a half-life of eight days) or longer-lived, like caesium-137, whose half-life is 30 years. In either case, phytoplankton, zooplankton, kelp and other marine life can absorb radioactive elements, with those elements passing up the food chain, including to humans.[118]

Studies in the UK, for example, have shown that seals and porpoises in the Irish Sea, into which a UK nuclear power plant released radioactive material for decades, had significant concentrations of caesium and plutonium—with the former concentrated "by a factor of 300 relative to its concentration in seawater, and a factor of three to four compared to the fish they ate".[119]

The bulk of marine oil contamination is from land-based sources such as untreated waste disposal from industry; accidents involving oil tankers or oil rigs are also a prominent source

The accumulation of radiation depends on several factors, including the dose received, the duration for which it is received and the half-life of the element concerned. The consequences can range from genetic damage to cancers or death.

1.10 Oil

Much of the oil and gas extracted annually comes from marine sources, and the processes that are tied to exploration and production are one of the contributors to this category of marine chemical pollution. More prominent, though, are accidents involving oil tankers or oil rigs, with the 2010 Deepwater Horizon explosion in the Gulf of Mexico a prominent example.

The bulk of marine oil contamination, however, comes from land-based sources: more than half of the estimated 2.7 billion litres of waste oil entering the ocean each year is from land drainage and untreated waste disposal from industry.[120]

Regardless of their source, oil spills not only kill wildlife and destroy habitats; they can also wreak a high economic cost for years through their impact on tourism and fishing, for example.[121]

Oil has about 10,000 components. Within these, a group of substances called polycyclic aromatic hydrocarbons (PAHs) are key polluters—in particular, so-called petrogenic PAHs. (A second type of PAHs, known as pyrogenic PAHs, are generated from the incomplete burning of organic matter—for example, forest fires, volcanic eruptions, vehicle emissions and when burning waste.)

More than 100 PAHs have been found in the environment,[122] with many able to cause cancers, mutations and birth defects in animals. Adding to the problem is that PAHs are relatively stable: they do not dissolve easily, and they accumulate in sediment, often for decades.[123]

The chemicals used to clean up after oil spills are another contributor to marine pollution. After the 2010 Deepwater Horizon disaster, which saw about five million barrels of oil spilled, some 47,000 barrels of dispersants Corexit 9500 and 9527.203 were used to tackle the oil. The purpose of applying dispersants is to break down the oil into microdroplets that are more easily diluted; however, this also increases their bioavailability. Additionally, the chemicals that comprise the dispersal agent have been shown to be toxic to animals in laboratory tests, with effects on their immune, neurological, cardiovascular and pulmonary systems.[124]

1.11 Household and consumer chemicals

The list of chemicals in the average household is long, with items like solvents and household cleaners, mould removers, laundry products, detergents, bleach, furniture polish, air fresheners, paints and varnishes, poisons (insecticides, for example) and batteries.

The list of household chemicals is long—solvents and cleaners, mould removers, detergents, bleaches, paints and varnishes, poisons and batteries. All contain harmful substances which can leach into the ocean

All contain substances that are harmful and which can leach into the ocean if improperly disposed of or when used as directed: windscreen-washer fluid, for example, ends up on the road and is washed by rain into drains, where it heads to rivers and the ocean; laundry products and detergents go down the sink to wastewater treatment plants, where those exist, from where treated effluent is often pumped into the ocean.

Most homes contain other chemicals too. Many cosmetics, shower gels, deodorants, shampoo and sunscreens, for example, contain benzophenone or its derivatives oxybenzone[125] and dioxybenzone,[126] which are used for their ability to absorb UV-A and UV-B light. Oxybenzone is toxic to aquatic life and has long-lasting effects,[127] as are other substances added to some sunscreens such as octinoxate, 4-methylbenzylidene camphor and butylparaben.

In response, some countries have acted. In mid-2021, for instance, Thailand said it would ban the use of sunscreens containing these ingredients from its marine national parks due to their damaging effects on coral.[128] Hawaii and Palau have enacted similar bans.

Triclosan, the antimicrobial agent mentioned earlier, is used as a preservative in cosmetics,[129] is present in some toothpastes and is used in hand-sanitising products.[130] (The US FDA banned the use of triclosan in antibacterial hand soaps in 2016, though it is still used in many other consumer products.)[131]

Indeed, triclosan is so common that, according to the CDC, three-quarters of Americans have detectable levels of it in their urine. And because it can survive treatment in wastewater plants, triclosan can flow into the seas where it kills bacteria. In the Mediterranean, for instance, where water scarcity means dilution is less pronounced, one study concluded that "the potential environmental risk of triclosan is high".[132] Beyond its direct effect on bacteria in the ocean, triclosan has also been shown to impair the thyroid function in fish.[133]

1.12 Pseudo-persistent chemicals

Some chemicals dissipate relatively quickly in the aquatic environment, which should mean they have no long-lasting negative effects. Others, like POPs, for example, last far longer.

As seen earlier, the persistence of chemicals is a key parameter for assessing candidates for inclusion in the Stockholm Convention. How long is too long? For UNEP, a half-life longer than 60 days in water falls into the persistent category.[134]

Pseudo-persistent chemicals are an intriguing category. While their half-life is relatively short, the concentration of these substances keeps rising in the environment. That is because they are prevalent in products that are constantly in use. Pharmaceuticals are one example.

Determining half-lives, though, can be tricky as the results found under laboratory conditions can vary significantly from those measured in the field, where conditions like temperature and the presence of sunlight can make a major difference, as found by an assessment of three pharmaceuticals (including carbamazepine, an anti-epileptic drug, and ibuprofen, a pain-reliever and anti-inflammatory drug).

One laboratory result for carbamazepine, for instance, calculated a half-life of just 3.5 days, while two field studies calculated that the half-life was 63 days and 1,200 days. Results for ibuprofen, on the other hand, found that the compound seems to break down faster in the environment than the laboratory results had indicated.[135]

If nothing else, the results show that much more research is needed to see how long chemicals persist in the environment versus their supposed persistence in a laboratory setting, not least as persistence is one of the key criteria for inclusion in the Stockholm Convention and other regulatory lists of hazardous chemicals.

1.13 Other chemical pollutants of concern

While the above categories incorporate some of the approximately 300,000 chemicals in use, they do not cover a range of others that daily pollute the ocean. One example is from the shipping of bulk hazardous cargoes, where sources for ocean contamination can vary. Shipwreck is one risk, while others include the illegal dumping of chemicals or the washing of tanks at sea after unloading cargo.

Another is the use of dyes for clothing, with the garment industry a major polluter. Take blue jeans: these use synthetic indigo, which requires the use of large amounts of water (up to 100 litres per pair of jeans) and chemicals to dye clothing—some 40,000 metric tons of synthetic indigo, 75,000 metric tons of sodium hydrosulphite and 48,000 metric tons of lye annually.[136] Much of that ends up washed down the drain, particularly in developing countries where many dyeing processes take place, and from there to the ocean.

But, in a rare piece of good news, researchers in the US have developed a method that uses nanotechnology to dye jeans, cuts the amount of water required and eliminates the need for toxic chemicals. While the process has not yet been commercialised, researchers said it marks a positive step for an industry that manufactures billions of pairs of jeans annually.[137]

Regardless of the sources of ocean chemical pollution—and often these sources overlap—resolving this colossal challenge requires first understanding how the chain of accountability works. In a globalised world it has become increasingly hard to connect the links in the chain that sees chemicals end up in the ocean. As the next section will show, that chain starts with the extraction of the raw material.

Please see Notes for references

Chemical pollution and marine biodiversity: What do we know?

There is no shortage of scientific gaps that need closing. At the broadest level, this requires improving our understanding of ocean ecosystems, the biodiversity of Earth's saltwater hydrosphere (from coastal zones to the deep ocean), the complex gradation zones that constitute the marine environment, as well as the crucial link between ocean and freshwater aquatic systems.

There is also a pressing need to monitor and study the ecological, biogeochemical, climate and other processes that are at the heart of all ocean functions.

When it comes to marine chemical pollution specifically, significant gaps remain in terms of how this affects biota, biodiversity and ecosystem functions, as well as the impact of different sources of marine chemical pollution (whether these enter the marine environment via, for example, atmospheric deposition or rivers).

And, as noted earlier in this chapter, there is an near-wholesale lack of knowledge of the effects that the hundreds of thousands of synthetic chemical contaminants might have on the marine environment—whether individually, in concert with other chemicals, and when factoring in the effects of climate change-related consequences like shifts in water temperature and salt concentrations.

In short, although the world's knowledge of marine chemical pollution in all its complexity has grown in recent years, it remains far short of what is needed. Such research would help to build a more complete understanding of how the ocean functions and of how chemical pollutants are likely to affect those functions in the short- and long-term.

While much research is either underway or being planned, far more is needed. Gratifyingly, this has been recognised by the UN, which in 2021 launched its Decade of Ocean Science for Sustainable Development. The programme ("the science we need for the ocean we want") runs until 2030, and has as one of its seven goals "a clean ocean where sources of pollution are identified and reduced or removed".[138]

The programme identifies ten challenges, the first of which is to understand marine pollution and end it. This includes not only determining sources of contaminants and removing them or mitigating their impact, but also understanding "their potential impacts on human health and ocean ecosystems".[139] To that end, the UN is involving scientists, governments, businesses and others to map pollution, ensuring that it is eliminated at its source.

This push to understand the ocean better will doubtless pay dividends, and help to build upon the knowledge that has been gained in recent decades—and from which we can already conclude that chemical pollution constitutes a large-scale risk to ocean health, marine organisms, biodiversity and ecosystems.

Here, for instance, is what science can tell us about five key marine contaminants.

1. Microplastics and nano-plastics

Microplastics are an important conduit for marine chemical pollution. Along with nanoplastics, the impact that these small plastic particles have on marine biodiversity is a growing concern, not least because they can be transported vast distances, while adsorbing chemicals and microbes.

Plastics and microplastics can be ingested by fish, seabirds and marine mammals that mistake them for food, where they can get trapped in their digestive systems causing malnutrition, reproductive impairment and death.[140] Microplastics can also damage cells and cause inflammation,[141] while nanoparticles can cross the gut lining and accumulate in animal tissues.[142]

Another concern is that the toxic chemical additives found in plastics can leach into the water and enter the tissues of marine organisms,[143] while microplastics and microfibres in the marine environment can transport and shelter hazardous microorganisms, including vectors for both human and non-human diseases such as E. coli.[144] Lastly, the species involved in harmful algal blooms that can destroy coastal ecosystems are able to colonise microplastics, thereby hitching a ride to expand their geographical range.[145]

2. Major chemical pollutants

These fall into three broad categories: toxic metals like mercury, cadmium and lead; manufactured chemicals including persistent organic pollutants (POPs), hydrocarbons, pesticides and organometals (including tributyltin, or TBT, an antifouling treatment for the hulls of vessels); and radioactive substances like nuclear waste. Some are long-term persistent polluters, while others are short-term with a high impact.

Much chemical pollution affects marine biodiversity and ecosystems over a time scale of years, and often has a bio-accumulative effect in which chemicals become more concentrated further up the food chain. As such, they can cause the irreversible breakdown of local ecosystems.

Short-term events release high levels of pollutants that can have a lasting impact on marine organisms, biodiversity and ecosystem services, directly and indirectly affecting individual species through, for instance, local population die-off, genetic mutations or the introduction of new diseases.[146]

Research has shown some chemicals disrupt key functions of marine animals—their hormones, immune systems, ability to reproduce and behaviour—with contamination often starting in biota at the base of the food chain. UV filters in sunscreens, for example, have been shown to harm coral reefs and other aquatic ecosystems.[147] Other pollutants are taken up by phytoplankton, which are eaten by krill, which are in turn consumed by small fish and whales. Small fish are eaten by larger fish, which in turn provide food for seals, which are themselves eaten by polar bears or sharks.

POPs, for instance, damage the immune systems of polar bears and their ability to reproduce; they can also cause cancers.[148] And PCBs are so prevalent in some orca populations around the world that they can no longer breed.[149] No less importantly, chemical pollutants can kill off marine plant life, undermining and even destroying local ecosystems.

3. Harmful algal blooms

Life in the seas and ocean is founded on algae—the invaluable primary producers of oxygen and of fixed carbon, a vital nutrient that supports aquatic ecosystems. Free-living planktonic algal species dominate the ocean, with a small number accounting for the majority of global algal biomass. In coastal ecosystems, many algae emerge seasonally and are vital ecosystem components.

Continued on next page

Floating tropical beds of brown macroalgae, for instance, serve as habitats and nurseries for many marine species, fostering and maintaining tropical marine biodiversity. They also absorb CO_2, helping to mitigate global warming and acidification, buffering marine pH and maintaining optimal conditions for a wide range of shell-making marine organisms under a warming climate.[150,151]

Some marine algal species, however, produce powerful toxins and, under certain conditions, accumulate in high densities to form harmful algal blooms, or red tides. Although this can occur naturally, their frequency and scale has increased sharply in recent decades due to higher levels of pollutants (from wastewater as well as nitrogen and phosphorus from fertilisers), sea-surface warming and acidification. These harmful algal blooms disrupt food sources and alter marine chemistry, including by lowering dissolved oxygen levels to an extent that causes mass die-offs of plants, fish and crabs.

4. Introduced pathogens

This refers to a range of bacteria and viruses that are normally land-based but that enter the marine environment through, for example, sewage effluent or agricultural run-off.

Horizontal gene transfer can see these pathogens introduce harmful new genetic traits into indigenous marine microorganisms, thus increasing their virulence and capacity for antimicrobial resistance.[152] Studies have shown that the more polluted the seawater, the more likely it is that these pathogens can survive.[153]

5. Less-studied technology-critical elements

The final group covers chemicals and elements used in new technologies in electronics, defence and related industries. These include trace metal elements such as niobium, tantalum, gallium, indium and germanium, as well as rare earth elements like neodymium, gadolinium and ytterbium.

Although some studies have been carried out (or are being carried out) on some elements, much about their effects on the marine environment remains unknown. A 2019 study, for example, noted that, while the geochemical behaviour of elements like gallium, indium and germanium was well-constrained, there was very little understanding on the chemistry of these elements in coastal waters. That makes assessing their status in environmentally impacted coastal areas extremely challenging.

In addition, although concentrations of some elements have been reported in several organisms, there is little information on how they might harm certain types of marine organisms, their potential to be bio-accumulated through the food web (as mercury is, for instance) or their safety threshold in the marine environment.

Conclusion

The UN Decade of Ocean Science for Sustainable Development should give a significant boost to our knowledge of numerous facets of the marine environment, not least in terms of the effects that marine chemical pollution has and the steps needed to remedy it. While the programme will surely advance scientific knowledge of the ocean, its existence is a clear reminder that there is much that we still do not know—and that far more work is needed before we have a full understanding of the complex and vital role that the ocean plays.

Continued on next page

2: Sources of marine chemical pollution

This chapter 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 the use of fire-retardant chemicals.

  - Other underappreciated sources of marine chemical pollution include **e-waste**, of which just 20 percent was properly recycled in 2016; **untreated sewage**; and **plastics**, which can break down into micro- and nano-plastics 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 in the Asia-Pacific, the Middle East and Africa, and that two-thirds of sales of industrial chemicals (excluding pharmaceuticals) will by 2030 be in Asia, 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 percent 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 multiple players, all of whom 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 into rivers that lead ultimately to the seas.
- 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 percent versus 20 percent 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 percent, according to a commonly cited statistic, versus 20 percent 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 well be done in a particular area by a sea-based source of pollution—for example, the case in 2021 of a tanker carrying tons of nitric acid, other chemicals and plastic pellets that caught fire and sank off Sri Lanka.[1]

"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

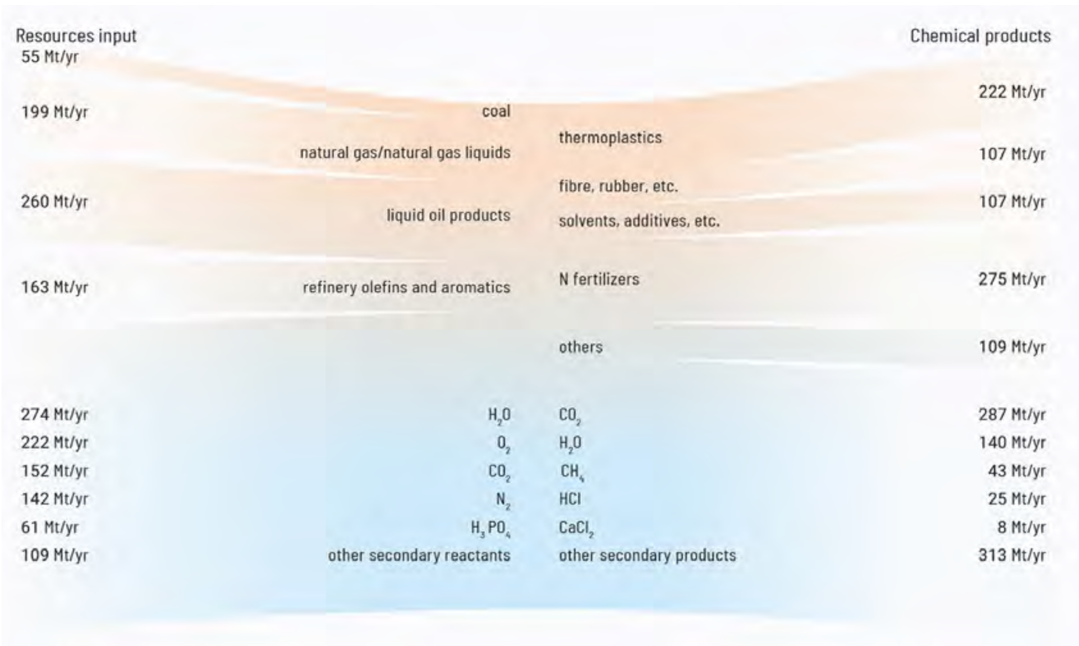
The companies that comprise the global industry vary from multinationals, of which there are several hundred, to the many thousands of smaller firms. And while some segments of the industry (pharmaceuticals and basic chemicals, for example) are dominated by a handful of very large companies, others,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

In addition, the industry itself—the largest industrial consumer of energy,[2] accounting for about 10 percent of global energy demand and 7 percent of global greenhouse gas (GHG) emissions[3]—is neither the starting point nor the endpoint 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 which 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 metric tons) for the chemicals industry, with water, oxygen, carbon dioxide, nitrogen, phosphoric acid and secondary reactants comprising the remaining 960 million metric tons. The main outputs are carbon dioxide, nitrogen-based fertilisers, thermoplastics and secondary products, which together total about 1.1bn metric tons



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/ Transportation
	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 & Construction
	Bio-based materials (e.g. sugars, starches, natural oils and acids)		Composites	Recreation/sport
	Others (e.g. ammonia, phosphorous)		Synthetic Fibers	Industrial
			Rubber Products	Medical
			Paints & Coatings	Pharmaceuticals
			Adhesives & 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 percent of the entire chemical market by 2025.[4]

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 climate change effects worsen.

Background on the chemicals industry

With global sales in 2020 of nearly €3.5 trillion (almost US$4 trillion)—which excludes pharmaceuticals sales—chemicals is the world's second-largest manufacturing industry.[5] Factoring in pharmaceuticals brings that total to just under €5 trillion for 2020, up from about €2 trillion in total at the turn of the century, according to European industry body Cefic.[6]

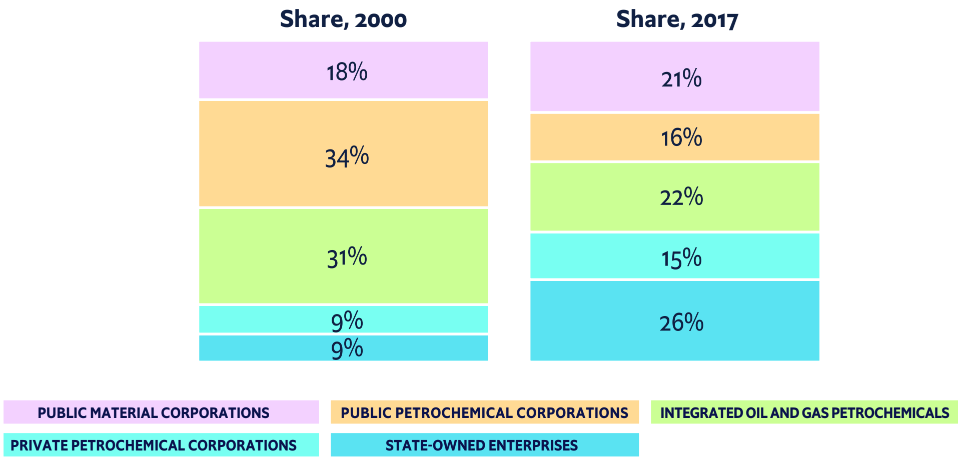
By 2030, Cefic predicts global sales of chemicals (excluding pharmaceuticals) will climb to €6.2 trillion, with China accounting for just under half of that total.[7] And by 2060, the OECD predicts, the value of chemicals produced globally will reach nearly US$22 trillion.[8] As sales increase, so too, logically, do production volumes: chemicals' production capacity doubled to 2.3bn metric tons between 2000 and 2017, and will keep climbing.[9]

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 percent of the industry's global revenues, nearly three times the proportion they had in 2000.[10]

Revenue share: How the global chemicals industry has changed, 2000-2017

From having the smallest share of revenues in 2000, state-owned enterprises now enjoy the largest at 26 percent. 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 percent to 38 percent. Some of that share has been taken by private petrochemical corporations, which saw their take climb to 15 percent.



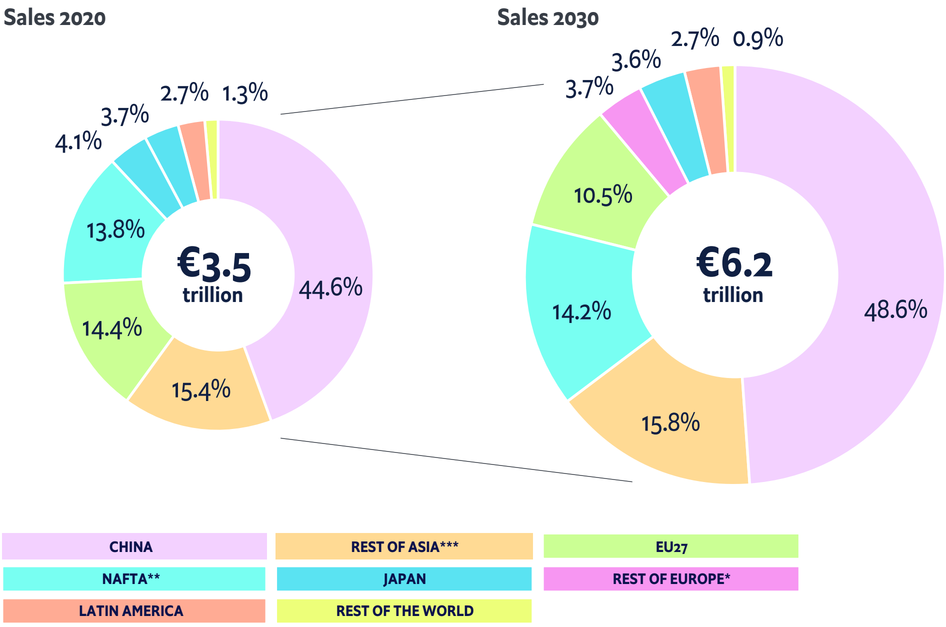
Source: Global Chemicals Outlook II, UNEP (2019)

Another crucial development is the development of 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".[11]

When it comes to manufacturing, China is by far the world's biggest player, recording about 45 percent of global sales in 2020, followed by Asia (excluding China, Japan and South Korea), the NAFTA bloc and the EU.[12] 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.[13] By 2030, it is estimated that about two-thirds of sales of industrial chemicals (excluding pharmaceuticals) will be in Asia (see graphic).[14]

Projected growth in global chemical sales, 2020-2030

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 percent of the industry is expected to be operating in the Pacific Ocean region by 2030.[15] 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 25-100kg of waste for every kilogram of finished product versus 1-5kg for basic chemicals production and 5-50kg for fine chemicals (see chart).[16]

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 1kg of product generates 10kg 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 measured 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 percent of hazardous waste in 2011, much of which was treated on site; petroleum and coal products manufacturing added a further 19 percent while agricultural chemicals and fertilisers contributed 5 percent.[17] For its part, the EU's chemicals and pharmaceuticals sector was the source of a combined 13 percent of hazardous waste generation in 2015, with petroleum comprising 8 percent.[18] (At 51 percent, 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 percent of municipal and industrial effluent globally is thought to be pumped into the environment without being adequately treated.[19]

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.[20] Other sources of marine chemical pollution include: chemical run-off from the land; from contaminated groundwater seeping directly into the seas;[21] from illegal or historical cases of direct dumping[22] (for example, of an estimated half a million barrels of DDT-laden sludge off the California coast[23] and of two million car tyres in Florida's waters[24]); 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[25]—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.[26]

2.4 Industry—other parties

Industrial users of chemicals cover nearly every sector imaginable, and they overlap significantly with each other. 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.[27]

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".)[28]

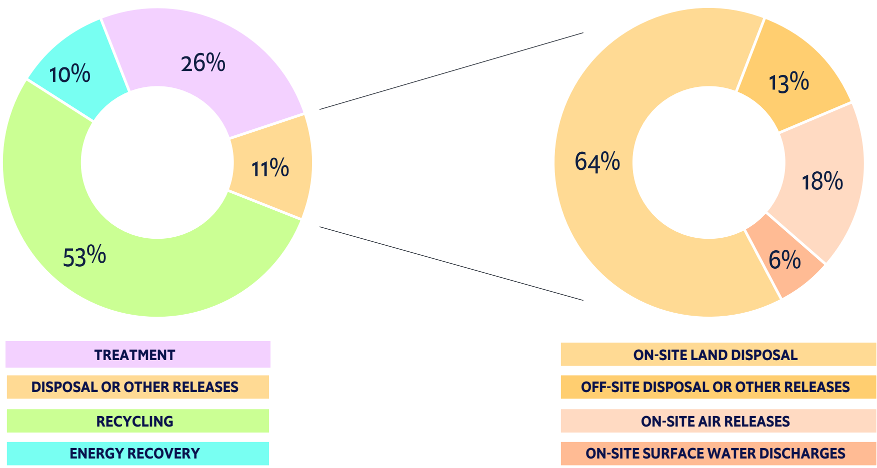
Another is the US EPA's Toxics Release Inventory (TRI) that compiles emissions data of 770 chemicals and 33 chemical categories as reported by 21,000 US-based facilities operating in certain industries.[29] It shows that production-related waste in those sectors totalled 30.7bn pounds (about 14 million metric tons) in 2019. While nearly 90 percent was recycled, burned for energy or treated, the remaining 3.4bn pounds (about 1.5 million metric tons) 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 percent is dumped

Production-related waste managed, 2019
30.7bn pounds

Disposal or other releases
3.4bn pounds



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 metric tons was released on-site at the facilities—typically into landfills or injected underground. The remaining half a million metric tons of chemical waste was pumped into the air, shipped to off-site landfills or released into water.[30]

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".[31] 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.[32]

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.[33] A related and increasingly important area (though 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.[34] The contaminants that are released vary depending on what is being mined.[35] 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:** Emissions of nitrogen oxides (NOx) and sulphur oxides (SOx) are significant sources of marine chemical pollution, and stem from the combustion of fuel. 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 percent.[36] Additionally, the introduction of low-sulphur fuels and scrubbers that clean exhaust gases will cut SOx emissions globally, though 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.[37] 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 cooperation can tackle a range of ship-sourced marine pollution issues.[38]

- **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.[39] 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 Southeast 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.[40] 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.[41] Produced water, for instance, contains levels of metals like cadmium, lead, mercury and chromium that are between 100 times and 10,000 times their background concentrations, as well as hydrocarbons and naturally occurring radioactive material.[42]

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 percent], Europe [14 percent] and the Americas [12 percent]) account for 99 percent 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.[43] 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 nations have long dumped their e-waste.

2.5 Consumers

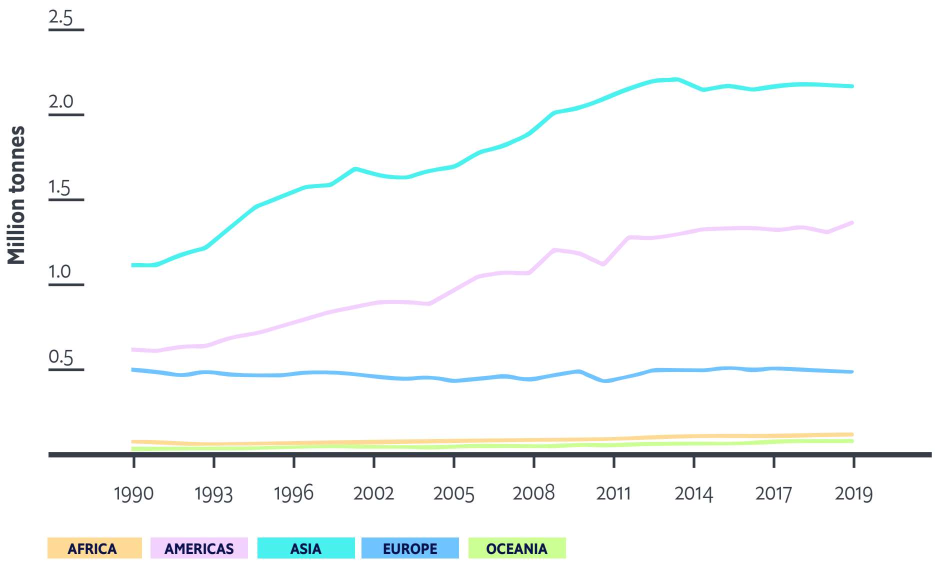
This category covers a vast array of the items manufactured by many of the players in the previous two sections—from mobile phones to TVs, personal care products to pharmaceuticals, and from household cleaning products to transport-related purchases like fuel and tyres.

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 percent 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.[44]

When it comes to pesticides, Asia (and China in particular) uses more than any other region (2.2 million metric tons), which is about twice the amount that the continent used in 1990 (see chart). Asia also uses the most pesticide per hectare of cropland at 3.7kg/hectare, or one kilogram per hectare 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 likely change



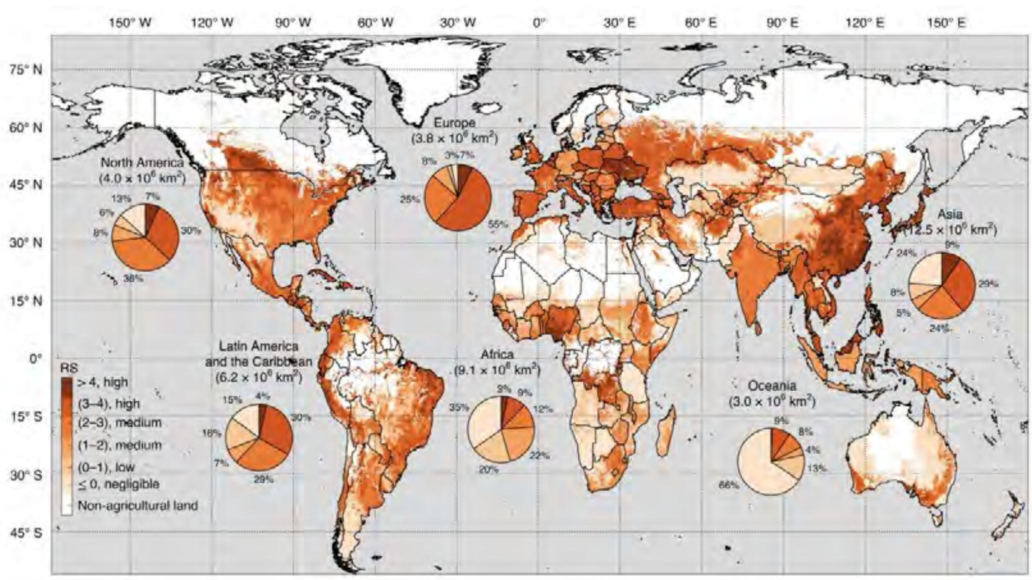
Source: Pesticides use, pesticides trade and pesticides indicators 1990-2019, FAO (2021)

China uses more pesticides—1.8 million metric tons—than the rest of the top ten countries combined,[45] with the country's land and migration policies leading to small-scale farmers using agricultural chemicals, including pesticides, extremely inefficiently.[46] 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.[47]

China's heavy reliance on pesticides is clear from the map (below), which is taken from another study on the use of pesticides globally.[48] 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

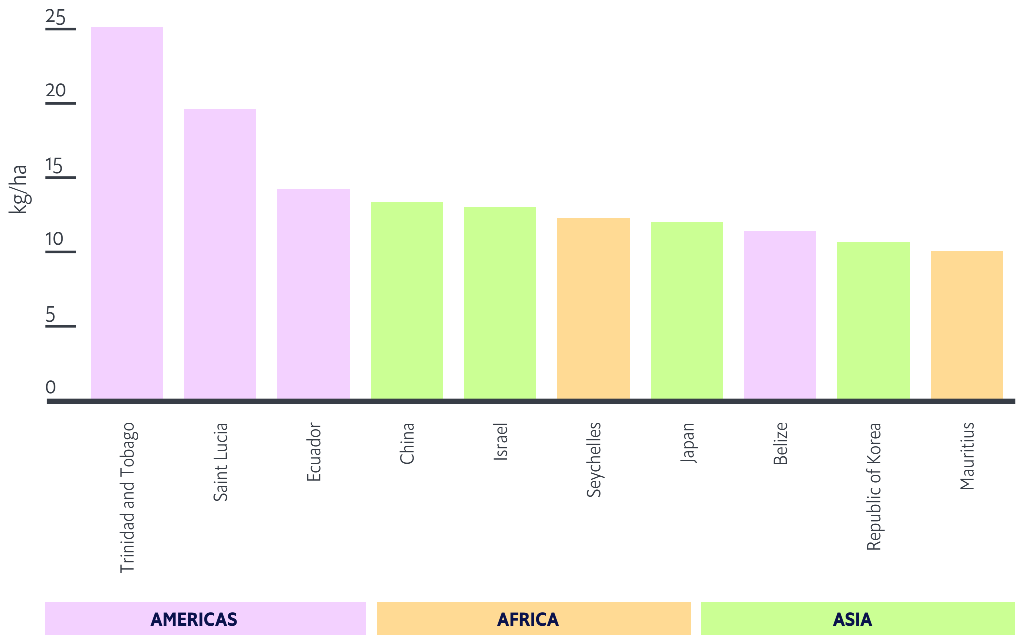
The study assessed the environmental pollution risk from 92 active ingredients in pesticides in 168 countries. Regions were scored as at risk of pollution if pesticide residues in the environment exceeded the level below which they would likely have no toxic effect. High-risk areas were those areas where 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 (25kg/ha), Saint Lucia (20kg/ha) and Ecuador (14kg/ha) applying more.[49] 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".[50]

Top 10 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.[51] 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 percent, followed by coal-burning for power (21 percent).[52]

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[53]—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 metric tons in 2015 (see graphic).

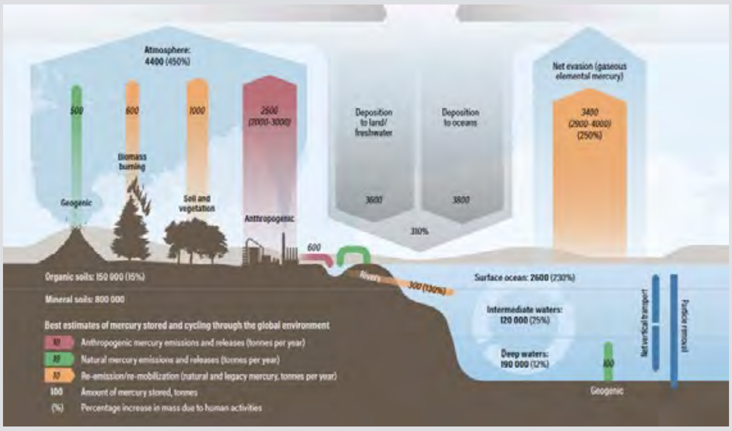
While artisanal gold-mining is the main human-based source of mercury emissions, it is not the only one. Burning coal to generate power ranks second (21 percent), while non-ferrous metal production and cement production contribute 26 percent combined.[54]

In water, bacteria convert inorganic metallic mercury to methylmercury, which is highly toxic, and which 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.[55]

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 which overlaps with the section on industry, above, 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, and which the WWF described as "the most toxic chemical ever deliberately released into the seas".[56]

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."[57]

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 metric tons, and for a variety of reasons will keep climbing over the coming decades, while at least 3,000 PPCPs are currently on the market, with more entering each year.[58]

As populations grow, particularly for our purposes 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[59]—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 aging 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.[60]

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 the most affected, along with Europe, where the Baltic Sea and the North Sea are the most extensively researched.[61]

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".[62]

HELCOM, which is an inter-governmental organisation that monitors the Baltic Sea area,[63] stated in a 2013 report that 40,000 metric tons 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, are extremely toxic in very small doses).[64] 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.[65]

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".[66] 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.[67]

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,[68] all of which are toxic to marine life.[69] 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.[70]

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 percent 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.[71] 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 see 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.[72]

"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."[73]

2.7 Accidents

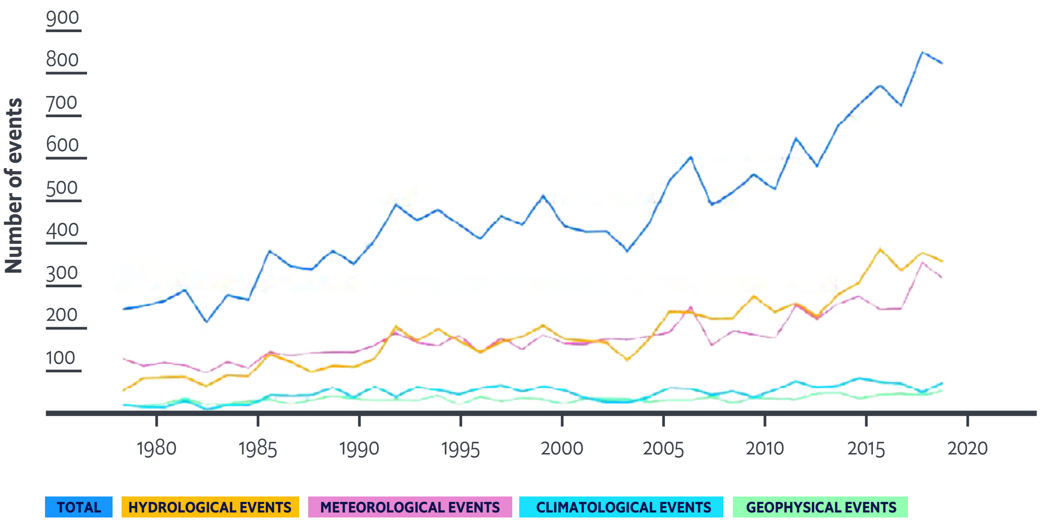
For many people, the subject of marine chemical pollution stemming from accidents suggests listing oil tankers, vast oil slicks spread across sea, sand and rocks, and sea-life and birds coated in a toxic black sheen.

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

While shipping accidents remain an important source of oil spills, large spills are less common. The number of oil spills greater than seven metric tons declined from an annual average of 35.8 in the decade to 1999 to 6.4 in the years 2009-2018—in part due to better safety measures after the use of single-hull tankers was phased out.[74]

Natural events are an important source of marine chemical pollution, and these will likely become more important 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).[75]

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 them were within 80 kilometres of the coast "putting them at particular risk from storm surge, strong winds and heavy rain".[76]

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 percent "rely on some form of industrial chemical process" when being made.[77] Those end-of-life considerations are often ignored, which is why numerous products—not least those containing plastics—can contribute to marine chemical pollution.

End-of-life considerations are often ignored, which is why numerous products—not least those containing plastics—can contribute to marine chemical pollution

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 into water sources. In many poorer countries, vehicle lead-acid batteries are manually recycled, which releases large amounts of the toxic element into the environment.[78]

The rapid increase in the production of electrical and electronic items over the past 50 years has had a huge impact on global waste generation in terms of both the volume of e-waste that is generated and in terms of the chemicals it contains. Global e-waste totalled nearly 45 million metric tons in 2016, and was expected to reach more than 52 million metric tons 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.[79]

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

Significantly in terms of marine chemical pollution, just 20 percent of 2016's e-waste 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.[80] Other chemicals detected at the dump include PCBs, PBDEs and short-chain chlorinated paraffins (SCCPs),[81] which are harmful to aquatic organisms, highly persistent and do not break down in the natural environment.[82]

E-waste has proven to be a significant problem, with as much as 80 percent 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.[83] Although the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal has some measures to tackle e-waste,[84] 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, e.g. 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 (e.g. 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 percent 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.[85]

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 between 80-90 percent, with toxins typically including heavy metals like lead, cadmium and mercury.[86] 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[87] or are contained in the finished product.[88]

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.)[89]

Linked to that, and looking to the coming decades, population growth for this century will be concentrated in these poorer countries—Africa, for example, is expected to see its population triple from 2020 levels to more than four billion people by 2100.[90] That could have profound implications for marine chemical pollution, which is at heart an anthropogenic challenge.

Please see Notes for references

3: Towards an anthropogenic crisis?

While some marine chemical pollution is wholly independent of human activity (natural emissions of some heavy metals, for example, some nitrogen and radioactive materials emissions, and the significant release of minerals and gases from undersea volcanoes), its rapid growth in recent decades is due to humans. In other words, the source of this growth is anthropogenic, with most occurring in the past century or so. This chapter will look at marine chemical pollution in this broader context to explain why the need to act has become urgent, and why doing so will prove crucial both to the health of the ocean and to that of the planet itself.

3.1 Principal findings and recommendations

- **Marine chemical pollution is a human-made problem that will get worse.**
  Marine chemical pollution is predominantly due to human actions. Natural chemical emissions of mercury, lead, radioactive materials and oil products, and the impact of sporadic volcanic activity, are far less significant. In addition, much marine chemical pollution stems from manmade industrial chemicals, some of which travel long distances, are resistant to decay, and can enter the food chain. Since humans are producing far more chemicals and in ever-greater volumes, and will continue doing so for decades, the impact on the marine environment will get more severe.

  Exacerbating factors include the so-called "greening" of economies (not least the push for deep-sea mining to meet resource needs); the expansion of production by the chemicals industry, particularly in Asia and to countries with limited oversight; and growing populations—predominantly in poorer countries with a limited capacity to deal with chemical pollution.

  Worryingly, a 2022 study concluded that the world has already crossed the planetary boundary where chemicals threaten the very ecosystems upon which humans and most other species depend. Among the urgent solutions it suggests is to cap chemicals' emissions, as has been done with greenhouse gases, to ensure they do not exceed the planet's ability to cope.

- **Tackling marine chemical pollution is crucial for meeting humanity's sustainability goals.**
  Tackling marine chemical pollution will help the world to meet many of the Sustainable Development Goals (SDGs), particularly SDG 14 about conserving and sustainably using

the ocean. Given that ocean sustainability is "under severe threat", according to the UN, and given that three billion people rely on the seas for their livelihoods, avoiding a collapse of the ocean ecosystem is a fundamental imperative for humanity.

- **Climate change and marine chemical pollution are profoundly connected.**
  The way chemicals interact with environmental factors like temperature, acidity and salinity—all of which are affected by climate change—and the way they react to other chemicals has a big influence on their effect in the marine environment. Modelling projections show climate change could cause chemical concentrations in marine environments to rise as much as three-fold, with that increase driven largely by higher water temperatures. At the same time, recent laboratory research indicates that the presence of a single chemical contaminant can speed up effects linked to climate change. Given these deep connections, tackling climate change—by, for instance, reducing the use of fossil fuels in energy generation and in chemical production—will help to reduce chemical pollution. And halting global warming and ocean acidification will lessen the impact that chemical pollution has on marine life.

- **Tackling marine chemical pollution is inextricably linked with tackling plastic waste.**
  Plastics constitute a central challenge to marine chemical pollution: not only do they contain numerous toxic chemicals; they also adsorb chemicals and help to transport them in the marine environment. Microplastics have known negative effects on marine life, including weight loss, lower growth and reduced fecundity, while nanoplastics have been shown to affect reproduction, and can be bioaccumulated and biomagnified in the marine food chain. Sunlight can chemically alter certain plastics as they break down, producing a range of thousands of new, water-soluble products that do not resemble the original material.

- **Significant knowledge gaps remain; funding is needed to close them.**
  The world knows almost nothing about how most of the hundreds of thousands of chemicals affect the marine environment; understanding this will require much more funding. Additionally, the complexities of the interactions of these chemicals in the marine environment—with its numerous contaminants and multiple drivers—are little understood, with significant uncertainty as to their impact.

  Far more research is needed, and that will require increased funding, including for the many chemicals of emerging concern, including pharmaceuticals (such as antibiotics), personal care products, liquid crystal monomers, new generations of flame retardants and biocides, as well as nanomaterials and rare earth elements. When it comes to chemicals of emerging concern, those in most urgent need of assessment are chemicals that are persistent, toxic, bioaccumulative, frequently used and produced in large volumes.

- **Business needs to factor in its impact on marine chemical pollution—as it has begun to do on climate change.**
  Although many in the chemicals industry and the wider business sector know they need to factor climate change into their operations, few are concerned with chemical pollution. Given the links between the two, the chemicals industry (and business more broadly) must also take marine chemical pollution into account. At the same time, the burgeoning demands of a growing global population mean the chemicals industry and business must work to help countries meet the sustainable consumption and production targets in SDG 12. This includes being more

efficient with resources, improving the sustainable management of materials, and prioritising source reduction, reuse and recycling.

There is a significant risk that marine chemical pollution and climate change will combine to accelerate the wider anthropogenic challenges facing the planet. It is essential, therefore, to protect ocean health and limit chemical pollution

Numerous factors contribute to the increased dangers associated with marine chemical pollution. A greater volume of chemicals being produced is one—driven in part by a growing population—but experts stress that less obvious aspects must be considered too: factors like temperature, acidity levels and deoxygenation, for example, all appear to affect the mobility, speciation and toxicity of chemicals in the seas.

Professor Kenneth Leung Mei-yee, Director of the State Key Laboratory of Marine Pollution at City University of Hong Kong, says issues like the concentration of chemicals, their combination and the environmental conditions in which they appear in the environment also play a part in this complex interaction. In addition, he says, it is crucial to consider aspects like spatial and temporal variations.

Looking ahead, a key concern for researchers like Professor Leung is that the ways in which chemicals interact might alter as climate change (among other drivers) makes our seas warmer and more acidic, and as dissolved oxygen levels in the water drop in some areas (a phenomenon known as hypoxia). As a result, the relative importance of different contaminants and the tolerance or susceptibility of marine organisms to them might also change.

In other words, there is a significant risk that marine chemical pollution and climate change will combine to accelerate the wider man-made challenges facing the planet.

For that reason alone, protecting ocean health (and therefore limiting chemical pollution) is essential. Yet succeeding at this also requires protecting the broader hydrosphere—the rivers, lakes and estuaries that, together with the ocean and seas, constitute Earth's aquatic ecosystem covering 75 percent of its surface.[1]

The European Union is arguably the most proactive in this space. It recognises the interconnectedness of these disparate systems, and notes that all life "depends on a healthy hydrosphere to maintain a rich biodiversity and functioning ecosystems that provide oxygen, drinking water and food".[2]

But, as the EU states, aquatic systems are "rapidly degrading", with this process being driven by three interlinked factors:

- Unsustainable exploitation of resources.
- Pollution (including chemical pollution).
- Climate change caused by humans.

It also stresses that legislation has proven insufficient. As a result, the value of the natural capital of the marine and freshwater systems has declined 40 percent since 1992, with this degradation "undermining the hydrosphere's essential functioning as the planet's life-support system".[3]

"Pollution-free waters are critical for the health of both citizens and planet … Healthy ecosystems support the transition to climate-neutrality, as the ocean is one of the planet's most important carbon sinks, and its resources, wind, tides and waves provide clean energy," it notes in its 2021 report *Restore our Oceans and Waters* by 2030.[4]

The EU plans to achieve its 2030 goal by applying three specific objectives: protect and restore aquatic ecosystems and biodiversity; prevent and reduce pollution in line with its Action Plan for Zero Pollution; and make the sustainable blue economy carbon-neutral and circular by, for instance, combating greenhouse gases (GHGs).[5]

3.2 Marine chemical pollution and the Sustainable Development Goals

It is increasingly apparent, albeit not yet sufficiently understood, that marine chemical pollution is inextricably linked with achieving humanity's broader sustainability goals. At the least, since it is incontestable that protecting the health of the ocean is fundamental to life on Earth, eliminating marine chemical pollution is evidently a broad sustainability imperative. Indeed, failure to act could provoke a crisis.

In mapping out its approach to restore the bloc's aquatic environments by 2030, the EU highlights the impact that doing so would have on attaining the bulk of the UN's 17 Sustainable Development Goals (SDGs).

Marine chemical pollution is inextricably linked with achieving humanity's broader sustainability goals

Most obviously, the plan would help to meet SDG 14 ("to conserve and sustainably use the ocean, seas and marine resources for sustainable development"),[6] and SDG 6 (the provision of sanitation and clean water, which is undermined by the discharge of untreated or under-treated wastewater). Additionally, it would help to combat climate change and its effects (SDG 13) and would improve terrestrial ecosystems, including halting biodiversity loss (SDG 15).

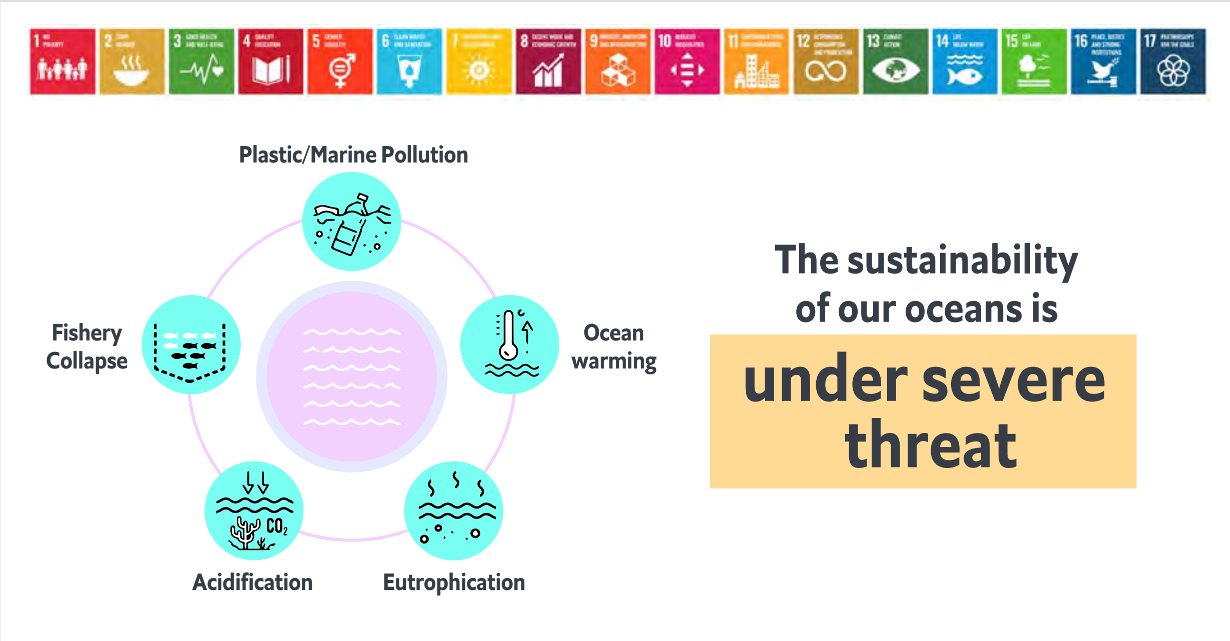
A healthy hydrosphere also sustains livelihoods (SDG 1) and provides food security (SDG 2), while a decarbonised blue economy can provide clean, sustainable energy for all (SDG 7). Importantly, success would also help to drive "circular and responsible production and consumption patterns" (SDG 12). (It is worth noting that Target 12.4 within SDG 12 covers the sound management of chemicals and wastes, and that this was not attained by the goal date of 2020.[7])

Achieving SDG 12 would help to make cities and communities more sustainable (SDG 11) while generating jobs and economic growth (SDG 8).

The fact that combating marine chemical pollution is linked to meeting the majority of the SDG goals is a clear indication of the overwhelming importance of the ocean and the hydrosphere more broadly, and explains why tackling marine chemical pollution would go a long way to help nations in their efforts to meet their SDGs and create a more sustainable future.

As noted, SDG 14 is the goal most directly linked to marine chemical pollution. Success here is crucial because, as the UN points out, ocean sustainability "is under severe threat" from a range of interlinked factors (see box). The collapse of global fisheries is a major concern and one that, as 3 billion people rely on the ocean for their livelihoods, according to UN data, would prove catastrophic for a vast swathe of humanity.

SDG 14—Conserve and sustainably use the seas and ocean



Source: UN SDG 14

Ten targets underpin SDG 14. Three stand out in terms of this report's scope:

- **Target 14.1:** "By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution."
- **Target 14.3:** "Minimise and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels."
- **Target 14.a:** "Increase scientific knowledge, develop research capacity and transfer marine technology … to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing countries."

In some places, however, the process of degradation is already underway. The number of so-called "dead zones", which are areas of the seas or ocean so depleted of oxygen that they cannot support life, climbed from 400 to 700 between 2008-2019—a situation that the UN describes as "alarming". (A case study in Chapter 4 investigates the economic cost of dead zones via their impact on fisheries.) A lack of protection is part of the problem: the UN notes that more than half of the globe's key biodiversity areas in the seas and ocean are unprotected, while just 1.2 percent of national research budgets are allocated to ocean science—despite the fundamental importance of the ocean to all life on Earth.[8] That needs to change.

The number of 'dead zones', areas of seas or ocean so depleted of oxygen that they cannot support life, climbed from 400 to 700 between 2008-19—a situation the UN describes as "alarming"

Dr Kevin Helps, UNEP's senior programme officer responsible for the UNEP-GEF chemicals and waste portfolio, says SDG 12—responsible consumption and production—is one of the most significant thematic areas in terms of his team's work.

"That's because it deals with what chemicals are going into the components such as plastics, electronics and textiles," he says. "Take plastics, for example. Nobody other than the manufacturers and polymer companies knows the exact mix of chemicals going into the virgin plastic beads. The chemicals add characteristics that make them very useful, for sure, but at what long-term cost? Plastics aren't bad—but it is clear that it's how we use them in a linear manner that is bad, as well as a general lack of systems by which we manage the plastic waste in a more circular manner."

As Dr Helps points out, humans and the environment have been exposed "to things which we know very little about—we simply don't know what's going into a lot of the materials we handle and use in our everyday lives". This combination of inputs and misuse has contributed to marine chemical pollution, whose very existence, in his view, shows "things have gone wrong far higher up the chain, and it is time to be transparent about what we are being exposed to".

"Because once [plastic and other waste] gets into the ocean, it's too late," he says. "And then you have to question what is released from the waste, the effluent, etcetera that can potentially bioaccumulate, and which can have an impact on life and planetary health. The impacts could be as simple as interfering with photosynthesis in the plankton layer, or they could be the chemical reaction of a mimic-type chemical that stops normal biological processes. We simply don't know, and research into these issues takes time. The trouble is that we've used the ocean as a deposition ground for so long assuming it will absorb all of this, because it is very forgiving, very deep and very large, but the time is approaching where we will have more plastics in the ocean than fish."

3.3 Marine chemical pollution and climate change

Eliminating marine chemical pollution, then, is a broad sustainability imperative. And, given the interplay between climate and the impact on the marine environment (in particular, when it comes to acidification and warming), failing to address climate change could greatly increase the dangers posed by marine chemical pollution.

The role of the ocean in regulating climate is crucial—by storing carbon and generating oxygen, for example—and there is no shortage of evidence to show human activity is hampering this

The role of the ocean in regulating climate is crucial—by storing carbon and generating oxygen, for example—and there is no shortage of evidence to show human activity is hampering this, particularly through ocean warming.

The Intergovernmental Panel on Climate Change (IPCC), for instance, said in its 5th Assessment Report, published in 2014, that more than 90 percent of the energy accumulated between 1971-2010 had been stored in the ocean, with the greatest warming occurring near the surface.[9] The upper 75 metres, for example, warmed by 0.11C every decade during that period, the IPCC said, and it predicted the ocean would continue to warm and acidify over the rest of this century, with the global mean sea level rising further.[10]

Warming has been documented as deep as 1,000 metres, causing more stratification—where water no longer mixes due to the varying properties of different water masses.[11] It has also caused ocean current regimes to shift, and has seen the number of deoxygenated zones rise (with help from the likes of CO_2, nitrogen and phosphorus, as well as from atmospheric pollution that has caused glaciers and ice to melt). At the same time, oxygen levels in the upper ocean are dropping.[12]

As the EU points out, climate change effects attributable to humans have already altered "the physical and biological state of the ocean, seas and waters, and disturb[ed] their ecosystems".[13] And higher CO_2 emissions have not only caused changes in acidification, as seen earlier, but also shifts in terms of water temperature and deoxygenation. The result is changes "in the diversity, distribution and abundance of marine species".[14]

Dr Saleem Ali, who is the Chair of the Department of Geography and Spatial Sciences, University of Delaware, and a member of the Global Environment Facility's (GEF) Scientific and Technical Advisory Panel (STAP), says more needs to be done to understand how factors like temperature change could affect how pollutants are mobilised, and the impact that can have on marine life.

"There's a temperature sensitivity to a lot of chemicals and their availability—so as we are seeing higher temperatures in the water, you may see greater mobilisation in some cases, and that has to be monitored," he says. "We have enormous amounts of marine garbage out there, and it may well be that with these climatic changes you get mobilisation of some of that."

As this report has shown, marine chemical pollution has had major impacts on sea-life and aquatic ecosystems, and while much remains unknown, what we do understand about well-known GHGs like CO_2, for instance, should give pause beyond simply their direct effects on climate.

CO_2 emissions, for instance, are known to have a range of biodiversity-harming effects, including to ocean acidity, which has climbed 30 percent since the start of the Industrial Revolution.[15] Higher acidity increases the vulnerability of calcifying organisms that rely on the formation of shells or similar structures for survival, such as shellfish, plankton and coral, as it inhibits their construction, while CO_2 emissions lower the rates of survival for some of these species early in their lives.[16]

Studies have shown that acidification and warming affect the toxicity of certain chemicals, further increasing stresses on marine ecosystems and organisms

Acidification and warming can also change the form of different metal contaminants. That can alter those metals' properties, including, as laboratory tests have shown, making them more bioavailable and toxic to marine organisms. Precisely how that plays out in the marine environment, however, where metals interact with multiple factors, including other contaminants, will require more research.

Studies have already shown that acidification and warming affect the toxicity of certain chemicals, further increasing stresses on marine ecosystems and organisms. "Ocean acidification decreases plankton weight, dissolves calcareous shells and harms corals," the EU report notes. "Both acidification and warming affect the availability and toxicity of several chemicals, leading to cumulative effects of multiple stressors on organisms and ecosystems … Changes in ocean temperatures and currents brought about by climate change are leading to alterations in climate patterns in Europe and around the world. Live ecosystems are affected by these changes, modifying migratory patterns and generating habitat loss."

Risking a vicious cycle?

Failing to act on marine chemical pollution, then, and continuing along the polluting path of the last few decades, risks causing an anthropogenic crisis. If that sounds outlandish, we already know that climate change effects alter how certain chemicals react. Now we are learning that some chemicals might interact to speed up climate change effects. In other words, there is the potential of a vicious cycle emerging, in which climate change and chemical contamination combine to worsen each other's impacts.

To take one example, a recent experiment at the Scripps Institution of Oceanography at the University of California San Diego, found that, using a purpose-built tank dubbed the "ocean-in-a-lab", pollution affected microbes in the water, which in turn shifted the make-up of the aerosols and gases that they released into the atmosphere from natural processes.[17]

This function is crucial, because microbes have an important role in controlling climate—with "the potential to influence atmospheric composition, cloud formation and weather".[18]

The researchers found that the presence of just one air pollutant could affect this process. Adding hydroxyl radicals, an oxidant found in greater concentrations in polluted atmospheres, made an immediate difference: the oxidant reacted with the gases that the microbes produced, "transforming them into compounds that changed the composition of the primary sea spray aerosol and formed new types of particles". Altering natural biological processes in the seawater, on the other hand, caused "only a very small change in the ability of the primary particles to form cloud droplets".[19]

The Scripps study shows the potential effects on weather patterns that just one pollutant can have. Of course, there are many more than that, which is why researchers concluded that it was crucial to look at "the complete gas phase mixture of pollutants to mimic and understand real-world chemical reactions".[20]

Yet while it is important to understand more about these effects, we already know enough to conclude that the effects of human-produced GHGs (including CO_2) are harmful, says the International Union for Conservation of Nature (IUCN), a global body with 1,400 member organisations. The damage being done disproportionately affects the ocean and coastlines.

"[I]ncreased GHG emissions exacerbate the impact of already existing stressors on coastal and marine environments from land-based activities (e.g., urban discharges, agricultural runoff and plastic waste) and the ongoing, unsustainable exploitation of these systems (e.g., overfishing, deep-sea mining and coastal development)," the IUCN has stated. "These cumulative impacts weaken the ability of the ocean and coasts to continue to perform critical ecosystem services."[21]

Understanding complex interactions

The link between climate change and marine chemical pollution is a particularly taxing area for researchers. Professor Leung of City University of Hong Kong, who describes this area as "very complex indeed", says research shows the key environmental factors for the seas are temperature, salinity and the pH, or acidity—with temperature the crux.

"We did some experiments and concluded that temperature remains the main driver when it comes to changing chemical toxicity, and also by means of changing the chemical properties [of pollutants], and how organisms respond to multiple stressors," Professor Leung says.

The effects of temperature should not be a great surprise: after all, it has significant effects on, for example, the taste of red wine, a glass of which contains thousands of chemicals. Warming the wine increases its acidity, and the resultant evaporation and aeration alter the taste. In other words, a higher temperature changes the wine's chemical composition, and that changes the reactions.

In the marine environment, there is evidence that temperature shifts alter the metabolism of marine organisms. The thermal performance curve theory, for example, explains the performance of fish in terms of aspects like growth and reproduction rates. Performance climbs as the temperature rises until the fish reach their optimal temperature—beyond which their performance drops fast. So some marine organisms perform far worse at temperatures that are much higher or much lower than the optimum.

Adding certain chemicals to the water further depresses this curve, which means their performance declines even faster at those higher temperatures.

"Based on that prediction, many species may suffer more in the presence of chemical stressors under global warming," Professor Leung says.

Bad though this is, it is not the end of the matter. Climate change can bring changes in the intensity and distribution of rainfall; as a result, some places will experience a sudden drop in salinity.

"For chemicals like metals, low salinity and high temperatures [bring on] the stress much quicker, because in a condition of low salinity the ions of the metal will be more available to the marine organism," Professor Leung says. "And then on top of that, you have the slow reduction of pH [due to] the increase of CO_2 levels, and this will also change the chemical composition in the sea—as, with low pH, the metals may release more ions."

While this does not hold true for all organic chemical pollutants, modelling projections show climate change could result in chemical concentrations in marine environments changing by two- or three-fold—with temperature the key driver behind that shift. The effects this could have might be worrying, he says, though for now are unclear.

Improving predictions: Contaminant behaviour in a complex environment

A major reason for the lack of certainty about the impacts of chemical contaminants on climate change and the marine environment is the complexity of the interactions at work. By necessity, much research examines a specific contaminant and a specific climate change driver in a laboratory to try to determine how they interact. The marine environment, though, is far more complex, with numerous contaminants and multiple drivers.

Failing to act on marine chemical pollution, and continuing along the polluting path of the last few decades, risks causing an anthropogenic crisis

To assess and better understand these interactions, a dozen scientists from GESAMP, an expert group that advises on marine environmental issues, are engaged in a systematic review of existing studies from around the world looking at four groups of pollutants: nutrients, metals, organic contaminants and radionuclides.[22]

"The dumped radioactive waste in the ocean and associated issues are what brought this group together, but the problem is much bigger than that," says Professor Vanessa Hatje of the Instituto de Química & Centro Interdisciplinar de Energia e Ambiente (CIENAM) at Brazil's Federal University of Bahia, and who is one of the scientists involved. "Nutrients are very important in terms of contaminants for the coastal zone, causing eutrophication and harmful algal blooms. And then we have metals, especially mercury and lead, and the persistent organic pollutants that contaminate the ocean. We also have this whole new group of metals that are used in the high technology industries and products, and which are starting to show up in ocean waters."

One concern is that climate change is significantly increasing the amount of material being remobilised from the continents and deposited into the seas. This means much larger amounts of organic and mineral particles will reach the ocean. And while it is unclear how that will play out, the situation will likely be more complex and pronounced closer to the land—in estuaries, mangroves and other coastal ecosystems—than in the deep seas.

"One of the issues that causes concern is around some of the metals—for instance, iron, which is also a micronutrient that is essential for phytoplankton to grow," says Professor Hatje. "In fact, it's one of the most limiting elements for phytoplankton in several areas of the ocean. With the changes we have in temperature and pH, the solubility of iron may change and, with that, its potential uptake by biota changes as well."

This has a significant impact—not just in terms of the primary production that helps to regulate temperatures, but also in terms of the transportation of carbon and pollutants from the surface of the ocean to the seabed.

Once the GESAMP review is complete in 2023, the scientists will be better able to determine the sensitivity of each of the four groups of contaminants to a range of climate change drivers like higher temperatures, the melting of snow and ice, changes in acidity, and deoxygenation of ocean waters.

The process will also reveal the most significant knowledge gaps. Once those are filled, that information can be added to existing data to predict changes more accurately for the range of contaminants—for instance, the impact that a drop of 0.4 pH (i.e., a rise in acidification) would have in conjunction with a temperature increase of one degree.

Rare-earth metals

One area of uncertainty is the effect that rare earth elements—which, ironically, are far from rare—might have on the marine ecosystem, particularly in terms of their presence causing changes to organisms.

Rare earth elements are used in many electronic items, which have become far more prevalent as a growing population wants more mobile phones and laptops, for instance. This has driven "exponential growth in waste of electrical and electronic equipment (e-waste) generation",[23] much of which is not processed properly at the end of its life, contaminating the environment.

A recent study, for example, determined the effects on mussels of gadolinium—one of 17 elements classed as rare earth elements.[24] When combined with lower levels of salinity, gadolinium increased mussels' metabolism and their antioxidant responses, while higher salinity levels with gadolinium damaged their cells, and lowered their metabolism and their enzymatic defences.[25]

Gadolinium has multiple uses, including in alloy with other metals for electronic items, and as a contrast agent for medical diagnostic scans. Professor Vanessa Hatje has measured gadolinium levels in the aquatic environment in the US, Brazil, Canada and Taiwan.

"If you have an MRI [magnetic resonance imaging] scan, you may get injected with a very stable form of a gadolinium complex," she says. "It's eliminated fast from the body, within 40 hours and, because it's very stable, it goes through wastewater treatment plants into the environment without being changed. It can be used as a tracer of wastewater discharges."

But while gadolinium injected into the blood for an MRI scan is safe for humans, consuming it after it appears in drinking water having been through a treatment plant might not be.

"We are now measuring anthropogenic gadolinium in tap water from different countries—Brazil, Germany, Spain, France, Chile, Canada, and even Antarctica—to try to determine how widespread this problem is," she says. "Our worry is when we ingest drinking water that's contaminated with gadolinium, our body seems to be able to absorb it."[26]

Professor Hatje says it is easy enough to mobilise people to think about plastics pollution, which is visible, but that it is the multitude of contaminants that, like gadolinium and mercury, are present in the environment but invisible that are the greater concern.

"That's what scares me the most," she says. "Because if you are not aware of that, you may get contaminated either from the water or by eating contaminated seafood, and you don't even realise it—and this is just one example."

Looking ahead, says Professor Hatje, there could be health impacts on human and marine health from other contaminants like the platinum group elements, as well as from nanoparticles and other chemicals "that are still very challenging to measure".

"And they are everywhere," she says. "They are still in very low levels, and perhaps they are not in concentrations that would significantly impact our health—but we need to monitor their evolution in the environment in order to safeguard population and ecosystem health, because they are getting more widespread."

3.4 Marine chemical pollution and plastics

The previous chapter showed how the plastics industry is already a major emitter of GHGs during the production and manufacturing processes—and will become even more prominent as it ramps up production. However, the connection between marine chemical pollution and plastics does not end there.

Plastics 101

Before examining plastics and marine chemical pollution more closely, it is worth outlining some background to plastics themselves. (For a far more comprehensive look, please see our Plastics Management Index report.)

Although mass production of plastics started only around 1950, the world had by 2015 produced some 8.3bn metric tons—just 2bn metric tons of which was still in use.[27] The rest was waste, with nearly 80 percent sent to landfills or polluting the environment, including the ocean, where it will take centuries to degrade (though even then it will not disappear).

Huge amounts of plastics end up in the ocean, lakes and rivers—between 19-23 million metric tons in 2016 alone.[28] And the world keeps making more of it—some 367 million metric tons in 2020[29], with most of it used in packaging and construction.[30] Production of plastics is expected to double by 2040,[31] with researchers predicting that the total amount of plastics made by 2050, marking a century of mass production, could have reached more than 25bn metric tons.[32] As much as 12bn metric tons could by then be in landfills or in the environment.[33]

From fossil fuels to plastic bags

Plastics are typically produced from fossil fuels like oil, natural gas and coal, or by synthesising the chemicals that those fossil fuels contain.[34] Also known as polymers, most plastics are based on the carbon atom—with those atoms connecting to hydrogen, oxygen, nitrogen, chlorine or sulphur to form the plastic.

Long chains of such connections of atoms are known as **thermoplastics**. Once shaped by heat, these can be melted again and reshaped. Most plastics fall into this category, and include polyethylene (PE), polypropylene (PP), polyvinyl-chloride (PVC), polyethylene terephthalate (PET), polystyrene and polycarbonate.[35]

The other category of plastics is **thermosets**. These set into a particular shape once heated as their molecules undergo a chemical change to form a three-dimensional network. As they cannot later be re-melted or reformed, they constitute a much tougher recycling challenge. Examples include polyurethane (PUR), unsaturated polyesters, epoxy resins and silicone.[36]

Plastic waste is often graded by size:

- **Macroplastics:** Pieces of plastic waste larger than 5mm, including bottles, bags, fishing gear, straws, cup lids and food packaging.
- **Microplastics:** Measure between 5 mm and 1 micrometre (one thousandth of a millimetre). *Primary microplastics* are often added to products like cosmetics in the form of microbeads, or come from the wear and tear of car tyres (about 100,000 metric tons wash into the ocean each year[37]) or clothing made from synthetic materials. *Secondary microplastics* come from macroplastics that break down in the natural environment.
- **Nanoplastics:** Less than 1 micrometre in length.

Much plastic waste consists of single-use items like plastic bags or cutlery, which some countries have banned, as well as bottles, food packaging, electronics, clothing that uses synthetic fibres, and fishing nets.[38] In the marine environment, larger items like packaging typically break down into smaller plastics, with microplastics, for instance, easily mistaken for food by wildlife like fish, turtles and shellfish. As a result, they not only become malnourished; they can also accumulate the chemicals contained within those plastics, which can then bioaccumulate up the food chain to higher-order predators—and to humans.

The list of species affected by plastics is long: nearly 700, according to a 2021 report, ranging from zooplankton to polar bears, barnacles to birds, and fish to marine mammals. Fish and tiger prawns caught in the Persian Gulf, for example, had microplastics in their muscle, while every deep-sea fish sampled from the South China Sea was found to have microplastics. Microplastic fibres were also found in fish caught in the English Channel and in nearly two-thirds of a commercially important variety of shrimp from the North Sea.[39]

Almost every plastic contains numerous chemical additives—products added during the manufacturing process to provide flexibility, colour, transparency, fire-retardancy, durability, bulk or any other commercially attractive outcome

While the list of contaminated marine life is lengthy, so too are the associated negative effects of microplastics on marine life: weight loss, less energy, lower growth, disruption to the endocrine systems, increased immune response, higher death rates and lower fertility, to name a few.[40]

Nanoplastics are a further concern: they have been shown, for example, to affect fish activity and to enter the yolk sac of hatched juvenile fish,[41] while a 2019 review of studies of nanoplastics found they could affect the reproduction of organisms and could even kill them. And, the review noted, the data shows that nanoplastics have a high potential for bioaccumulation or biomagnification along the marine food chain because organisms easily retain them.[42]

If there is one positive note, it is that the issue of contamination by microplastics and nanoplastics is becoming recognised by international bodies. The United Nations' most recent report on the ocean, for example, described it as a matter of concern "not only because of the potential ecological impacts, but also the potential to compromise food security, food safety and consequently human health". The fact that such contaminants in marine animals are now being consumed by people is, it stated, "an emergent global phenomenon that requires further research to determine whether there is human health risk".[43]

Chemical soup

The issue of plastics as a contaminant goes far beyond the impact of their fossil fuel constituents. Largely unappreciated is that almost every plastic contains numerous chemical additives—products added during the manufacturing process to provide flexibility, colour, transparency, fire-retardancy, durability, bulk or any other commercially attractive outcome.

Examples of additives include plasticisers (such as phthalates, some of which are known endocrine-disrupting chemicals), flame retardants (including brominated or chlorinated organic compounds), stabilisers (nonylphenols, cadmium and lead, for instance), curing agents (like formaldehyde), colourants (lead, titanium dioxide and cadmium compounds, for example), and fillers that cut costs and make plastics harder (such as calcium carbonate or talc).[44]

Some of those additives have known consequences on marine life and the broader ecosystem. A 2011 study, for example, found that almost every commercially available plastic that the researchers had sampled "leached chemicals having reliably detectable endocrine activity".[45] It has also been shown that many common additives (phthalates, BPA and PBDEs, for instance) are endocrine-disrupting chemicals, with studies showing that phthalates and BPAs, for example, "affect the development and reproduction in molluscs, crustaceans and amphibians" even at very low concentrations in the environment.[46]

Plastics in the marine environment are known to adsorb chemicals from the surrounding waters, which adds further to their potential toxic load

It is not just the chemicals that are added to plastics during manufacturing that are of concern. Plastics in the marine environment are known to adsorb chemicals from the surrounding waters (and often in far higher concentrations), which adds further to their potential toxic load.

While some of the effects of certain chemical contaminants are reasonably well understood, researchers are still learning significant amounts about how plastics react in the real world during their (lengthy) end-of-life stage—including their possible effects on climate change. A 2018 study, for example, showed that certain plastic types immersed in water release large volumes of methane and ethylene, both of which are GHGs, when exposed to sunlight.[47]

For this study, the researchers tested seven common types of plastics. They found that polyethylene ("the most produced and discarded synthetic polymer globally") was the worst offender, though all seven produced measurable quantities of methane and ethylene when exposed to sunlight (see table).

The results showed that low-density polyethylene (LDPE) was the largest generator of methane and ethylene. Polystyrene and PET were the next-largest generators of methane, while polystyrene and high-density polyethylene were the second- and third-biggest generators of ethylene.[48]

Mean production rates of two GHGs (methane and ethylene) from a variety of plastics placed in water under ambient solar radiation and dark conditions

Plastic type	Source	Methane ($pmol\ g^{-1}d^{-1}$)		Ethylene ($pmol\ g^{-1}d^{-1}$)	
		light	dark	light	dark
Polycarbonate (PC)	www.amazon.com/dp/B000FP83PO/ref=biss_dp_t_asn	10±2	NS	24±5	NS
Acrylic (AC)	ww.miniplastics.biz/acrylic_products.html	30±3	NS	24±1	20±1
Polypropylene (PP)	www.amazon.com/dp/B000ILG19U/ref=biss_dp_t_asn	170±10	NS	50±1	NS
Polyethylene Terephthalate (PET)	www.amazon.com/dp/B0015H4BIE/ref=biss_dp_t_asn	500±20	50±10	64±11	NS
Polystyrene*	commercial.owebscorning.com/products/foam/	730±110	120±30	910±10	60±5
High-density Polyethylene (HDPE)	www.amazon.com/dp/B000ILG0TQ/ref=biss_dp_t_asn	90±10	NS	190±20	NS
Low-density Polyethylene (LDPE)	www.amazon.com/dp/B000ILG118/ref=biss_dp_t_asn	4100±200	NS	5100±400	NS

Relevant information regarding the polymer sources is also included. The errors represent the standard deviation of triplicate samples.
NS: final concentrations not significantly different from those in the control treatment (t-test, P>0.05).
*:Polystyrene incubations lasted for 14 days and were conducted in MilliQ water.
https://doi.org/10.1371/journal.pone.0200574.t001

Source: Production of methane and ethylene from plastic in the environment, Royer S-J et al (2018)

With plastics production expected to ramp up heavily in the coming years as petrochemical firms seek alternatives to fossil fuels, the sheer quantity of plastics that will end up dumped in the marine environment is sure to climb too. This study shows that the negative climate change effects of plastics in the marine environment should not be ignored. As the authors wrote: "Our results show that plastics represent a heretofore unrecognised source of climate-relevant trace gases that are expected to increase as more plastic is produced and accumulated in the environment."[49]

More recently, research by scientists at the Woods Hole Oceanographic Institution's (WHOI) Marine Chemistry and Geochemistry Department in the US has overturned a commonly held belief that plastics in the environment break down into smaller and smaller pieces that remain the same in chemical terms.[50]

Instead, they found that sunlight not only "chemically transforms plastic into a suite of polymer-, dissolved-, and gas-phased products"; they also determined that this reaction is able to "produce tens of thousands of water-soluble compounds, or formulas" in just a few weeks, in a process that is far more complex than was previously thought.[51]

They came to that conclusion after running tests more representative of real-world conditions. While earlier research typically used pure plastics, which do not contain the additives used in the manufacturing process, the WHOI scientists took four single-use polyethylene plastic bags from three of the largest US retailers (with as much as one-third of the mass of each bag comprised of inorganic additives), and assessed those against pure polyethylene film to compare how they degraded.[52]

They found that sunlight not only physically breaks down the plastic, which was known, but that "it chemically alters it, producing a suite of transformation products that no longer resemble the parent material".[53]

"It's astonishing to think that sunlight can break down plastic, which is essentially one compound that typically has some additives mixed in, into tens of thousands of compounds that dissolve in water," co-author Collin Ward was quoted as saying.[54]

For that reason, the transformation process that plastics undergo in the environment is something that must be considered. Although the fact that the plastics broke down faster than they had expected might seem positive, "it's unclear how these chemicals may affect the environment", Ward said, adding: "We don't really know yet what impacts these products might pose to aquatic ecosystems or to biogeochemical processes such as carbon cycling."[55]

3.5 Marine chemical pollution and changing economic factors

The issue of marine chemical pollution is challenging and complex—with thousands of new chemicals, limited (at best) oversight of the chemicals sector, and the impacts of pollution already apparent. Yet it is likely to become more challenging still as a range of population-level factors exert an ever-larger effect. Chief among these are the following economic aspects:

- The development and "greening" of economies as they shift to renewable energy sources.

- Implications of a changing global economy for the chemical economy, including: higher demand, increasingly complex supply chains and greater investment by petrochemicals majors in plastics production; the expansion of industrial capacity to Asia and, more broadly, to countries with less oversight.

- Population growth, particularly in developing nations, and the consequent increased demand for goods.

Greening economies

While it is crucial to understand better the complex interplay between climate change and marine chemical pollution, more research is also needed to grasp how related efforts could play out across the broader climate change picture. Take, for instance, the impact wrought by measures necessary to adapt whole economies to climate change, with the building of infrastructure to deal with rises in sea levels central to those. Another is the effect of the offshore infrastructure being built to help combat climate change, like wind farms and solar farms.

Technologies used to mitigate climate change are a bigger concern, and those are likely to be a cause of marine chemical pollution twice over—when setting up the infrastructure, and when its life ends

Dr Saleem Ali, the Chair of the Department of Geography and Spatial Sciences at the University of Delaware, is more concerned about those offshore developments, because the infrastructure used to protect from sea-level rise will be mostly concrete, which limits the negative impact on the seas.

It is the technologies used to mitigate climate change that are a bigger concern, as those are likely to be a cause of marine chemical pollution twice over—first when setting up the infrastructure, and later when its life ends. In part, he says, that is because much of this infrastructure uses heavy metals and complex technologies, whose effects on the ocean are poorly understood.

"Climate change is pushing us to develop enormous amounts of infrastructure for mitigation for the energy transition, and a lot of it is being pushed offshore because of the challenge with meeting land use," says Dr Ali, whose research focuses in part on climate diplomacy and industrial ecology, particularly where that involves extractive industries. "We are building huge offshore wind farms; we are talking about solar being put offshore. And there is very little research on what has happened with what's out there already. So, that is something that we should be at least concerned about and monitor."

Linked to that is the sourcing of the minerals and metals needed for the world to transition to a low-carbon economy: finding, removing and processing the vast amounts of materials needed, for example, for energy storage (like the aluminium, cobalt, iron, lead, lithium, manganese and nickel used in lithium-ion batteries) as well as those needed for energy generation. Solar photovoltaic cells, for example, can require cadmium, copper, gallium, silica and zinc.

Without those minerals and metals, the world's necessary transition to a low-carbon economy will be in jeopardy. So, where will these materials come from? The two options are land-based mining and deep-sea mining. The damage done by land-based mining is all too clear, including habitats destroyed, people uprooted and dispossessed, and colossal pollution.

Deep-sea mining, its proponents say, avoids the pollution caused by land-based mining, and does not directly affect human populations in terms of social disruption. A 2022 study, which was funded by The Metal Company, a deep-sea mining firm, concluded that collecting and processing metallic nodules from the seabed might produce less waste than terrestrial mining of those metals, though it also cautioned that the impact of disrupted sediment on the marine environment was uncertain.[56]

That said, deep-sea mining is highly controversial—and, indeed, has yet to get underway in earnest, with the UN's International Seabed Authority yet to issue global rules to govern the sector.[57]

In 2021, a group of more than 600 scientists and policy experts called for a pause to deep-sea mining on the grounds that undertaking it would add to existing anthropogenic stressors like bottom trawling, climate change and pollution. Among their concerns were that deep-sea mining would lead to:

- The loss of "unique and ecologically important species and populations … many before they have been discovered".
- The generation of "large, persistent sediment plumes" that would harm even those species and ecosystems that were far from the mining sites.
- The release of metals, toxins and sediment into the water column from mining activity and when the ships discharge the mining wastewater, which could contaminate commercially important fish species like tuna.[58]

Dr Mariann Lloyd-Smith, Senior Adviser to the International Pollutants Elimination Network, a global network of non-profits, says deep-sea mining carries "significant pollution risks", adding that the need to green economies is being used by industry and governments to justify a narrative in favour of the practice.

A 2018 report that Dr Lloyd-Smith co-authored noted that deep-sea mining is "gaining interest due to the decrease of land-based mineral reserves" and the presence on the seabed of large quantities of mineral deposits.[59] And, it stated, modelling studies of its potential impacts suggested wide dispersal of any sediment discharged, particularly within the first kilometre radius and as far as ten kilometres.[60]

"This may smother organisms and release toxic metals and other contaminants into the ocean. Toxic effects of plumes discharged at depth from dewatering are also possible, as is spillage of ore or hazardous material from the mining surface vessel or from hydraulic leaks," the report noted.[61]

Others, though, are more sanguine, particularly when comparing the effects that land-based mining has been shown to have. Dr Ali, a systems scientist, is cautious in recognising that advancement often requires making tough choices.

"Given the fact that we do have tough choices, we need to keep the systems perspective in mind, and that's what I try to do," he says. "[T]he whole tenet of industrial ecology is a systems perspective. It's recognising that industry is now part of the planetary system, and we can't just think of greenfields and brownfields. We have to start to think collectively and then make choices which are optimal for the system, rather than just for one sub-part of the system."

That approach, he says, applies to deep-sea mining.

"One of the reasons why I've been willing to engage with deep-sea mining is because if you compare, for example, the tailings impact on land versus ocean, deep-sea mining does not have a tailings disposal issue, even though they're mining the ocean, but they're not actually generating waste which will go back, because the ore is very concentrated and it will be processed without large-scale tailings," he says. "You would just have sediment that would come up with the nodules, and the sediment would be deposited back in the ocean."

Land-based mine tailings typically contain heavy metals and other toxins, along with sediments, and are either pumped to dams or, if the mining operation is close enough to the sea, piped offshore and dumped—even in fragile ecosystems.

"These tailings are often enriched in heavy metals and other pollutants," says Dr Ali. "The industry has said that it's safe, but we need far more evaluated studies to really appreciate what the impact in the long-term will be."

One example is New Caledonia in the South Pacific. The islands—a French overseas territory—hold the world's second-largest nickel reserves,[62] and boast the world's second-largest coral reef, which surrounds, among other islands, the main island of Grand Terre.[63] A large mine in the southern part of the island carries out submarine tailings disposal, as do many others in Indonesia, Papua New Guinea (see box) and elsewhere. And although much has been done to study tailings generally, "there hasn't been enough long-term research undertaken on the marine tailings disposal issue," Dr Ali says.

Nickel—how green is the revolution?

As global demand for nickel rises with electrification of vehicles, for example, the effects on the marine environment are also likely to rise—unless mining companies and governments take steps to mitigate the impact of tailings waste dumped in the ocean.

Chinese-owned Ramu NiCo, which operates a nickel and cobalt mine in Papua New Guinea, made global headlines in mid-2019 when a 200,000-litre tailings spill caused the sea around its processing plant in north-eastern Papua New Guinea to turn red, killing marine life.[64]

Ramu NiCo, which is majority-owned by the Metallurgical Corporation of China, has run the mine and processing plant since 2012, with a submarine pipeline that pumps tailings waste 450 metres offshore at a depth of 150 metres.[65]

Since then, millions of tons of mining waste have been dumped into the sea from what is regarded as the world's most productive battery nickel plant. In 2017 alone, the facility produced 34,000 metric tons of nickel, dumping 5 million metric tons of tailings, according to environmental news outlet Mongabay.[66]

A study by Swiss consultancy SVQ found high concentrations of cadmium, manganese and sulphides, with areas on the coast "distinctly contaminated" by heavy metals, and with much of that contamination above the levels allowed under European standards.[67]

In 2020, a coalition of 5,000 local people joined with the provincial government to sue Ramu NiCo to pay billions of dollars in compensation, cease dumping tailings waste into the sea, and remediate the damage they say has been done to the environment.[68] As at the time of writing, the case appeared not to have been heard.

The environmental pollution wrought by mining operators extracting nickel has been seen elsewhere in the region. In Indonesia's Sulawesi province, the seas also turned red, marine life disappeared, and local people complained of serious health problems.[69]

The future of the chemicals economy

One of the most important trends in terms of marine chemical pollution in the coming years is the expansion of the chemicals economy, which Chapter 6 examines in more detail. As petrochemical firms see the demand for fossil fuels decrease, their need to double-down on increased plastics and chemicals production will climb.

That shift is already well underway: in 2020, for example, ExxonMobil in the US was reported to be spending US$20bn for chemical and refining facilities on the Gulf Coast, while Royal Dutch Shell was investing billions more on a massive ethylene cracker plant in Pennsylvania (ethylene crackers use heat to generate ethylene from natural gas-derived ethane).

A worrying trend for environmental and human health is the increasing movement of chemical production to low- and middle-income countries where public health and environmental protections are often scant

Other firms spending billions on petrochemical facilities included China's Sinopec, Total, Chevron Phillips Chemical, Russia's Gazprom and Rosneft, and Abu Dhabi's ADNOC. This combined capital spending was estimated to increase the production of ethylene capacity globally by 13 million metric tons a year—or about 60 percent more than the increase in demand.[70] More ethylene crackers are also being built in Asia—for example, in South Korea by Hyundai Oilbank (850,000 metric tons capacity per year by late 2021), and another in northern India by HPCL-Mittal Energy (1.2 million metric tons per year as of 2022).[71]

The building of facilities in poorer countries is a worrying trend, as The *Lancet* Commission on pollution and health noted in its 2017 report. It said its concern over the vast number of synthetic chemicals created in recent decades, many of which have never been tested for their potential effects on environmental or human health, was "heightened by the increasing movement of chemical production to low-income and middle-income countries where public health and environmental protections are often scant".[72]

"Most future growth in chemical production will occur in these countries," The *Lancet* Commission's report stated.[73]

This offshoring by wealthy nations of polluting industries like chemicals to poorer countries that have weaker environmental legislation has become a feature of global business.[74] Although the OECD nations are still the main producers of chemicals, output in less-wealthy countries is rising more than twice as quickly—for instance, in countries like China, India, Indonesia, Brazil and South Africa.

As The *Lancet* report points out, this shift of production often takes place in nations with "little or no environmental and occupational regulation, and weak public health infrastructure".[75]

With the chemical economy shifting towards the developing world, the importance of implementing safeguards in those countries will continue to climb. Yet, regardless of what protective steps, if any, are taken, the quantity of chemicals that will be manufactured, whatever their location and use, is set to keep rising, with pressures on the marine environment set to climb concomitantly.

Offshoring, increased production and higher capital expenditure are not the only features of the industry. In recent years, global giants like BASF and Dow Chemical have gone on an acquisition spree in a bid to boost efficiencies, while other players have merged—notably Sinochem International and ChemChina in 2021. The two Chinese chemicals groups will enjoy combined annual sales of US$152bn as the government seeks "to create state-backed champions to challenge international leaders".[76] In the Middle East, Saudi Aramco finalised its acquisition in 2020 of its 70 percent stake in SABIC, the major chemicals player in Saudi Arabia, which cost it US$69bn.[77]

Population growth

The final aspect driving the urgency to act to protect the marine environment from chemical pollution is the projected growth in the world's population. Much of that growth is concentrated in poorer parts of the world that have far less infrastructure to deal with pollution of any kind.

According to the UN, the global population is expected to rise from 7.7bn in 2019 to 9.7bn by 2050, and to about 11bn by 2100. More than half of the growth by 2050 will come in just nine countries, and in this order: India, Nigeria, Pakistan, the Democratic Republic of the Congo, Ethiopia, Tanzania, Indonesia, Egypt and the US. Much of the growth, then, will be seen in South Asia and sub-Saharan Africa, with the latter's population likely to double by 2050 (see table).[78]

Global population growth by region to 2100

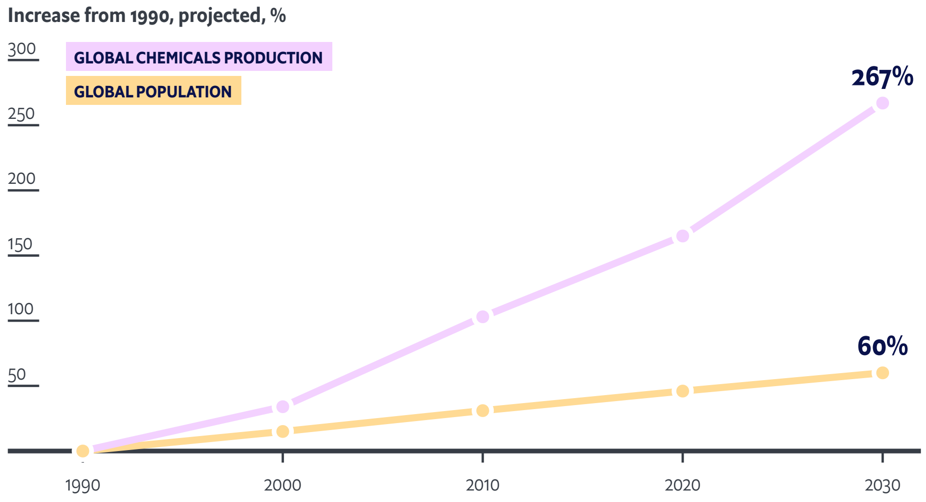
Region	Population in millions			
	2017	2030	2050	2100
World	7,550	8,551	9,772	11,184
Africa	1,256	1,704	2,528	4,468
Asia	4,504	4,947	5,257	4,780
Europe	742	739	716	653
Latin America and the Caribbean	646	718	780	712
Northern America	361	395	435	499
Oceania	41	48	57	72

Source: Global Chemicals Outlook II, UNEP (2019)

"A growing population will drive demand for chemicals and chemical-intensive products," the UN said in its Global Chemicals Outlook II report, with the rate of growth of chemicals production projected to exceed population growth until 2030 (see table). "This means per capita consumption of chemicals is increasing steadily, further amplifying the effect of population growth on demand for chemicals."[79]

Population growth and the chemicals industry

A growth model by UNEP shows the correlation between population growth and chemicals production



Source: Global Chemicals Outlook II, UNEP (2019)

These changes emphasise the importance of meeting the sustainable consumption and production targets contained in SDG 12, the UN noted, adding that they also "reinforce the need to decouple material use from economic growth, enhance resource and eco-efficiency, advance sustainable materials management, and prioritise source reduction, reuse and recycling, as called for by the waste hierarchy".

Simply put, a fast-increasing population and a growing middle class will change consumption patterns, with large numbers of people switching from purchases based on necessity to purchases based on choice. Given that more than 95 percent of manufactured products "rely on some form of industrial chemical process" when being made[80]—to say nothing of the chemical inputs used for food, packaging, pharmaceuticals or consumer goods like soaps, shampoos and toothpastes—failing to change how these are designed, made and discarded will further harm the health of the ocean.

Dr Kevin Helps, the United Nations' Environment Programme's (UNEP) senior programme officer responsible for the UNEP-GEF chemicals and waste portfolio, says a growing global population, with much of that growth coming in developing countries that lack infrastructure for dealing with plastics and chemical waste, will see billions of people rightly aspiring to a middle-class lifestyle that is taken for granted in wealthier countries.

"The growing middle class in the developing world will rightly want what we have. That will drive the demand, consumption and production of products that use lots of chemicals and, unless we're careful, will result in a catastrophic increase in the deposition and dumping of wastes and residues," he says.

Dr Helps says that while there is much talk about the three 'Rs'—reduce, reuse, recycle—and the nine 'R's (which add aspects like resilience and the revaluation of resources), "nobody is currently talking about the most dangerous R: the harmful residues that have no value".

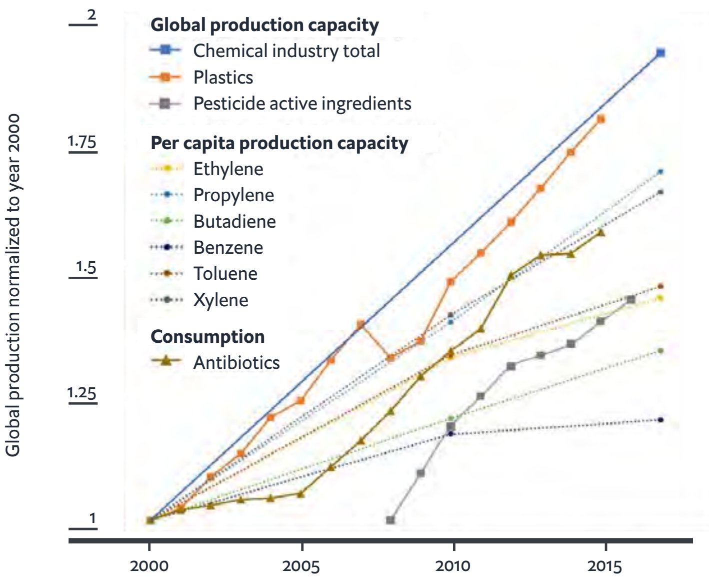
"Nobody talks about these residues, and that's the big cost—those nasty chemicals that are contained in our waste and that don't break down, that bioaccumulate, that interfere with our life systems," he says. "It's a huge cost and we have to start paying for it. The old 'polluter pays' principle needs some new emphasis if we are to combat the growing global crisis from waste and pollution."

A step too far?

This cascade of growing production volumes of chemicals whose effects in most cases the world does not understand raises a crucial question: How much is too much? Or, to put it another way, at what point does the world risk crossing the planetary boundary where chemicals threaten the very ecosystems upon which humans (and most other species) depend?

The answer, a 2022 study concluded, is that it already has.[81] The annual production and release of "novel entities", meaning chemicals and plastics, has increased faster than the world's capacity to assess and monitor them. While conceding major data limitations, the scientists said the weight of evidence allowed them to conclude "that humanity is currently operating outside the planetary boundary".[82]

Global increases in chemicals and plastics production



The chart shows the rising global trend in production in the chemicals industry as measured by the relative growth in certain chemicals and plastics between 2000 and 2017. Pesticides data begins in 2008. Data for the six key monomers and solvents is calculated in terms of per capita production capacity in weight

Source: Outside the Safe Operating Space of the Planetary Boundary for Novel Entities, Persson L et al.

"The increasing rate of production and releases of larger volumes and higher numbers of novel entities with diverse risk potentials exceed societies' ability to conduct safety-related assessments and monitoring," they wrote.[83]

Among the "urgent actions" required—including "a more preventive and precautionary hazard-based approach"—was that the world follow the example of caps on greenhouse gas emissions by "globally capping emissions of [novel entities] at a rate that is commensurate with the physical and chemical capacity of the Earth system".[84]

Please see Notes for references

4: Measuring the impact and risks of marine chemical pollution

This chapter sets out the evidence—to the extent that this can be established—of the impact of marine chemical pollution on the ocean environment and on human health. Determining a baseline for these costs is an urgent need, as this would allow a series of recommended interventions and actions to be modelled according to their estimated future benefits. It concludes with an in-depth case study on the impact that marine chemical pollution has had on the fishing industry in the Gulf of Mexico.

4.1 Principal findings and recommendations

- **Trillions of dollars in ocean services are at risk, though the true impact of marine chemical pollution is by no means fully quantified.**
  The ocean provides three crucial services worth trillions of dollars annually: economic (fishing, mariculture and tourism, for example); tangible ecosystems services that are vital for human health (including producing oxygen, regulating the climate and capturing carbon); and intangible ecosystems services (including their cultural and aesthetic value). Marine chemical pollution inflicts a cost on all three. Not enough is currently known about these costs overall, though there is plenty of evidence in specific instances. Closing the knowledge gaps on chemicals' impacts on health and the marine environment requires improved understanding through measurements and modelling of how chemicals used by society are transported and transformed in the environment; how they accumulate in food chains; and what risks they pose to marine biodiversity and human health.

- **The precautionary principle demands immediate action be taken.**
  Experts agree that we need more data on the magnitude of the risks posed by chemical pollution in the ocean, including to determine its long-term ecological impacts, and that its effects in some ecosystems are already pronounced—particularly for highly polluted environments near some coastal cities. Some experts are concerned about the *potential* for catastrophic impact on a global scale if these problems are not addressed. The ocean's capacity to absorb all pollutants is clearly limited, so it is fair to assume that increased marine chemical pollution is likely to be even more damaging—and possibly highly damaging. Delaying action to continue measuring and calculating the impacts would breach the tenets of the precautionary principle. Action is needed now.

- **Chemicals producers and users of chemicals externalise the costs.**
  Central to marine chemical pollution is that industry has for decades been able to externalise its costs—passing these on to society, and often to the poorest and most vulnerable. Part of the problem is that economics does not account for the impact that human activity has on nature, despite the fact that the planet's ecosystems and biodiversity underpin our very existence. This trajectory is unsustainable. Governments and regulators must ensure that the potential costs of sources of marine chemical pollution are not ignored, as currently happens in a range of areas including, for example, unplugged offshore oil and gas wells—a particular risk for developing countries like Angola and Nigeria.

- **Regulation and actions can help mitigate the impact.**
  The European Commission has concluded that regulation cuts the costs inflicted on the environment and on human health, with better water quality and fewer releases of hazardous materials among the measurable benefits. However, even the European Commission recognises it is in a state of catch-up when it comes to the risks that chemicals pose—and it is arguably the global leader. Research has also shown that actions make a difference. The phasing out of some PFAS production in the US, for instance, resulted in lower PFAS blood contamination in different human populations in the US, Sweden, Australia and the Faroe Islands, and lower levels in marine organisms.

- **Quantifying the costs of inaction and the rewards of intervention may help motivate change.**
  Although putting a dollar value on everything at risk is challenging, combating marine chemical pollution has been shown to bring sizeable economic benefits in areas where measurement can be done. In a case study in this paper on the costs of hypoxic "dead zones" in the Gulf of Mexico, the EIU found that should the issue worsen and contribute to a greatly reduced landing weight of fish catch, the US stands to lose nearly US$838m in annual fisheries revenue. Conversely, if measures were taken to reduce the dead zone, contributing to increased marine biodiversity and fisheries landing weight, the best-case scenario (a 15 percent increase in landing weight) could see an increase in revenue nationally of over US$117m.

- **Coordinated action is needed from all stakeholders.**
  Although we lack complete knowledge about the harm chemicals are imposing on the marine environment, we have more than enough evidence of the damage being done to conclude that it is time to act. The scale of pollution and the complexity and importance of marine ecosystems mean that action by governments, industry, finance and civil society is crucial if pollution is to be reduced to acceptable levels. Worryingly, though, where co-ordinated action has been taken, the pace of consensus-building and action has often been glacial.

The ocean provides three crucial services, the global value of which is estimated to be trillions of dollars a year.[1] (The European Commission says the bloc's blue economy, for instance, generated €658bn in 2017.[2]) Much of this value worldwide is produced in coastal areas, with the services categorised as:

- Economic activities like fisheries, shipping and tourism.

- Ecosystem services that are tangible and essential to human life—producing oxygen, acting as a carbon sink, regulating the climate, and protecting coastal areas from storm surges and waves.

- Ecosystem services that are intangible, such as their cultural, religious and aesthetic value.[3]

Marine chemical pollution inflicts a clear cost on all three. A core problem at the heart of marine chemical pollution is that measuring this cost accurately in environmental, human and financial terms is not yet possible.

There are several reasons for this. First, because existing studies typically assess the impact that a chemical (or group of chemicals) has had on a limited geographical area and within a set time frame—an oil spill, say, or the impact on human health in the EU of the toxic PFAS "forever chemicals".

Second, it is not easy to measure much of what is at risk. How, for instance, does one determine the value of, say, a coral reef or calculate the damage done to the marine environment by an uncapped deep-sea oil well? Third, and perhaps most importantly, it is because economics has failed to value the world's natural capital, including calculating the destructive impact that our economic activities have had on it, and continue to have.

Given the complexity of the subject, a comprehensive analysis of the costs of marine chemical pollution is beyond the scope of this report, though it will be a focus of the expert working groups in the second phase of the Invisible Wave initiative. Their remit will include, in part, establishing a baseline cost to estimate the past, present and projected future costs of marine chemical pollution, something that is urgently needed.

This chapter will therefore draw on current best estimates of impacts, where known, to try to quantify the costs of marine chemical pollution as best as it can. In setting out the extent of the science, and what remains unknown, it also aims to define a path towards determining the overall potential costs of marine chemical pollution—both to underline the potentially catastrophic risks of inaction and to illustrate the beneficial impacts of specific remedial actions.

Impacts can be measured in terms of the extent of environmental and biota degradation, the effect on human health, and the financial cost that marine chemical pollution inflicts on the three ocean services. This chapter looks at what is known about each category, though far too little is understood of the costs—and, inevitably, some categories overlap.

Additionally, and unsurprisingly, the world knows far more about the effects that land-based chemical pollution has on human health than it does about the direct impact of chemical pollution on the marine environment or about the effects that marine chemical pollution subsequently has on human health. Inevitably, then, this report is forced to rely in many instances on the costs that land-based chemical pollution visits on humans. Again, this use of a proxy reinforces the urgent need for baselines that can be used to determine what the world has lost or is at risk of losing when it comes to marine chemical pollution.

Lastly, by way of illustration, this chapter includes a comprehensive case study that calculates the impact of marine chemical pollution in the Gulf of Mexico on the US fisheries sector. The aim of this focused study is to suggest the type of methodology that must be repeated for all marine chemical pollutants if we are to understand, at least in the most readily quantifiable context, the damage we are doing to the ocean.

4.2 A potential catastrophe?

Coming up with numbers may be difficult, but that does not detract from the fact that marine chemical pollution is today being recognised as a major concern—and one that is set to get worse before it gets better.

One question asked of numerous experts during the research for this paper was whether marine chemical pollution would prove catastrophic. Opinions were divided. While most felt the risk of ocean collapse on a large geographical scale was unlikely, there was consensus that we simply do not know enough about marine chemical pollution and its potential ecological impacts, and that more work was needed to understand the risks better.

That said, there was also consensus that we know enough now to be greatly concerned about the current impacts and the *potential* global impacts, and that each day we are learning more. As one interviewee noted, the collapse of localised fisheries due to chemical pollution has been extensively documented.

To that end, this report's working assumption is that marine chemical pollution is likely to be highly damaging, and that we should therefore operate on the principle of hazard avoidance, not risk mitigation. The precautionary principle (see box) dictates that the world should not spend time trying to measure the impacts to a great level of precision before acting, given the potentially catastrophic risks of inaction.

The precautionary principle

The precautionary principle, which can be summarised as "better safe than sorry", holds that activities that could threaten human or environmental health should be subject to actions "even if some cause-and-effect relationships are not fully established scientifically".[4]

A 2001 paper written to apply the principle to the environment noted that it is designed to encourage "policies that protect human health and the environment in the face of uncertain risks", and outlined four key components that constitute a definition of the precautionary principle:

- Preventative action should be taken if outcomes are uncertain.
- The burden of proof should shift to those who wish to act in certain ways that might harm the environment.
- There should be an assessment of "a wide range of alternatives to possibly harmful actions".
- The public should have greater participation in decisions.[5]

In many cases and for a range of reasons, the authors wrote, science cannot come up with cast-iron proof of harm with which to guide policymakers, and there is typically a significant grey area "in which science alone cannot (and should not) be used to decide policy".[6]

"The precautionary principle, then, is meant to ensure that the public good is represented in all decisions made under scientific uncertainty. When there is substantial scientific uncertainty about the risks and benefits of a proposed activity, policy decisions should be made in a way that errs on the side of caution with respect to the environment and the health of the public," they concluded.[7]

A key assumption should be that marine chemical pollution is likely to be highly damaging, and that we should thus operate on the principle of hazard avoidance, not risk mitigation. Apply the precautionary principle, in other words

In terms of the costs that we do know, the best estimates are the impacts that certain chemicals have had on humans. While the studies are almost all about land-based chemical pollution, they are useful proxies for what might be happening (and that in some cases is known to be happening) to marine biota and, by extension, potentially to human health:

- In Europe, PFAS substances are estimated to cost €52bn-84bn annually in health costs.[8]
- Endocrine-disrupting chemicals (EDCs) are conservatively thought to add €157bn to health costs in the EU, with the authors of a recent paper stating that EDC exposures were "likely to contribute substantially to disease and dysfunction across the life course with costs in the hundreds of billions of euros per year"[9].
- Childhood lead exposure is estimated to cost low- and middle-income countries nearly US$1 trillion a year.

While these are significant in both human and financial terms, they reflect the human-related costs of just a few of the many thousands of industrial chemicals and elements used. Additionally, these are not global costs—simply those calculated on a regional or an income-weighted basis—and they ignore the wider impact the chemicals have on ecosystems and the natural world. The true cost of chemicals, then, is clearly far higher.

Central to the issue is that chemicals manufacturers and their clients have been able to externalise their costs, i.e., pass them on to society. This failure stands at the core of marine chemical pollution, and resolving it requires that costs are internalised. As UNEP states: "The vast majority of human health costs linked to chemicals production, consumption and disposal are not borne by chemicals producers, or shared down the value-chain. Uncompensated harms to human health and the environment are market failures that need correction."[10]

With the ocean providing at least US$2.5 trillion worth of economic value each year, and with its value as an asset conservatively estimated to be worth ten times that amount, the economic risks alone are colossal.[11] In truth, though, the value of the ocean is incalculable: were we to poison it beyond repair, life on Earth would be impossible.

4.3 Human health costs

One of the toughest challenges is the lack of visibility of marine chemical pollution, which makes it wholly different even to chemical pollution on land, says Professor Elsie Sunderland of Harvard University. Resolving land-based pollution is a matter of sending in teams to clean up the contaminated area. In the marine environment, that is not possible, which is why the global background exposure of marine chemical pollution is slowly rising.

"Think about the 'boiling a frog' metaphor: that's what we're talking about," she says. "We're the frog, the background levels are slowly rising, and we're not looking at it."

That said, the impact of chemicals on human health is becoming increasingly clear, with known consequences in terms of, for example, neurotoxicity, immunotoxicity and cardiovascular health. Epidemiological studies in the US have shown a gradual yet growing incidence of those health conditions, as well as of developmental abnormalities, obesity and diabetes, all of which are linked to classes of key chemical pollutants.

"And these are epidemiological studies, so you correct for lifestyle factors and other things that you would commonly associate with this," Professor Sunderland says. "That suggests there's this environmental vector."

Mercury is a key example. While it does occur naturally, a landmark 2017 study that Professor Sunderland co-authored concluded that 1.54m metric tons of mercury were emitted over the past 4,000 years, with three-quarters of that released between 1850 and 2010. In this 160-year period, humans were responsible for 78 times more mercury emissions than were released via natural routes, with nearly 80 percent of emissions taking place in the Northern Hemisphere.[12]

Chemicals manufacturers and their clients have long been able to externalise their costs, passing them onto society. This failure stands at the core of marine chemical pollution; resolving it requires that costs are internalised

Mercury poisoning was at the heart of what is arguably the most infamous case of marine chemical pollution affecting humans: that of the residents of Minamata fishing village in Japan, with the emergence in the 1950s of an illness named Minamata Disease.

It was caused by the decades-long dumping of methylmercury into the bay of Minamata by the Chisso Corporation, which used mercury in the manufacture of acetaldehyde, an ingredient in plastics.[13] This had appalling health consequences for residents, who relied for food on fish, shellfish and other marine biota, which had become highly toxic.

Mercury accumulates in the brain, spinal cord and the myelin sheaths that coat the nerves, and high-level exposure damages the brain, heart, lungs, kidneys and immune system. It also has significant development impacts on unborn babies and children.

According to Japan's Ministry of Environment, by 2001 nearly 3,000 people had been recognised as Minamata Disease patients in and around Minamata and at the Agano River basin, another site polluted by industrial mercury.[14] By then, at least 1,000 patients had died.[15] However, the strict certification process that was used meant many residents did not seek to be recognised, so the true number afflicted is certainly higher.[16] According to the WHO, at least 50,000 people were in some way affected.[17]

What happened at Minamata and the Agano River basin was the consequence of a single contaminant, and it resulted in chronic long-term consequences for tens of thousands of people. In an important way, one aspect has not changed in the decades since: today, people's main exposure to methylmercury, the organic compound into which bacteria convert mercury in the environment, is through eating fish and shellfish.[18]

Mercury's devastating consequences explain why the WHO ranks it as one of the world's top 10 chemicals or groups of chemicals of major public health concern, with humans most at risk falling into two groups. The first is unborn babies, for whom methylmercury exposure can affect the brain and nervous system as they grow, damaging their neurological development, with consequences including impairments to cognitive thinking, language skills and attention.[19] Experts note that these cognitive deficits from prenatal exposure to methylmercury seem to persist into adulthood.

The second is people who are regularly exposed to mercury, including artisanal gold-miners and their families, as well as those relying on subsistence fishing. Studies of children in subsistence fishing populations in Brazil, Canada, China, Columbia and Greenland found that regular intake of mercury from fish consumption had resulted in mild mental retardation for between 1.5-17 of every 1,000 children.[20]

Sobering though the costs of mercury are, other chemicals exert a huge toll on people (see box). The WHO's remaining nine chemicals or groups of chemicals that it regards as representing a major public health concern are: air pollution; arsenic; asbestos; benzene; cadmium; dioxins and dioxin-like substances, including PCBs and POPs covered by the Stockholm Convention; inadequate or excess fluoride; lead; and highly hazardous pesticides.[21] As this paper has shown, these have impacts on the marine environment too.

Chemicals management and the cost to human health

The effects of chemical pollutants on human health have understandably received more attention than their impact on the environment. In quantifying the human cost, the WHO assesses their impact in terms of their contribution to global deaths and to disability-adjusted life years, or DALYs, which represent the loss of one year of full health.[22]

In its 2021 update, the WHO concluded that the sound management and reduction of chemicals in the environment would have prevented about 2 million deaths in 2019 (about 3.6 percent of all deaths) and 53.5 million DALYs (around 2.1 percent of the global total).[23]

In reaching those numbers, the WHO divided the chemicals assessed into three categories:

- Chemicals in acute poisonings, like pesticides, kerosene and methanol: about 235,000 deaths and about 12.8 million DALYs.
- Single chemicals with mostly longer-term effects, of which lead is the most significant: about 900,000 deaths and 21.7 million DALYs.
- Chemicals in occupational exposure, which typically have longer-term effects, and which include a range of known carcinogens (benzene, arsenic, asbestos, diesel engine exhaust, cadmium and formaldehyde) and particulates like dust, fumes and gas: about 875,000 deaths and 19.5 million DALYs.

As the graphic shows, Southeast Asia and Europe record the highest proportion of deaths from chemical exposure, while children and older people are more likely to be affected by the impact of chemicals.

The 2019 data show a significant increase in the WHO's previous estimates of 1.3 million deaths and 43 million DALYs in 2012, and 1.6 million deaths and 45 million DALYs in 2016. However, as the WHO makes clear, its estimates are based on the data that is available "for a small number of chemical exposures, and people are exposed to many more chemicals every day".

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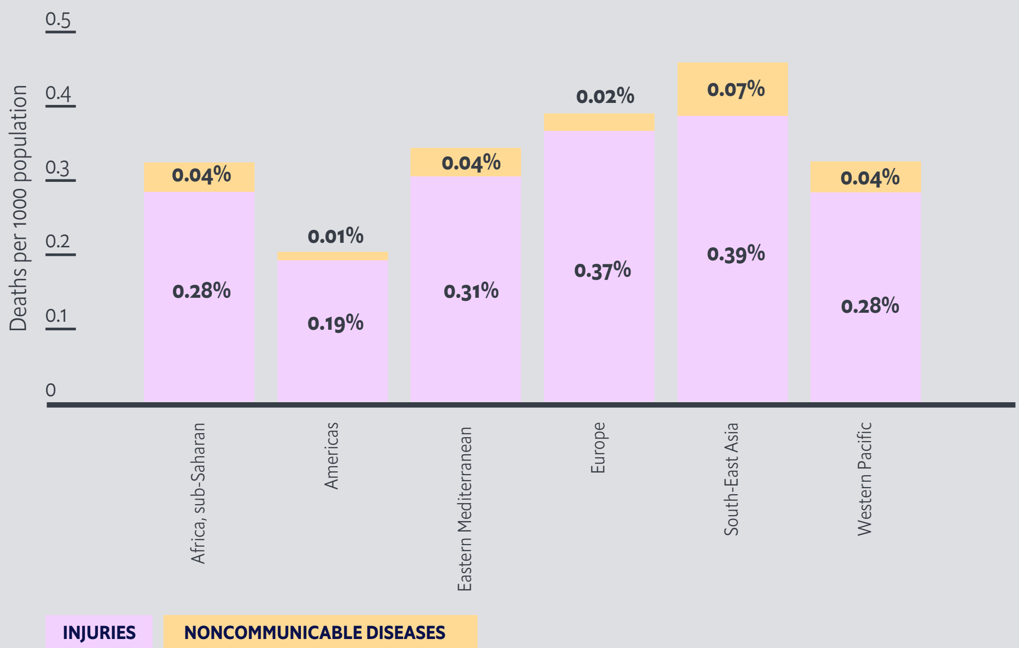
Total age-standardised deaths attributable to chemicals by region and disease group

The figures show the numbers of deaths attributable to chemicals around the world, and exclude deaths from ambient air pollution due to combustion sources. The data for non-communicable diseases reflect the effects that chemicals have on the cardiovascular system or on the development of cancers; injuries data reflect unintentional poisonings and suicides, both of which are often attributed to pesticides. The numbers are age-standardised, which means they are adjusted for differences in the age distribution of the population to produce comparable numbers. On a gender basis, the updated figures for 2021 show that males are twice as likely to die from chemical exposure as females.



Source: Public health impact of chemicals: knowns and unknowns, WHO (2016)

The effect that even this limited assessment of chemicals has on human disease is significant: the WHO estimates that cancers from workplace chemicals cause between 2 percent and 8 percent of all cancers—hardly surprising, given its conclusion that the "list of chemicals classified as human carcinogens with sufficient or limited evidence is long".

And, it notes, about one-third of heart disease (the world's leading cause of deaths and disability) and 42 percent of strokes (the second-biggest cause of death) could be prevented if exposure to lead, chemicals like ambient and household air pollution, as well as second-hand smoke, were reduced or removed.

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By far the bulk of the chemicals in existence, though, are not assessed in the WHO report, and it is clear that the deaths and DALYs they inflict, were they able to be calculated, would raise these estimates significantly. Adding in the damage that these chemicals cause to the environment, and particularly to the marine environment, would increase those costs yet further.

Although there is plenty of bad news on chemicals, there is some good news too. The first is that regulation helps

Actions speak louder

Although there is plenty of bad news on chemicals, there is some good news too. The first is that regulation helps. The European Commission (EC), which has for decades legislated on chemical pollution to protect human health and the environment, says benefits include deaths avoided, lower health-care costs, fewer releases of hazardous materials, and better water quality. Regulation in the bloc, it says, has:

- Over 50 years generated tens of billions of euros of benefits annually (and perhaps more) in terms of cancers alone—with several million fewer deaths from cancers since 1995.
- In relation to lead, €450bn of avoided damage annually in terms of higher earnings and DALYs.
- The regulation of pesticides has benefited the bloc to the tune of €15-50bn annually.
- Other actions on chemicals have saved billions of euros more. Avoided exposure to mercury in fish, for example, is estimated to have prevented the loss of 650,000 IQ points a year, which it values at about €9bn annually.[24]

And, the EC points out, data constraints mean its conclusions are based on only a subset of potential benefits, with "the known value of these benefits likely to increase, perhaps significantly" as improved methods are implemented.[25]

While the EC is clearly ahead of the global curve on chemicals, even it recognises that it is in a state of catch-up. Chemicals still inflict a significant health and environmental impact, and those need to be tackled.

"Nor is the situation static, new risks are emerging. Moreover, there is still much we do not know about the health and environmental hazards and risks of many existing chemicals in the EU," its 2017 report states.[26]

Among the EC's substances of concern are certain phthalates, as well as dioxins and PBDEs. It has also highlighted that endocrine-disrupting chemicals (EDCs) are likely linked to a range of human health issues, including IQ loss, ADHD, endometriosis, obesity, diabetes, male infertility and increased mortality due to lower testosterone levels—with the median annual cost of EDCs alone estimated to be €163bn.[27]

The second piece of good news is that actions help. A multi-year study of children from the Faroe Islands—positioned in the North Atlantic roughly equidistant from Iceland, the United Kingdom and Norway—found a significant decline in their blood levels of certain PFAS chemicals, the "forever chemicals" which are associated with a range of serious health conditions including cancer, immune suppression and metabolic disruption.[28]

One of the many exposure sources for PFAS chemicals is seafood. Others include PFAS-laden consumer products and, potentially, drinking water, although levels measured in past studies were below detection. (The rocky nature of the Faroes means all food is either harvested from the ocean or imported.) Young children are particularly vulnerable to PFAS chemicals, and so between 1993-2012, researchers decided to assess their levels of 19 legacy PFAS chemicals.

They found that median concentrations peaked in 2000—about the time that 3M, a major manufacturer of the compounds, discontinued production of a particularly toxic variant called PFOS, one of 19 they measured. Concentrations of the chemicals declined after that by about 14 percent annually on average.

While that is clearly positive, the problem is that all 19 legacy PFAS chemicals were still detectable in 2012; additionally, numerous new PFAS compounds with shorter carbon chains have since entered the market. (There are thousands, and we are yet to understand what effects many of those might have.)

Improved waste management—and, in particular, better wastewater management—is an important part of tackling marine chemical pollution

When it comes to PFAS and declines in their levels in humans, researchers have found similarly beneficial results in Norway, Australia, the US and Sweden. As the authors of the Faroe Islands paper point out, the results emphasise "the global benefits for human exposure of the phase-out in production of PFOS around the year 2000 and the PFOA stewardship initiatives in the United States and the European Union around 2006".

Professor Sunderland, the senior author of the Faroe Islands paper, says it shows actions can have a significant effect, even on communities far from the source of the pollution. Researchers not only found declines in PFOS levels in the ocean after industry phased them out; they also detected changes in the levels of pilot whales, an important food source for the Faroese.

"You see a very rapid decline in PFOS in the surface of the ocean that's most relevant to biota, and you see changes in the levels of pilot whales very quickly," she says. "And then in the Faroe Islands, you see levels of PFOS in the blood of kids dropping rapidly as well."

Gaps in science

Unsurprisingly, there are still significant gaps in our understanding of the connections between human health and the marine environment. The UN, for example, states that when it comes to our knowledge of pollutants (including nanoparticles), pathogens and non-indigenous species, science needs to:

- Improve the measurement and monitoring of their distribution.
- Improve the knowledge of how they are transported and transformed.
- Improve the assessment of their risks to humans.[29]

We also do not know enough about how waste management affects the marine environment, particularly coastal ecosystems, and human health, or about the connections between the marine environment and observed health benefits.[30] This is particularly important when it comes to our treatment of the slew of POPs, endocrine-disrupting chemicals, bioaccumulating chemicals and nanomaterials, with the UN regarding this as one of the five key environment and health challenges of our time when it comes to the marine environment and human health—particularly the health of people who depend on that environment.[31]

As the next chapter will show, improved waste management—and, in particular, better wastewater management—is an important part of tackling marine chemical pollution. Studies have shown that chemically laced litter can also have unexpected human health costs. In the Caribbean, for example, items like plastic bottles and Styrofoam containers constitute as much as 15 percent of the breeding habitat for mosquitoes carrying dengue, malaria and chikungunya, with those diseases affecting more than 15 million people in outbreak years in the region—at a cost as high as US$31bn during an outbreak year. (Outbreaks harm tourism too, costing US$700m in outbreak years.)[32]

The other challenge is wastewater. The estimated cost to global public health of polluted coastal waters (not all of which, of course, is due to wastewater management) is about US$12bn, with around 120 million cases of gastroenteritis and 50 million cases of Acute Respiratory Distress.[33] A separate study by GESAMP and the WHO concluded that polluted seas caused 250 million cases of gastroenteritis and upper respiratory disease annually, totalling 400,000 DALYs and a cost of US$1.6bn.[34]

Island nations, many of which rely on tourism, are particularly susceptible to contaminated wastewater as few have the infrastructure to deal with, for instance, domestic sewage. Some simply pump it untreated into the sea, which can have unforeseen costs: a study in Barbados showed that two-thirds of tourists would not return to the island if they fell ill from contaminated seawater.[35]

4.4 Economic costs

Aside from human health costs, marine chemical pollution also exerts significant economic effects, particularly in areas like fisheries, tourism and recreational activities. And while some impacts are short-term, others can last decades, as the example of mercury poisoning at Minamata shows.

Calculating the commercial cost of marine chemical pollution on, say, fisheries or tourism is easier than determining a value for non-commercial aspects. How, for instance, does one put a complete price on chemical-induced sterility in orcas (beyond calculating the impact that less local tourism would have years down the track) or the damage done to a protected area?

Net worth: Valuing the marine environment

In recent years, the Organisation for Economic Co-operation and Development (OECD) has worked on an ambitious project to improve how countries measure the twin pillars of their ocean economies: the economic activities and assets that the ocean contributes, and the ecosystem services provided by the marine environment.[36]

The goal is to generate internationally comparable statistics on ocean economic activity, which would in turn provide the foundation for more comprehensive ocean accounts that include marine economic-environmental linkages. Knowing the value in dollar terms of each country's marine environment could put some sort of price on the damage done by, for instance, marine chemical pollution.

Ocean economy satellite accounting, as the OECD refers to it, has become increasingly important, says Claire Jolly, who heads the Ocean Economy Group at the OECD's Directorate for Science, Technology and Innovation, because there "has never been so much need for understanding better the ocean and the often-competing activities that impact it". (Satellite accounting is a statistical framework that ensures that a specific field of economic measurement—in this case, ocean economic activities and, eventually, their interactions with the marine environment—can be linked to a country's central accounts.[37])

Six countries in particular are working closely with the OECD as pilots for the satellite accounting exercise: South Korea, Portugal, Ireland, Norway, the US and Canada—with all six well-prepared in terms of how their existing statistical infrastructure can measure ocean economic activity. Italy and the Belgian region of Flanders are also contributing data. The long-term goal is to expand ocean accounting to all 38 OECD member countries and beyond.

"This work complements national efforts and data, which are by definition more granular, as the satellite account should ideally provide comparable time series that are more aggregated," says Jolly. "It will be very useful for countries around the world."

The project, which is in its experimental phase, is focused on the first pillar: measuring the supply and use of products associated with ocean economic activities. Broadly speaking, this covers goods and services targeted at ocean activities (shipbuilding, for instance), the extraction of living resources (like fish) and non-living resources like oil and gas, as well as activities that would likely not exist but for their location close to the sea (desalination plants and coastal tourism, for example).[38]

Measuring marine natural assets and ecosystem services—the second pillar—is farther off because methods for doing so are largely theoretical. But, says Jolly, encouraging progress is being made.[39]

Jolly says the biggest challenge has been ensuring that source data is coherent across countries so that the accounts produce comparable statistics. This stems from the fact that countries measure economic activity differently or because they do not split out land-based and marine-based activities. The offshore generation of wind-power, for example, falls under the same international data-capture code (the ISIC code) as all electrical power generation, transmission and distribution, whether land-based or not.[40]

By late 2021, Portugal, the US, Norway and South Korea had either released national satellite accounts for ocean data or were close to doing so. Meanwhile, the OECD is working with the six pilot nations to ensure the information available to construct the tables that will measure ocean economic activity is as exhaustive as possible. The first set of results is scheduled for release towards the end of 2022.

Although coming up with a number for the full economic cost of marine chemical pollution is difficult, focusing on these commercial areas is easier, and that is because the economic incentive to measure the damage it does is simpler when it comes to aspects that can be invoiced, like landed fish weight or a reduction in tourist numbers.

Take the Caribbean where, according to the World Bank, more than 35 economies are reliant to some degree on marine ecosystems like tourism—which accounts for 15 percent of the region's GDP—as well as fisheries, shipping and ports. The seas are also a crucial source of food and livelihoods for poorer communities.[41]

Still, 80 percent of marine pollution in the Caribbean comes from land-based sources, with untreated wastewater, litter and agricultural run-off accounting for the bulk. This constitutes a serious threat to these economies, with key drivers being the size of the coastal population and the level of waste management systems. Industrial pollutants, heavy metals and shipping waste, though less well-documented, are potentially as important.[42]

Coral reefs are at particular risk, although pollution also affects mangroves and seagrass beds. Reef degradation alone costs the region between US$350-870m annually, with 20 percent of that due to pollution. Wastewater, a major source of marine pollution, enters the seas either untreated (85 percent of the total) or partially treated. Other than sewage, it also includes industrial and agricultural effluent.[43]

It is easy to see how this can damage fisheries and tourism. Less well appreciated is that marine chemical pollution can also cause species that are typically not harmful to become threats. In 2018, for instance, Sargassum seaweed washed up in large quantities in the Caribbean, causing mass die-offs of fish and damaging tourism. While warm water temperatures were partly behind the event, the growth of the seaweed was also due to higher nitrogen levels from sewage and fertilisers.[44]

What is needed in the Caribbean, then, is effective management of plastics, solid waste and wastewater—with the World Bank listing those as its main priorities in terms of halting and reversing the region's marine degradation.[45] Needless to say, such an approach would apply to many other parts of the world too.

The example of the Caribbean is just one that shows the significant economic costs of marine chemical pollution. A 2010 study of the marine ecosystem adjacent to China's Pearl River estuary, for instance, determined that marine pollution (principally inorganic nitrogen, phosphate and oil) would cost about US$5bn annually, a sizeable portion of that marine ecosystem's estimated US$30bn total value.[46]

And oftentimes, these potential costs are either ignored or simply unappreciated—with unplugged offshore oil and gas wells a salient example (see box). These represent a significant marine pollution threat and an economic burden that to date has been largely ignored, with developing nations like Angola and Nigeria regarded as being at particular risk.[47]

Unwanted: The hidden costs of orphaned wells

The number of active and orphaned—or abandoned—oil and gas wells on land and offshore globally is unclear but easily numbers in the millions. While most are onshore, tens of thousands are offshore wells.

Regardless, all orphaned wells should be plugged to ensure that they do not pollute. Why? Because beyond the obvious pollutants like oil, unplugged wells that are no longer in use also release large quantities of methane, a GHG.

In a 2021 paper, the Center for International Environmental Law (CIEL), a non-profit, noted that about 15,000 offshore wells existed in the North Sea alone, with researchers detecting methane leaks at nearly two-thirds of the plugged and unplugged wells. CIEL said one small area alone in the North Sea was emitting thousands of tons of methane.[48]

Part of the problem is that decommissioning oil wells and sealing them is costly, and that holds doubly true for offshore wells. Various factors influence the final cost, but when it comes to deep-sea offshore wells, which are typically at a depth of more than 120 metres, CIEL estimates a cost to plug of US$5-11m per well. Factor in other measures, and the final cost of decommissioning a deep-water well can run into tens of millions of dollars.[49]

Little wonder that so many operators simply shut up shop and sail away. And, CIEL notes, with the market for oil and gas set to decline in the coming decades as the world moves towards a low-carbon future, "the fiscal and environmental risks associated with shutting down wells, especially fracked and offshore wells, loom larger and closer on the horizon than many countries may anticipate".[50]

"For developing countries that already have offshore wells but where decommissioning of assets has largely yet to occur, such as Angola and Nigeria, the true costs of decommissioning may come as an unwelcome surprise — and one that operators and governments may be unprepared to pay," CIEL states.[51]

The solution, says CIEL, is for these costs to be factored in for all proposed oil and gas developments, with regulatory oversight to ensure that firms that extract the fossil fuels do not shirk their responsibilities at the end of the well's life.

Some steps are being taken, with the US announcing at the COP26 conference in late 2021 that it would institute a programme to cut millions of metric tons of methane emissions across the country, including from an estimated 300,000 oil and gas wells. The oil and gas industry is the US's largest industrial emitter of methane, a potent GHG.[52]

That was part of a global US-EU partnership announced at the COP26 summit to cut methane emissions. The Global Methane Pledge, signed by about 100 countries representing two-thirds of the global economy, seeks to cut methane emissions by 30 percent by 2030 compared to 2020 levels. Russia, China and India—all major emitters—did not sign.[53]

Yet while the monetary costs of marine chemical pollution are sizeable, other examples show that combating it can bring significant benefits. The European Commission, for instance, estimates that regulating tributyltin, an antifouling paint applied to the hills of boats and ships, boosted the bloc's commercial fishing revenues by between €20-160m annually, "alongside potentially substantial benefits to nutrient cycling".[54]

While the monetary costs of marine chemical pollution are sizeable, combating it can bring significant benefits. Regulating an antifouling paint applied to boats boosted EU commercial fishing revenues by between €20m-160m annually

A 2019 study of four beach areas in the US by the NOAA determined that reducing marine debris on beaches to nearly zero would add about US$400m in economic value through tourism to those areas alone, creating more than 6,700 jobs. Doubling the level of marine debris would forego more than US$800m in revenues and cost the areas more than 13,500 jobs.[55]

And a 2018 study of the impact of installing a wastewater treatment plant (WWTP) in 1990 at the Nerbioi estuary in northern Spain found that it brought a benefit of at least €3m annually in increased tourism revenues alone. That was enough to cover the maintenance costs for the three beaches surveyed and 12 percent of the annual costs of running the WWTP—to say nothing of the benefits brought to the estuary's ecosystem from the sharp decrease in water pollution.[56]

4.5 Environmental and biota degradation

If calculating the human and economic costs of marine chemical pollution is challenging, it is harder still to determine the costs in terms of the degradation that this additional stressor inflicts on the environment, its overall biodiversity and the multitude of organisms that rely on the ocean and seas.

Central to the problem is that economics fails to account for the impact that humans have on Nature. In his independent review for the UK Treasury in 2021, Sir Partha Dasgupta, emeritus professor of economics at Cambridge University, outlined the issue: that since World War II, economics has emphasised reconstruction and reducing poverty to the exclusion of considerations about the cost to Nature.[57]

As a result, what counted—and therefore what was counted—was "the accumulation of produced capital (roads, machines, buildings, factories, and ports) and what we today call human capital (health and education)". Factoring in Nature—or the world's natural capital—"would have been to add unnecessary luggage to the exercise".[58]

Yet doing so is crucial, he says, because our economies, our livelihoods and our well-being depend on Nature, and on the biodiversity that underpins Nature's resilience. Consequently, our failure to factor this in must change, because economic growth has come at Nature's expense—and our trajectory is unsustainable.[59]

"Between 1992 and 2014, produced capital per person doubled, and human capital per person increased by about 13 percent globally; but the stock of natural capital per person declined by nearly 40 percent," the review notes. "Accumulating produced and human capital at the expense of natural capital is what economic growth and development has come to mean for many people."[60]

At the heart of this are market failure and institutional failure, with many institutions proving themselves "unfit to manage the externalities", and with nearly every government making the problem worse "by paying people more to exploit Nature than to protect it, and to prioritise unsustainable economic activities".[61]

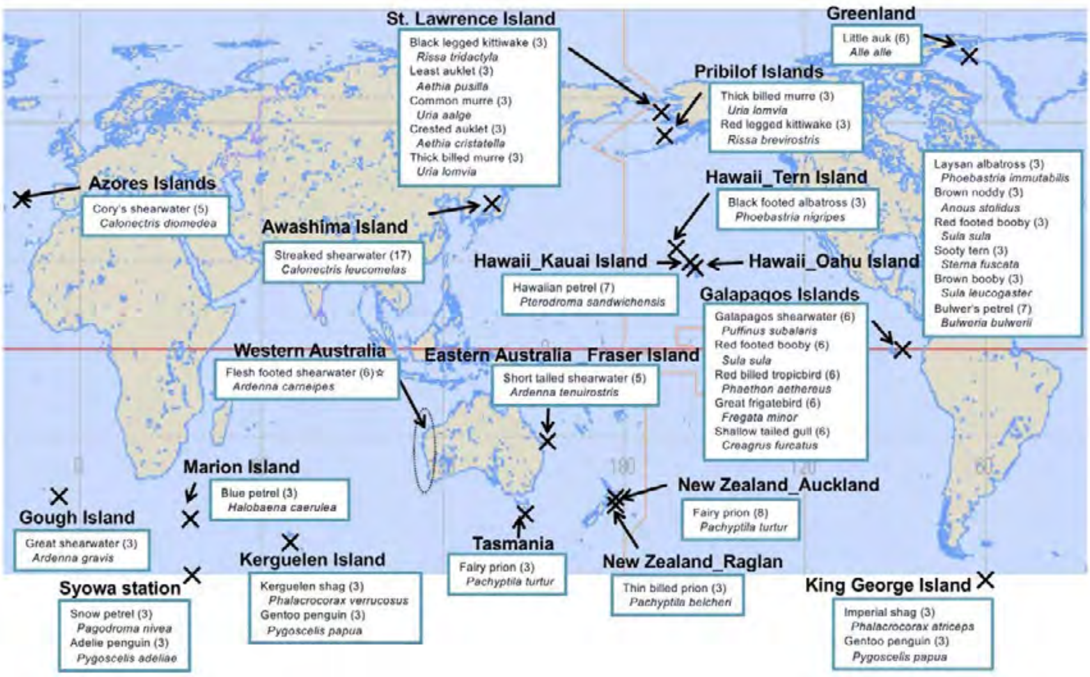
In short, our prosperity has inflicted "a devastating cost to Nature" to such an extent that we would need 1.6 Earths simply to keep the planet's current living standards.[62] That, of course, is impossible.

Part of Professor Dasgupta's "devastating cost" has been visited on the marine environment, and most noticeably on higher-order predators:

- Orcas in waters off the UK, California, Brazil, the Straits of Gibraltar and Japan are so polluted with PCBs that they can no longer breed.[63]
- Climate change effects mean polar bears in Greenland eat more harp and hooded seals, rather than their usual diet of ring seals. Harp and hooded seals typically migrate to northern European waters, where the fish they eat are more contaminated than those consumed by the more sedentary ring seals.[64] As a result, the harp and hooded seals are more contaminated with legacy POPs, which polar bears bioaccumulate when they eat them.[65] POPs are known to harm polar bears' immune systems and their ability to reproduce, and can cause cancers.[66]
- Seabirds whose bodies are riddled with pollutants from plastics and legacy POPs.[67]

To take the last as an example, a study released in late 2021 assessed 146 seabirds from around the world (see map) from 32 species including albatrosses, shearwaters, penguins and petrels.[68]

Locations of birds from which samples were taken, 2008-2016



Source: Plastic additives and legacy persistent organic pollutants in the preen gland oil of seabirds sampled across the globe, Yamashita R et al, Environmental Monitoring & Contaminants Research (2021).

It assessed the preen gland oil of the birds, and found contamination of brominated flame retardants, DDTs, PCBs and six UV stabilisers—with PCBs and DDT being detected in nearly every bird sampled. About half of the birds were contaminated by UV stabilisers, while 11 percent had levels of brominated flame retardants. (UV stabilisers are more commonly added to plastics than brominated flame retardants are, which explains the higher contamination rate of the former.)[69]

The ocean produces more than 50 percent of the planet's atmospheric oxygen; mangroves and seagrasses are natural carbon sinks; and reefs and mangroves offer protection to coastal areas from storm surges and waves. Marine chemical pollution harms all of these

The researchers concluded that the presence of PCBs, which biomagnify, was due to the birds' diet, and that the correlation of PCBs with DDTs indicated that the latter was the result of diet and biomagnification. Some seabirds had plastics in their stomachs, and the detection of the brominated flame retardants and UV stabilisers showed "a significant proportion of the examined seabirds accumulated chemicals from ingested plastics".[70]

One bird—a great shearwater, found on the southern Atlantic island of Tristan da Cunha—had nearly 200 pieces of plastic in its stomach. Blue petrels, which spend their lives in the Southern Ocean off Africa, had high concentrations of additives from eating large plastic loads, with one researcher saying he was concerned that they could "find enough plastic to be affected in this way", given that the Southern Ocean's concentration of floating plastic is the lowest.[71]

This study is just one of many to show how the damage done to higher-order predators often comes from biota further down the food chain—pollutants travel from phytoplankton to krill, for example, then from krill to smaller fish and to birds and larger fish, and ultimately from larger fish to seals and to polar bears. They also travel, of course, from fish and shellfish to humans, or in certain societies from marine mammals to humans. And while contamination in marine life often occurs through eating other contaminated creatures, this study and others show that sea-life like birds, turtles and even krill can ingest toxins after mistaking plastics and microplastics for food.

Damaged goods: From food chains to ocean services

While the damage to the food chain is partly visible, that being inflicted on the services that the ocean provides is less so: the ocean produces 50-80 percent of the planet's atmospheric oxygen, with most of that generated by plankton;[72] mangroves and seagrasses are natural carbon sinks; and reefs and mangroves offer protection to coastal areas from storm surges and waves.[73] Marine chemical pollution harms all of these.

In addition, the ocean itself is a crucial store of carbon, absorbing 34 billion metric tons of carbon from fossil fuel combustion between 1994-2007, or about 2.6 billion metric tons annually. That was four times the annual amount emitted between the start of the Industrial Revolution in 1800 to 1994, when the ocean absorbed a total of 118 billion metric tons of carbon.[74] Assuming a carbon price of US$20/metric ton, this means the ocean provides an annual economic benefit for carbon alone worth US$52bn. The cost, of course, is increased acidification.

Seagrasses and microplastics: Under pressure

Seagrass meadows are found around the world and are key to marine health. They provide shelter and food for a wide range of biota, while their presence slows the speed of water. While this helps to protect coastlines, it also means that particles—including microplastics—can more easily settle on and in seagrass sediment.

A recent study assessed the accumulation of microplastics over the past century in three seagrass locations off Spain. Two are on the Mediterranean coast near Almería, which in recent decades has seen a horticultural boom with extensive use of plastic greenhouses and canopies—so much so that the Western Almería region, with 30,000 hectares of greenhouses, is known as "the plastic sea". The third location is on a nearby island that is part of a national park, where there is no horticultural activity.[75]

The key finding was that the seagrass soils in the first two areas had seen a "dramatic increase in microplastic pollution since the mid-1970s", with a direct link between the levels of contamination and the rise of intensive agricultural methods. The most recently deposited layers of seagrass soil exhibited the highest levels of microplastic contamination.

"In the light of this finding, we conclude that the transformation of the Almería region into a highly productive agricultural complex over the last 45 years has come [at] a high environmental cost in terms of microplastic contamination," they wrote.

The risks to the environment and the food chain are significant. Microplastics are not only toxic; they can also adsorb other contaminants like heavy metals and organic pollutants. This can see contamination enter the food chain when organisms like crustaceans and bivalves filter the sediment for food—and then travel further up the food chain. In addition, the researchers found microplastics on seagrass leaves, which puts herbivorous organisms like fish and crustaceans at risk.

A further concern is that microplastics are thought to change the properties of soils on land, which—as seagrass and land-based plants are physiologically similar—raises fears that they could do the same to seagrass soils, harming the seagrasses.

Central to the problem is that the region lacks adequate waste management. As a result, one area of seagrass that was studied (Roquetas) is classed as degraded, another (Agua Amarga) as being in an intermediate state of degradation, while the third site—off Cabrera Island southwest of Mallorca—remains largely pristine.

That, however, could change. The researchers found evidence that, while current microplastic levels off Cabrera Island were far lower than at the other two sites, contamination was increasing, "showing that plastic pollution is spreading far from its sources, even into remote protected areas like the national park of Cabrera".

All of the services that the marine environment provides are affected by chemical pollution, though the extent of the damage being done remains unclear. Most interviewees ruled out the likelihood of a total system collapse of the ocean in the next few decades, which would be calamitous for life on Earth. That is in line with the findings from the 2021 Ocean Health Index (OHI) for Exclusive Economic Zones (EEZs), which assessed the state of marine waters of 220 coastal countries and territories as far as 200 nautical miles (370 kilometres) from land—the international border.[76]

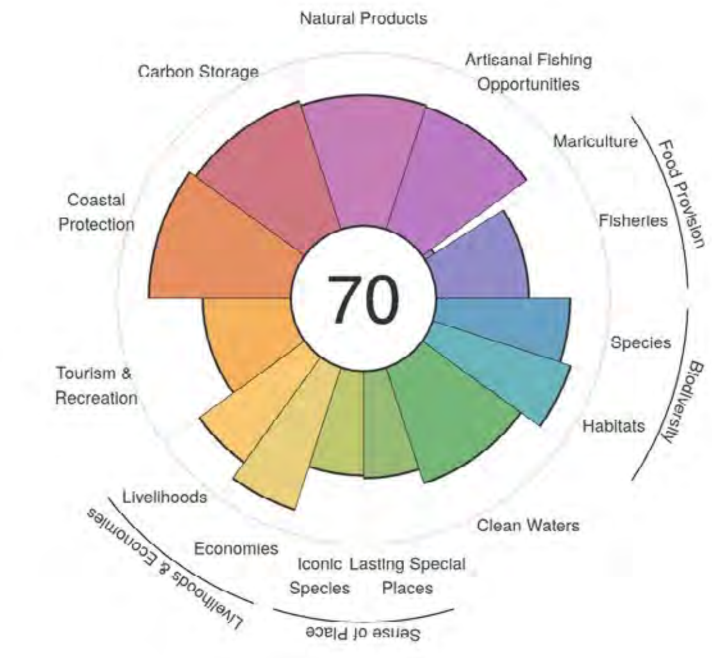
The survey, which covers 40 percent of the ocean, examines the health of the marine environment that provides the greatest benefit to humans, and which suffers the most from human activity.[77] (Notably, the 2021 OHI results do not assess the high seas or a range of benefits that the ocean provides, including climate regulation and the production of oxygen by plant plankton. The index also incorporates only a limited amount of data on marine chemical pollution.)[78]

With an overall score of 70, a slight downtrend over the past decade, the report highlighted a number of patterns in the 10 benefits and goals that it assesses the ocean as providing.[79]

“Scores for many regions are reasonably good, and global scores have overall increased since 2012 for some goals,” it stated. “However, we observed some worrisome patterns for fisheries, iconic species and species condition, all of which had the lowest reported scores since the start of the index in 2012.” [80]

Ocean Health Index, 2021

Some of the worst-performing areas in nations’ exclusive economic zones (EEZs) were fisheries, tourism and iconic species. Biodiversity rankings were among the highest—as were economies and coastal protection



Source: Ocean Health Index (2021)

On the whole, though, the OHI has a relatively optimistic view of ocean health. Not everyone shares that. Dr Mariann Lloyd-Smith, Senior Adviser to the International Pollutants Elimination Network (IPEN), a global network of non-profits, says the evidence of chemical pollution on mammalian sea life, like orcas, seals and polar bears, is damning. Those animals are "the canaries for human beings, because they're the top of the food chain in the ocean, and they're dying—they are not reproducing at the speed that they need to".

"The lack of reproductive ability, the viability of ocean species is, as I say, just a warning for us because it's coming for us as well," she says.

Dr Lloyd-Smith predicts many ocean species will become extinct in the coming decades and says this will have profound effects on coastal communities that rely on fisheries.

"If we do nothing, we will not have a viable ocean within the next 20 years. I very much doubt we even have that long," Dr Lloyd-Smith says. "By 2050 at least, I can imagine there will be certain ecosystems within the ocean that will have started to collapse."

"We already have many coastal communities who can no longer depend on fish for their only form of protein. And, tragically, then they don't have protein," she says. "Many coastal communities in Africa and many island communities will either cease to exist or will be so sick that they won't be able to exist, because they just cannot get what they need from the ocean."

The solution is to act fast, because "if we do nothing, we will not have a viable ocean within the next 20 years".

"I very much doubt we even have that long," Dr Lloyd-Smith says. "By 2050 at least, I can imagine there will be certain ecosystems within the ocean that will have started to collapse."

Central to the problem is that the microplastics, nano-plastics, PFAS chemicals, methylmercury, PCBs or many other pollutants that are in the ocean cannot be removed.

"All you can do is to ensure that nothing more goes in. And to do that, you have to put a stop to this idea that we can just keep creating chemicals and letting them go. We must have full lifecycle analysis for all chemical regulation and use," Dr Lloyd-Smith says. "Unless you can tell me exactly where your chemical is going to end up, don't even bother thinking about creating it—instead, start at the end and work out what you will do with those chemicals once their use-phase is over."

Dr Lloyd-Smith is not alone in her concerns. In 2021, the GOES Foundation, a UK-based environmental company, released a paper that pulls together a range of research, and predicts that, unless action is taken, there will be a catastrophic collapse in the marine environment.[81] Ocean acidification will be a key driver, it states, combined with the ongoing release of vast quantities of chemicals and plastics—with the last two in large part responsible for the sharp decline in marine species in recent decades.[82]

The impact that human activity has had on marine species is clear: a 2015 WWF study of nearly 6,000 populations of 1,234 species (including fish, sharks, marine mammals, seabirds and turtles) showed their numbers had nearly halved between 1970 and 2012, with overfishing, damage to their habitats and climate change the key drivers affecting marine biodiversity.[83]

The GOES Foundation predicts that increasing acidification from the pH 8.04 level of 2020 will "result in the loss of more marine plants and animals, especially those that have carbonate shells and body structures [that are] (aragonite)-based". Should the rise in ocean acidification continue, the GOES Foundation concludes, research indicates that ocean pH will have declined to 7.95 by 2045.[84]

"These reports … estimate that with this, 80 percent to 90 percent of all remaining marine life will be lost," it states. "The GOES team's opinion is that this is a tipping point: a planetary boundary which must not be exceeded if humanity is to survive. No ecosystem can survive a 90 percent loss; the result is a trophic cascade collapse. We will lose all the corals, whales, seals, birds, fish and food supply for 2 billion people—an outcome worse than climate change."[85]

While some might regard the GOES Foundation's position as alarmist, even the European Commission fears that inflicting further environmental harm risks going too far.

"The degradation of marine and freshwaters is threatening the EU's natural capital, the essential goods and services that the water system provides, and risks to perturb the self-regulatory characteristics of the water system beyond tipping points of no return," the European Commission wrote in 2021.[86]

It noted that much of the continent's commercial fisheries stocks were "not in good status", with chemical pollution in part to blame, while numerous aquatic species and habitats were "vulnerable or endangered, or their status [is] unknown". The ability of the ocean to act as a carbon sink is declining as its health worsens, with 20-50 percent of the world's coastal ecosystems "converted or degraded", and with those degraded ecosystems releasing as much one billion metric tons of stored CO_2 each year.[87]

Among the consequences of a changing climate and harm to the ocean—both of which link directly to marine chemical pollution—the EC expects more extreme storms and floods, with those "likely to occur more frequently by orders of magnitude" and visiting harm on people in Europe and around the world.[88]

The ocean, after all, constitutes a vastly complex combination of interlocking causes and effects, many of which we do not yet fully understand. Improving our understanding of how chemicals react in this environment is crucial, and is the goal of a global scientific research project (see box). As we learn more about these aspects, we will understand more about the potential costs to the ecosystem.

Framing the questions that count: SETAC's Global Horizon Scanning Project

In 2013, the Society of Environmental Toxicology and Chemistry (SETAC), an international body that aims to help scientists in different fields communicate better, established the Global Horizon Scanning Project (GHSP).[89]

Its purpose is to determine where research is needed to better understand environmental stressors in different parts of the world. Central to this are lists of priority research questions that scientists devised, and that are tailored for specific circumstances found in Asia-Pacific, North America, Latin America, Europe and Africa.[90]

The logic is straightforward: the sheer complexity that chemicals present in real-world settings means existing efforts to understand them are simplistic. As the paper on key questions for North America notes, determining how multiple species will interact with anthropogenic chemicals in the environment is far from easy.[91]

"For example, there are nearly 3,000 species of vertebrate animals and over 18,000 plant species in North America alone … and it is clearly impossible to determine how each will react to the 67,000 chemicals currently listed in the Toxic Substances Control Act (TSCA) chemical substance inventory," it states.[92]

Ensuring that the world manages chemicals properly requires a wholesale shift in the way that science assesses how they behave in the environment, and that must start by identifying the questions that matter.[93] To that end, each regional paper lists between 20 and 40 priority questions—for example:

- How can we develop quantitative analytical methods for next-generation emerging contaminants (e.g., nanomaterials, microplastics, fracking fluids, organometallics, ionisables, engineered biomolecules—synthetic biology/biologically inspired design)?[94]
- How can we better use field data and incorporate new big data (e.g., ecological genome) approaches for improving ecological risk assessments and decision-making?[95]
- How can interactions among different stress factors operating at different levels of biological organisation be accounted for in environmental risk assessment?[96]
- What are the most appropriate toxicological approaches to use when developing guidelines to regulate chemicals of emerging concern?[97]
- Are current environmental regulations (e.g., for effluents, pesticide use) sufficient, and how can they be implemented and enforced in Latin America?[98]

As can be seen, the range of questions is wide. They examine, among other aspects: the issue of multiple stressors; sustainability and green chemistry; regulation; using technology to better predict the behaviour of chemicals in the real world; and the environmental fate and risks of chemical contaminants.

The aim is to map a "path forward for the research, regulatory and business communities to better assess and manage chemicals in the natural environment", and in that way help the world to meet the UN's Sustainable Development Goals.[99]

And although different regions developed similar questions, those regions can differ significantly in terms of the resources, infrastructure and policies that are available to manage chemicals and related waste. For that reason, solutions will need to factor in country and regional variances.

4.6 Unknown impacts

This chapter opened with the three key services that the ocean provides: economic, like fisheries and tourism; tangible ecosystem services, like producing oxygen; and intangible ecosystem services, like the ocean's cultural, religious and aesthetic value.[100]

Decades of research mean we know far more today about some of the costs of marine chemical pollution, particularly when it comes to its impact on economic services like fisheries. However, even in those areas we know too little, with much of the knowledge based on local or regional events. When it comes to the effects that marine chemical pollution has on tangible and intangible ecosystem services, we know far less. What price, for instance, does one put on the destruction of cultures (see box)?

The cultural cost of marine chemical pollution

One area of marine chemical pollution that gets too little attention is the cost it can inflict on local cultures. Take the example of the Faroe Islands, whose inhabitants relied for centuries on what could be harvested from the sea—with pilot whales a key food source.

As apex predators, pilot whales are highly susceptible to certain chemical pollutants, including mercury, PCBs and PFAS. So, when studies showed mercury contamination levels in pilot whale meat of 2 micrograms per gram—100 times that found in cod, another staple—scientists advised the local population to steer clear of eating the mammals.[101]

From a health perspective, that made sense. The harmful effects of eating pilot whale meat saw the chief medical officer of the Faroe Islands subsequently advise that all islanders consume pilot whale meat and blubber no more than twice a month, and that women looking to become pregnant within three months avoid it altogether.[102]

From a cultural perspective, the issue is much more complex, says Professor Elsie Sunderland of Harvard University. Hunting pilot whales is a communal activity that sees islanders share the catch, and many Faroese are willing to accept the risks involved.

"They've been told very directly: Don't consume this food," she says, "yet a large fraction of the population continues to do it, because that is their culture."

Discussion of marine chemical pollution, says Professor Sunderland, typically misses this angle.

"When we talk about the costs of ocean pollution, those costs extend far beyond reductionist Western health costs that we like to talk about," she says, adding that it is also important to consider "the cultural tipping point" of such advice.

"You can see this in indigenous communities whereby something is so polluted that they can no longer observe their traditional lifestyle," says Professor Sunderland. "And in terms of those indigenous communities, you can see a direct link between their ability to conduct their traditional hunting and fishing activities, and rates of alcoholism, obesity, suicide rates—these are well-documented phenomena."

Health policies that are put in place to help protect people from chemical pollution can have cascading impacts.

"And if we reach that tipping point, you're going to lose the way of life for a lot of these people," she says, adding that those costs could outweigh even the human health and economic costs. "But how do we value that? And how can we act before we reach that level?"

The solution, of course, is to tackle marine chemical pollution proactively—and the next chapter will examine that in more detail. Yet doing so is complicated, and not only because we do not yet know how to value much of what is at risk. It is also because:

- Even where we know harm is being inflicted, there is often a lack of certainty about the scientifically provable scale of certain problems. (Yet as the precautionary principle makes clear, that must not preclude acting to prevent further harm.)

- Necessary actions have often been avoided. Additionally, even when actions are taken, this often takes years or decades. The Minamata Convention on Mercury is an example: nations agreed in 2009 to begin negotiations, decades after the damage mercury had done to the residents of Minamata was obvious to the world. That culminated in the convention being open for signature in 2013; it entered into force in 2017[103]—an eight-year long process that is considered speedy by international standards. (That said, just 135 nations have ratified it to date, with Australia, Russia and Spain among the dozens that have not.)[104]

- Past performance shows that governments tend to act only when the scientific evidence is impossible to counter, and not least because of the heightened public pressure this exerts on them. The Montreal Protocol, which phased out nearly 100 synthetic chemicals that deplete the ozone layer, is one example.[105]

- And then there is the range of unknowns, including how various chemicals react in the real-world marine environment, where temperatures and oxygen levels vary (which SETAC's Global Horizon Scanning Project is aiming to improve)—to say nothing of the impact that might be done by the vast range of tens of thousands of chemicals about which we know nothing. When it comes to unknown impacts, this could well be the most significant.

Even though we lack anything like complete knowledge of marine chemical pollution and its effects, its sheer scale and the incredibly complex links involved require actions and interventions by governments, industry, finance and civil society if it is to be reduced to acceptable levels.

As the next chapter will show, success will require a range of responses from these key stakeholders, and better policies lie at the heart of any approach. As the European Environment Agency (EEA) concluded in a 2013 report, better policies help to balance the opposing interests of society and business, with regulations able to compel businesses to operate more responsibly and ensure they internalise the many costs that they currently impose on society.[106]

What is clear is that continual hesitation in the face of insufficient knowledge of the costs of marine chemical pollution is not only unnecessary—it is dangerous. The precautionary principle alone dictates that we must act now.

Please see Notes for references

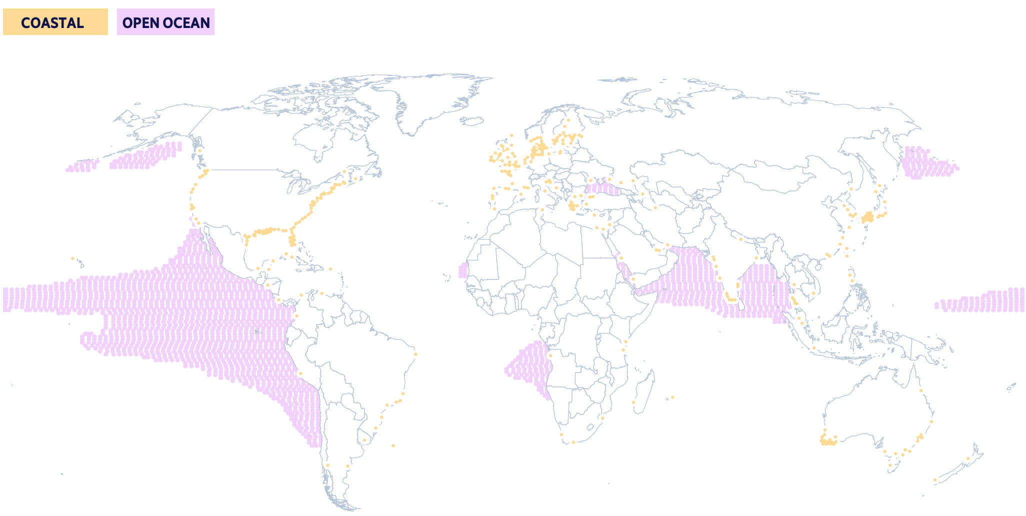
Case study: Quantifying the economic impact of dead zones

Context and rationale for selecting our case study

Aquatic and marine "dead zones" can be caused by an increase in chemical nutrients in the water, particularly nitrogen and phosphorus. Cyanobacteria—or blue-green algae—feed on these nutrients when at normal levels. With an excessive increase in nutrients cyanobacteria grow out of control, and when they decompose consume dissolved oxygen from surrounding waters. This creates pockets of low oxygen (hypoxic zones) that threaten marine biodiversity. Chemical fertilisers have been identified as one of the main human-related causes of these "dead zones" around the world.[1]

Low-oxygen dead zones

Areas identified where water has too little oxygen to support life



Given the link between chemicals in the ocean, dead zones, and the threat to marine life, there are clear economic costs that can be attributed to the flow of chemicals into the ocean. Our case study quantifies these economic costs for one specific dead zone, in the Gulf of Mexico, and maps the impacts of this phenomenon on the fisheries industry at both the regional level (i.e., in the Gulf of Mexico) and the national level (for the US economy).

We do this by estimating the changes to regional and national revenue for the fisheries industry in the US that result from a potential loss in fish catch, measured through landing weight, to which the Gulf of Mexico dead zone contributes.[2]

We assume a number of scenarios or thresholds—percentage changes to landing weight based on impacts noted in existing research—and model the corresponding changes to fisheries revenue at the regional and national level. Alongside a decrease in landing weight, one scenario also estimates the impact of a potential increase in landing weight, resulting from efforts to reduce the size or incidence of the dead zone and thereby promote greater marine diversity.

In this way, our study highlights the importance of taking action in two ways: first, by drawing attention to scenarios where the dead zone gets worse, highlighting potential revenue and job losses, and second by depicting scenarios where the situation gets better, highlighting potential revenue gains.

Why the Gulf of Mexico and why fisheries?

We have selected the Gulf of Mexico dead zone as a focus area based on the reliability and availability of updated time-series data. The Gulf of Mexico dead zone is one of the largest in the world and the most widely covered.

The coastal wetlands of the Gulf of Mexico encompass over five million acres (about half of the US total) and serve as an essential habitat for numerous fish and wildlife species, including migrating waterfowl (about 75 percent traversing the US), seabirds, wading birds, furbearers, and sport and commercial fisheries.[3] Algal blooms that fuel dead zones are detrimental to tourism and recreation as they make the water unsafe for swimming, release unpleasant odours, and cause fish kills that can wash hundreds of dead fish onto beaches.[4] Additionally, there are human health costs associated with the dead zone. Elevated nutrient levels and algal blooms cause problems for drinking water in nearby communities. The harmful algal blooms release toxins that contaminate drinking water, causing illnesses for animals and humans.[5]

Although the deleterious effects of marine chemical pollution in general go beyond dollars and jobs, their economic impact is considerable and, importantly, quantifiable. The case study focuses on commercial fisheries and data on landing weight and revenue as these are the best available signals to understand the extent of the problem as it exists. A shortage of information and data to develop robust estimates precludes quantification of the impacts on other areas, such as biodiversity and human health.

The US seafood industry is a powerful economic driver, with 23 coastal states where the fishery industry is an important contributor to local jobs and GDP. Nationally, the sector supported 1.2 million jobs and added US$69.2bn to gross domestic product in 2017.[6] Within the US, the Gulf of Mexico is a major source area for the seafood industry. In 2017, the Gulf of Mexico accounted for 22.4 percent of total jobs in the US seafood industry and 20.1 percent of the national fishery industry's contribution to total GDP.[7]

It has been noted that if the hypoxic zone continues or worsens, fishermen and coastal state economies will be greatly affected.[8] This builds an interesting and relevant case to map the potential impacts on the industry at both the regional level and at the national level.

Table 1: US seafood industry economic contributions

	2012	2013	2014	2015	2016	2017
Jobs	1,270,141	1,350,627	1,394,833	1,179,848	1,190,092	1,246,366
Value added (US$m)	59,017	60,309	64,071	60,566	60,768	69,177

Table 2: Regional contribution, 2017, %

	Jobs	Sales	Income	Value added
Gulf of Mexico	22.40	20.87	19.35	20.14
South Atlantic	21.24	26.06	27.25	26.40
North Pacific	15.57	19.33	21.79	20.46
West Pacific	2.19	2.05	2.10	2.15
New England	29.34	22.01	20.55	21.49
Mid-Atlantic	9.26	9.68	8.95	9.36

Source: National Oceanic and Atmospheric Administration (NOAA)[9]

Why a reduction in fish catch?

It is challenging to isolate the impact of hypoxia from other human and natural variables that could affect fish populations. Based on findings from our literature review, we have adopted the approach taken by numerous research studies that link the increased incidence of dead zones with a reduction in fish catch.

According to the literature, fisheries yield is one ecosystem service that can be hit both directly and indirectly by hypoxia. Mortality of fisheries species is a direct mechanism by which services are lost. Loss of forage for bottom-feeding fish and shellfish due to hypoxia is probably more important in most cases and also amounts to a loss of ecosystem services.[10]

Numerous studies have found a largely negative association between Gulf hypoxia and indicators of the health of fish, crustaceans and other marine species, including their abundance and spatial distribution. Moderate to severe seasonally recurring hypoxia in the Gulf has reduced the abundance of species such as crustaceans, molluscs, sponges and other species that occupy the sea floor. Other research studies have found that Atlantic croaker populations could decline by up to 25 percent in the future if hypoxia in the Gulf is not reduced significantly.

Studies have also shown definitive declines in fish catch due to hypoxia specifically in the Gulf of Mexico. For instance, an assessment by the National Oceanic and Atmospheric Administration (NOAA) found that brown shrimp catches declined significantly from 1992 to 1997, coinciding with a substantial decrease in dissolved oxygen concentrations in Gulf waters.[11] Moreover, a research study has suggested that summer flounder catch rates have been reduced by as much as 20 percent due to hypoxia, while striped bass fisher and blue crabber revenues have been collectively reduced by hundreds of thousands of dollars in a single year due to this problem.[12] Another study found that hypoxia may have resulted in a 12.9 percent annual decrease in the brown shrimp harvest during the period 1999–2005.[13]

As a measure of fish catch, we have selected landing weight as the key variable to examine. Studies have shown that hypoxia has direct effects on fisheries stocks related to reduced growth, movement to avoid low oxygen, aggregation and predation pressure, resulting in lower landings and increased time fishing as potential economic effects.[14]

It is also important to highlight that the dead zone affects the fisheries sector, and fish population, in many secondary ways. For example, a NOAA-funded study led by Duke University found that the Gulf of Mexico dead zone drives up the price of large shrimp relative to small shrimp. Due to the dead zone, fishermen catch more small shrimp and fewer large ones, making small shrimp cheaper and larger ones more expensive. The total quantity of shrimp caught could remain the same during hypoxic periods, but a reduction in the highly valued large shrimp would lead to a net economic loss.[15]

How did we select the scenarios/thresholds?

We scanned the available literature to understand whether there is evidence of the magnitude of reduction in fish catch caused by an increase in the size or incidence of a dead zone. While there are no estimates for fish catch overall (inclusive of all species), the studies mentioned above suggested thresholds for certain species of fish. We also studied the existing variations in the landing weight of fish caught based on data from 1985-2020. We selected 15 percent and 20 percent as two thresholds for the reduction in landing weight, assuming business as usual and given the observed trends over the past two decades.

As an upside and downside scenario respectively, we considered a 15 percent increase and a 40 percent decrease in landing weight. We selected a 40 percent decrease in landing weight as a potential scenario assuming the current situation gets worse i.e., the size of the dead zone continues to increase, and fish catch is reduced even further. Conversely, we use a 15 percent increase in landing weight scenario to illustrate the impact of an improvement in the situation; potentially through greater efforts targeted towards reducing chemical pollution and hence the size of the dead zone. Yet since climate change and rising temperatures may also exacerbate the size of the dead zone, the analysis includes more downside scenarios than upside.

The following table presents the resulting fisheries revenue estimates for the four thresholds at the regional and national level. The column on the right depicts the overall estimated percentage changes from the base figure, a 10-year average. We used a 10-year average as the base given the volatility of data over the past 10 years (some years recorded a drastic increase while others recorded a decrease in landing weight, with no clear trend).

Table 3: Modelling results: Impact of change in fish catch in the Gulf of Mexico on the national fisheries revenue

Scenario description (changes to landing weight)	**Gulf of Mexico revenue, nominal** (US$m)	**National revenue, nominal** (US$m)	**Net change (US$m) nominal** (national)	**% change from baseline, nominal** (national)
Baseline: 10-year average (2011-2020)	864.66	5,387.18		
Scenario 1: Upside 15%	909.36	5,504.46	117.28	2.18%
Scenario 2: Downside -15%	832.25	5,037.71	-349.47	-6.49%
Scenario 3: Downside -20%	817.59	4,948.98	-438.21	-8.13%
Scenario 4: Downside -40%	751.47	4,548.75	-838.43	-15.56%

Source: Economist Impact calculations

The economic implications

Under a business-as-usual scenario, a 15 percent decline in the fish catch in the Gulf of Mexico leads to a 6.49 percent decline in national revenue. Although no one-for-one comparison on employment is possible owing to other potential factors, at the very least a continuation of this trend puts at risk a considerable proportion of the 76,880 local jobs and 1.2 million national jobs in the fishing industry.

The analysis also shows that in the worst-case scenario, should dead zones worsen and contribute to greatly reduced landing weight (-40 percent), the US stands to lose nearly US$838m in fisheries revenue.

Conversely, if measures are taken to reduce dead zones, contributing to increased marine biodiversity and fisheries landing weight, the best-case scenario (15 percent increase in landing weight) could see an increase in revenue nationally of over US$117m.

Efforts are in place to monitor and manage the Gulf of Mexico dead zone (for instance, the interagency Mississippi River/Gulf of Mexico Hypoxia Task Force was established in 1997), but it remains an issue.[16] Experts interviewed for this study said much remains to be done: financial responsibility to address the problem is not adequately attributed, and the annual predictions of the dead zone size are not coherent. For instance, earlier in 2021 scientists had predicted that the Gulf of Mexico dead zone would be significantly smaller than average, but in fact it was reportedly larger than the average hypoxic zone.[17]

It has been noted that if the hypoxic zone continues or worsens, fishermen and coastal state economies will be greatly affected.[18] Indeed, it is important to note that smaller countries in lower-income bands that are heavily reliant on fisheries with fewer resources available would see livelihoods (employment and health in particular) threatened even further if the issue remains unaddressed and a structured approach to tackling dead zones is not taken. The Gulf of Mexico dead zone is only a small subset of what is, in reality, a much larger global concern.

Please see Notes for references, methodology, regression analysis and other statistics

Part 2: Mitigation, resolution and prevention

Part 2 has four chapters, each of which outlines a stakeholder's role in mitigating, resolving and preventing marine chemical pollution. In so doing, it lists barriers to progress and concludes with a wish list of actions that each should take.

Chapter 5: Regulations

This chapter looks at the role of regulators and policymakers. It outlines the legal landscape and explains why existing regulatory processes are inadequate—in part due to excessive caution in acting, but also because it is far easier (and quicker) for industry to place chemicals on the market than it is for regulators to remove them. The chapter highlights one key area for action, which is better global treatment of domestic and industrial wastewater and effluent, most of which goes into the rivers and seas untreated or under-treated.

Chapter 6: Industry

This section puts the role of the chemicals industry, as well as the companies further along the value chain, in the spotlight. The chapter notes that the sector faces an existential crisis should it fail to address upcoming climate-related and financial pressures, while pointing out that it has seen far too little change—despite the valuable opportunities that exist for first-movers in sustainable and green chemistry. Unless the sector changes its culture, it risks having change foisted upon it. This could come either directly from regulators, but also indirectly via consumers, who are growing increasingly aware of the dangers of chemical pollution, and who are pressuring the consumer-facing companies that are the sector's clients to take action.

Chapter 7: Finance

The role of finance in marine chemical pollution is the subject of this chapter, which notes that—despite limited investor awareness of the drivers of and solutions to marine chemical pollution—new regulatory taxonomies will compel improved understanding of the issue and the need to act. This, in turn, will shape the extent to which ESG-focused investors and the broader finance sector are prepared to fund those responsible for marine chemical pollution. One crucial factor will be how to clarify the transition risks and potential rewards for investors; another will be how best to fund the transition, with private equity and M&A among the mechanisms that have the potential to drive innovation in the chemicals sector.

Chapter 8: Consumers and civil society

The final chapter looks at the roles that civil society and consumers can have in curbing marine chemical pollution. It notes that, although public awareness of this largely invisible issue is low, this can be turned around with compelling, science-based storytelling. It also points out that while civil society has a long history of focusing and co-ordinating popular action, it must ensure its campaigns provide consumers with measurable, achievable actions, particularly when it comes to making informed purchasing choices.

5: Regulations

This chapter looks at regulatory and policy solutions to prevent marine chemical pollution, as well as ways to mitigate and resolve it. To that end, it outlines key aspects of international, supranational and national regulation, explains the current state of play—including explaining why the EU is the global leader—lists key barriers to progress, and details a number of crucial interventions needed on the regulatory and policy sides.

5.1 Principal findings and recommendations

- **The current legal and regulatory landscape is complex and ultimately ineffective.** There is a vast array of treaties, laws and regulations designed to mitigate the effects of types of marine chemical pollution, including at a supranational, regional, national and sub-national level. Europe's REACH legislation, for instance, is among the most proactive, and puts the burden of proof on companies to show their products are not harmful. This approach, however, is unusual. The existing landscape has significant shortcomings: there is no comprehensive international law to tackle marine chemical pollution; laws are far weaker for the open seas than they are for areas that fall within countries' exclusive economic zones; and what does exist is fragmentary and runs up against laws covering trade and intellectual property, for example, whose goals are often at odds with protecting the marine environment.
- **Excessive caution, misframing and time lags are key risks in tackling marine chemical pollution via regulation. Yet getting it right remains crucial.** Regulatory actions to combat marine chemical pollution could be undermined by the lobbying of different stakeholders or by poor framing of what is needed—as happened with initial attempts to combat climate change. Another risk is that governments are excessively cautious or reactive, acting only when faced with incontrovertible scientific evidence of harm. A third risk is that, even when actions are agreed, they take overly long to implement. However, analysis shows that robust policies do help to manage the conflict between the goals of business and society, and that it is effective to apply the precautionary principle, which guides decision-makers to reduce delays between early warnings and acting. And regulatory clarity and accountability does help to encourage businesses to be more sustainable.

- **Progress in regulation requires overcoming awareness, capacity and timescale problems—and vested interests.**
  The barriers to progress on regulation include failure to acknowledge that the capacity of the ocean to dilute chemical pollution is limited; a lack of data to inform policymaking; a lack of awareness among policymakers and the public of the dangers of chemicals and of the risks of failing to act; insufficient knowledge of the effects of the chemicals that are in use; and the length of time often needed to act on harmful chemicals. The actions of chemicals industry players in deliberately shifting operations to other countries in order to take advantage of inferior regulatory oversight, as well as the fact that regulators are in a constant state of catch-up with the chemicals industry (and that industry, politics and finance operate on a short-term horizon) are also problematic.

- **Best practices in regulation stipulate monitoring and assessment, as well as steps specific to the marine environment.**
  Some agreements and regulations offer useful best practice lessons. The OSPAR Convention, for instance, has a mandate to identify priority chemicals in the marine environment of the North-East Atlantic, measure their levels, and then feed that evidence-based research into recommendations for policies and regulations, while the EU's Marine Strategy Framework Directive contains specific descriptors that look at chemicals and food chains, including food for human consumption, as well as at chemicals and their impact on fish and shellfish. In some instances, "good practices" might be sufficient, given that it takes time to define best practices.

- **Better regulations to improve the treatment of wastewater and solid waste, and better enforcement of them, is a priority to protect coastal ecosystems.**
  Global progress on wastewater treatment has been slow, with nearly half of household effluent (and much industrial effluent) still not safely treated. Even where wastewater is treated, numerous chemicals remain, and much wastewater ends up polluting the seas. Lowering the levels of toxic chemicals in wastewater is an important step in combating marine chemical pollution. Also important is improved treatment of municipal waste, much of which contains chemicals. Given that Asia and Africa are set to be the largest generators of municipal waste in the coming years and decades, and given that many of those nations are poor, rich nations will need to step up their technical and financial assistance. Regulatory failure is a problem in even the richest countries. Linked to this, stringent regulatory oversight—including levying penalties of sufficient scale—is crucial.

- **A regulatory wish list: Ten interventions to combat marine chemical pollution.**

  1. **Raise awareness** of the causes of and remedies for marine chemical pollution, including by improving communication between science and policymakers.

  2. **Improve the regulation** of harmful chemicals **and the enforcement** of restrictive measures internationally; in addition, agree a global treaty to tackle marine chemical pollution.

  3. **Follow a risk-based approach and use the precautionary principle,** which states that where there are threats of "serious or irreversible damage" to the environment, "a lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation".

4. **Establish a global science-policy body** whose remit covers all chemicals and waste, yet that does not duplicate the work being done by bodies like those under, for instance, the Stockholm Convention.

5. **Create a comprehensive register** of chemicals at the national and global levels using best practice (or even "good practice") methods.

6. **Mandate disclosure** of all chemicals in products and their potential effects.

7. **Adopt best practice laws and principles** and ensure better enforcement, with nations acting in concert to overcome key imbalances. Countries should also use funding and policy measures to increase the take-up of green chemistry, and must ensure the terms "green chemistry" and "sustainable chemistry" are properly defined in law to avoid industry greenwashing.

8. **Provide more funding to measure the impact** of chemicals, with developing countries particularly in need, and many of which suffer disproportionately from marine chemical pollution.

9. **Make the polluter pay** by using a range of fiscal measures like taxation, removing subsidies for high-risk substances, or using subsidies to encourage good behaviour by industry.

10. **Promote efforts to restore ocean health,** including measures at the national level to cut the flow of chemical pollution into the seas, fiscal measures to encourage improved behaviour, and regenerating areas that have been degraded, like seagrass beds, mangroves and coral reefs.

5.2 Current regulations: A patchwork net

When it comes to regulatory actions taken to tackle marine chemical pollution, the EU leads. Whether through its REACH regulation, which imposes obligations for manufacturers, importers and downstream users of chemicals, its Water Framework Directive (WFD), which deals with the input of chemicals and nutrients into the aquatic environment, or its Marine Strategy Framework Directive (MSFD), which seeks to protect the marine environment and use it sustainably, the bloc has for years been well ahead of the world.[1]

Take REACH, for example. Its goal is to protect the EU's people and environment from the harmful effects of chemicals, and it applies (in principle, at least) to all chemicals used in the bloc—whether in industrial processes, domestic cleaning products, clothing or furniture, to name a few. REACH puts the burden of proof on the companies that fall within its scope, and those firms must "identify and manage the risks linked to the substances they manufacture and market in the EU".[2]

To that end, companies need to show the ECHA, the EU's chemicals regulatory agency, how their chemicals can be used safely. They must also ensure that users are aware of measures to manage risks associated with those chemicals. Those chemicals whose risks cannot be managed are subjected to restrictions, while those regarded as the most hazardous are meant to be replaced over time with less harmful substances.[3]

Europe's Green Deal and Chemicals Strategy

A key element of Europe's approach to better chemicals management is its Chemicals Strategy. It was published in 2020 and is part of the bloc's Zero Pollution goal under its 2019 Green Deal, the goal of which is to ensure that Europe is the world's first climate-neutral continent.[4]

The Chemicals Strategy, which was under review at the time of writing, has two key objectives:[5]

- First, to improve the protection of citizens and the environment by: banning the most harmful chemicals from consumer products (unless their use is deemed essential); accounting for the risks associated with multiple chemicals (the "cocktail effect"); and phasing out PFAS chemicals (unless their use is deemed essential).
- Second, to improve innovation for safe and sustainable chemicals, including by implementing a simpler process for risk and hazard assessment, and by promoting high standards for chemicals worldwide.

For its part, the Green Deal encompasses the EU's newly integrated approach to tackling pollution—the first time that it has dealt collectively with the various realms of pollution (for soil, marine and health, for instance) rather than in silos. Attaining the goal of Zero Pollution does not mean having no pollution whatsoever, though; instead, the aim is to ensure that whatever pollution is emitted does not have a harmful impact on human health or the environment.

Another area that overlaps with the marine environment is the EU's Farm to Fork Strategy, which is at the heart of the Green Deal, and which seeks to take regulatory and non-regulatory steps "to make food systems fair, healthy and environmentally friendly"—including ensuring that seafood is not contaminated, and reversing the loss of biodiversity.[6]

Another piece of EU law is its POPs Regulation,[7] which implements the bloc's obligations under the UN's Stockholm Convention on Persistent Organic Pollutants, which is itself the key global agreement on eliminating or limiting several dozen of the most harmful synthetic chemicals, many of which have found their way into the marine environment.

There are numerous international agreements related to marine chemical pollution, with two others that fall within the UN's remit being the Basel Convention, which aims to cut the cross-border movement of most hazardous waste, and the Rotterdam Convention, the prior informed consent procedure of which is designed to ensure that the listed chemicals—many of them pesticides—are not exported to countries that object to their import. The Minamata Convention on Mercury is another landmark treaty, while the box below lists some of the other international and regional instruments that are directly or indirectly designed to address marine pollution.

Key international instruments to address marine pollution

Global instruments and strategies

Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972)

Also known as the London Convention, it addresses deliberate at-sea disposal of land-based waste, with each member regulating discharges of waste on its own ships. Eighty-seven states are currently party to the convention.[8]

International Convention for the Prevention of Pollution from Ships (MARPOL) (1973)

Addresses pollution and dumping from ships due to operational losses or accidents. Various annexes deal with specific aspects including oil (Annex I), noxious liquid substances (Annex II), sewage from ships (Annex IV) and air pollution (Annex VI). Annex V focuses on reducing the amount of garbage—including plastics—disposed of at sea by vessels.[9]

UN Convention on the Law of the Sea (UNCLOS) (1982)

It sets out rules for the use of the ocean and its resources, and includes measures to protect and preserve the marine environment. Among these are restrictions on pollution from vessels, land-based sources and dumping. It also restricts the transfer of pollutants between nations.[10]

International Convention on the Control of Harmful Anti-fouling Systems on Ships (2001)

The convention, which entered into force in 2008, requires parties to ensure that ships that fly under their flag, use their ports or shipyards, or that operate under their authority do not use organotin anti-fouling paints that stop sea life like barnacles and algae from attaching to hulls.[11]

Strategic Approach to International Chemicals Management (SAICM) (2006)

The SAICM is a global policy framework to promote chemical safety, with objectives covering five areas: risk reduction; knowledge and information; governance; capacity-building and technical cooperation; and illegal international traffic. Its initial goal, which was not achieved, was that by 2020 chemicals would be produced and used "in ways that minimise significant adverse effects on the environment and human health".[12]

Selected regional instruments

Convention for the Protection and Development of the Marine Environment in the Wider Caribbean Region (1983)

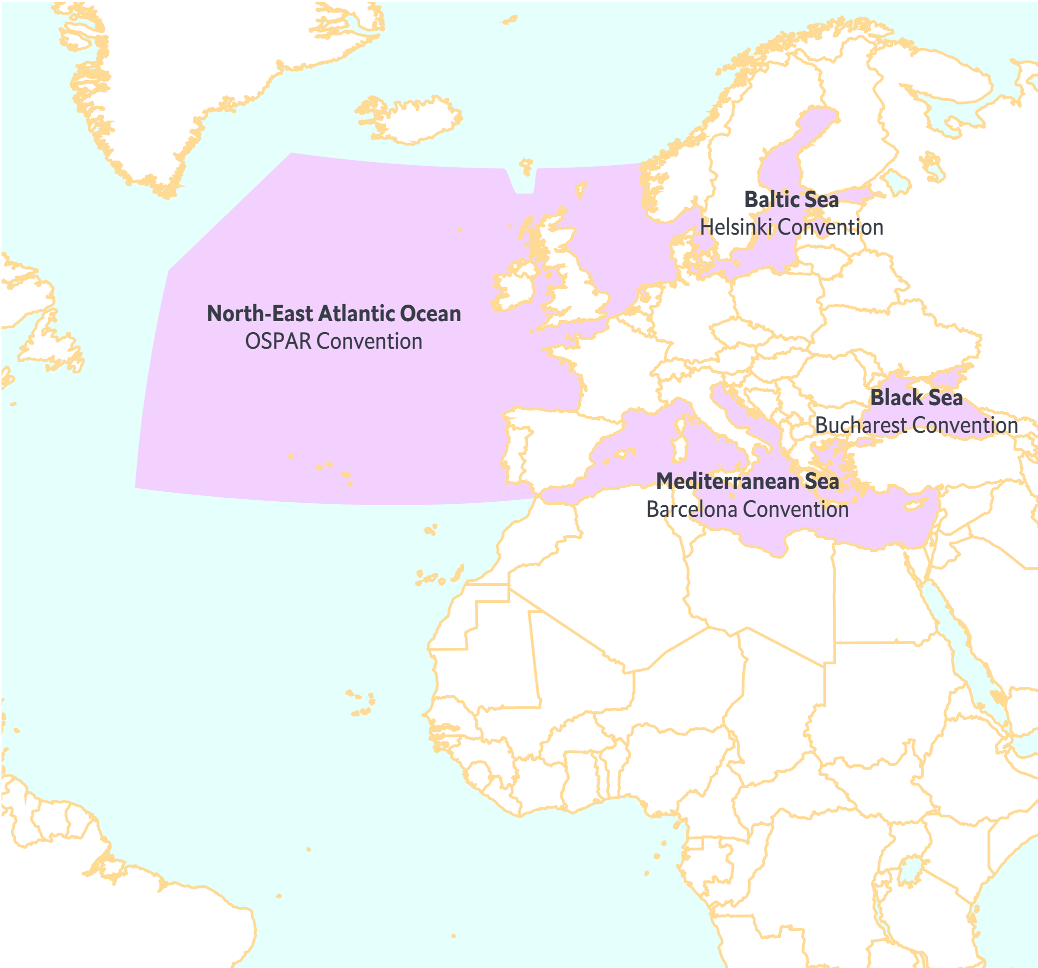
Also known as the Cartagena Convention, it addresses pollution from ships, dumping at sea and land-based sources of pollution in the Wider Caribbean Region. It has been ratified by 26 UN member states.[13]

EU Marine Strategy Framework Directive (2008)

It is designed to protect the bloc's marine environment and ecosystem from, among other aspects, chemicals. Among its provisions are tackling litter in European Union seas based on where it is found (for example, washed ashore, detected in the water column or ingested by marine animals) and by type (for example, microplastics).[14] Each member state must develop a management strategy for its marine waters, and must also monitor and report on chemicals and pollutants.

Another regulatory layer consists of the four Regional Seas Conventions (RSCs) that seek to conserve Europe's marine environment by engaging EU and non-EU countries to cooperate, and which cover the maritime areas on the map below.

Europe's four Regional Seas Conventions (RSCs)



Source: Regional Seas Conventions, WISE Marine (EU and EEA)

The four RSCs are:

- *The Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (1978)*: Also known as the **Barcelona Convention,** it addresses land and ocean-based waste from dumping, runoff and discharges (including plastics) in the Mediterranean Sea region. It has 22 contracting parties, one of which is the EU.[16]

- *The Convention on the Protection of the Marine Environment of the Baltic Sea Area (1980)*: Also known as the **Helsinki Convention,** it seeks to protect the Baltic Sea from all sources of pollution, whether from the land, sea or air, and commits its nine contracting parties and the EU to conserve the habitat and biodiversity of the marine environment, and to use its resources sustainably. Members must also establish legislation for the prevention and abatement of marine pollution.[17]

Impressive though the range of national and supranational legislation is, the system does not work as well as it needs to

- *The Convention for the Protection of the Marine Environment of the North-East Atlantic (1992)*: Also known as the **OSPAR Convention,** this seeks to prevent and eliminate pollution in the North-East Atlantic, including from ship discharges, lost and discarded fisheries materials from vessels, land-based waste from coastal or riverine disposal and recreational littering. It also requires its 16 contracting parties to monitor the marine environment and report regularly on their findings.[18]

- *The Convention on the Protection of the Black Sea Against Pollution (1992)*: Also known as the **Bucharest Convention,** it is the legal framework around which the six member countries work to protect the Black Sea and conserve its living resources.[19] It is the only one of the four RSCs of which the EU is not a member.[20]

In addition to this array of global and supranational instruments and legislation, many countries have adopted laws that target chemicals—which, given that chemicals are in almost everything we use, means the scope of legislation can range widely. Such laws might, for instance, regulate factory emissions, vehicle emissions and other forms of pollution, or they might ban or restrict single-use plastics and microbeads.

Other measures by which countries can influence the impact of chemicals include economic and fiscal measures like the taxation of plastic bags, control and demand approaches in which restrictions are imposed on the use of chemicals within their jurisdiction and in specific areas (for instance, in food packaging), or mandating packaging and labelling requirements for hazardous chemicals.[21] Whichever approach is chosen, the goal is typically to reduce and/or avoid the harm that chemicals inflict on human health and the environment.

Impressive though the range of national and supranational legislation is, the system does not work as well as it needs to. Later in this chapter, we will examine in more detail the barriers that hinder protection of the marine environment from chemical pollution and will outline interventions needed to drive improvements.

Why the EU leads the world on marine chemical pollution

The fact that the EU is—for the most part—ahead on marine chemical pollution is no accident, says Dr Aleke Stöfen-O'Brien, a lawyer and policy expert at the WMU-Sasakawa Global Ocean Institute at the IMO-World Maritime University in Sweden.

Crucial to this leading role is the EU's *sui generis* legal system that has seen member states hand over some of their sovereign competences to the supranational level. As a result, nations cannot simply do what they want in those areas.

Specifically, protection of the environment—and therefore of the marine environment—is a shared competence between the European Commission and EU member states, and relevant laws are passed by a qualified majority in the European Parliament. In other words, even those member states that vote against environmental laws will be bound by them should they pass.

In addition, says Dr Stöfen-O'Brien, the EU is guided by robust principles that can be used in countries' courts as well as at the European Court of Justice. These include the polluter pays principle, the principle of prevention, and the principle of source, which requires that countries address pollution at source instead of waiting until it enters the environment.

"And this is legally binding," she says. "Also, you can legally measure every single act by a private entity against these principles, and you can measure any legislation against these principles."

Furthermore, the European Commission's mandate to protect the environment has seen it implement ambitious goals to ensure high legislative standards—for example, in REACH and the Marine Strategy Framework Directive, but also in areas like ship emissions, plastics and chemical pollution.

"The European Commission has developed an extremely ambitious set of instruments, sometimes against the will of some member states," says Dr Stöfen-O'Brien. "And if those are adopted, then they can be used as a legal basis for action by countries and therefore also against polluters in those countries, and they need to comply."

Finally, further underpinning the regulatory regime, nations can be held responsible by the European Commission for failing to act against polluters within their jurisdiction. That creates an additional incentive for national regulators to implement and enforce EU law obligations.

Learning lessons

Examining the different approaches taken can help by showing what works and what does not. How to learn these lessons was the subject of a report by the European Environment Agency (EEA). Despite being published in 2013, many of its conclusions remain valid—among them, that sound policies can help to manage the often-conflicting goals of business and society.[22]

The EEA's report also noted how matters of profound importance can be manipulated (as seen in decades of lobbying by the tobacco industry, for instance) or poorly explained. Climate change is an example of the latter, and saw a false choice presented to the American public. Instead of being asked whether climate change was something worth worrying about, US Vice President Al Gore framed the question as "a matter of choice between believers and sceptics," the EEA stated. This saw the public required to assess a matter of profound importance when most lacked the necessary scientific qualifications to do so.[23]

The EEA drafted a series of steps, the first of which was to apply the precautionary principle and to reduce the delays seen between early warnings and taking action. It also noted that there was little reason to fear that acting pre-emptively was unwise

The obvious risk is that marine chemical pollution, which some interviewees feel could have as big an impact on Earth as climate change, and with which it is inextricably linked (see Chapter 3), suffers a similar fate. That would lead to delays, confusion and inaction—despite a litany of early warnings. And, as the EEA has made clear, ignoring early warnings often ends badly.[24] When it comes to the environment, the EEA notes, success requires an effective response, and that requires, among other actions, creating better-quality risk assessments, and rethinking the way that existing studies on the environmental and health impacts are funded, with too much focus on well-known hazards like mercury and lead, and not enough on emerging ones.[25]

"A more equal division of funding between known and emerging issues, and between products and their hazards, would enrich science and help avoid future harm to people and ecosystems and to the long-term economic success of those technologies," it states.

To avoid repeating past mistakes, the EEA drafted a series of steps, the first of which was to apply the precautionary principle and to reduce the delays seen between early warnings and taking action. It also noted that there was little reason to fear that acting pre-emptively was unwise—on the contrary, it was clearly effective, with just four out of 88 potential risks that it assessed turning out to be false alarms. In addition, experience had shown that acting in this way stimulated innovation rather than hindering it.[26]

"The frequency and scale of harm from the mainly 'false negative' case studies indicate that shifting public policy towards avoiding harm, even at the cost of some false alarms, would seem to be worthwhile, given the asymmetrical costs of being wrong in terms of acting or not acting based on credible early warnings," the report concluded.[27]

That goes to the heart of one of the core issues with respect to marine chemical pollution: being overly cautious, which can see insufficient action taken on potentially catastrophic developments. History shows that governments are inclined to act only when there is indisputable evidence of harm from a specific chemical or groups of chemicals, as shown by the Montreal Protocol, which targets ozone-harming chemicals, and the Minamata Convention, which tackles mercury.

This also holds true for organotin compounds like tributyltin (TBT) that were for years used as anti-fouling paints on ships and boats, stopping organisms like barnacles and algae from attaching to their hulls. Once it was clear that these compounds were extremely damaging to the marine environment—they also enter the food chain—their use was made subject to the provisions of the International Convention on the Control of Harmful Anti-fouling Systems on Ships, which largely banned or restricted them for that purpose. Under the convention, parties must ensure that ships using their flag, under their authority or entering their ports and dockyards do not use such paints on their hulls.[28]

The convention entered into force in 2008, and to date has been signed by 91 states parties representing nearly 96 percent of world tonnage.[29] While that is clearly beneficial to the marine environment, researchers have found that even tributyltin, with its known toxicity, remains available in many countries.[30]

Excessive caution is one problem. Another is that action can easily take years or even decades. Although the IMO recognised in 1989 the harm that organotin compounds inflict on the marine environment, the convention itself did not enter into force until 2008—nearly two decades on. Interim steps included:[31]

- In 1990, an IMO committee adopted a resolution recommending that governments take measures to bar the use of anti-fouling paint that contains tributyltin on vessels with non-aluminium hulls longer than 25 metres, or where the paints leach more than four micrograms of TBT each day.
- In 1992, the Rio Conference on Environment and Development asked states to act against organotin compounds in anti-fouling paints to reduce pollution.
- In 1999, the IMO's assembly called on one of its committees to draft a legal instrument to tackle such anti-fouling paints.
- In 2001, the document that would later be named the International Convention on the Control of Harmful Anti-fouling Systems on Ships was adopted.
- In 2008, the convention came into force.

Furthermore, the convention applies only to anti-fouling paint. Yet organotin compounds, including tributyltin, are still widely used in biocides, PVC plastics (as a stabiliser) and disinfectants, even though some are known neurotoxins and immunotoxins, or are harmful to reproduction and development.[32] And because some of those products will enter the ocean, so too will tributyltin, if on a smaller scale than before.

That is not all, because having a convention does not mean the battle against toxic anti-fouling agents is won. Regrettable substitution remains a risk, as seen by the efforts in 2017 by an IMO committee to amend the convention to include cybutryne, another anti-fouling agent that "causes significant adverse effects to the environment, especially to aquatic ecosystems". As of late 2021, that work was still ongoing.[33]

When it comes to tackling marine chemical pollution, then, several aspects stand out:

- Regulation, while crucial, particularly for global instruments, takes too long to put in place. And without effective enforcement, regulation is of limited value.
- Adding chemicals to the scope of existing treaties is a lengthy process that typically takes years.
- Existing agreements are fragmented, and their objective (to protect the environment) is often at odds with international laws that protect economic interests, like trade law and intellectual property law.

Best practice

Despite the shortcomings of existing agreements when considering marine chemical pollution on an overall basis, some do offer useful best practice lessons, says Dr Aleke Stöfen-O'Brien, a lawyer and policy expert at the WMU-Sasakawa Global Ocean Institute at the IMO-World Maritime University in Sweden.

Part of the problem with many international agreements that seek to protect the broader environment is that they do not specifically focus on the marine environment

One such example is the OSPAR Convention that seeks to protect the North-East Atlantic, and which has undertaken significant work on hazardous substances. This includes identifying priority chemicals in the marine environment, in part by assessing biota for certain chemicals, with that evidence-based approach then feeding into efforts to guide policy.

"So, they start with evidence-based [data] and then move on to regulation," she says.

That approach—a mandate that allows the negative effects of chemicals to be subject to evidence-based assessments—is a good example of best practice. And while such a mandate might seem logical, not all conventions that cover regional seas have one. A best practice approach, Dr Stöfen-O'Brien says, should encourage countries to monitor and assess, and then to take measures relating to the marine environment—and not just the broader environment.

Another agreement with best practice elements regarding marine chemical pollution is the EU's Marine Strategy Framework Directive, which contains specific descriptors that look at chemicals and food chains, including food for human consumption, as well as at chemicals and their impact on fish and shellfish.

"This means countries are obliged to monitor the marine environment and some vital biota for chemicals, and then create measures [in response]," says Dr Stöfen-O'Brien.

For similar reasons, the International Maritime Organization's (IMO) antifouling convention is another, as is its ship recycling convention, where beach-based shipbreakers in, for instance, India and Bangladesh, are increasingly required to have an environmental chemical protocol. A fourth is the IMO's Ballast Water Convention, which requires the use of UV light rather than chemicals to treat ballast water prior to release.

Part of the problem with many international agreements that seek to protect the broader environment is that they do not specifically focus on the marine environment. From a technical perspective, says Dr Stöfen-O'Brien, drafting agreements to tackle chemicals that focus on the terrestrial or atmospheric environment means they are of far less use for the marine environment. This is because they lack key information on chemical pollution in the marine environment, and will not incorporate the means to capture data or to initiate regulatory monitoring and reporting on the impact that chemicals have on the seas.

"The marine environment is something different—but if you don't know enough about the topic, how can you develop and identify pressing issues and pick them up in a regulatory system?" she says. "I'm not saying that all of these environment treaties need to be changed, but there needs to be more focus on the marine effect of chemicals."

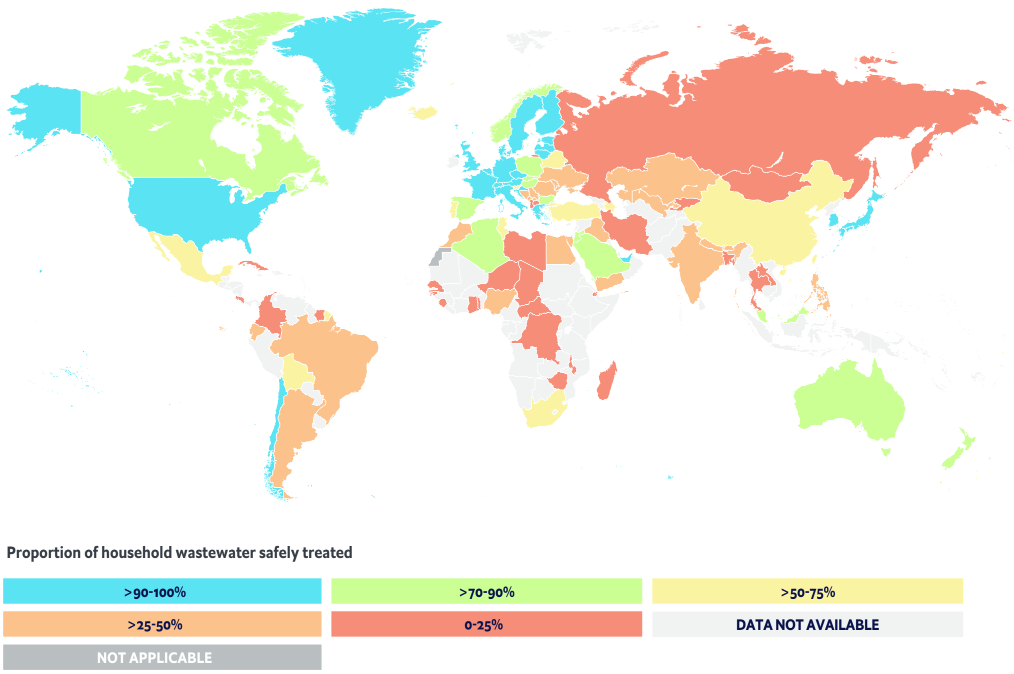
Focus on wastewater

As noted earlier, a key source for marine chemical pollution is wastewater from households and industry. Wastewater treatment is one of eight targets contained within the UN's SDG 6, the goal of which is the provision of water and sanitation for all by 2030.[34]

Progress has been slow. When it comes to household wastewater, 44 percent worldwide is not safely treated, the UN says, with significant regional disparities (see map). Meanwhile, it is impossible to say how much industrial wastewater is safely treated globally: just two nations have data on that, compared with 128 countries that collect data on the safe treatment of household wastewater flows. Logically enough, the UN says a greater proportion of countries' populations must be connected to sewers and septic tanks, and it wants less direct discharge of sewage into the environment.[35]

SDG 6.3.1: The percentage of safely treated household wastewater flows, 2020

The figures denote the proportion of domestic wastewater flow that is safely treated in 128 nations. In 62 of those countries, less than half of the wastewater generated by households was safely treated. Among the goals of Target 6.3.1 is that water quality is improved by 2030 by "reducing pollution, eliminating dumping and minimising release of hazardous chemicals and materials", and by halving the proportion of wastewater that is untreated



Source: Summary Progress Update 2021: SDG 6 — water and sanitation for all, UN Water

The treatment of wastewater

The three main stages of wastewater treatment are known as primary, secondary and tertiary. Each stage removes certain pollutants, and the remaining water becomes progressively cleaner. A fourth stage can be used to generate even cleaner water.[36]

- *Primary treatment*: the flow is pumped into a settling tank, where heavier solids sink to the bottom of the tank and are pumped to a sludge treatment facility.
- *Secondary treatment*: the flow from the primary treatment is subjected to processes that lower the levels of biodegradable contaminants. These include biofiltration, aeration and oxidation ponds. Typically, secondary treatment does not remove nitrogen.[37]
- *Tertiary treatment*: the flow from the secondary treatment further raises the quality of the water, including by the removal of pathogens so that the water is fit for human consumption.[38] Removing nitrogen typically requires tertiary treatment.[39]

Household wastewater is classed as “safely treated” if it is “treated by secondary or higher processes or that effluent discharges met relevant standards”. The reason that 44 percent of household flows worldwide did not fall into this category is because they are not collected at centralised treatment plants or in septic tanks.[40]

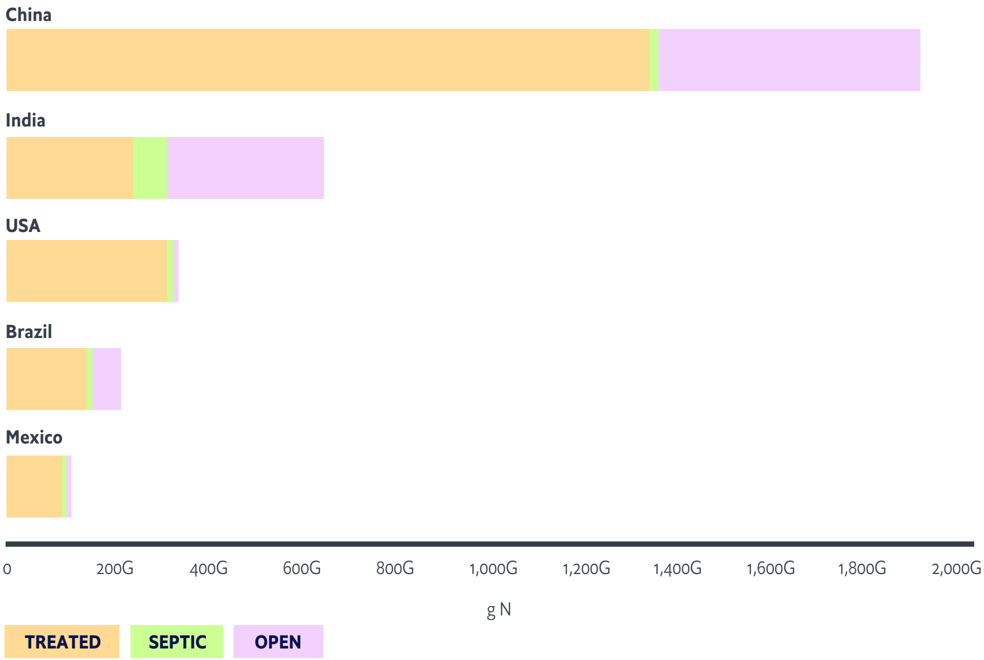
Improving this is far from an academic exercise. A ground-breaking 2021 study mapped global wastewater outputs, specifically nitrogen and pathogens (known as faecal indicator organisms, or FIOs) from human sewage, for about 135,000 watersheds around the world to understand what treatment wastewater gets and where it ends up.[41]

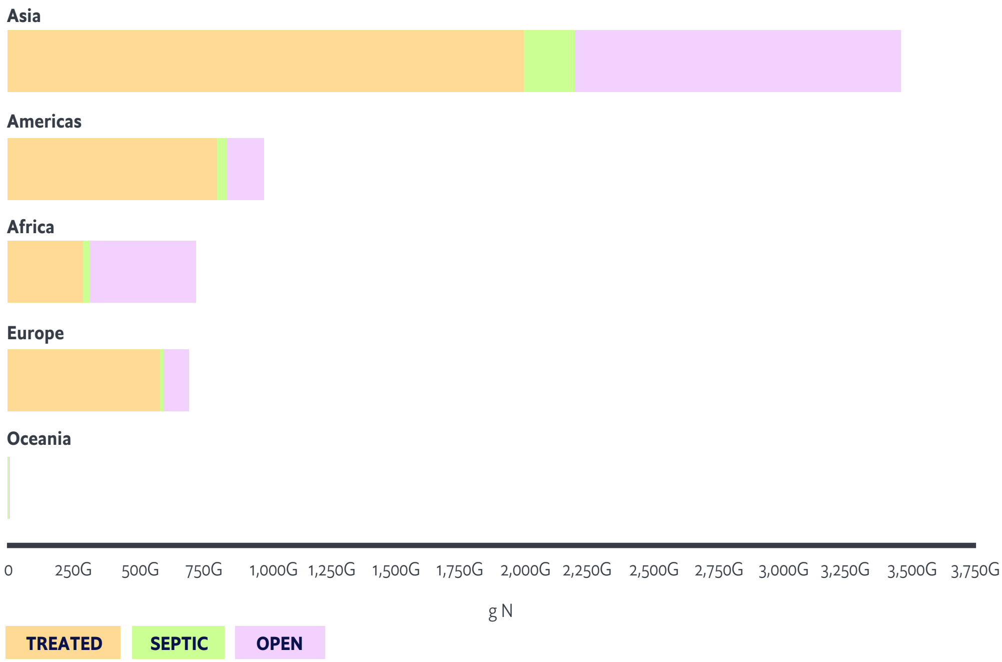
Among the findings is that wastewater adds 6.2Tg of nitrogen annually to coastal waters—or about 45 percent of the total nitrogen flow into the ocean from agriculture. Almost two-thirds of wastewater nitrogen comes from sewered systems, while nearly a third is from direct input to the seas. The remaining 5 percent comes from septic systems.[42]

“We find that just 25 watersheds contribute nearly half of all wastewater [nitrogen], but wastewater impacts most coastlines globally, with sewered, septic, and untreated wastewater inputs varying greatly across watersheds and by country,” the authors wrote.[43]

Of the 25 watersheds responsible for the largest amounts of nitrogen, nine are in China (the Yangtze River alone accounts for 11 percent of the global total) and three are in India. Others include Bangladesh, Egypt, Pakistan, the US, Argentina, Russia and Niger as well as three European nations: Romania, the Netherlands and Ukraine. Overall, just five countries account for half of all the wastewater input measured, while Asia’s flows of wastewater nitrogen comfortably exceed the rest of the world combined (see charts).[44]

Top five countries (above) **and regions** (below) **as measured by total nitrogen** (g) **input into their coastal zones by source type** (sewer, septic, direct)





Source: Seminal Study Maps Impacts of Wastewater on Coastal Ecosystems: An Interview with Dr. Ben Halpern, Our Shared Seas (2021).

Of those 25 watersheds, the five rivers with the most nitrogen per square cubic metre are DRC's Congo (36,679 N(g/m2), the US's Mississippi (27,602), Argentina's Rio Parana (26,329), Niger's Niger River (25,580) and Russia's Amur River (24,424). Others exceeding the 20,000 N(g/m2) level are Egypt's Nile, Iraq's Shatt al-Arab and Ukraine's Dnieper.[45]

The consequences of nitrogen and FIOs—whose input levels the study found were generally correlated—are well-known, with excess nitrogen, for example, leading to eutrophication and dead zones in the marine environment. The study concluded that 58 percent of coral and 88 percent of seagrass beds were exposed to nitrogen from wastewater. China, Kenya, Haiti, India and Yemen had hotspots for nitrogen exposure for coral, while hotspots for seagrass were found in Ghana, Kuwait, India, Nigeria and China. Other hotspots for coral reef impacts from wastewater include the Caribbean and Indonesia.[46]

When it comes to wastewater treatment, different countries have vastly different approaches. In the US, for example, nearly all households are on sewerage systems or use septic tanks; that is not the case for 3.6 billion people around the world.[47] As a result, the UN says, more than 80 percent of wastewater globally is released into the environment without being sufficiently treated, with most water-related pollution due to "intensive agriculture, industrial production, mining and untreated urban runoff and wastewater".[48]

Take India, for example. Government figures show that of the 16 billion gallons (60 billion litres) of sewage generated in the country's urban areas, less than half is treated. Much of the rest ends up in India's rivers. Wastewater treatment in rural areas is non-existent. A big part of the reason for the failure to resolve the country's urban sewage problem is red tape and regulatory overlap which, a government adviser admits, have stymied progress on wastewater treatment for decades.[49]

In most developed countries, wastewater from households and industry, as well as that emanating from hospitals, restaurants, educational institutions and businesses, is fed into the same system and ends up at the same centralised wastewater treatment plant (although local regulations might require certain industries to treat their effluent to some degree prior to pumping it into the centralised sewerage system).

This approach makes sense, says Professor Paul Westerhoff of the School of Sustainable Engineering and The Built Environment at Arizona State University, because it is more cost effective and makes regulating discharges into the environment easier. In the US, he says, wastewater from industrial sources accounts for about 10 percent of the volume, while households comprise just under half.

What is interesting, Professor Westerhoff says, is how the US's 15,000 wastewater treatment plants differ in the processing that they carry out. Research he has undertaken in recent years shows a clear difference between the quality of water discharged from inland wastewater treatment plants versus that from coastal-based plants.

Most US wastewater treatment plants discharge their flows into surface waters. For plants on the coast, that is the sea; for inland plants, it is rivers or lakes (though even then, he says, many of the chemicals discharged end up in estuaries and the sea).

"The first thing that comes out of the study is that [coastal-based plants] have a much lower level of treatment in general than those further inland," he says.

The reason is regulation. The US has more stringent rules on discharging treated water into rivers than into the sea, and that is largely because rivers have a lower capacity to dilute. In particular, the US imposes specific limits on the levels of nitrogen and phosphorus. Coastal-based wastewater treatment plants, on the other hand, are not required by law to remove nitrogen or phosphorus. That, it turns out, has important consequences for other contaminants.

"As a consequence of improved treatment of nitrogen and phosphorus, you actually remove pharmaceuticals and industrial chemicals better. And the reason is because to remove, say, nitrogen, you have to add oxygen, but then you also need other microbes—bacteria that operate in the absence of oxygen," he says. "So, if you can remove nitrogen—it's called biological denitrification—you actually get better removal of most of these pharmaceuticals and personal care products. It's a double benefit."

Cleaning up: How Los Angeles is looking to improve its water reuse

Los Angeles County—home to Los Angeles, the second-largest city in the US—currently pumps about 1 billion gallons (about 3.8 billion litres) of partially treated wastewater directly into the ocean daily, with the contaminants polluting the marine environment.

In the near future, the body that treats and delivers drinking water for the broader region, the Metropolitan Water District of Southern California, is set to implement a project that could see a sizeable amount of that wastewater reused. In large part, this is being driven by the need to deal with the effects of droughts and water shortages.[50]

The Regional Recycled Water Program (RRWP) is currently in its demonstration phase, with a US$17m water purification facility designed to treat 500,000 gallons (1.9m litres) of effluent from Los Angeles County daily. Once the approach is proven to the satisfaction of regulators, the goal is to implement a full-scale regional programme costing around US$3.4bn to build and US$129m annually to operate. That should be functioning by 2032, and could produce as much as 150m gallons (570m litres) of treated wastewater each day—enough for 500,000 homes.[51]

The RRWP would take effluent from homes, businesses and industry. After undergoing advanced treatment, it would be further purified using microorganisms, membranes, reverse osmosis, ultraviolet light and advanced oxidation to produce high-quality, purified water.[52]

While producing water in this way is much cheaper than desalination, it still leaves the remaining wastewater which will by then be additionally concentrated with the salts and chemicals that were removed by the advanced treatment processes. This mix of treated wastewater and concentrate from the advanced treatment plant will continue to be pumped several miles offshore into the ocean. In short, cleaning wastewater in this way does not maximise the potential environmental benefits to the ocean.

However, from an environmental perspective there are opportunities to treat what remains in this concentrated stream before its disposal into the ocean. And, although this mix is heavy with salts, their concentrated presence is advantageous as it means other technologies that work well in salty solutions (for instance, using advanced oxidation processes like ultraviolet light irradiation in the presence of titanium dioxide[53]) can be used to remove the problematic chemicals that remain.

Pharmaceuticals are a particular challenge for wastewater treatment plants, which typically use bacteria to remove chemicals, because oral pharmaceuticals are designed not to stick to fatty biological tissues. (If they did, manufacturers would need to increase the dose to ensure enough was delivered to the target site in humans.)

Pharmaceuticals are a particular challenge for wastewater treatment plants, which typically use bacteria to remove chemicals, because oral pharmaceuticals are designed not to stick to fatty biological tissues

"Wastewater treatment plants essentially just grow bacteria, and a lot of things stick to the bacteria—lots of carcinogens, whether those are polyaromatic hydrocarbons or PCBs, for instance," says Professor Westerhoff. "That's because bacteria aren't so different from us—they have an outer cell membrane made up of liposomes, which are kind of fatty, and so things stick into these fatty parts of their cells. After that, you take out the bacteria [and dispose of it]."

But because pharmaceuticals are designed not to stick to fat, they get through. To remove pharmaceuticals requires other technological solutions, and those cost more, which is why few countries bother to do so. One exception is Switzerland, where wastewater treatment plants will have to implement one of two technologies—either activated carbon, which absorbs trace organics, or ozone, which oxidises and breaks down chemicals.[54]

The reliance on bacteria at many wastewater treatment plants explains why the chemicals that tend to get through are hydrophilic chemicals that do not accumulate in fatty tissues.

"These are the things that move through the environment very quickly. They oftentimes react more slowly, but they don't necessarily bioaccumulate," he says. "So, if you think about the ecosystem in the ocean, there are lots of chemicals that build up in whales, other mammals and predatory fish at the top of the food chain in their fatty tissues, because they eat smaller things—that's biomagnification. But a lot of those chemicals, if they were at a wastewater treatment plant, probably would have gotten absorbed or stuck on to bacterial cells."

Improving wastewater treatment around the world is only part of the challenge in addressing marine chemical pollution; other solid waste from households and business is also a concern. With increased urbanisation, particularly along coastlines, and with more people and industries generating more effluent and more waste, the need to tackle these twin problems will increase.

Take municipal waste. By 2030, Asian nations are forecast to be the largest generators of municipal waste, much of which contains chemicals, while Africa is expected to overtake Asia later this century. In 2012, countries in Africa, where infrastructure to deal with waste is the exception, generated 125 million metric tons of municipal solid waste; that figure is forecast to double by 2025.[55]

UNEP's Dr Kevin Helps, a geochemist who spent a decade in the waste management industry removing hazardous waste from developing countries, and more than 22 years in the UN system working on waste issues, considers issues such as better wastewater management to reduce the levels of pollutants in effluent as key to curbing marine chemical pollution.

"Technologically, it's not a matter of, 'Can it be done?' The answer is yes. It's a matter of the standard to which it needs to be done. The technology exists to take out microplastics and harmful chemicals, for example, or to take out or reduce the levels of pharmaceutical residues which can interfere with biological systems," he says.

The challenges are the cost and the access to technology in developing countries that often lack basic sanitation.

"And one of the points that I consistently try to get across is that all the 'stuff' we crave in a modern consumer society is just too cheap. Basically, we don't internalize the externalities of dealing with things later in the product life cycle properly," Dr Helps says.

To ensure sustainable consumption and production, then, requires adopting circular approaches where possible, redesigning and retooling—not simply recycling—and, he says, "designing out the dangerous chemicals which go into the processes—because they ultimately all end up in the air and the ocean because they get rained out, and they end up depositing in our water".

Good enough to drink?

Wastewater treatment plants are one of the main ocean sources of PFAS compounds, says Professor Elsie Sunderland of Harvard University, "because they're receiving all of the consumer products that contain PFAS, and then whatever goes through your body" goes into the wastewater.

And while microplastics generate headlines, it is chemicals like the PFAS group that are likely of far greater consequence to human and marine health.

"Should we do something about microplastics? Absolutely," she says. "And if microplastics raise awareness, and people care about microplastics, then that's a great transition point to chemical pollution. But in terms of the severity of the issue in terms of health, I do not believe [microplastics] are on the same magnitude at all."

Professor Paul Westerhoff of the School of Sustainable Engineering and The Built Environment at Arizona State University says existing wastewater treatment plants cannot remove all chemicals (though they do remove about 90 percent of nanomaterials). However, they could do so if they were upgraded to use technologies like reverse osmosis membranes—as happens in some places in the US and Australia, as well as in Singapore.

"You can take wastewater and make drinking water," he says. "So, we could remove everything. However, I know of no wastewater treatment plant in the world that uses reverse osmosis, and then just discharges that clean water into the ocean or river just because they want to clean things up—instead they do this when extremely high-quality water is wanted for human or industrial reuse."

While using reverse osmosis is more costly than simply using existing wastewater treatment, it is only about half the cost of desalination, "which is why some cities want to do that instead of de-salting seawater". Going down this route, however, still means that they are left with 20 percent of the wastewater flow "that contains everything that you physically removed".

One option to deal better with this remaining 20 percent of water is Zero Liquid Discharge (ZLD), a solution that the US Department of Energy is helping to fund. ZLD evaporates the remaining 20 percent of water that contains the concentrated levels of salt and chemicals, leaving those behind. However, ZLD is expensive—as much as ten times the cost of existing wastewater treatment.

Continued on next page

All of which raises another question: Existing wastewater treatment typically uses bacteria, which grow fat on the chemicals during their time at the plant. What happens to them after that?

"In the United States, roughly half are land-applied. So, we concentrate all this stuff, and then we spread it back out in the environment," Professor Westerhoff says. "This can be on farms to grow hay or cotton and other non-human consumptive crops. Or they put them in forests to grow tree forests. Some people see them as a resource—and they are pretty nutrient-rich—but I think that's a mistake."

In the US, about half of these so-called sewage solids, or bio-solids, are land-applied, about 30 percent go to landfill, while the rest is incinerated. In Switzerland, on the other hand, all sewage solids must be incinerated, "and I think that is the right thing", Professor Westerhoff says. Using them on the land, on the other hand, means that the organic chemicals and metals in the original wastewater end up in the soil, and from there they can leach into the air or water sources, "and these things are persistent".

Yet innovative solutions abound. One option is to extract the chemicals in the remaining water; another is to generate 98 percent clean water, which would leave 2 percent of high-salt, chemical-laden water. Other advanced technologies will likely bring other solutions. However, says Professor Westerhoff, very few countries are currently putting in place such measures.

"And that's because there are no regulatory drivers even to treat these chemicals in this 20 percent and, outside of a few countries in Europe, there are no regulatory drivers to manage pharmaceuticals [in wastewater]," says Professor Westerhoff.

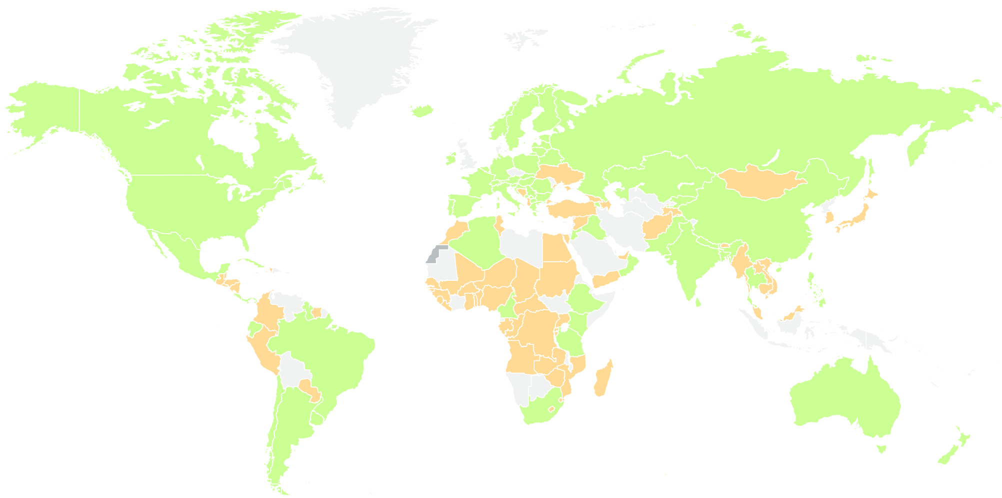
Acting on toxic chemicals takes far too long. It typically takes years for legislation to be drafted, agreed upon and implemented, whether at a national or supranational level

Although the cost of building infrastructure to mitigate factors like wastewater pollution is high—which explains why nearly half of the planet's population lacks access to sewerage systems and septic tanks—it is also the case that many countries fail to act on pollutants even when doing so is largely cost-free.

Take lead, whose dangers are well-known, and which accounted in 2019 for nearly half of the world's two million excess deaths due to chemicals. As at the end of 2020, the WHO says, just 41 percent of countries had confirmed to the global health body that they had legally binding restrictions on lead in paints.[56] And when it comes to the use of lead paint in the marine environment, this toxic chemical element is still used as an additive in marine paints—which brings contamination concerns.[57]

Countries with legally binding controls on lead paint, 2020

Just 41 percent of countries (in green) told the WHO that they have regulations controlling the production, import, sale and use of lead paints. Countries in most of Africa and the Middle East and much of Southeast Asia and South America either lack controls (in orange) or have not provided data (in grey)



Source: The public health impact of chemicals: knowns and unknowns - 2021 data addendum, WHO (2021)

5.3 Barriers to progress: One ocean, many jurisdictions

The narrative with lead—that, even today, too few countries have acted against a contaminant whose harm is clear—explains some of what lies behind marine chemical pollution: at an international and national level, action requires overcoming barriers, and that can be difficult.

The list of barriers is long. One is the failure to acknowledge the finite nature of the ocean, and its interconnectedness with human activities on land. For too long, the world has mistakenly assumed that the ocean can continue to absorb and dilute chemical pollution.

Another is that there is insufficient chemical data to inform regulatory decision-making. Linked to this is a lack of knowledge about which chemicals are being produced, used and released, the amounts involved and their potential effects. A fourth is the pressure to side-line or ignore science in regulatory processes.

It is also the case that acting on toxic chemicals takes far too long. It typically takes years for legislation to be drafted, agreed upon and implemented, whether at a national or supranational level, or for parties to file applications for, say, the Stockholm Convention to consider adding a chemical—which then must be considered and ruled on.

A recent example is provided by PFAS chemicals, the dangers of which have long been apparent to researchers. However, it was only in late 2021 that the world's wealthiest nation, for instance, announced it would target them, after decades of river pollution, ill-health and contamination of the seas. Michael S. Regan, the head of the US's Environmental Protection Agency (EPA), said the agency would set legal limits for levels of PFAS in drinking water, boost research and monitoring of the chemicals, and designate them as a hazardous substance, with further steps to come in 2022.[58]

Additionally, manufacturers of PFAS compounds will need to test the levels of PFAS, divided into 20 sub-categories based on their characteristics, in household items like furniture and cookware, and report those results publicly—with those costs borne by industry. Regan said it was "time for manufacturers to be transparent and provide the American people with this level of detail".[59]

The PFAS story is a complex one that covers many issues, not least industry deception. A lawsuit brought by the North Carolina attorney general, for instance, claims that polluters knew for decades that some PFAS chemicals were toxic to humans and animals, with links to cancer and liver damage, yet told regulators they were safe.[60] And even in 2019, a senior executive at PFAS manufacturer 3M told a Congressional inquiry that "the data available today show no conclusive evidence of adverse health effects", despite studies from 3M and DuPont finding higher rates of cancer among workers making PFAS chemicals.[61]

What has happened with PFAS chemicals in the US also illustrates other shortcomings of the existing global system. Among these are a failure by governments to implement legislation, a failure by regulators to understand the toxicity of chemicals and to exert stronger oversight over them, and a lack of extended producer responsibility (EPR), which seeks to boost industry accountability by making polluters pay.

Other barriers include:

- A lack of awareness among policymakers and the public of the dangers that many chemicals pose to human health and to the marine environment, and of the significant risks to the environment of failing to act. In part, that is due to a lack of communication between researchers and policymakers, and because much research is carried out in silos.
- Linked to the lack of awareness is that the effects of tens of thousands of chemicals are wholly unknown. When Dr Zhanyun Wang of the Technology & Society Laboratory, Swiss Federal Laboratories for Materials Science and Technology (EMPA) compiled his ground-breaking list of 350,000 chemicals in 2020,[62] he found at least 75,000 polymer and other substances about which, in terms of their composition, "we just have no idea".
- Less scrupulous players take advantage of regulatory arbitrage to move operations to countries or regions with lower standards and less oversight. Often these are poorer nations, whose people and environments pay the price.
- Regulators are in a constant state of catch-up with the chemicals industry. In part, that is because regulation typically tackles only a single chemical (or occasionally chemicals within the same group, as with PFAS). However, it is relatively straightforward for the industry to create "drop-in" replacement chemicals that have similar chemical structures, and firms know they have years before regulators get around to assessing its effects—if they ever do.

When the European Environment Agency (EEA) undertook its "Late lessons from early warnings" review in 2013, it highlighted other barriers to taking precautionary measures. One is that technology advances so fast that it can prove impossible to act in a timely manner. Others include the fact that politics and finance typically function on a short-term horizon, that technology often operates within monopolies, that science is inherently conservative and works in silos, and that policymaking usually favours the status quo.[63]

Those are a particular challenge at the national level, where pressure exerted by corporations and lobbyists on politicians can slow or stymie legislation and can undercut enforcement. And, as has become clear, some firms in wealthy countries simply ignore their obligations on the grounds that they are unlikely to get caught and that, if they do, the penalties are worth paying (see box).

England's wastewater landscape—regulatory failure meets corporate deception

Regulatory failure is central to the problems associated with the privatised water companies in England and Wales, with weakness by Ofwat, the regulator, described as "a systemic part" of the issue.[64]

England and Wales privatised their wastewater treatment companies in 1989, and today most are owned by private equity, sovereign wealth funds and pension funds. The companies have long been accused of excessive executive pay and overly generous dividends while loading up on debt.[65]

At the same time, they have for years effectively enjoyed a free pass to offload untreated or under-treated sewage in rivers and the seas, with significant environmental and human health consequences. (That is not the situation in Scotland, whose state-owned water firm vastly outperforms its privatised peers in England and Wales, and whose water standards are on a par with Scandinavian nations).[66]

In theory, such pollution should happen only rarely and be notified to the regulator. However, data analysis in late 2021 determined that 95 percent of dry and early sewage spills are not recorded by the UK's wastewater treatment companies. (While firms are permitted to discharge some untreated sewage during extreme rainfall, they are not allowed to do so if there is no rain—so-called dry spills.)[67]

To many, it is no coincidence that firms have since 2009 had the responsibility to monitor and report those sewage outflows, a case of the fox guarding the henhouse. Court actions against two UK companies—Thames Water and Southern Water—showed both firms breached legal limits on numerous occasions at some sewage plants.[68]

After years of public outrage over firms dumping sewage into the seas and rivers, the water and environmental regulators decided to investigate the sector's conduct and announced a major probe to determine non-compliance at about 2,000 wastewater treatment plants in England and Wales.[69]

That level of scrutiny is overdue. Southern Water, for example, was fined £90m—a record—in 2020 for dumping raw sewage, with the judge saying the firm had shown "a shocking and wholesale disregard for the environment" and human health.[70] In 2019, Thames Water was fined £20m for dumping 1.4 billion litres of raw sewage in the Thames. The previous year, Southern Water was fined £2m after releasing raw sewage into the seas off southern England, forcing beaches to close for days.[71] A 2019 investigation by Ofwat concluded that Southern Water had "deliberately misreported data" and water samples for years to avoid paying fines.[72]

The situation has become so egregious that the chair of the Environment Agency said directors guilty of repeated breaches should be barred from holding directorships and, in the most serious cases, jailed.[73] If nothing else, the saga shows that regulatory failure and corporate misdoings are a significant risk in even the wealthiest nations, with pollution of the marine environment in these cases an inevitable consequence.

Two further barriers mentioned by interviewees are the lack of a single global body to tackle marine chemical pollution (an issue to which this chapter will return), and insufficient funding at a national and international level for research about marine chemical pollution and for solutions to it.

The world lacks the comprehensive international legislation necessary to tackle marine chemical pollution. The existing system is highly fragmented and also at times in conflict with a range of other laws and agreements

There are also significant shortcomings in law. First, the world lacks the comprehensive international legislation that is necessary to tackle marine chemical pollution. Second, the existing system, which includes numerous multilateral environmental agreements and instruments like REACH and the Minamata Convention, is not only highly fragmented; it is also at times in conflict with a range of laws and agreements that cover trade, intellectual property (like patents) and the protection of national and corporate economic interests, and whose inherent objectives are wholly different to protecting the marine environment.

Structural issues in law relating to intellectual property rights, for example, allow companies—to a certain degree and depending on the jurisdiction—to keep secret any information about the harm that certain chemicals cause, even though there is a clear public interest to the contrary. That is the unintended consequence of a system that seeks to protect national interests or keep companies competitive, says Dr Stöfen-O'Brien.

"[The drafters] did not think about the negative externalities that these measures have on the marine environment. And that's also why there is such a long timescale when it comes to taking action, because to translate that between these different systems takes a long time," she says, adding that very few people work across these areas. "In my opinion, there's very little exchange—it's very much working in silos."

The issue of intellectual property also raises its head when it comes to scents that firms create, and which are typically comprised of dozens of chemicals. Dr Wang says the ability companies have to claim that "everything is confidential business information" is a significant problem that stems in part from the fact that the global system underpinning such rules is decades old, "so maybe it's time for us to reflect on that".

By way of an example, Dr Wang had recently sought information online on the use of a specific group of fluorinated polymers, the group to which PFAS belong.

"There were about 75 substances on my list, and when I went through them most were claimed as confidential business information," he said. "That means the public definitely doesn't know where they're used or how much they are used. And then we just release them all during the use phase and the disposal phase."

In recent years, much of the effort to counter marine chemical pollution at the use and disposal phases has centred on green chemistry, which this report assesses in more detail below (see Chapter 6). However, much of the promise of green chemistry—whose goal is "the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances throughout the life cycle of products" to support the goals of a circular economy[74]—remains unfulfilled.

In part, that is because it is difficult to measure the impact that green chemistry has, which slows its uptake, and in part because most countries lack sufficient policy incentives for chemicals firms to pursue green chemistry solutions. That said, green chemistry is starting to increase in importance: a 2021 study noted "significant growth" in recent years, and predicted this would continue—fuelled in part by increased demand by consumers and institutional investors for less-harmful products.[75]

That study also concluded that robust government policies help to overcome barriers to the adoption of green chemistry. It highlighted the European Commission's Chemicals Strategy for Sustainability, policies enacted by individual states in the US, as well as the implementation in the US of the Lautenburg Chemical Safety for the 21st Century Act. Those, it stated, "have created strong regulatory signals to the marketplace that are influencing investors"—a clear indication of the importance that regulation can play in surmounting barriers to marine chemical pollution.[76]

"Policies that foster increased investments in research and development, preferred acquisition status on government contracts, preferred product placement in retail establishments, and private and public labelling and certification programs that assist consumer and institutional purchasers in identifying safer and more sustainable products are attracting more and more companies to pursue green chemistry objectives," the report stated.[77]

Interviewees said that regulatory clarity is crucial when it comes to encouraging business to follow a more sustainable line, not least because this helps to create incentives to change corporate behaviour by, for instance, driving improvements in production methods, locations and the chemicals used.

Also important is an environment of entrepreneurship and business innovation—areas in which the US, for example, excels. And that aspect of differing national values in areas that are central to marine chemical pollution, like the tolerance for risk, raises far-reaching contextual issues around how different countries or regions perceive and deal with pollution. That will feed into determinations of how best to craft a global body of law, or refine what currently exists, to protect the marine environment.

Switzerland, Sweden or Norway, for instance, are more risk-averse on chemicals than, say, the US, and typically have more restrictive emissions and pollutant regulations, says Dr Stöfen-O'Brien, "and this is reflected in their regulations".

"It comes down to the threshold of acceptability of risk in a society, and the society's values when it comes to environmental protection and the use of chemicals," she says. "This is very important to consider—the threshold of acceptance of risk in a society. And I would argue that the US has a higher tolerance for risks associated with chemicals than, say, the European Union."

That societal tolerance extends to awareness-raising. In Sweden, where Dr Stöfen-O'Brien lives, even young children learn about chemicals and the harm that people can do to the environment, "because there's not a lot of tolerance to have toxic pollutants and chemicals flying around".

"And I think Sweden does this right—they start with educating people, and then people will look out for this, and say, 'This is enough,'" she says. "Again, it comes down to values: What does society expect? And that has implications for how you shape and negotiate national, regional and international law."

5.4 Interventions and pathways to success

While there are many barriers to tackling marine chemical pollution, there are also many interventions that can be taken at the sub-national, national and international levels. At their heart, these need to be based on a framework that is underpinned by the principles of sound chemicals management and equity, with that framework a central part of the material that the Invisible Wave programme will develop at a later stage.

One of the core tenets is to employ the "essential-use" concept, which reduces the unnecessary production and consumption of chemicals. Many chemicals that are added to products are not essential to the technical function—for example, they are used as fillers or bulking agents—and could be removed, cutting chemical pollution at the source.

This section will focus on ten interventions that our expert panellists believe are the most important when positioning the ocean and humanity for a healthier future.

Intervention 1. Raise awareness

The first intervention is to **raise awareness** nationally and internationally of the causes and potential remedies for marine chemical pollution. Although knowledge of plastics pollution has risen fast in recent years among policymakers, consumers and businesses, chemical pollution in the marine environment is far less understood.

One way to change this is to improve the two-way flow of knowledge between policymakers and researchers. That requires better communication of scientific knowledge to policymakers, but it also means that the needs of policymakers are relayed to researchers. Additionally, the often-siloed areas of scientific enquiry would benefit from better communication with each other.[78]

Another difficulty is that the various bodies tasked with chemicals and that talk to policymakers do so within their specific field of expertise, like mercury, POPs or e-waste. While this is understandable, it breeds inefficiencies due to the overlapping nature of marine chemical pollution. In addition, these bodies often do not communicate the developments in the policy space to the scientific community or the needs policymakers have for further information. As a result, researchers are less able to meet emerging policy needs on a timely basis.[79]

Lastly, communicating this knowledge of threats and solutions for marine chemical pollution should not stop at the doors of policymakers, but must be part of the wider public discourse through education, media and other outreach efforts, including promoting behavioural shifts like "reduce, reuse and recycle".

Intervention 2. Improve the regulation of harmful chemicals

The second intervention is to improve the existing system whereby chemicals or groups of chemicals are **regulated or banned**, and ensure tighter enforcement of such regulation. Currently, it can take years or even decades before chemicals that are known to be toxic go through the bureaucratic process of being placed on a list for restriction or elimination—and, even then, enforcement might be patchy or carried out only on a sub-national, national or regional basis.

The transboundary nature of marine chemical pollution, though, requires a consistent approach. One obvious solution is a global treaty to tackle marine chemical pollution. Although discussions would take years, the outcome would have universal (or near-universal) coverage, which would constitute a significant step forward. Additionally, the negotiating process itself would see stakeholders learn at each stage, and build awareness of key issues.

BPA: A tale of two regulatory regimes

Bisphenol A, or BPA, offers a clear example of how different regulatory regimes approach harmful chemicals. BPA, an industrial chemical, has for decades been added to plastics and the plastic linings of tins, among other uses, and is a known endocrine disruptor for humans and animals.

In the US, the Food & Drug Administration has not banned BPA in plastic food containers or the linings of tins on the grounds that it is safe, and that reviews of studies "have shown no effects of BPA from low-dose exposure".[80] (The FDA did ban the use of BPA in baby bottles in 2012, but only after manufacturers had stopped using it.)[81]

The EU's ECHA, on the other hand, says BPA's "hazardous properties" have seen it classified as causing "toxic effects on our ability to reproduce", which is why it is listed in the agency's Candidate List of substances of very high concern.

To that end, its use "has been limited or is being limited in the EU to protect people's health and the environment", including an outright ban on the use of BPA in infant feeding bottles and food packaging for children under three. (France has banned BPA in food packaging, containers and utensils outright.)

The ECHA notes, too, that its risk assessment committee is supportive of a bid by Germany to have BPA classified as a hazard for the aquatic environment.[82]

Regulation and international policy are crucial because they provide signals to business, which often will not act until there is certainty in direction. (The COP process, for instance, has catalysed sectors to adopt net zero targets.) And it is clear that regulations to protect the marine environment work. A 2017 assessment of the impact of the Stockholm Convention, for instance, concluded that "monitoring results indicate that regulations targeting POPs are succeeding in reducing levels of POPs in humans and the environment", with the greatest gains seen in those POPs that were listed earliest.[83]

POPs are not the only chemicals to have been targeted in recent years. In mid-2021, for instance, Thailand announced that it would ban from its marine national parks the use of sunscreens whose chemical ingredients (oxybenzone and octinoxate) are known to be harmful to coral.[84] Similar bans exist in the US state of Hawaii and the Pacific nation of Palau.

At a broader level, the issue of banning chemicals from products entirely (as opposed to banning certain products like sunscreen from marine national parks) raises an important issue about the need to eradicate regrettable substitution—or the replacement of one toxic chemical with another that is later also found to be toxic. Take BPA: one common replacement is BPS, which is a similar chemical and which the European Commission is now considering as "a substance that may damage fertility and the unborn child".[85]

A further challenge is developing regulations to deal with mixture toxicity, which involves determining the effects in the real-world that exposure to multiple chemicals can have. This is crucial because existing safety assessments of chemicals typically focus on the effect that individual substances might have—yet it is known that exposure to multiple chemicals, even if each is within their safety level, can cause harm.[86]

One regulatory solution is to apply what is called a Mixture Assessment Factor (MAF) when risk-assessing individual chemicals, which involves testing that chemical with others to determine their combined effects.[87] The idea is gaining traction in some quarters. CHEM Trust, a collaboration between British and German charities, has called for MAF legislation as part of its "12 Key Asks" to the United Kingdom's government,[88] which is revising its Chemicals Strategy following its departure from the EU.[89] The European Commission is also examining MAF at the time of writing.[90]

REACH shifts the burden from one where science needs to prove damage to environmental and human health to one where companies need to show that their production, use and disposal of chemicals will not do harm

However, the solution is unpopular with at least some in industry: the Association of the European Adhesive and Sealant Industry (FEICA), which has more than 450 member companies across Europe, described MAF as "a political decision" with "no scientific justification behind the MAF concept as it is too broad, largely covering hypothetical exposures and risks rather than real-life scenarios". The result, it predicted, would be the disappearance of numerous products from the market, including building insulation, lightweight vehicles and paper products like books and labels for bottles.[91]

Intervention 3. Use the precautionary principle

The **precautionary principle** as it applies to business is hardly new—the UN Global Compact's Principle 7, for example, which covers the environment, outlines why a precautionary approach is strategically sensible, because it is cheaper to prevent damage than to clean it up afterwards.[92]

That logic, though, assumes that firms will be compelled to clean up. With marine chemical pollution, tracking who is responsible for what pollution is often impossible; even where it can be done—for example, the UK's wastewater treatment company Southern Water polluting beaches with untreated sewage—it is clear that some firms prefer to take the risk.

The solution is to regulate based on the precautionary principle, which is what the EU's REACH legislation largely does—Article 1 states that its provisions are explicitly underpinned by the precautionary principle,[93] as per the overriding principle expressed in the 1992 Maastricht Treaty, and it operates on a "no data, no market" approach, as per Article 5.[94]

In this way, REACH shifts the burden from one where science needs to prove damage to environmental and human health to one where companies need to show that their production, use and disposal of chemicals will not do harm. Or, as REACH puts it, the legislation "shifts the responsibility from public authorities to industry with regards to assessing and managing the risks posed by chemicals and providing appropriate safety information for their users".[95]

(The principle was at the centre of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, one of the world's most effective agreements, when the signatories agreed to protect the ozone layer by "taking precautionary measures to control equitably total global emissions of substances that deplete it".)[96]

Although there is no definitive definition of the precautionary principle, the version in Principle 15 of the 1992 Rio Declaration is one that many states recognise:[97]

"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

When it comes to chemicals legislation, though, the approach of REACH remains unusual; in many countries, the burden of proof lies on governments or civil society to prove harm, not on the chemicals companies to prove their products are safe.

A global science-policy body on chemicals and waste could warn policymakers of the issues, and the need for action, and help tackle marine chemical pollution in numerous other ways

More countries need to adopt the precautionary principle to tackle marine chemical pollution, not least because it is a transboundary issue. Another to consider adopting is the polluter pays principle,[98] which the European Environment Agency identified in 2013 as one way to create an effective response, and in particular to correct market failures.[99]

Intervention 4. Establish a global science-policy body on chemicals and waste

The fourth intervention is to **create an international science-policy body** whose scope covers all chemicals and waste, yet does not duplicate the efforts made by other science-policy bodies such as those under the Stockholm Convention. EMPA's Dr Zhanyun Wang says such a body could help to tackle marine chemical pollution in numerous ways.

First, he says, the science on chemical pollution is moving extremely quickly, with more than 20,000 papers published annually. Not only is much of that research hidden behind paywalls, making access expensive, but following this volume of material is impossible for individuals.

"A global body, though, could capture what is happening in the science space and tell policymakers [and scientists] that we have identified these issues, and we should take action as soon as possible," Dr Wang says, adding that such an approach would have seen much quicker action on, for instance, PFAS and PCBs.

Second, while policy development often requires scientific evidence, it is also true that scientists are often unaware of the information that policymakers require. This lack of hard evidence can be used as a reason to delay action.

"Such a body could close the gap between science, scientists and policymakers, and also help to inform scientists of policymakers' needs so that scientists can generate timely research," he says, adding that it could also act to provide an early warning system on problem chemicals, thereby closing another gap in the existing approach.

A further benefit would be to promote the two-way transfer of knowledge between developed and developing nations. Another would see the body able to support the global community to work together on issues of concern, with pesticides a prominent example. Marine chemical pollution is, after all, a global challenge, and such an institution would be able to paint a picture of the global situation to drive global actions.

Having a global science-policy body established by international agreement and operating as an intergovernmental institution would help to close two other gaps in the existing system:[100]

- The current lack of coverage that stems from the limited remits of each of the existing bodies such as those under the Stockholm and the Basel conventions.

- The lack of interaction on chemicals between different disciplines. Scientists, physicians and lawyers, for example, typically operate within their own silos, yet when it comes to marine chemical pollution, they all have crucial insights to bring in drafting solutions.

Intervention 5. Create a comprehensive register of chemicals

A key step in mitigating marine chemical pollution is to **create national registers as well as a global register of chemicals**. As noted earlier, the 2020 study by Dr Wang determined that there were at least 350,000 chemicals in existence, though as the research excluded dozens of countries, the true number is certainly higher.[101]

One recommendation in his study is to develop global "good practices" to help countries that lack a chemical inventory to establish one. (Why not "best practices"? Because, says Dr Wang, "sometimes it takes a very long time to reach consensus on best practices, but we actually just need practices that are good enough".) Another is to establish a global inventory of chemicals which—among other things—could be used to study and understand what is called the "planetary boundary" of chemical pollution, or the point beyond which such pollution risks inflicting irreversible harm.[102]

The study suggests that information about chemicals in the inventory, which should be publicly accessible and managed by an independent third party, should be provided by the owners of the various national inventories.

As for corporate concerns about the intellectual property (IP) associated with chemical compounds—those are overdone, says Dr Wang. Claiming IP protection as a reason to withhold such information—to protect trade secrets from competitors—is flawed, he says, because technological advances mean those competitors can already determine the chemical compounds through reverse engineering. Falling back on IP protection, then, simply serves to prevent regulators from protecting the interests of the public and the environment, he says, as regulators lack the means to reverse engineer chemical compounds.

Another aspect to tackle is the issue of chemical mixtures. Existing chemicals legislation typically focuses on individual substances, which means mixtures currently do not need to be registered. What is key, says Dr Wang, is that the register be a global effort, otherwise less scrupulous players might move production to countries or regions with less rigorous legislation, and those chemicals could return to more regulated markets as mixtures or constituents in manufactured articles. Failing to act on a global basis, then, would not resolve the problem but create a new one.

It should be said that global registries are not new. The OECD, for instance, has a 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 does have 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".[103] Dr Wang's approach would see consistent nomenclature, terminology and standards to avoid that drawback.[104]

Intervention 6. Mandate disclosure of all chemicals in products and their potential effects

In a sea of challenges, one of the most significant is the lack of knowledge of the chemicals in products and their effects. One solution is to **mandate disclosure** at an international level of all such chemicals and their known consequences.

Some firms already do this. As UNEP notes, these so-called frontrunner companies (which include some chemicals producers and retailers) are implementing sustainable supply chain management, with full disclosure of materials used.[105] Currently, though, transparency is optional. What customers of chemicals companies and end-consumers need are ways to know what chemicals are in the products that they are buying, and the risks those hold. This requires an international, policy-driven approach.

One of UNEP's key messages to policymakers in its 2019 report on chemicals management is that they use a lifecycle approach to ensure, in part, full material disclosure. This would involve "developing harmonized approaches across sectors to share chemical information and to advance full material disclosure across supply chains, including chemical-intensive industry sectors and the recycling/waste sector".[106]

Success would require overcoming legislative gaps, enforcement issues, providing information to end-of-life users, and raising awareness and building capacity for such measures in poorer countries.

However, it need not compromise confidential business information, as UNEP notes: balancing that with users' right-to-know could involve the use of non-disclosure agreements between business parties, or of a third-party that holds the information and provides users with a proof of compliance. Importantly, UNEP notes, "information on chemicals relating to the health and safety of humans and the environment shall not be regarded as confidential".[107]

Although the frontrunner companies are currently the exception, there are no technological barriers preventing others from following their lead. Sourcemap is a US-based firm that works with multinationals to help them account for all inputs along their supply chain, whether they wish to do so for compliance reasons or to be more efficient or productive. That allows them to track every input for every product—from the raw material to the finished good itself.

Dr Leonardo Bonanni, the founder and CEO of Sourcemap, notes such an approach—accounting for all inputs at every stage of the process—meets the best practice requirements for environmental assessments. Achieving that can be hard for firms to attain on their own because the further up the supply chain one goes, the murkier the source of materials can become, while the further down the supply chain one goes, the more removed the firm is from end-of-life factors.

"We specialise in getting multinationals extremely familiar with what's going on three, four or five steps away from them in their supply chain. And that includes the environmental impact like land use, but also chemicals-use in places like farms or on mines, where there has been relatively little record-keeping before we showed up," he says.

Such an approach may be new, but it will become more common, because "it's only a matter of time" before firms will have to account for their waste outputs, for example, whether those be solid waste, liquid waste or gas emissions. Regardless, the idea of supply chains constituting a trade secret is outdated, "because no one knows a company's supply chain better than its competitors—they're competing every day for the same suppliers".

Being transparent can be profitable for firms—and that includes chemicals companies, several of which are Sourcemap clients.

"Because, very simply, if you have to choose between two suppliers and one of them isn't willing to tell you even what is in the products that you're buying from them but the other one is willing to give you full transparency, you can effectively de-risk the entire product," says Dr Bonanni. "Increasingly, brands are choosing the transparent supplier, even if there's a price premium, because it carries so much less risk."

Being transparent can be beneficial for chemicals companies. Increasingly, brands are choosing the transparent supplier, even if there's a price premium, because it carries so much less risk

Intervention 7. Adopt best practice laws and principles, and ensure implementation and better enforcement

While there is no shortage of laws that tackle some of the causes of marine chemical pollution, most could do better in terms of **implementation, best practice and enforcement**. Chemical regulation and chemical management systems are highly complex areas that vary nation by nation, which makes a scorecard between nations impractical. Yet although many countries have initiatives from which others can learn, most face four major imbalances:

- Legislation almost always focuses only on new chemicals. This means countries are ignoring the potential impact of the tens of thousands of existing chemicals that are in use within their borders on the misguided assumption that they are all safe. (A few countries, like Canada and Australia, examine existing chemicals, but they are outliers.)
- It typically takes years to phase out problematic chemicals, but just weeks to evaluate and register new chemicals. In short, it is far easier to get chemicals on to the market than off it.
- Developing nations typically have less robust, responsive, equitable and effective regulatory systems than wealthy nations, which allows firms to engage in regulatory arbitrage by moving production, for example, to poorer countries with less or no oversight.
- Even when laws are well-drafted, enforcement is often inadequate—and such laws can have unintentional consequences. In China, for example, which leads in areas like wastewater treatment, it costs a producer hundreds of thousands of dollars to test a new chemical; however, the fine for not bothering to register is about US$1,000, which creates an incentive to release untested chemicals on the market. And in many nations, it is cheaper to break the law than follow it—assuming firms even get caught.

The solution is for nations to act in concert and on an international basis, and this includes better funding for enforcement agencies. Acting in concert would also benefit industry—after all, it makes no sense for a producer to test the same chemical in 50 countries if there were instead an internationally recognised assessment system that allowed companies to undertake a single safety test that was accepted globally.

Countries can do better in other areas too. As noted earlier, the regulatory process typically assesses only single chemicals, not mixtures. However, many chemicals—pesticides being one example—when considered on their own have limited toxicity, yet when a surfactant is added can become highly toxic. That additive, however, is not something that regulatory processes currently take into account. They should.

It is also the case that developing nations need far more funding and assistance to help them implement best practices at home in areas like regulation, enforcement and reporting. Helping countries to build capacity in reporting, for example, would see data used in a more systematic and comparable manner, which would help to monitor progress and drive improvements globally.[108]

Greater focus is needed on 'green' and 'sustainable' chemistry, where much promise lies for chemical pollution. But without clearer definitions for these terms, chemicals companies will paint themselves greener than they are

Another area that requires a heightened focus is that of green chemistry and sustainable chemistry, where much of the promise in tackling marine chemical pollution lies. However, even the terms "green chemistry" and "sustainable chemistry" are insufficiently defined in law in Europe and elsewhere, says Dr Aleke Stöfen-O'Brien. That has allowed chemicals companies to create definitions that favour their industry, and allow them to paint themselves as greener or more sustainable. While using such weaknesses in the regulatory framework to the industry's advantage is smart business, it also heightens the risk of greenwashing. Consequently, a key step for policymakers is to define the terms "green chemistry" and "sustainable chemistry".

Additionally, although the green chemistry industry has been in existence for two decades, the adoption rate is still low. As noted below, funding to encourage green and sustainable chemistry would help to promote its uptake, while policy measures can help to level the playing field between innovators and less progressive chemicals players, including by crafting incentives to pursue green or sustainable chemistry solutions.

Among the policies that have been shown to work are those that foster investment in green chemistry research and development, preferential status on government contracts, and certification programmes that help customers and end-users to choose more sustainable options.[109]

Some countries have implemented policies to promote green chemistry in governance, industry and education, including Canada, China, South Korea, Japan, Taiwan, the United Kingdom and the US.[110] There has been progress at the international level too. In 2017, the United Nations Industrial Development Organization (UNIDO) launched its global Green Chemistry project to boost awareness of its technologies, using it to "bridge the gap between the science of green chemistry and real-world application of green chemistry approaches".[111] Another UNIDO project, the Transfer of Environmentally Sound Technologies (TEST), provides small- and medium-sized enterprises with tools to improve business operations as they move towards sustainable production, and helping them to curb pollution.[112] A third, by UNEP, is its Green and Sustainable Chemistry Framework Manual that provides a high-level view of green and sustainable chemistry, and which is the first of a series of manuals on the subject.[113]

Boosting the adoption of green chemistry and sustainable chemistry, however, requires funding. One focus is to provide educational materials and training for teachers and students at secondary and tertiary institutions. Another is to provide basic training in environmental and public health factors for chemists, who could incorporate that knowledge when deciding which chemicals to use in products by screening them for adverse behaviours like toxicity, bioaccumulation and persistence. This would provide a relatively easy way to end the use of dangerous chemicals, and could save the industry money as it would not need to redesign products at a later stage.

Intervention 8. Funding to measure the impact of chemicals

One of the clearest messages to emerge from this study is that the amount of **funding available for research** to assess the impact of chemicals on the marine environment is woefully insufficient—at both the national and international levels. Given that the global chemicals market is likely to double by 2030 from 2017 levels, further increasing the chemical load on the marine environment, the need to act is clear. [114]

The amount of funding available for research to assess the impact of chemicals on the marine environment is woefully insufficient—at both the national and international levels

Doing so requires an approach that puts funding for ocean science on a sustainable footing, as UNESCO notes in its Ocean Science Roadmap, which found that the COVID-19 pandemic saw funding for marine World Heritage sites cut sharply. As a result, some essential monitoring was not carried out. A lack of funding, UNESCO states, is "the most pertinent obstacle to ocean research at marine World Heritage sites".[115]

In addition, as UNEP has stated, increased funding for research on chemicals and waste management would help to close existing gaps, meet priorities and inform policymakers. It would also allow for a global study that would determine the benefits of action and the costs of failing to act on chemicals and waste management.[116]

Funding could also help to extend the use of highly efficient and innovative technological solutions like artificial intelligence in monitoring marine environmental changes—for example, assessing satellite images of seagrass meadows so that researchers can determine their health and the effectiveness of restorative actions.[117]

It is also crucial that funding be made available to developing nations, which are typically not part of the conversation, says Dr Stöfen-O'Brien, despite the fact that they are the first to feel the brunt of chemical pollution through plastics and contamination of fish. Many lack the capacity and the ability to monitor, and as a result "we know almost nothing about marine chemical pollution in the Global South".

"These externalities imposed by chemical companies with a global reach must be considered," she says. "And funding needs to be much more structural and reliable. It needs to start with education, with regional knowledge centres based on specific regional chemicals, with strong monitoring and assessment programmes—and you need to have an inventory of what's going on. This might then lead to suitable evidence-based policy and regulatory measures."

Intervention 9. Make the polluter pay

The lack of sufficient funding for poorer nations is a well-known hindrance for better chemicals management. One **innovative fiscal measure** was the subject of a 2020 report by the Center for International Environmental Law (CIEL) and the International Pollutants Elimination Network (IPEN).

Given the difficulties of imposing a direct "polluter pays" tax, it proposed levying a 0.5 percent tax on the volume of feedstock chemicals—the basic chemicals produced from natural gas and oil, and that are the building blocks for almost all chemicals.

With 2018 sales of basic chemicals worth US$2.3 trillion, the tax would raise an estimated US$11.5bn, or about 85 times the total annual sums currently allocated to global chemicals management. This sum, it notes, "has the potential to generate sufficient financing for the global sound management of chemicals and waste".

"Such a fee places the financial responsibility for chemicals and waste management where it belongs: on the industries profiting from the production of those chemicals," the report notes. "The fee would be collected by the country where the company producing basic chemicals is registered and be paid to a global fund."

The proceeds would support "regulatory capacity, infrastructure, information and monitoring systems, and waste management and clean-up systems".

In this way, the 0.5 percent tax would help countries to implement the principle that the polluter pays, and would create a level playing field for the chemicals industry, as every manufacturer of feedstock chemicals would be taxed equally.

"Further benefits of the plan include that it would use existing domestic regulatory infrastructure to collect the taxes or fees while avoiding the challenges of delegating taxation authority to an international body. It is also in accordance with World Trade Organization law and would not affect consumer pricing," the report states.

At the time of writing, the issue of financing is one that the Strategic Approach to International Chemicals Management (SAICM) is working on, with an assessment of industry involvement in financing the sound management of chemicals and waste. That review came about after two reports—one by UNEP and the other by SAICM—that highlighted shortcomings on industry's part.

UNEP's report noted gaps "including lack of clarity of what counts as industry contributions, absence of a mechanism for tracking activities and financial flows, and poor understanding of industry involvement at the national level", while SAICM concluded that "insufficient progress had been made in taking forward the mainstreaming and industry involvement components of funding identified in the Integrated Approach to the sustainable financing of sound management of chemicals and waste proposal". In short, industry has not done enough.[118]

Taxation is one potential solution, but other fiscal measures are also possible. Among those highlighted in SAICM's review are:[119]

- The removal of harmful subsidies for high-risk substances, which is a particular issue with agrochemicals.
- Using subsidies to encourage good behaviour by industry by, for example, recognising steps taken to internalise costs, engaging in best practice and adhering to national or international regulations. Subsidies can also be used to fund public investments in research and development of sustainable chemical solutions.
- And using tradable permits to phase out harmful chemicals, and which can be of particular use as a policy to control agricultural pollution.

Intervention 10. Promote efforts to restore ocean health

The tenth solution is for countries to take steps to restore ocean health in their waters. Once again, Europe's legislative steps provide some useful best practice lessons including banning certain single-use plastic items and microbeads, ensuring that ships offload waste only at ports, and reducing the flow of pollutants into the rivers and seas.

There are many other steps that countries can take to mitigate marine chemical pollution, including:

- Protecting more of their nation's seas and ensuring that existing protected areas are not harmed.
- Curbing overfishing and other destructive practices.
- Working to reduce marine chemical pollution, including the excessive use of nitrogen fertilisers, and the influx of sewage and plastics.
- Using fiscal measures to encourage improved corporate and agricultural behaviour that will benefit the seas.
- And engaging in regenerative efforts such as planting kelp forests and encouraging the growth of shellfish populations—these steps can improve water quality by removing nitrogen and phosphorus, reduce CO_2, boost oxygen levels and provide improved habitats for other marine life.[120]

Lastly, given the imbalance in knowledge and capacity between developed and developing countries, nations in the Global South could partner with each other and with wealthy nations. This would not only bring access to expertise that might be lacking; it would also ensure that best practice lessons could be passed on, and that failures were not duplicated.

One such example is between Mauritania's Banc d'Arguin National Park and the Wadden See (Germany, Netherlands and Denmark), whose twinning agreement sees them jointly monitor migratory birds. Another, this time between rich countries, has seen the US's Glacier Bay National Park work with Norway's Geirangerfjord and Nærøyfjord to determine how best to reduce the impacts that cruise ships have on their marine environments.[121]

"From harm to harmony"—the legal effort to define the proposed crime of ecocide

In 2021, a panel of twelve international legal experts drew up a definition for the proposed crime of ecocide, which they hope will be added to the Rome Statute of the International Criminal Court. The definition was drafted after a global public consultation with, among others, youth, faith and indigenous groups.[122]

The reason for acting, the Stop Ecocide Foundation explained, was because science has shown that "the emission of greenhouse gases and the destruction of ecosystems at current rates will have catastrophic consequences for our common environment". It noted that international law has a role to play alongside initiatives in the political, diplomatic and economic arenas in shifting humanity's relationship with the environment "from one of harm to one of harmony".[123]

"Despite significant progress, the inadequacies of current global environmental governance are widely acknowledged," the foundation stated. "National and international laws are in place to contribute to the protection of the natural systems upon which our well-being depends, yet it is apparent that such laws are inadequate and more is needed."[124]

Should ecocide be added, it would join the other four international crimes: genocide, crimes against humanity, war crimes and the crime of aggression.[125]

The panel defines ecocide as "unlawful or wanton acts committed with knowledge that there is a substantial likelihood of severe and either widespread or long-term damage to the environment being caused by those acts".[126]

The idea of enshrining ecocide in international law has some high-level support. France's President Emmanuel Macron is in favour, as is Pope Francis who called on the international community to recognise the proposed crime. Should that happen, though, it would take years. [127]

In the meantime, those behind the push recognise that the proposal's mere existence could improve corporate behaviour—including by influencing how banks and insurers view potentially damaging projects. The campaign, said panel co-chair Philippe Sands QC, is adding to what is already underway: "A change of consciousness." [128]

What next?

In the view of the experts interviewed for this report, those ten steps would move the world from inaction—or insufficient action—to action on marine chemical pollution. That said, much of what is needed relies on the chemicals industry playing its part. But, as is clear, business has a chequered history when it comes to this, not least because it operates in opaque ways and with commercial, rather than environmental, priorities.

Yet while business often gets blamed for its failure to act on early warning signals about the harm that products or operations can do, this fails to account for the environment in which firms operate, where decisions are influenced by a range of factors beyond mere profit-seeking behaviour.[129]

As the EEA concluded, in nearly every case businesses failed to take account of early warning signs. Instead, they chose to focus on short-term profit. That held true for asbestos, lead in petrol and insecticides, to name just a few

Profit, though, is a powerful motivator. Part of the problem is that its influence is compounded by standard economics metrics that favour ignoring external risks to human health or the environment—unless those are likely to see the company sued, run afoul of regulators or harm its reputation. As the EEA report concluded, nearly every case that it reviewed saw businesses fail to take account of early warning signs that were available. Instead, they chose to focus on short-term profit. That held true for asbestos, lead in petrol, insecticides and fishing methods, to name just a few.[130]

The implication is that business was in many cases given too long a leash.

"Numerous case studies show that decisions to act without precaution often come from businesses. There are, however, several impediments to businesses acting in a precautionary manner, including a focus on short-term economic value for shareholders alongside psychological factors that lead to a so-called 'ethical blindness' or a 'self-serving bias', whereby people largely interpret ambiguous situations in their own interests," it states.

That echoes the conclusions of the Dasgupta Review, as noted in the previous chapter, which highlighted market failure as a key reason for the destruction of the environment.[131] With that said, it is time to turn to the other stakeholders in the effort to turn the tide on marine chemical pollution: the chemical industry itself, but also business in general (including banks and insurers), civil society and consumers.

Please see Notes for references

6: Industry

This chapter looks at the role of the chemicals industry in marine chemical pollution, assesses the steps it and its clients need to take, and looks at the risks it faces should it not act. It also examines pathways to progress (including green chemistry), assesses barriers to change, and concludes with a roadmap for industry-led action.

6.1 Principal findings and recommendations

- **The chemicals industry and companies along the chemicals value chain can have a massive impact on resolving marine chemical pollution.**
  Actions by the chemicals sector, encompassing fossil fuel-based commodity chemicals, specialty chemicals, pharmaceuticals and agricultural chemicals, present perhaps the most compelling opportunity to address marine chemical pollution. Yet the industry is sprawling, diverse, intertwined in long and complex global supply chains and dependent on capital-intensive infrastructure and processes that operate at low margins and demand huge scale. Change will be a complex, expensive and fraught process.

- **Failure to change may lead to an existential crisis for chemicals companies.**
  The chemicals sector is enormously dependent on fossil fuels, both as feedstock and to power its energy-intensive processes. If the industry does not begin to face up to looming climate-related regulatory and financial pressures, it will face an existential crisis. This necessary but painful transition can, and should, address the industry's impact on the marine environment as well as on climate.

- **Efforts to date have been piecemeal; real impact will require cultural and systems-level change.**
  Positive signs are beginning to emerge that parts of the industry take sustainability seriously, although there is little sign yet that activity by companies and sectoral consortiums has translated to widespread impact. There are numerous drivers of change. European chemicals giants, subject to relatively strict EU rules, are leading the way. Around the world, consumers and financiers are beginning to demand greater transparency about the industry's impact. Shareholders will need to recognise the long-term risk to the chemicals sector of not adopting greener business models, and be prepared to bear some of the shorter-term costs of transition.

Importantly, efforts to transform must include smaller producers in the value chain—and organisations in geographies like Asia and the Middle East, which will become increasingly important centres of chemicals production.

- **Momentum is growing for a circular economy; the bid to address plastic waste may help drive change.**
There are viable pathways for change. Growing segments of the industry have pledged to tackle plastic pollution. While some companies and industry groups still insist that recycling while producing ever-larger quantities is a solution, others have begun to acknowledge that a genuinely circular economy will require radical product redesign and may result in reduced sales. That such momentum has developed in the industry around plastic waste in the past five years or so suggests that an industry-led approach to tackling *liquid* pollution in the ocean is also possible.

The most exciting path to change rests on a quality inherent to the modern chemicals industry: scientific innovation. Green chemistry offers an opportunity to design high-performance products that are less toxic and less polluting

- **Green chemistry innovation may hold the key to sustainable change.**
The most exciting path to change rests on a quality inherent to the modern chemicals industry: scientific innovation. Green chemistry offers an opportunity to design high-performance products that are less toxic and less polluting. In many cases the technology already exists, and there is a vibrant green chemistry start-up scene. The usual roadblocks are there: the transition is slow, costly and difficult. Currently fewer than 2 percent of patent applications for chemicals are green, although green chemistry's share of the market is growing fast. Acquisitions of green chemistry start-ups may offer a cost-effective way for incumbent chemicals companies to introduce new, more sustainable products at scale.

- **Change is required along the value chain.**
It is not just the chemical industry itself that will have to transform. Downstream users are often hesitant to change the way they use chemicals in their products and manufacturing processes due to cost. Chemical companies and their customers will need to innovate collaboratively. The question is one of where chemicals producers' responsibilities begin and end: the chemicals industry favours a risk-based approach to assessing product safety and sustainability that fails to consider "leakage" through the lifecycle. Regulations typically do not consider production or end-of-life impacts, while consumers do not always understand that products can contain potentially toxic compounds that lead to pollution. The burden of proof in demonstrating which chemicals damage the marine environment currently lies with the government and civil society—not with the producer.

- **An industry wish list: six steps on the path to combating marine chemical pollution.**

1. **Innovation**: develop new, more sustainable products and processes, and shift from a risk-based approach to a hazard-avoidance one.

2. Create **commercial incentives** to change: if the private sector is to play a critical role in addressing marine chemical pollution, market conditions must allow it to profit from doing so.

3. Create an industry **coalition of the willing** to help mitigate "first mover disadvantage"

and that brings together industry players with other stakeholders from finance, governments and civil society.

4. Increase **transparency and collaboration across the supply chain**: chemicals users can demand greater openness about polluting and hazardous inputs into their products.

5. **Improve processes and practices for chemicals users**: best practices are also emerging in the agriculture, aquaculture and waste management sectors that demonstrate a pathway for using and managing chemicals more responsibly.

6. Conduct a conversation on **extended producer responsibility**: to tackle marine chemical pollution effectively, chemicals producers will need to accept more responsibility for what happens to their products after sale.

The only real solution is a systems-level change: it is unrealistic to expect the chemicals sector to shift voluntarily at the scale and speed required. In practice, this means a multitude of overlapping push and pull approaches

Actions by the private sector present perhaps the most significant opportunity to address marine chemical pollution. Promising developments in green chemicals, which can be profitable for industry and less polluting to the marine environment, offer a tantalising glimpse of a future ocean-friendly chemicals sector. World-leading consumer brands from footwear to furniture, responding to increasingly eco-conscious customers, are beginning to demand transparency and a more significant say over the chemicals that go into their products. Innovative technology and practices promise to transform how farmers think about using chemicals on land and at sea.

Yet while encouraging changes are happening, they are small in scale. Legacy business models still constrain the majority of the chemicals sector. Improved industry and agricultural practices can help reduce the amount of chemical waste reaching the ocean, but this will not be enough on its own. Products from building materials to shampoo bottles will need to be redesigned. Transforming systems, processes and supply chains is hugely complex and capital intensive. The commercial payoff is uncertain and distant.

The only real solution is a systems-level change: it is unrealistic to expect the chemicals sector to shift voluntarily at the scale and speed required. In practice, this means a multitude of overlapping push and pull approaches. On the pull side: There must be demand for more sustainable products as well as supply. Increasing consumer and retailer awareness (including, crucially, among small and medium-sized enterprises) about marine chemical pollution will be critical to ensure this demand increases. On the push side: shareholders must recognise the risk to the chemical sector of not transitioning to greener business models.

"The chemicals sector stands at an inflection point," says Guy Bailey, head of intermediates and applications at Wood Mackenzie, a consultancy that specialises in energy and chemicals. "It needs to address the environmental impact of its waste footprint and drastically reduce the greenhouse gas emissions associated with the production and consumption of its products."

Economic megatrends such as digitisation and carbon net-zero alignment present commercial opportunities for companies willing to be bold.[1] Currently, "the outlook is challenged by the environmental footprint of the sector," Mr Bailey notes. "If the industry cannot address the issue of mismanaged waste, its large and growing carbon footprint, air pollution or water consumption, some combination of regulatory intervention, investor exit or consumer revolt will clip the sector's wings."

6.2 Current approaches: Promising noises, little effective action

Marine pollution is "not on the industry's radar," says Anne-Sofie Bäckar, executive director of ChemSec, an NGO that works with businesses to reduce their use of hazardous chemicals. Most chemicals companies fulfil their regulatory obligations to manage wastewater in developed economies, says Ms Bäckar. Beyond that, "I don't think they consider how chemicals impact the ocean".

There are glimmers of hope: driven by consumer demand, tighter regulation, and increased investor scrutiny, some parts of the chemicals sector are beginning to consider their environmental footprint more holistically. Still, even among the most forward-thinking companies, marine chemical pollution is not a high priority (although some have policies to address plastic pollution).

ChemSec has analysed the world's 50 largest chemical companies and ranked them according to their use of chemicals of concern and green chemistry investments. The most recent results, released in late 2021, are sobering. The top scorer in the ChemScore index, Thai company Indorama Ventures, received a B grade. Dutch company DSM and US company Air Products received a B-. The remainder scored between C+ and D.

Encouragingly, several chemical producers have used the rankings as an opportunity to improve their score, says Ms Bäckar. Yet others have not. ChemScore found that while 76 percent of the 50 companies assessed actively market sustainable products, only 8 percent show evidence of a public strategy to phase out existing hazardous chemicals.[2]

"Our experience engaging with chemicals manufacturers regarding ChemScore rankings showed a surprising unwillingness to be transparent," says Eugenie Mathieu, a senior ESG analyst at Aviva Investors. Ms Mathieu uses the rankings to work directly with companies to improve their exposure to environmental, social and governance risks.

"Other sectors like food manufacturers are more advanced in their cooperation and dialogue with stakeholders, including key NGOs," she says. "Currently, it feels like the chemicals industry is taking a fairly passive attitude to engaging on sustainability. Like the tobacco industry did, there are many instances where companies in the industry deny a problem exists."

ChemScore ranks the world's 50 largest chemicals companies on their use of chemicals of concern[3]

Company	Country	Score	Grade
Indorama	THA	28.8	B
DSM	NLD	27.9	B-
Air Products	USA	24.8	B-
Avery Dennison	USA	22.6	C+
Johnson Matthey	GBR	20.2	C
Toray Industries	JAP	18.2	C
Air Liquide	FRA	18.0	C
Linde	DEU	17.5	C
Mitsubishi PLC	JPN	17.4	C
Lyondell Basell	NLD	17.2	C
Akzo Nobel	NLD	16.6	C
Sherwin-Williams	USA	16.6	C
Yara Intl.	NOR	16.1	C-
Covestro	DEU	16.0	C-
Mitsui Chemicals	JPN	15.9	C-
Sumitomo Chem	JPN	15.7	C-
Nan Ya Plastics	TWN	15.1	C-
BASF	DEU	15.0	C-
Nutrien	CAN	14.6	C-
Evonik Industries	DEU	14.0	C-
Nitto Denko	JPN	13.8	C-
SABIC	SAU	13.2	C-
Westlake Chem	USA	12.7	D+
Braskem	BRA	12.5	D+
LG Chem	KOR	12.4	D+
Ecolab	USA	12.3	D+
Lanxess AG	DEU	12.0	D+
Asahi Kasei Corp	JPN	11.6	D+
Lotte Chemical	KOR	11.4	D+
Mosaic USA	11.4	D+	
Sasol	ZAF	11.2	D+
PPG Industries USA	11.0	D+	
Eastman Chemical	USA	11.0	D+
Shin-Etsu Chem	JPN	11.0	D+
Bayer	DEU	10.6	D+
Dow	USA	10.5	D+
Corteva	USA	10.4	D+
Dupont Nemours	USA	10.4	D+
Showa Denko	JPN	10.1	D+
Tosoh Corp	JPN	9.7	D+
Umicore	BEL	9.2	D+
3M	USA	9.2	D+
Arkema	FRA	9.0	D+
Solvay	BEL	8.0	D
DIC Corp	JPN	8.0	D
PTT Global Chem	THA	7.1	D
Hanwha Solutions	KOR	5.1	D
Wanhua Chem	CHN	4.5	D-
Formosa Chem	TWN	3.6	D-
Sinopec Shang-A	CHN	3.6	D-

Source: ChemSec (2021)

Producers: recognising commercial opportunity

Nevertheless, as corporate sustainability becomes mainstream, encouraging examples of chemicals companies embracing new business models and transitioning to greener products are emerging. In Europe, where the strict REACH legislation is driving widespread change, this trend is particularly evident. Several chemicals companies report that environmentally sustainable products and solutions account for a growing share of revenue.

As corporate sustainability becomes mainstream, encouraging examples of chemicals companies embracing new business models and transitioning to greener products are emerging

BASF, a German chemicals conglomerate, publishes a Sustainable Solution Steering Methodology to enable its customers to assess the sustainability of each of the BASF products it uses. The company has identified more than 16,000 accelerator solutions to help customers reduce their environmental impact. BASF plans to sell €22bn worth of these products—about one-third of the company's revenue—by 2025. In 2020, BASF generated sales of €16.7bn with accelerator products.[4]

Sumitomo Chemical, a Japanese company, has launched an initiative called Sumika Sustainable Solutions (SSS) to identify products and technologies within its portfolio that contribute to climate change, reduce environmental burdens and improve natural resource efficiency. As of 2021, Sumitomo Chemical had designated 57 of its products or technologies as SSS products, accounting for 20 percent of revenues.[5]

Clariant is a Swiss manufacturer of specialty chemicals. In 2020, around 8 percent of its sales were generated by what the company calls "sustainability leading products", says Richard Haldimann, Clariant's head of sustainability. Yet while this number seems small, "sales of these products are growing at one and a half times as fast as the average of the portfolio," Mr Haldimann says.

Leading companies are also beginning to consider more carefully the health and sustainability impacts of their products. Dutch multinational DSM, for example, assessed its entire product portfolio in 2020 to determine which products contain substances of very high concern (SVHC). SVHCs include "CMR (Carcinogenic, Mutagenic or Reprotoxic), PBT (Persistent, Bio-accumulative and Toxic) and vPvB (very Persistent very Bio-accumulative), respiratory sensitisers, endocrine-disrupting chemicals, and suspected CMRs". DSM has developed an action plan for each product found to contain more than 0.1 percent SVHC, which includes risk-reduction and considers possibilities for replacement.[6] Other chemical companies, such as Dow Chemical, are undertaking similar initiatives.

Clariant now assesses its products against 36 sustainability-related criteria, but "this has been a journey over the past ten years," says Mr Haldimann. "It's not been super-fast, but it has been thorough. We now have businesses that won't consider an innovation project if it doesn't have a certain specific sustainability benefit."

Sector-led initiatives

For those companies thinking about how to transition, there are several industry-led initiatives and frameworks to guide them. Responsible Care is a voluntary initiative led by the International Council of Chemical Associations (ICCA) in which signatories commit to governance and sustainability principles (see box). Some 580 CEOs representing 96 percent of the world's largest chemicals companies have signed up to the charter, according to the ICCA.[7] Yet, as with

The Responsible Care Charter

Signatories of the Responsible Care Charter agree to adhere to six principles:

- Enable a corporate leadership culture that proactively supports safe chemicals management.
- Safeguard people and the environment by continuously improving our environmental, health and safety performance, facility security, and the safety of our products.
- Strengthen chemicals management systems around the globe.
- Work with business partners to promote safe chemicals management within their operations.
- Engage with stakeholders, respond to their concerns and communicate openly on our performance and products.
- Contribute to sustainability through the development of innovative technologies and other solutions to societal challenges.[8]

other industry-led initiatives, Responsible Care is voluntary. Several regional industry bodies have proposed more ambitious frameworks.

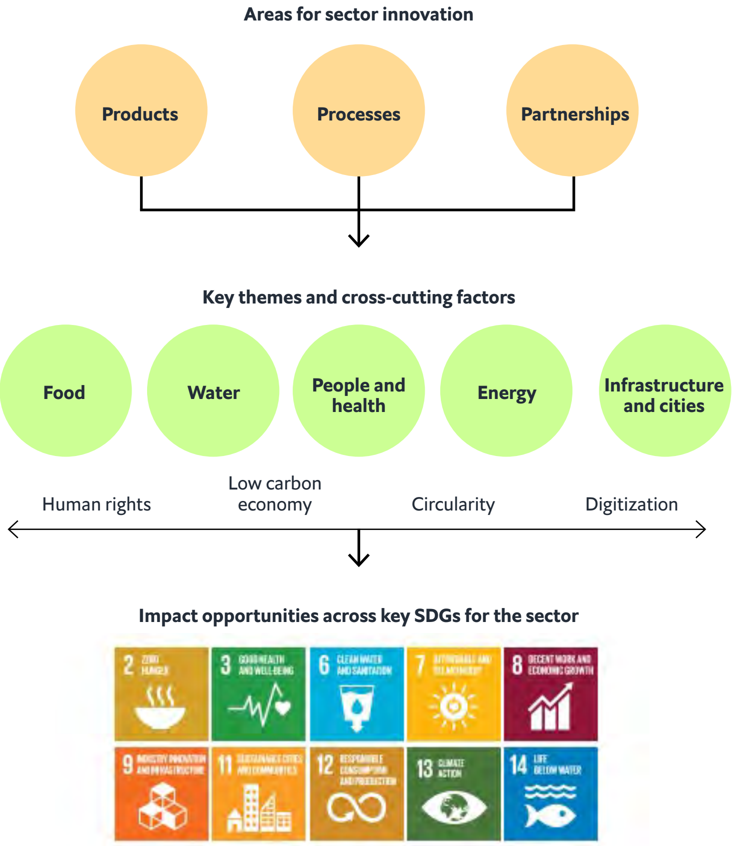
Cefic, the regional body representing European chemicals companies, has developed several sustainability-focused initiatives alongside Responsible Care. As well as a sustainability charter,[9] it is developing a set of Sustainable Development Indicators (SDIs) to align the industry with the European Green Deal.[10] Circularity, climate, environment and SDGs account for four of the eight pillars of Cefic's long-term industry vision.[11] In October 2021, Cefic published a report, *Sustainable by Design*, which proposes a pathway for the European chemical industry to "bring chemicals, materials, products and technologies to the market that are safe, bring environmental, economic and/or social value through their applications, are accelerating the transition towards a circular economy and climate-neutral society and prevent harm to human health and the environment."[12]

Together for Sustainability (TfS), a global network of 31 chemicals companies, claims to be the de facto international standard for chemical supply chains' environmental, social and governance performance, aligned with the UN Global Compact and ICCA's Responsible Care principles. Member companies commit to conducting a minimum number of assessments and audits of their suppliers each year.[13]

Broader sustainability initiatives such as the UN Global Compact and the Sustainable Ocean Principles, produced in consultation with over 300 stakeholders, provide a framework for responsible business practices across sectors and geographies to achieve SDG 14.

The chemicals sector working group of the World Business Council for Sustainable Development (WBCSD), which includes a global group of 11 large chemicals companies as well as Cefic and the American Chemistry Council (ACC), has adopted an SDG Roadmap. The roadmap, it says, will enable the industry to "explore, articulate and help realise the potential of the chemicals sector to leverage its influence and innovation to contribute to the SDG agenda".[14]

How the chemicals sector can contribute to the UN Sustainable Development Goals



Source: World Business Council on Sustainable Development Chemicals Sector SDG Roadmap (2018)

These early examples are encouraging, yet more widespread adoption of these principles will be necessary to achieve a zero-pollution ocean. "The manufacturing sector needs to take into account what the lifecycle cost of the current product portfolio will be ten years in the future, when increased true value-costing, new regulation and changing customer demand may add considerably to the total cost," says Marcel van den Noort, senior director, chemical industry at the WBCSD.

Chemicals companies that want to improve their environmental performance should, as a first step, undertake a Portfolio Sustainability Assessment (PSA), says Mr van den Noort. The WBCSD has developed a PSA methodology for the chemicals industry, which it says enables them to "proactively steer their overall product portfolios towards improved sustainability outcomes".[15] This type of assessment is becoming more commonplace but is still not ubiquitous across the industry.

"Many front-running companies are doing a great job applying this and report improved decision-making, a higher growth rate of their sustainable solutions and much stronger, positive, stakeholder relationships. Not thoroughly assessing one's portfolio today and taking subsequent appropriate decisions will put companies adhering to a wait-and-see strategy at a disadvantage," says Mr van den Noort. "Some will be caught by surprise."

"Rapid improvements in technology mean we can measure pollutants in the ocean at ever lower concentrations now than just ten years ago, and this will continue to improve," says Mr van den Noort. "This means that we are developing a much better picture of the true extent of pollution."

Assessing the total lifecycle impacts and cost of products is essential in improving the industry's environmental footprint, but ultimately, many products will need to be redesigned.

"Industry can put controls on chemicals in place at different points of the lifecycle, but if they don't go back and redesign products to eliminate the toxic chemical in the first place, the problem will remain unsolved," says Joel Tickner, professor at the Lowell Center for Sustainable Production at the University of Massachusetts Lowell and executive director of the Green Chemistry & Commerce Council. "Chemical pollution is increasingly not simply a manufacturing emissions problem, it's a product problem."

As Mr Tickner and his colleagues write in a 2021 article in the journal *Environment: Science and Policy for Sustainable Development* (see box), the industry has not yet begun to grapple with the more fundamental changes that will be required if it is to transition to a low-pollution future. Current initiatives are steps in the right direction, but "they focus on minimizing the impacts of the same chemistries and materials made in the same facilities with the same processes".[16]

A transition plan for an existential crisis

The chemicals industry must adopt a credible transition strategy to meet a series of "existential" sustainability and commercial challenges, according to a paper published in late 2021 by Joel Tickner, Ken Geiser and Stephanie Baima in the journal *Environment: Science and Policy for Sustainable Development*.

The paper describes an industry "mired in the status quo" that has "lost its once-lauded innovation leadership". Tied to hugely capital-intensive and fossil fuel-dependent infrastructure, with low margins that have eaten into R&D budgets, the authors argue that the chemicals sector must adopt a transition strategy that would address:

- Its dependence on fossil fuel feedstocks, which—while also environmentally damaging—present an enormous financial risk to the industry.
- Capital investments in fossil fuel-based infrastructure which make a genuine sustainability transition financially unviable.
- Vulnerability to supply chain disruptions.
- Falling research and development budgets that impede innovation.
- Carbon emissions.
- The impact of chemicals on health and ecosystems.

Without an urgent and complete reinvention, the authors argue, the chemicals sector will not be able to meet the environmental and financial demands it will face in the coming decades.[17]

Can the industry innovate itself to sustainability?

Perhaps the most exciting pathway to addressing marine chemical pollution, then, lies in the very essence of the chemicals industry itself: science.

Green chemistry (sometimes known as sustainable chemistry) is "the utilisation of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products."[18] There are several industry-led efforts to accelerate the adoption of greener chemicals. The Green Chemistry & Commerce Council (GC3) is key among these. This multi-stakeholder collaboration "drives the commercial adoption of green chemistry by catalysing and guiding action across all industries, sectors and supply chains".[19]

As well as several working groups which bring together industry sub-sectors, GC3 runs a Startup Network to connect green chemistry entrepreneurs with incumbent chemicals suppliers and users to accelerate investment in and markets for these companies.[20] Partnerships between large chemicals companies and start-ups provide a critical pathway for innovation in green chemicals, says Mr Tickner. And as the following section discusses in more detail, acquisitions of green chemistry start-ups offer a cost-effective way for incumbent chemicals companies to introduce new, more sustainable products at scale.

The chemicals industry itself also clearly sees value in these types of collaborations. Cefic, the European chemicals industry body, also runs its own Future Chemistry Network, which it says is a "global innovation hub and a hotspot for investments into breakthrough climate-neutral and circular technologies".[21]

The green chemistry start-up scene is vibrant, with several emerging companies valued at hundreds of millions or even billions of dollars.[22] Examples include:

- P2 Science, founded by one of the fathers of green chemistry, Paul Anastas, which uses "patented green chemistry processes to convert bio-based feedstocks into high impact specialty chemicals used by consumer-facing and industrial companies around the world."[23]
- Germany DexLeChem, which uses water-based chemical manufacturing to replace crude oil-based solvents in pharmaceuticals.[24]
- US-based Lygos, which produces "sustainable organic acid specialty chemicals and bio-monomers" for use in industrial and consumer products.[25]
- Japan's Green Earth Institute, which produces biofuels and green chemicals including resins, carbon fibres and feed additives.[26]
- Solugen, which opened the world's first carbon-negative molecule factory.[27]

The road to innovation is not always a smooth one, even for existing and well-resourced companies. The example of Omnia, a high-performance solvent produced by Eastman, an American chemicals company, is illustrative. After identifying cleaning products as an area with high demand for a more sustainable and less hazardous alternative, Eastman's chemists narrowed down a list of 2,400 solvents to a possible list of 70 molecules based on a series of toxicity tests. They then determined that 20 could be manufactured cost-effectively and subjected the final list to an additional battery of tests. They decided that the final candidate molecule was safer than traditional solvents: biodegradable and non-toxic to humans and aquatic life. A final round of tests showed that the candidate molecule was equally as effective as conventional solvents at cleaning surfaces.

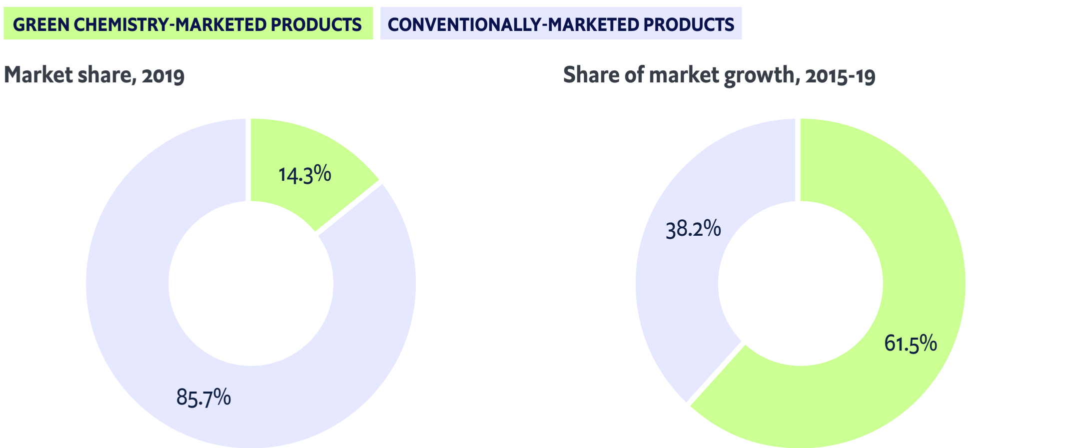
Yet the market was slow to adopt Omnia. Producers of cleaning products did not see a compelling reason to change their product formulations, which they saw as "safe enough". After Eastman's chemists visited 200 cleaning product manufacturers across the United States and Canada, demand for Omnia began to increase.[28]

"Omnia failed at first because customers are so used to the incumbent," says Mr Tickner. "They didn't want to pay for the cost of reformulating their products."

The thinking of many cleaning product manufacturers was, "incumbents work well and aren't restricted, so why would we change?" he says. The lesson is cautionary: chemicals companies have little incentive to produce less-polluting products unless customers demand it and are willing to pay for it, or regulations require it.

Green chemistry is not yet widespread. A previous study suggests that fewer than two per cent of chemical products are from green chemistry, says Zhanyun Wang of the Technology & Society Laboratory, Swiss Federal Laboratories for Materials Science and Technology (EMPA).[29] Yet it does account for a growing segment of the market. Research published in 2021 by the University of Massachusetts Lowell and the GC3 found that while green chemistry-marketed products account for a relatively small share of the overall chemicals market, that share is growing—driven by both customer demand and increasingly stringent regulation.[30]

The growth of green chemistry



Source: Green Chemistry & Commerce Council[31]

Reduce, reuse, recycle?

One emerging and often-touted solution to pollution is chemical recycling, which promises to help close the material and value chain by converting used chemicals into commercially viable products before they become waste. The UK Research and Innovation (UKRI) Interdisciplinary Centre for the Circular Chemical Economy, for example, is currently working with 20 multinational companies and SMEs to develop commercially viable solutions to recycle widely used chemicals such as ethylene and propylene.[32] Plastic recycling is attracting significant commercial and investor interest. Saudi Arabian chemical company SABIC has developed a portfolio of circular products and services it calls "Trucircle". Examples of products already in commercial production include recycled ice-cream containers and pet food packaging.[33]

There are downsides. Chemical recycling is more resource-intensive than mechanical recycling, releasing carbon emissions during the process which could reduce its utility in efforts to decarbonise the chemicals sector.[34] The technology has a lot of benefits, but there are still questions about its viability, says Mr Tickner. "At this point, it's not economically viable at large scale because fossil fuels are so cheap—and we still have very little knowledge about the emissions produced during the chemical recycling process."

Dilution is no solution: Treating liquid waste

Perhaps the most effective way to address marine chemical pollution is to stop liquid waste entering the ocean in the first place. This means capturing and treating industrial, agricultural or municipal waste before it reaches the sea.

The technology to capture and treat liquid waste—cost-effectively and at scale—exists, says Frédéric Madelin, head of the Liquid and Hazardous Waste segment of the French multinational Veolia. The main obstacle, he believes, is the enforcement of regulation. Often, there are rules that prohibit industry from releasing liquid pollutants. In practice, they are difficult to enforce, and liquid industrial waste often ends up in the sewerage system or in waterways.

Veolia has three "golden rules" when it comes to treating liquid waste, says Mr Madelin. The first is traceability. Information technology enables the company to work with ports, shipping lines, offshore oil rigs, factories and municipalities to track and sample each stage of a process to identify where hazardous waste exists and needs to be disposed of.

The second is no dilution. In many jurisdictions regulatory loopholes allow liquid waste to be released into the environment if it falls under a set toxicity threshold. Simply diluting the waste with water means it can be released without being treated. But, says Mr Madelin, "if we allow dilution, well, we might as well throw everything in the sea". Veolia declines to tender for projects which call for treatment via dilution, he says.

The third is treatment. Mr Madelin points to an experimental waste treatment facility that Veolia has developed in Huizhou, China, which uses incineration, chemical treatment and safe burial to manage hazardous waste generated by the energy, manufacturing and chemical industries. The critical feature of any treatment plant, says Mr Madelin, is that it allows no liquid waste to escape so there is no risk of marine contamination.

"Industries should treat waste in a proper way to avoid it being released in rivers, underground water or the ocean," Mr Madelin says. And while the technology exists to capture and treat waste at source, our ability to clean up pollution once it reaches the ocean is very limited. "Once it's in the sea, you cannot do anything. You are not going to decontaminate the whole ocean."

Down the supply chain: Addressing risk and responsibility

Innovation in products is certainly one potential solution, but solutions that do not recognise the downstream and lifecycle risks of chemicals in general are unlikely to stop chemicals ending up in the ocean.

The most effective way to address marine chemical pollution is to stop liquid waste entering the ocean in the first place. This means capturing and treating industrial, agricultural or municipal waste before it reaches the sea

One challenge is that, overwhelmingly, the chemicals industry favours a risk-based approach to assessing product safety and sustainability, says ChemSec's Ms Bäckar. In practice, chemicals producers often deem potentially hazardous chemicals low-risk if they are designed to be used in low concentrations or in settings where the risk of human or environmental exposure is low.[35] Yet a risk-based approach fails to consider "leakage" through the lifecycle, says Mr Tickner. " As an example, a flame retardant in an electronic product casing may be low risk, but when burned in an open landfill it creates exposures which the company doesn't consider."

The question is one of where chemicals producers' responsibilities begin and end. Most regulatory regimes allow chemicals producers to market certain hazardous or polluting chemicals if they are correctly labelled and used in a way that limits human or environmental exposure. Most households, for instance, own cleaning products that are toxic to humans if consumed. These products typically contain warning labels, and the responsibility lies with the consumer—not the producer—to ensure the products are used and disposed of correctly. Regulations typically do not consider production or end of life impacts.

In practice, consumers do not always understand that products can contain potentially toxic compounds that lead to pollution (such as oxybenzone in sunscreen). Yet the burden of proof in demonstrating which chemicals damage the marine environment currently lies with the government and civil society—not with the producer, says Alex Rogers, director of science at REV Ocean, a privately funded ocean research and expedition vessel. "This is a major problem," he says, and one which the chemicals industry seems mainly unwilling to address.

Use less, pollute less

There are encouraging examples of innovative practices along the chemicals supply chain helping to reduce marine chemical pollution, which—if deployed at scale—could have a profound positive impact.

Aquaculture is a significant contributor to marine chemical pollution, yet promising industry-led solutions are beginning to emerge. Integrated aquaculture pairs different species and organisms together to create an integrated "food web" like a biodynamic farm on land. Shellfish such as mussels and oysters feed on the excess food and faecal matter that escapes from fish farms. Macroalgae reduce the need for pesticides and become a feed-source for fish. Artificial lagoons or wetlands can purify water from land-based aquaculture sustainably.[36]

Co-culturing, or growing different fish species together, can reduce pathogens and therefore the need for antibiotics—as can vaccines. Cargill, a global food corporation, is one of the world's largest feed suppliers for the aquaculture industry. It has reduced antibiotics sold in medicated salmon feeds by 80 percent since 2015.[37]

As Chapter 2 explained, agriculture is one of the most crucial sectors for marine chemical pollution, with farm runoff one of the leading causes of marine pollution. One straightforward way to reduce fertiliser runoff is to use less of it. If China, Brazil, Mexico, Colombia and Thailand—some of the world's most significant users of fertiliser—adopted more efficient processes, they could reduce nitrogen pollution by around 35 percent—without a substantial loss of crop yield.[38]

Other, more high-tech solutions can help reduce fertiliser use too. Precision agriculture, which involves satellite data and remote-sensing technology, allows farmers to pinpoint precisely how much fertiliser is needed in specific areas, increasing yields while reducing both cost and pollution.[39]

Farmers are also beginning to implement both high- and low-tech solutions to reduce the amount of pollution that leaves their land. High-efficiency irrigation equipment can reduce water use (less water means less runoff), while on-farm water treatment facilities manage waste at the source. Nature-based solutions such as wetland buffer zones soak up pollutants before they reach waterways.[40]

Industry coalitions can provide businesses with the impetus to adopt these new practices in lockstep. Project Catalyst, a multi-stakeholder partnership between sugarcane growers and environmental NGOs in Queensland, Australia, is a leading example of the positive impact that improved farming practices can have on marine chemical pollution. By supporting farmers to enhance soil quality, implement chemical and nutrient management plans and improve water management, the project has significantly improved water quality in the adjacent Great Barrier Reef.[41]

Water credits: Policy innovations to reduce chemical runoff

Untreated urban wastewater, industrial and agricultural runoff are significant sources of marine pollution. Still, many countries have created a market for recovering, treating, and reusing wastewater before it reaches the marine environment by increasing the value of clean, unpolluted water.

Water quality trading schemes operate like carbon credits, allowing industrial and agricultural water users to buy and sell water rights at a variable price based on pollution levels, creating a financial incentive to lower pollution or treat polluted wastewater. Farmers and landowners in the Ohio River Basin in the US can earn Water Quality Credits—which have a monetary value of between US$12-14 per credit—by reducing nitrogen or phosphorus discharge into the water system. One pound of nutrient reduction earns one credit.[42] In Queensland, Australia, the Reef Credit Scheme pays farmers to reduce pollution reaching the Great Barrier Reef.[43]

Water quality schemes can also provide knock-on commercial opportunities, leading to a boom in farmers and landowners building, upgrading or "greening" water infrastructure. Novel financial instruments such as blended finance, help too. In Belize, Guyana and Jamaica, governments offer discounted loans to businesses to build and maintain wastewater treatment projects. Thailand's Kasikorn Bank offers discounted interest rates to waterfront hotels to finance wastewater and solid waste treatment facilities.[44]

The drawback to this type of scheme is that they tend to be local, so achieving scale is a challenge. But the principle—that businesses along the coastal fringe have a financial interest in reducing marine pollution—could be applied to larger schemes encompassing a more diverse range of industries.

Consumer-facing sectors such as cosmetics, healthcare, FMCG, furniture, technology and household goods can also play a critical role in forging solutions to marine chemical pollution and improving the overall sustainability of the chemicals industry

Consumer pressure further down the supply chain

Consumer-facing sectors such as cosmetics, healthcare, FMCG, furniture, technology and household goods can also play a critical role in forging solutions to marine chemical pollution and improving the overall sustainability of the chemicals industry. One major challenge is that producers of these products, which can have long and complex supply chains, are often unaware of the chemicals that go into their products. With few regulatory requirements to disclose the chemical make-up of products, and seemingly little interest from consumers in knowing, producers of finished goods have until now typically adopted a "don't ask, don't tell" approach—if they have thought about chemicals at all.

Growing consumer awareness of sustainability and product safety is driving change in some sectors.

"Companies that have a direct-to-consumer business model are getting serious about this problem because they risk a reputational hit," says Alix Grabowski, Director for Plastic & Material Science at the World Wildlife Fund (WWF). Several multinational consumer brands have taken an industry-leading approach to chemical management. These examples provide a roadmap for how other businesses and sectors can work to address marine chemical pollution.

Consumer goods companies' supply-chain policies on chemicals

Sportswear brand **Nike** publishes a "Chemistry PlayBook and Restricted Substances List", which it says is a "critical tool for helping suppliers understand how Nike defines chemistry and what they must do to demonstrate they're meeting our expectations".[45]

Sephora, a global chain of cosmetics stores, publishes a chemicals policy for its private-label products and third-party brands it carries. Sephora has an internal restricted substances list, which goes beyond the requirements of EU legislation, and uses independent auditing to ensure its products comply with the list. It has published a list of high-priority chemicals which it asks third-party suppliers to reduce or eliminate.[46] Almost 30 percent fewer products the chain sells contained high-priority chemicals in 2021 than in 2019.[47]

Furniture retailer **IKEA** requires that all suppliers adhere to strict requirements around chemicals in its products. IKEA carries out random site visits and conducts third-party tests of products in its supply chain.[48] Its chemical standards are often far stricter than legislation requires.

Technology giant **Apple** lists "smarter chemistry" as one of its three environmental priorities. Apple maps and catalogues all chemicals used along its supply chain and maintains a restricted chemicals list.[49]

Clothing manufacturer **H&M**'s chemical roadmap sets out a path to "toxic-free fashion" by 2030.[50]

Diversified consumer goods company **Unilever** maintains a dedicated Safety and Environmental Assurance Centre (SEAC), which conducts safety and sustainability assessments across its product range.[51] Unilever has committed to eliminating fossil fuel-derived chemicals in its cleaning products by 2030.[52] In 2021, it joined an industry task force convened by the Royal Society of Chemistry to explore scalable greener alternatives to polymers in liquid formations (PLFs) used in products such as shampoos, paints and adhesives.[53] Yet Unilever has also faced criticism for its ongoing use of disposable plastic packaging and microplastics,[54] demonstrating how challenging and complex the path to eliminating pollution can be even for those companies considered to be industry leaders.

Cosmetics multinational **Estée Lauder** published a peer-reviewed article in the journal *Green Chemistry* in 2021, which details the company's methodology for integrating green chemistry and sustainability considerations into raw materials selection and product development.[55]

"Sustainability is becoming a business decision," says Clariant's Mr Haldimann. "It's no longer a qualifier but it is becoming a driver for companies to select products." This doesn't mean, however, that sustainability trumps all other considerations. "A small portion of the population is willing to give up on certain performance aspects of certain products because it is more sustainable. But it's a small portion." Sustainability and performance must not be seen as a trade-off, Mr Haldimann believes. "We have to tie these two elements together."

There are also encouraging examples of companies along the supply chain coming together to address pollution. Roadmap to Zero is a multi stakeholder initiative in the textile and footwear sectors whose contributors aim to reduce the chemical footprint of the industry. "Consumers can play a vital role in driving companies to act on pollution", says Frank Michel, Executive Director of the ZDHC Foundation, which oversees the implementation of the Roadmap to Zero programme. However, he says, "consumers often don't have transparency on which brand is engaging in this field. Our Roadmap to Zero Programme is engaging the entire supply chain to transform the industry to create this transparency."

Clariant partnered with Unilever and TOMRA, a manufacturer of sorting equipment for the recycling industry, to design black plastic bottles that can be easily sorted by recyclers. The black colour typically used is not detectable by the sorting machines which results in lower quality, discoloured recycled plastic. This was a complex process, explains Clariant's Mr Haldimann. First, they had to design a black plastic colour that could be detected and sorted by industrial sorting machines. Then, they worked with Unilever to ensure the product would be acceptable to designers and consumers. Finally, they worked with TOMRA to ensure the product could be practically sorted using existing processes.

"A lot of the technical solutions already exist," says Mr Haldimann. "It's about bringing supply chain partners together and making them work in a new setup."

The International Association for Soaps, Detergents and Maintenance Products (AISE), which represents these industries in Europe, offers another example of how various parts of the value chain can work together. Along with the European Committee of Organic Surfactants and their Intermediates (CESIO), AISE funds a joint research platform called ERASM (which stands for Environmental Risk Assessment and Management), which undertakes scientific research aimed at improving the health and environmental impacts of detergent-based surfactants.[56]

The AISE has also introduced an industry-wide Charter for Sustainable Cleaning to reduce the sector's carbon and environmental footprint. More than 170 European companies have adopted it so far.[57] Another example, the Health Product Declaration Collaborative, brings together businesses along the building industry value change to assess and consistently report on the health impacts of products used in the built environment.[58] The charter is just one example of a sub-sector of the chemical industry working proactively to improve sustainability, suggesting that more widespread change is feasible.

6.3 Barriers to change: Cultural transformation required

Cost, scale and technology

There are three practical obstacles to the adoption of more sustainable products and practices, as Wood Mackenzie's Guy Bailey explains:

> "**Technology readiness**: to move from a concept in a lab to a deployed commercial material can take decades, as companies work through the size of the market and the

challenge of moving to commercial-scale production. Even when we know how to provide more sustainable alternatives, it takes time to roll out."

The chemicals sector is also highly competitive, with a ruthless focus on efficiency. Sustainable or less hazardous alternatives to existing products tend to be overlooked if they represent a squeeze on margins

"**Cost**: typically, new technologies have higher costs, which come down over time. These higher costs can deter buyers but have also historically been challenging for the investment community."

"**Scalability**: in plenty of chemicals markets, end-consumers need scale. For example, PLA is a bioplastic that can be considered a competitor with PET and PE. It costs about twice what the commodity polymers do, but it has some superior properties, and clearly, some in the market are willing to pay for it. But, if Coca-Cola decided to switch PET for PLA in its material portfolio, it would find enough PLA globally to meet just 7 percent of its needs. It takes time and partnerships for sustainable materials to incrementally build out scale before they can compete at the commodity level."

The chemicals sector is also highly competitive, with a ruthless focus on efficiency. Sustainable or less hazardous alternatives to existing products tend to be overlooked if they represent a squeeze on margins. Efficiency drives are common, but the dividends are routinely pumped back into the same—often polluting—parts of the business rather than being invested in developing less harmful alternatives, says Kakuko Nagatani-Yoshida, global coordinator for chemicals and pollution at the United Nations Environment Programme (UNEP).

Mr Tickner of the Lowell Center explains how these commercial barriers play out in practice. "We've had conversations with a group of chief technology officers of mid-size chemicals companies who say they are ready to produce more sustainable products," he says. Often, this means a long and expensive process developing new chemicals and manufacturing processes. "The problem is if a competitor is selling a cheaper, more polluting incumbent product and customers are not willing to absorb higher costs, that company is going to lose market share."

"I have heard of internal battles in companies where they have better alternatives ready to scale, but they're not going to stop selling the incumbent as long as it means losing that market," Mr Tickner says. In a for-profit entity that reports quarterly, short-term commercial considerations often trump environmental concerns—even if there is the potential for a longer-term payoff.

The need to build new infrastructure is also a significant barrier to adopting green chemistry at scale, says Mr Tickner. "We've heard a lot from chemicals companies that, unless they can drop more sustainable products into existing manufacturing processes, it is difficult to adopt them. The costs of building new manufacturing infrastructure are so high."

Marcel van den Noort agrees, “largely, the industry has the technology to solve the problem of direct pollution. The barrier is cost.”

Yet the flipside of cost is opportunity. Companies that produce hazardous chemicals face extremely high safety compliance costs. Sumitomo Chemical, for example, spends more than US$370m on environmental protection costs each year.[59] Transitioning to safer chemicals can also mean lower compliance costs. Pharmaceutical companies Pfizer saw a reduction in costs, for example, by employing green chemistry principles to reduce the amount of waste produced during its manufacturing process.[60]

Decarbonisation tops the sustainability agenda

The chemicals sector’s efforts to transition to net zero carbon emissions provide both a template and a cautionary tale for any future efforts to achieve a zero-pollution ocean. It is difficult to estimate the projected cost of transitioning to net-zero emissions versus net-zero pollution. Still, it is easy to imagine that both transitions would involve similar challenges: redesigning products, rebuilding supply chains, and re-engineering legacy processes. In short, both will be expensive and complicated, decades-long efforts.

The necessary drive to decarbonise the chemicals sector cannot become a missed opportunity to address ocean pollution

ShareAction is an NGO that aims to encourage investors to improve their portfolios’ environmental and social impacts. They say that despite the chemicals sector’s high emissions, few companies have credible transition plans in place to achieve net zero. One particularly thorny issue for the industry is its Scope 3 emissions, which measure indirect emissions up and down the value chain. For many sectors, switching to renewable energy and fuel sources will eliminate most emissions. Yet chemicals face a double whammy: not only are they energy-intensive to produce, but most are created using fossil-fuel feedstocks. Even if the process used to make chemicals becomes substantially greener, the products themselves still account for about 50 percent of the sector’s emissions.[61] The road ahead will be a rocky one.

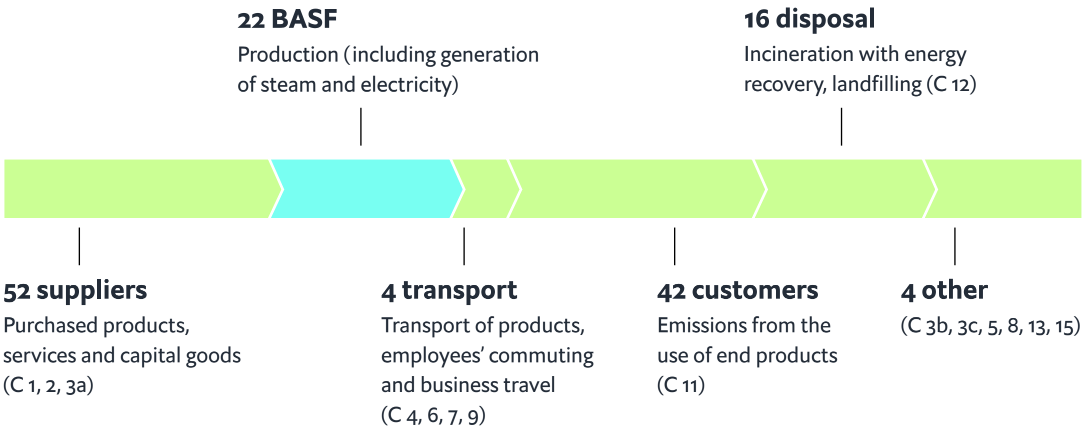
Some efforts to decarbonise the sector, such as reducing fertiliser use, will positively affect marine pollution. Yet, the causes of carbon emissions and pollution do not always neatly overlap. “We need to go back to the basic chemistry causing toxicity in the ocean,” says Mr Tickner. Unfortunately, “replacing carbon sources doesn’t solve that”.

The reality, then, is that pollution may remain a second-order environmental problem for some time for an industry that faces an enormous and expensive decarbonisation transition. That means the industry must look for win-win solutions that simultaneously address carbon emissions and pollution. The necessary drive to decarbonise the chemicals sector cannot become a missed opportunity to address ocean pollution.

The bulk of BASF's greenhouse gas emissions are Scope 3

BASF's GHG emissions along its value chain
BASF Annual Report 2018

Greenhouse gas emissions along the BASF value chain in 2018*
Million metric tons of CO_2 equivalents



Source: World Business Council for Sustainable Development, TCFD Chemical Sector Preparer Forum Guide to Climate-related Financial Disclosure (2019). * BASF operations including the discontinued oil and gas business; according to Greenhouse Gas Protocol, Scope 1, 2 and 3; categories within Scope 3 are shown in parentheses

A change in corporate culture

To overcome these significant commercial barriers, large parts of the sector will need to undergo a substantial shift in corporate culture. One interviewee, who wished to remain anonymous, highlighted the "cognitive dissonance" of many executives in the chemicals industry, who see themselves as drivers of innovation and prosperity. They simply cannot accept that they may be part of the problem. Or, as another interviewee said, "they are dinosaurs".

This is, of course, not a universal characterisation. In large, complex organisations, there can be a multitude of norms. Some parts of the business may embrace the opportunity to reduce pollution, while others dismiss it or have not considered it at all. Even in organisations with well-resourced and active sustainability departments, there can be patchy adoption of new norms. Nothing short of a revolution is required. "It is about an organisational change," says Eric Usher, head of the UNEP Finance Initiative.

There is cause for optimism, says Craig Halgreen, an independent consultant whose career has been in sustainability at large chemicals companies, including Austria's Borealis. "Many more executives in the chemicals sector recognise the need for change than they did even five years ago," he says. "It's now quite common to hear discussions in boardrooms about the need to act responsibly on behalf of their children and grandchildren. That was unheard of a decade ago."

Still, one major challenge for the industry is that the transition will not always be profitable. In some cases, companies can swap a polluting product for a less polluting one that will generate a profit—in time, at least. In other cases, the solution is to reduce or eliminate chemical products altogether. These are more difficult shifts for the industry to make.

To overcome these significant commercial barriers, large parts of the sector will need to undergo a substantial shift in corporate culture

"For the longest time, the chemicals industry focused on finding markets and not functionalities," says Mr Tickner. Instead of chemicals companies creating a product and then looking for places to sell it, in the future new product growth will need to be driven by customers asking chemicals producers for products that meet product and toxicity needs, he says. Some companies see value in becoming service providers and not just product manufacturers. For example, P&G Tide is now setting up commercial laundries as a model for the future. Many companies offer chemical leasing services. "Not every product redesign needs a chemical solution," he says.

This challenge is already becoming apparent in the transition to circular economy models, which will inevitably mean reduced demand for chemicals. Yet despite this commercial reality, says Mr Halgreen, many companies in the chemicals sector are now embracing circularity. They have begun to rethink how to redesign their plastic production processes to enable reuse and recycling. With the right commercial and regulatory incentives in place, such a radical shift in industry culture and practice might be entirely possible.

Cultural change comes from the bottom as well as the top. One barrier to change is the lack of accredited tertiary degrees in safe and sustainable green chemistry. "We need to train a generation of chemists and engineers that you don't design something without thinking about toxicity and sustainability," says Mr Tickner. A growing number of universities have begun to embed green chemistry and sustainability into their curricula, but green and sustainable chemistry education (GSCE) needs to expand before it can be considered mainstream, according to a paper prepared for the UN Environment Programme's Global Chemicals Outlook.[62]

Changing corporate culture to support biodiversity

The Proteus Partnership, a collaboration between the UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) and a group of leading companies, helps member companies to assess and manage their impacts and dependencies on biodiversity, and shows the challenges—and opportunities—of working to instil a culture of sustainability in large companies.

Proteus's member companies, including oil supermajors such as BP and ExxonMobil and miners such as BHP and Rio Tinto, look a lot like the world's largest chemical companies: huge, diversified conglomerates with sprawling global operations.

The challenge of engaging these companies is similar, says Stacey Baggaley, senior programme officer for Nature Economy at UNEP-WCMC. Some parts of the business will be highly engaged, while other parts of the organisation are typically not. To overcome this, the Proteus Partnership encourages both a top-down and bottom-up approach, she says.

This means working with the C-suite and leadership teams to highlight both the business risks and opportunities from biodiversity whilst equipping sustainability champions throughout the business with the data, tools, and skills they need to manage biodiversity and communicate horizontally across the organisation.

It is crucial, Ms Baggaley says, to embed knowledge and capacity not just in the environment function but across the broader business.

Engaging the "missing middle" of the sector

Cultural inertia is a powerful barrier in even the most progressive parts of the chemicals industry. Still, perhaps an even more significant challenge is engaging the parts of the industry for which sustainability is not yet even a consideration. Large multinationals tend to be demonised for their environmental records, but they often operate under greater scrutiny and in markets with strict regulatory standards. Usually, the multitude of smaller businesses and those working under the radar in jurisdictions with laxer rules are the most polluting. Reaching the middle tier of companies which perhaps have the resources and incentives to solve the pollution problem but have not yet thought about doing so will be a necessary—if challenging—part of any solution.

Indeed, efforts to improve the industry's environmental footprint tend to include the usual suspects: prominent, often Western, multinationals that use sustainability as a point of market differentiation, or consumer-facing brands fearing a reputational backlash. For those trying to champion sustainability in the industry, this is a pragmatic approach. "You can do an awful lot by working with big companies when the door is already open," says Ms Baggaley, senior programme officer for Nature Economy at UNEP-WCMC.

These businesses play a vital role in setting the tone and direction of travel for the wider industry. "The value chain is incredibly convoluted, but there are a much smaller number of big companies at the top of the value chain—producing and processing base chemicals—and in the consuming sectors," says Mr Bailey of Wood Mackenzie. "If companies in these 'bottlenecks' can move in a more sustainable direction, the wider industry has little choice but to follow."

And yet, unless the "missing middle" sees the value in adopting new norms, large-scale impact will remain elusive. Geographical shifts in the chemical sector threaten to compound this problem further: much of the progress on sustainability is happening among European and, to a lesser extent, North American companies, while the chemical sector's geographic centre of gravity is inexorably moving towards Asia and the Middle East (see box).

Unless the "missing middle" sees the value in adopting new norms, large-scale impact will remain elusive

Interviewees for this report continually cited European examples of sustainability-related transformations in the chemicals industry. Driven by the EU's relatively strict REACH legislation, the region's companies do appear to be, on average, further ahead on sustainability. ChemScore, which awards an average score of 15.1 for European companies, 13.6 for US and Canadian companies and 11.6 for Asian companies[63], confirms this widely held observation. But without an effort to engage a geographically wider group of companies, any plan to achieve a zero-pollution ocean will founder.[64]

Megatrends shaping the chemicals industry of the future

Chemicals production is forecast to grow by almost 60 percent by 2050. Yet this headline figure obscures a more complex picture. Fossil fuel-based commodity chemicals make up the bulk of global sales yet shrinking margins and fierce competition—compounded by pandemic-related disruptions—have eaten into profits. There are bright spots. Specialty chemicals, pharmaceuticals and agriculture are growing segments. Perhaps unsurprisingly, most R&D spending is also happening in these (higher margin) categories, suggesting they will be a key driver of future industry growth.[65]

Megatrend #1—Geography

The modern chemicals sector was born in Europe and North America, and throughout the twentieth century big Western conglomerates such as Germany's BASF and the United States' Dow Chemicals dominated the industry.

This picture has been quietly but rapidly changing. Since the turn of the century, much of the growth in the global industry has happened in Asia. The region now accounts for half of all global chemicals sales; by 2030 this figure will be closer to two-thirds.

Big, diversified conglomerates will still rule. But it will be Sinopec, ChemChina and SABIC that dominate in volume, sales and profits. China is currently a net importer of chemicals, but on current trends this will soon reverse.[66]

Megatrend #2—Sustainability

The chemicals sector's fortunes are inextricably tied to fossil fuels. Action to address climate change will have an outsized impact on the sector, which is the third-largest industry source of CO_2.[67]

Around half of the sector's emissions come from energy use; the other half are embedded in the chemical products themselves.[68] There will be no cheap or easy way for the sector to transition. The good news? The chemical sector is so intertwined with other sectors that if it does manage to successfully decarbonise, its efforts will have an outsized positive impact on global emissions.[69]

The industry's shifting centre of geographic gravity also has important implications for its climate impact. China's chemicals sector produces more of its emissions from coal than from the relatively cleaner feedstocks such as oil or natural gas compared to its international counterparts. And much of the industry's growth is forecast to happen in emerging economies with relatively weaker regulatory frameworks to manage the environmental impact.[70]

Megatrend #3—Volatility

The chemical sector's heavy dependence on fossil fuel feedstocks and China's growing importance also exposes it to other risks. Any slowdown in China's economy or decoupling of Chinese and Western supply chains would upend the industry. Volatility in commodity prices is an ongoing threat: profit margins of fossil-fuel based chemicals are so thin that even minor swings can have a deleterious impact on the bottom line.[71]

Megatrend #4—Technology

It is not all doom and gloom, however. The chemicals industry today, locked into legacy production processes, looks—from a technological perspective at least—remarkably like it did in the 1960s.[72]

Technology offers a chance to change that. While the market for commodity chemicals is ever less profitable, demand for specialty chemicals and niches such as biotechnology and fuel cells is growing.[73] These segments are small relative to the industry's overall size, but suggest a viable future for the industry to survive—and even prosper through—decarbonisation.

Technology will underpin this shift. Smart manufacturing, artificial intelligence, the Internet of Things, better data availability and processing, engineering innovations such as digital twins and breakthroughs in materials science offer a tantalising glimpse at what a leaner, greener chemicals industry might look like in the future.

6.4 Pathways to progress: Why the sector needs system-level change

Another disincentive for the industry to act on marine chemical pollution (or, in fact, on any other environmental or social issue) is that individual businesses often face a first-mover disadvantage. Before new revenue streams are well-established, those that stick out their necks risk scrutiny or face high transition costs. Industry alliances, which reduce the risk to individual companies of moving too far ahead—or being left too far behind—their peers, will be critical to persuade businesses to contribute to achieving a zero-pollution ocean.

This "first-mover disadvantage" has driven the creation of many industry coalitions to address other environmental and social issues. Several initiatives already exist that contribute in some way to addressing marine chemical pollution, although none focuses specifically on it. Nevertheless, these alliances may provide a template for a broad-based chemicals industry alliance (see box).

A central feature of these collaborations is bringing together industry players with other stakeholders from finance, governments and civil society. This multi-stakeholder approach is crucial: different norms and expectations between these groups can be a significant roadblock to progress, which several interviewees highlighted as a major challenge.

Even within the private sector, industries such as chemicals, agriculture and waste management tend to be siloed, says Erik Giercksky, head of the Ocean Stewardship Coalition at the UN Global Compact. The most powerful coalitions tend to be multisectoral.

"We need to have the conversation between policymakers, scientists and business. And it's not only about the chemicals industry, but also the finance industry and consumer goods," agrees EMPA's Mr Wang.

Strength in numbers: Industry alliances as potential templates for action

- The **Getting to Zero Coalition** is an alliance of 150 companies within the maritime, energy, infrastructure and finance sectors that aims to decarbonise the shipping sector by developing commercially viable deep-sea zero-emission vessels by 2030. Coalition members commit to a "race to the top" to adopt carbon-neutral vessels ahead of regulatory requirements.[74]
- Members of **ReSource Plastic**, a consortium of eight multinational packaging companies under the leadership of environmental NGO WWF, have committed to track, disclose and reduce the plastic waste they produce.[75]
- **The Alliance to End Plastic Waste** comprises 80 member companies and invests in downstream solutions to manage plastic waste.[76]
- Members of **Operation Clean Sweep**, including chemicals, manufacturing and packaging companies, pledge to prevent pollution from plastic resin and pellets.[77]
- The **Ship Recycling Transparency Initiative**, "a market-based approach to improving ship recycling practices in the current absence of global standards," allows shipowners to disclose information about their ship recycling efforts to inform cargo owners' and investors' purchasing and lending decisions.[78]
- **The Ocean Stewardship Coalition**, previously the UN Global Compact Action Platform for Sustainable Ocean Business, brings together industry players across key "blue" sectors: aquaculture, energy production, fisheries and shipping. The platform provides a framework for responsible practices in these sectors, aiming to unlock opportunities for profitable and sustainable solutions.[79]

Standards bodies such as the International Organization for Standardization (ISO) and ASTM International provide well-established, voluntary systems to drive greater sustainability. Standards give confidence to consumers (for example, that the products they buy do not contain certain hazardous chemicals). Standards bodies also present an opportunity for the industry to agree on best practices voluntarily.

That said, it is worth noting that these for-profit organisations serve their customers:, i.e. the industries that use their standards. This means there can be a tendency to favour standards that are inexpensive, fast and convenient to administer instead of those that are time-consuming but potentially more rigorous, says Linda Amaral-Zettler, chair of the ASTM D20.96 Subcommittee subsection on Natural Environment Degradation/Biodegradation (Anaerobic/Aerobic). Standards bodies are not regulators: they primarily respond to industry needs rather than forward a policy agenda, limiting their capacity to move ahead of the industry at large.

Other types of standards are emerging too. The Chemical Footprint project is a survey that "evaluates responders' chemicals management systems against best practice to measure and reduce chemical footprints."[80] Safer Choice is a certification programme run by the United States' Environmental Protection Agency that allows consumers to find products that don't contain harmful chemicals.[81]

It is unrealistic to expect the chemicals sector to act alone. Regulatory change, public pressure and demand from retailers for more sustainable chemicals, and investment from the finance sector, will all be required if there is to be a shift to less polluting business models

A roadmap for corporate change

Despite some encouraging noises, the reality is that the incentive to change is simply not strong enough for many businesses along the chemical supply chain. One barrier is financial. Polluting, hazardous products are often the most profitable, and corporate leaders must still consider the bottom line first. Executives have to weigh the (often substantial) upfront cost of refitting plants and redesigning processes to produce less harmful products against an uncertain and trailing revenue stream.

Shareholders might have an increasing focus on environmental, social and governance risks (discussed in more detail in the next section). However, they still expect a financial return on their investment. For the private sector to play a critical role in addressing marine chemical pollution, market conditions need to be sufficiently attractive, says Torsten Thiele, founder of the Global Ocean Trust.

Ultimately, it is unrealistic to expect the chemicals sector to act alone. Regulatory change, public pressure and demand for more sustainable chemical inputs from retailers, and substantial capital investment from the finance sector, will all be required if the industry shifts to less-polluting business models. "There are chemicals companies ready to make better,

A roadmap for industry-led action on marine chemical pollution

- **Innovation**: develop new, more sustainable products and processes, and shift from a risk-based approach to a hazard-avoidance one.
- Create **commercial incentives to change**: if the private sector is to play a critical role in addressing marine chemical pollution, market conditions must allow it to profit from doing so.
- Create industry-wide or sector-specific **coalitions of the willing** to help mitigate "first-mover disadvantage" and bring together industry players with other stakeholders from finance, governments and civil society.
- Increase **transparency and collaboration across the supply chain**: chemicals users can demand greater openness about polluting and hazardous inputs in their products.
- **Improve processes and practices for chemicals users**: best practices are also emerging in the agriculture, aquaculture and waste management sectors that demonstrate a pathway for using and managing chemicals more responsibly.
- Conduct a conversation on **extended producer responsibility**: to tackle marine chemical pollution effectively, chemicals producers will need to accept more responsibility for what happens to their products after sale.

safer and more sustainable chemistries," says Mr Tickner. "But no one wants to pay for it. We are slowly getting there, but there is a lot more to change."

The only feasible way to reduce pollution while still providing the products the world needs is to innovate. The chemicals industry is the only stakeholder with the resources and know-how to do this at scale

In some ways, it is difficult to imagine how the chemicals sector, which is so sprawling, so diverse, and so reliant on revenue from polluting products, can be a proactive driver of change. But there are encouraging examples that—if replicated and scaled—could dramatically reduce chemical pollution in the ocean.

For many, the chemicals sector itself is the problem. But given the crucial role they play in modern life, there is no choice but to cooperate and engage with the industry. The only feasible way to reduce pollution while still providing the products the world needs is to innovate. The chemicals industry is the only stakeholder with the resources and scientific know-how to do this at scale.

Underpinning this effort must be a conversation about risk and responsibility. To tackle marine chemical pollution effectively, chemicals producers will need to accept more responsibility for what happens to their products after sale. Consumers increasingly expect and demand this, and their voices may yet be the key to persuading chemicals producers to be more accountable.

Some retailers now require not just transparency about chemicals along their supply chain but demand safer chemicals, too. These examples provide a clear pathway for how other chemicals users can demand greater openness about polluting and hazardous inputs in their products.

Processes are as important as products, and best practices are also emerging in the agriculture, aquaculture and waste management sectors that demonstrate a pathway for using and managing chemicals more responsibly.

Most businesses will be unwilling to act alone in both the chemicals sector and along the chemicals supply chain. An industry coalition focused squarely on reducing marine chemical pollution could agree on best practices and give commercial cover to first-movers. The challenge will be filtering changes throughout the industry. Preaching to the choir is one thing, but it will be crucial, too, to engage the congregation.

Nothing short of a green chemical revolution is needed. The key to unlocking it is the creation of commercial incentives for the industry to profit from the transition. Encouragingly, a few chemicals companies have started to embed sustainability in their business model—and profit from it. The following section will examine how the finance sector can work with industry to achieve this.

Please see Notes for references

7: Finance

This chapter looks at the role that finance can play in tackling marine chemical pollution, and assesses the steps that financiers and their clients need to take—not least given the increasing prominence of ESG considerations, and the shift within ESG from solely green factors to blue factors. It also examines the need for better information and data to help investors in their decision-making, and the risks and rewards of a chemicals industry in transition, and assesses how that transition can be funded.

7.1 Principal findings and recommendations

- **Investors are not sufficiently aware of the problem of marine chemical pollution: better information is needed.**
  A lack of awareness among the finance community about the profoundly damaging effects of marine chemical pollution is a barrier to change: the current level of awareness mirrors the sector's understanding of climate change in the mid-2000s. While demand for sustainability-linked investments is strong, data about marine chemical pollution, the role that industry plays and the possible impact of regulation is patchy. Better information about the material risks the chemical sector will face from a transition to a zero-pollution ocean will be an important first step for any finance sector-led solution—in tandem with an appreciation of the potential rewards for early movers.

- **Pressure on sustainability issues could encompass zero-pollution, but the changing nature of the chemicals sector is a complication.**
  The chemicals sector is beginning to face pressure from investors to reduce its environmental impact. Increased regulatory scrutiny and the burgeoning environmental, social and governance (ESG) investment market means that this pressure will increase. Until now, the sustainability focus has been on decarbonisation and plastics—challenges that few chemicals sector players have genuinely begun to address. New regulatory taxonomies like the international Taskforce on Nature-related Financial Disclosures (TNFD) will radically reshape how companies measure and disclose their impact on the marine environment. As yet, detailed ESG and sustainability reporting is far from uniform across the chemicals sector, though some producers and end users are starting to respond to investors' demands to provide it.

A complication is the changing ownership of the sector, with a smaller proportion of revenues generated by publicly listed companies that are the initial targets of new ESG rules and investor pressure.

- **Clarifying transition risks and potential rewards will be crucial for investors.** Many of the net-zero transition risks the chemicals sector faces also apply to the transition to a low-pollution sector (even though solving for one will not automatically address the other). Though the path to a zero-pollution ocean is not yet clear, the financial risks that industry faces—including difficulty accessing finance, litigation, reputational damage and changing downstream market conditions—are similar, and increasingly apparent. On the reward side, the opportunities that may arise from the transition to a low-carbon economy through innovation and first-mover advantage are considerable, in particular to those that can attract financing on a sufficient scale.

The most important challenge in catalysing finance-sector led solutions to marine chemical pollution is making the necessary transition a financially attractive and investable proposition

- **Eliminating marine chemical pollution needs to be an investable proposition.** The transition to a low-pollution chemicals industry will require targeted engagement of "true believers" in the finance sector. Investment guidelines that integrate strict assessment frameworks will be crucial. Additional funding through sustainability bonds, blended finance and impact investing will have a helpful role to play. Private equity engagement and M&A will be crucial to innovation in the sector. Ultimately, however, chemicals companies will need access to very large sums of money via traditional sources if they are to undertake the type of capital-intensive and long-term transition required, especially given the commercial pressures most industry participants face. The most important challenge in catalysing finance-sector led solutions to marine chemical pollution is making the necessary transition a financially attractive and investable proposition.

- **A finance wish list: five steps for investor-led action on zero marine chemical pollution.**

  1. Develop **improved ESG guidance and clear regulatory standards**, particularly around emerging nature-related frameworks such as TNFD.
  2. Publish **more and better data,** particularly around companies' impacts on marine chemical pollution.
  3. Based on the climate-related risks and transition framework, deliver a template to investors that **sets out the risks that investors will face** during the transition to a zero-pollution ocean.
  4. Processes that help **industry and investors collaborate to uncover opportunities** for transition financing, aligning the supply of and demand for large-scale deals.
  5. Use **private equity and M&A activity** to drive innovation and scale in the burgeoning green chemistry start-up scene.

The enormous cost of transitioning legacy processes and products to less-polluting alternatives is perhaps the most significant barrier to the transition to a zero-pollution ocean, as the previous section explained. Stricter environmental regulations and customer demand are likely to result in significant transition costs, which will require capital.

Less innovative companies will be particularly exposed. The finance sector, then, can play a critical role in determining what the chemical value chain of the future looks like: with innovative, clean and green chemicals making up the products that we buy.

The good news is that investors are increasingly concerned about the environmental and social impact of the ventures they fund. For an increasingly large proportion of investors, new regulatory requirements and an appreciation of the long-term financial risks of climate change and other environmental, social and governance (ESG) factors make sustainability an important consideration in investment decisions. On current trends, around one-third of all assets under management will be ESG-focused by 2025: around US$53 trillion worth.[1] This tsunami of capital could present an unmatched opportunity to address the sources of marine chemical pollution.

As in any capital allocation decision, investors will need to balance risk and opportunity. Investors will first need to understand, and then to mitigate, the financial, regulatory, legal and reputational risks that companies along the chemical supply chain will face due to pollution, including marine pollution, which could undermine their viability. They will also be attracted to the opportunity to profit from the returns due to those companies that take the lead now in the capital-intensive process of transitioning to a less-polluting future. If the finance sector is to contribute to achieving a zero-pollution ocean, both aspects will be crucial.

It is important to note that the ESG finance revolution, which has so far focused on large, listed companies, is not a panacea. ESG is, so far, less of a consideration for SMEs, private companies and state-owned enterprises, all of which rely less on capital markets for funding and may face less regulatory scrutiny. Likewise, it is still unclear the extent to which private equity investors take ESG considerations into account. Some consider it as carefully as large institutional investors. For others, it appears not to be a consideration at all.[2] Yet, one thing is clear: if the chemicals industry is to transition to a zero-pollution model, finance will have an important role to play.

7.2 Current approaches: From net zero to zero pollution

The evolution of green finance standards

One reason for the central role of finance is regulatory: financial regulators and stock exchanges in many jurisdictions are rapidly introducing ESG disclosure requirements for companies and investors. Rules vary between jurisdictions, but the fundamentals are the same:

1. Businesses or investors must disclose any environmental, social or governance issue that could be a material financial risk to their company or investment.

2. Businesses or investors must disclose their impact on a particular ESG issue that the regulator or exchange deems essential. This could mean, for example, that chemicals companies could be required to disclose whether there have been any breaches of local environmental laws that prohibit marine pollution. Investors could be required to report whether companies in their portfolios have breached such rules.

3. Increasingly, businesses and investors are required to report on and comply with ESG rules. In the example above, this would mean not just disclosing whether there have been breaches of environmental laws but also showing a credible plan to reduce or eliminate violations in the future. Under this scenario, an investor would need to work with polluting portfolio companies to help them improve their performance or divest from that company to be compliant.

Two important pieces of European Union legislation are reshaping how companies and investors think about their environmental and social impact: the EU Taxonomy and the Sustainable Finance Disclosure Regulation (SFDR).

"Corporate sustainability is now mainstream, much thanks to the EU Taxonomy," says Erik Giercksky, head of the Business Action Platform for Ocean at the UN Global Compact

The Taxonomy and the SFDR are globally significant for a few reasons. First, they apply to non-EU funds and businesses that market their products within the EU.[3] Second, the EU is often seen as a de facto global rule-setter.[4] In November 2021, the EU and China published a "Common Ground Taxonomy" on climate mitigation, which identifies areas of agreement and convergence between the two jurisdictions' rules on climate disclosure.[5] The UK looks set to use the EU rules as a template for its own legislation.[6]

Even in areas where the rules do not converge, the experience of the General Data Protection Regulation, which regulates how companies use their customers' data, suggests that many multinational businesses find it more practical to comply with EU rules across their operations voluntarily. They may assume that EU rules indicate the future global direction of regulatory travel.

It is difficult to understate the impact these combined pieces of legislation have had in a relatively short period. "Corporate sustainability is now mainstream, much thanks to the EU Taxonomy," says Erik Giercksky, Head of the Business Action Platform for Ocean at the UN Global Compact. Where responsibility for ESG previously sat with the sustainability department, it has now become the purview of the chief financial officer, he says. A company's environmental performance was once a public relations concern. Now it is critical for compliance and investor relations.

Jurisdictions that have developed taxonomies influenced by the EU Taxonomy

Countries that use the EU Taxonomy as a benchmark:	Countries that use the EU Taxonomy as a source of inspiration:
• Mexico	• Chile
• United Kingdom	• Canada
• Georgia	• Malaysia
• South Africa	• Singapore
• Bangladesh	

Source: Natixis Corporate and Investment Banking[7]

Alongside mandatory ESG compliance requirements, it is now commonplace for large companies to report voluntarily on their ESG performance. Primarily, this is to meet the demands of existing investors and attract the growing avalanche of ESG-focused capital.

Detailed ESG and sustainability reporting is far from ubiquitous across the chemicals sector

Several frameworks for reporting ESG performance exist, and no single framework is dominant in the chemicals industry. However, most of the leading frameworks cover pollution in some way. Some noteworthy examples include:

- The **Task Force on Climate-related Financial Disclosures (TCFD)**, a framework for companies to report on the financial risks they face due to climate change, is currently voluntary. However, financial regulators are beginning to adopt its recommendations, and in some jurisdictions, it may become mandatory for large companies to show that they are TCFD-compliant (as it already is in the finance sector in New Zealand).[8] The TCFD has worked with a group of chemicals companies to develop detailed advice on how the industry can implement the framework.[9]

- The **Global Reporting Initiative (GRI)** is a standards organisation that allows businesses to measure and report on their environmental and social impacts. The GRI is developing sector-specific standards for 40 industries, including the chemicals industry.[10]

- The **International Sustainability Standards Board**, launched at the COP26 climate negotiations in November 2021, will attempt to create **a single, harmonised reporting framework**.[11] One of its constituent members, formerly called the Sustainable Accounting Standards Board, has 77 industry-specific standards, including one for the chemicals sector.[12]

- The **UN Global Compact** is a set of 10 environmental and social principles that CEOs can pledge to adhere to, aligned with the UN SDGs.[13]

These are just a few examples of what has developed into a morass of competing and overlapping frameworks, leading to frustration among investors who say it is complicated to compare businesses' ESG credentials accurately. Adding to the confusion are the efforts of several for-profit ratings agencies, such as S&P Global, MSCI and Sustainalytics, whose scores for specific companies may not agree with each other.

Detailed ESG and sustainability reporting is far from ubiquitous across the chemicals sector. Standout performers are typically the large, listed companies looking to attract investment from global capital markets. Small-to-medium enterprises, private companies and state-owned enterprises are much less likely to publish ESG-related information. These account for much of the chemicals production sector. Yet, those that do demonstrate a clear and encouraging pathway could set a standard for the industry. Some examples include:

- Thailand's Indorama Ventures, which publishes a detailed sustainability report using the GRI. Indorama has undertaken an extensive stakeholder analysis to determine 13 financially material ESG topics on which to centre its sustainability strategy. These topics include product stewardship (which covers product toxicity), supply chain management, compliance management, plastic waste and recycling.[14]

- Dutch conglomerate DSM, which publishes an integrated annual report combining both ESG and financial information. The headline environmental figures that DSM reports are on climate, but its most recent (2020) report also includes nature and biodiversity and product stewardship.[15]
- Sherwin Williams, a US-based paint and coating manufacturer, publishes a comprehensive annual sustainability report. Its Global Product Stewardship organisation monitors environmental trends and regulations, and works with industry associations to proactively improve its products.[16]

DSM says nature and biodiversity are of high societal interest and have a moderate to a significant impact on its business

Materiality matrix 2020

Source: DSM, Integrated Report (2020)

ESG—from green to blue

So far, most of the E in ESG has focused on persuading companies to reduce their climate emissions—hence the global wave of corporate pledges to reach a net zero carbon impact. Still, there is growing investor interest in the impact of the economy on nature more broadly, says Matt Jones, head of nature economy at the UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC). While the focus on climate will remain, momentum is also growing for investments that are net zero, nature-positive and socially just.

While the focus on climate will remain, momentum is also growing for nature-positive investments, which also take other environment-related risks into account

This trend will be an essential driver in the push for a zero-pollution ocean. The EU Taxonomy, for example, has until now focused on climate impacts. In 2022, it expects to publish new rules on:

- The sustainable use and protection of water and marine resources.
- The transition to a circular economy, waste prevention and recycling.
- Pollution prevention and control.
- The protection of biodiversity and ecosystems.[17]

These new taxonomies could radically reshape how companies measure and disclose their impact on the marine environment and how investors assess their portfolio companies' environmental performance.

Another important example is the international Taskforce on Nature-related Financial Disclosures (TNFD) framework, which will build on its climate-related cousin and launch in 2023. The TNFD will consider biodiversity and non-climate related ecosystem impacts, including pollution, and will likely adopt a similar framework to the TCFD considering:

- Nature-related physical risks and opportunities, including biodiversity loss, ecosystem damage and natural disasters.
- Nature-related transition risks including policy, legal, technology and market changes.
- Nature-related systemic risks across economies (although these will be more of a concern for governments and regulators rather than investors and businesses).
- Litigation or liability risks.[18]

The prospect of these two initiatives means that many investors are, for the first time, beginning to think about broader environmental impacts as well as climate. "2020 was the year when investors started to ask different questions," says Anne-Sofie Bäckar, executive director of ChemSec. "They not only asked about climate but also about water and chemicals with a much broader interest than we had seen before."

Blue finance innovation

The finance sector is, of course, not homogeneous. Across the industry, attitudes, awareness and understanding of the risks and opportunities in sustainability-related investing vary widely. It is also essential to distinguish between different types of investors, each of which has differing incentives and motivations.

Asset owners such as sovereign wealth and pension funds look for returns over decades rather than months. They may be more likely to consider the long-term financial, regulatory, legal or reputational risks their portfolio companies may face due to marine chemical pollution. Insurance and reinsurance companies also take a typically long-term approach to risk to offset future liabilities.

Asset managers and other intermediaries, on the other hand, invest on their clients' behalf. They can advise on sustainability-related considerations, but ultimately, client demand will determine how deeply embedded these considerations become. ESG investing is now very popular due to the (hotly debated) perception that it provides superior returns.[19] Should ESG funds begin to underperform the market, it is not clear that client demand would remain as strong.

These subsectors of the finance industry are essential because of their scale. Yet smaller players have typically been the most innovative and proactive when it comes to sustainable investing. Impact investors, which aim to generate an environmental or social return and financial returns, and blended finance, which brings together private sector investors with development banks and philanthropic capital, are the main drivers of a promising yet nascent blue finance trend.

Mainstream private-sector capital will be required to finance the large-scale transition to a zero-pollution ocean

Blue bonds (like green bonds) are similar to traditional bonds: investors provide the issuer with upfront capital in return for the promise of future interest payments. Unlike conventional bonds, the money must be invested in projects that advance ocean health.[20] Blue bonds are modelled on the booming green bond market, which reached US$1.1 trillion in 2020.[21]

Blue bonds account for only a fraction of this, yet promising case studies have emerged. In 2018 Seychelles launched the world's first sovereign blue bond, raising US$15m to finance the transition to a sustainable fishing industry.[22] Then in 2019, the Nordic Investment Bank issued a blue bond aimed at rehabilitating the Baltic Sea, raising US$200m.[23]

A significant recent development is the Asian Development Bank's Action Plan for Healthy Oceans and Sustainable Blue Economies, which commits US$5bn of investment and technical assistance to the development of a sustainable blue economy between 2019-2024.[24] In September 2021, it issued US$300m-worth of AUD- and NZD-denominated blue bonds to Japan's Dai-chi Life Insurance Company and Meiji Yasuda Life Insurance Company. The ADB says the bonds will finance projects that "enhance ocean health through ecosystem restoration, natural resources management, sustainable fisheries and aquaculture, reduction of coastal pollution, circular economy, marine renewable energy, and green ports and shipping."[25]

These examples are encouraging, but they are still small in scale and often driven by sovereign issuers. Mainstream private-sector investors will be required to finance the large-scale transition to a zero-pollution ocean.

Several chemicals companies have secured discounted loans attached to sustainability-linked performance criteria. In 2018, DSM concluded a €1bn line of credit to finance emissions reduction.[26] Corporate bonds may provide another vehicle. In 2020, BASF issued what it said was the industry's first green bond, raising €1bn to finance its sustainability strategy.[27] The green bond market can provide a helpful template for ocean-linked blue bonds, according to the Blue Natural Capital Financing Facility.[28]

Sustainability-linked loans are emerging as a viable source of capital in the chemicals sector

Green trailblazers
Several European and Asian chemical firms have taken out sustainability-linked loans.

Company	Amount	Metric for interest rate
DSM	€1bn (about $1.1bn) credit line	Greenhouse gas emissions
Indorama Ventures	€100m and $100m loans	Overall environmental performance
Kemira	€400m credit line	Overall environmental performance
Solvay	€2bn credit line	Greenhouse gas emissions
Stora Enso	SEK 6 billion (about $635m) green bonds	Overall environmental performance

Source: Chemical and Engineering News (2019)

But for scale, blue finance innovation requires better standards and guidelines. Several initiatives and groupings aimed at creating common standards and practices to drive sustainable investing have emerged. These could be a crucial driver of awareness and investment into addressing marine chemical pollution.

For scale, blue finance innovation requires better standards and guidelines

One important group is the United Nations Environment Programme Finance Initiative (UNEP FI), which works with 400 private sector financial institutions, including banks, investors and insurers.[29] The Sustainable Blue Economy Finance Principles were released in 2018 as "the world's first global guiding framework for banks, insurers and investors to finance a sustainable blue economy."[30] The principles include practical guidance on five key ocean-linked sectors: seafood, ports, maritime transport, coastal and marine tourism, and marine renewable energy.[31] UNEP FI is in the process of developing new guidance for other ocean-dependent industries.

Similarly, the UN Global Compact's Sustainable Ocean Business Action Platform has developed a set of Sustainable Ocean Principles. Ending waste entering the ocean is a crucial focus, particularly plastic waste and nutrient runoff from farms and wastewater. Major investment funds are working with the UN Global Compact to support companies using the principles as a reporting mechanism, says Erik Giercksky, head of the UN Global Compact's Business Action Platform for the Ocean. In the future, he hopes, a wide range of insurance companies, lending banks and investment funds will ask their portfolio companies to report against the principles. "In a couple of years, this might prove to be a major game-changer" for ocean health, he says.

"Companies have a responsibility towards their shareholders to align with the sustainable ocean principles. This shows that they are delivering on the expectations in the market," according to Mr Giercksky. "We need regulations to have a fair playing field, but while we wait for that to happen, the business sector can act. Governments do not make these principles. They are made by industry, and it works seamlessly."

7.3 Barriers to progress: Low awareness and misaligned incentives

Lack of awareness, lack of data

Investors remain largely unaware of the critical drivers of and solutions to marine chemical pollution. "The broad issue of chemical pollution tends to sit lower on investors' agendas than other areas of concern," says Eugenie Mathieu of Aviva Investors. Eric Usher, head of UNEP FI, agrees: "For the blue economy overall, we are still very much in awareness-raising mode, trying to get the finance industry to understand the nature of the problem."

If investors' understanding of marine chemical pollution comes to equal their understanding today of climate-related risk and opportunity, the outlook for a zero-pollution ocean may look very different—and much more encouraging

This lack of awareness mirrors, in many ways, the sector's understanding of climate change in the mid-2000s. When the insurance company Allianz and the environmental NGO WWF released their 2005 report, "Climate Change & the Financial Sector: An Agenda for Action," they began with a statement of fact that few would think was necessary today: "Climate change is real." The report then outlined the opportunities and the risks to the finance sector of climate change: knowledge that just 15 years later is mainstream and ubiquitous.[32]

If investors' understanding of marine chemical pollution comes to equal their understanding today of climate-related risk and opportunity, the outlook for a zero-pollution ocean may look very different—and much more encouraging.

Significantly, investors' lack of awareness extends not just to the effects of chemical pollution on the marine environment itself but also to which sectors and companies are contributing to it. "There is currently a clear lack of data, particularly when it comes to assessing which companies are having the most detrimental impact," says Ms Mathieu. "A ranking of the companies deemed to be causing the most pollution [in the ocean] and similarly of their efforts to minimise this impact would be particularly useful. Likewise, a ranking of which companies are in breach of environmental regulations would likely be of interest to a range of investors."

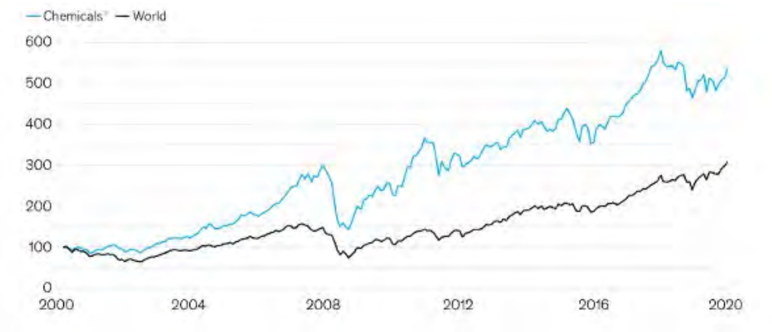
"Important data gaps remain, notably concerning the natural capital, the benefits of a sustainable ocean for the people, and the environmental and resource productivity of the ocean economy," agrees Ivan Haščič, senior economist at the OECD.

Pressure for profits, not progress

It is also important to recognise that—despite the booming ESG market—sustainability is not a crucial determinant of many investors' decision-making. This appears to be particularly the case for the chemicals sector, which after many decades of delivering spectacular returns, has been on a bumpy ride since 2018.[33] The industry has long been the subject of campaigns by activist investors intent on forcing managers to slash costs and focus on growth,[34] and M&A activity picked up in 2021. Sustainability is one factor behind this new wave of acquisitions, but the search for high-margin, pandemic-proof products appears to be the primary driver.[35] In this context, it is not difficult to imagine why CEOs of public chemicals companies seem to be more focused on cost efficiency than sustainability.

Profits in the chemicals sector have been falling since 2018

Total shareholder returns (TSR), %, index (100 = January 2001)



The chemicals industry has outperformed the world index over the long run but not in the past few years

Total shareholder returns (TSR), compound annual growth rate, %

	10 years Jan 2010—Dec 2019	5 years Jan 2015—Dec 2019	3 years Jan 2017—Dec 2019	2 years Jan 2018—Dec 2019
CHEMICALS	8.0%	6.9%	7.7%	-1.6%
MSCI WORLD INDEX	10.1%	9.4%	13.2%	8.6%

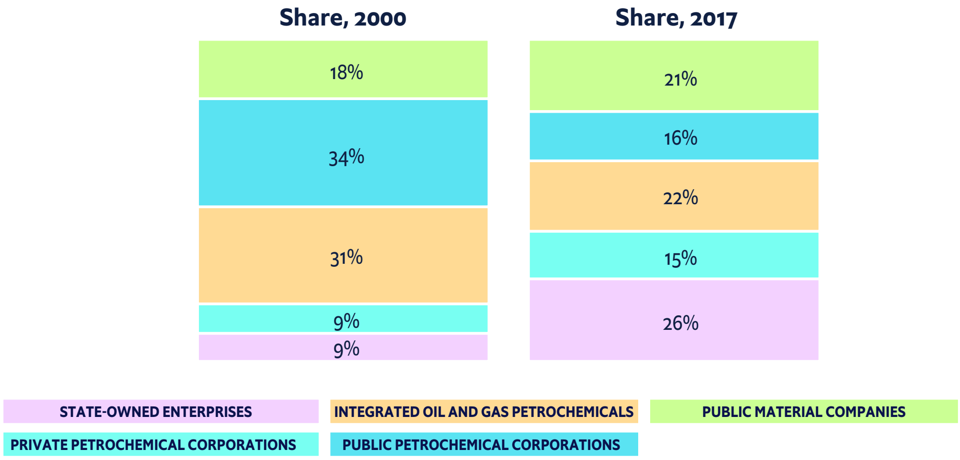
Source: The state of the chemical industry—it is getting more complex, McKinsey & Company (November 2020).
See: https://www.mckinsey.com/industries/chemicals/our-insights/the-state-of-the-chemical-industry-it-is-getting-more-complex

The changing ownership of the global chemicals sector is another complicating factor. In 2000, publicly traded materials and petrochemicals companies generated 52 percent of the sector's revenue. By 2017 this had fallen to 37 percent. At the same time, the share of revenue generated by state-owned enterprises grew from 9 percent to 26 percent.[36] The growing share of the sector operating outside the purview of new ESG rules, which typically target listed companies, may not be a bad thing: research published by the University of Virginia's Darden School of Business found that state-owned enterprises perform better on environmental measures, on average, than their privately owned counterparts. But the average hides large geographical variations.[37] It is not necessarily safe to assume that better data about the sector's environmental impact would suddenly sway many of its long-term owners and investors.

Even the big global banks that market themselves as leaders in sustainability do not seem to have so far been swayed by concerns about the sector's environmental impact. In the plastic polymers sector, for example, 20 banks, including Barclays, HSBC and Bank of America, have lent the industry an estimated US$30bn since 2011 to finance the production of single-use plastics.[38] According to the Minderoo Foundation's Plastic Waste Makers' Index, "twenty institutional asset managers hold over $300bn worth of shares in the parent companies of polymer producers".[39]

The share of revenue generated by public companies in the chemicals sector is shrinking

World chemical industry structure evolution, share of revenue, 2000-2017 (adapted from Cayuela and Hagan 2019)



Source: UNEP. Global Chemicals Outlook II, Part 1, p. 37.

Policymakers, business leaders and investors still have a relatively limited understanding of marine chemical pollution. This makes it difficult to describe the financial risks industry may face from pollution itself or from attempts to reduce it

Ultimately, this means that large-scale financing of the transition to a zero-pollution ocean will only materialise when it becomes profitable or the risks of not transitioning become too great. Any viable solution, then, must be predicated on this risk-reward calculus.

"No framework will, in itself, be effective unless there is sufficient disincentive to pollute and incentive to invest in the transition," says Torsten Thiele, founder of the Global Ocean Trust. "Regulation is part of this, but the willingness to invest must come from the private sector."

7.4 Pathways to action: Minimise transition risk, maximise innovation reward

Mitigating transition risk

As this report has demonstrated, policymakers, business leaders and investors still have a relatively limited understanding of marine chemical pollution. This makes it difficult to describe the financial risks industry may face from pollution itself or from attempts to reduce it: we simply don't know yet what kind of legislative or market conditions will emerge.

However, the transition required along the chemical value chain is akin to addressing climate change. An analysis of the chemicals sectors' exposure to climate-related risks (which, as Chapter 3 notes, are inextricably linked with the impact and extent of chemical pollution in the ocean) can provide valuable clues about the type of risks the transition to a zero-pollution ocean might entail.

The chemicals sector has high exposure to environmental risk

Qualitative sector listing of relative environmental exposure: chemicals
Greenhouse gas emissions, waste, pollution, and land use

Source: S&P Global Ratings, ESG Industry Report Card: Chemicals

The transition required along the chemical value chain is akin to addressing climate change

The TCFD divides climate-related risks into two main categories:

- Transition risks arise from the transition to a low-carbon economy and include financial risks that may arise from regulatory change, litigation, reputational damage, changing market conditions (such as falling demand for specific products) and the cost of new technology.
- Physical risks arise directly from changes in the climate, including chronic changes such as higher temperatures or increased sea levels and acute changes including more frequent and severe flooding and forest fires.[40]

Scope 3 emissions, which result from activity along the supply chain, present a particularly large, and probably underappreciated, financial risk to the chemicals sector. The chemicals industry is heavily reliant on fossil fuels, both as feedstock and to power its energy-hungry manufacturing processes. As fossil fuels become more expensive, the industry will face growing costs. Downstream, there are substantial risks too. Much of the sector's Scope 3 emissions are embedded in consumer and industrial products; chemical companies' customers, which have themselves set targets to reduce their own Scope 1 and 2 emissions, will attempt to eliminate carbon-intensive chemicals from their supply chains. End-of-life presents an additional challenge, as the embedded carbon in fossil fuel-based chemicals is released if they are incinerated or break down.[41]

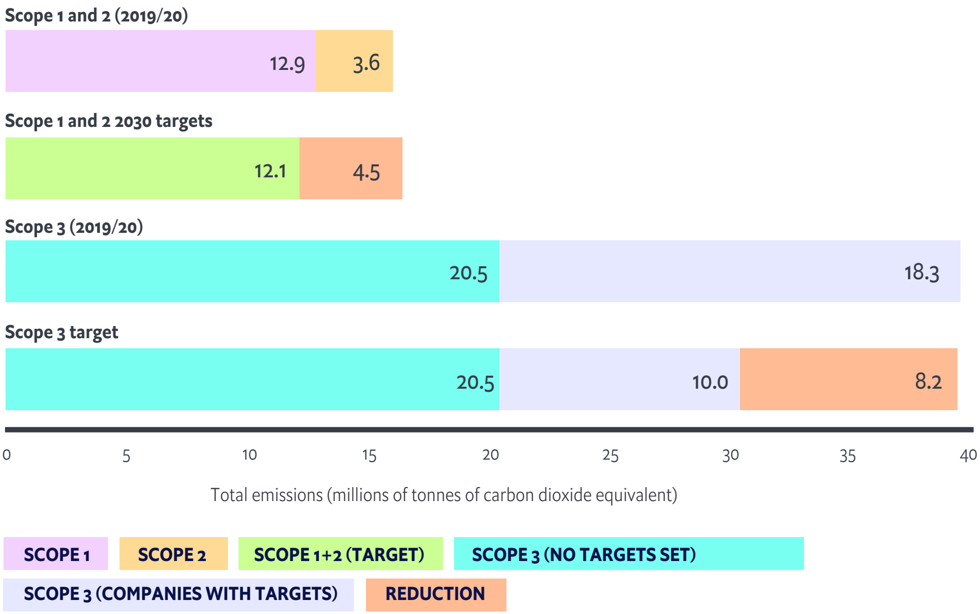
One example is the automotive industry, which is a major customer of the chemicals sector. Around half of car manufacturers' revenues are linked to Scope 3 reduction commitments. This, in turn, represents around US$110bn in revenue for the chemicals industry.[42]

Scope 3 emissions account for an outsized proportion of the chemicals industry's carbon footprint

Tracking the targets—chemicals

This chart shows the 2019-20 emissions from 10 chemicals companies that have reported their emissions and have set verified emissions targets for 2030 with Science Based Targets initiative (SBTi).

The emissions are broken down into scope 1 (direct operational), scope 2 (purchased energy) and scope 3 (indirect, supply chain) emissions. Most companies set a combined target for their scope 1 and 2 emissions, so these have been combined. Scope 3 emissions are considered separately.



Data presented for 10 companies with measured Scope 1,2 and 3 emissions, and SBTi targets for reduction of at least Scope 1+2 emissions
Of the 10 companies included, 5 have no comparable Scope 3 target for 2030

Source: Industry tightens emissions reduction targets, Angeli Mehta, Chemistry World (July 2021). See: https://www.chemistryworld.com/news/industry-tightens-emissions-reduction-targets/4013930.article

The transition to net zero will be immensely costly and challenging for the chemicals industry. The industry is so diverse—from large petrochemical producers to diversified conglomerates to small specialist materials companies—and its products so interwoven with almost every other sector that it is virtually impossible for investors to choose a single, comparable metric or scenario that will enable them to understand the sector's accurate exposure to climate-related risk.[43]

Does action on climate equal action on pollution?

Shareholder activist group ShareAction launched a campaign in September 2021 targeting the chemicals industry over its carbon emissions, after its research suggested that the sector had received relatively little scrutiny over its transition plans.[44] Their report found that seven fossil fuel-based feedstock chemicals make up 70 percent of the sector's emissions. Reducing or eliminating these feedstock chemicals would dramatically reduce the sector's emissions (along with the transition to renewable energy). The chemicals are ammonia, methanol, ethylene, propylene, benzene, toluene and xylene. Phasing out these seven feedstocks would provide the sector with a credible decarbonisation pathway, ShareAction argues.

Would this have a beneficial knock-on effect on other types of pollution? Joel Tickner, executive director of the Green Chemistry and Commerce Council and a professor at the University of Massachusetts Lowell, is not so sure: "[D]ecarbonisation is important but that won't address toxicity if the same chemicals are being made using the same platforms," he says.

A fundamental transformation which sees the chemical sector embrace new innovations, new systems and new business models will be required if the industry is to meet its climate, pollution and financial challenges.

Perhaps because of this complexity and cost, very few large chemical companies have so far committed to a credible transition plan.[45] We do not yet have a clear picture of what a decarbonised chemicals sector would look like or what it would take to get there. There are clues, however. The World Business Council on Sustainable Development convened a group of five chemicals companies (AkzoNobel, BASF, DSM, Solvay and Sumitomo Chemical) to assess how the sector should respond to the TCFD. These companies consider transition risks to be the most material to their operations, in the short-medium term at least.[46]

It seems safe to assume that many of these transition risks would also apply to any transition to a low-pollution sector, including:

- Policy and legal: enhanced reporting obligations; mandates on, and regulation of, existing products and services, exposure to litigation.
- Technology: substitution of existing products and services with lower [pollution] options, unsuccessful investment in new technologies, costs to transition to lower [pollution] technology.
- Market: changing consumer behaviour, uncertainty in market signals, increased cost of raw materials.
- Reputation: shifts in consumer preferences, stigmatisation of sector, increased stakeholder concern or negative stakeholder feedback.[47]

Climate risk has been and will continue to be an essential consideration for investors. But a new focus on nature-related risks, driven by the TNFD and new EU Taxonomies, means that concerns about the risks that may arise from pollution (or the transition to a zero-pollution ocean) could quickly become relevant to investors, says Matt Jones of the UNEP-WCMC. His team has developed a web-based tool called Encore to help investors quantify natural capital risk across their portfolios. UNEP-WCMC is also working with ESG data providers to help them understand how to quantify nature-based exposure and risk.

"It's not straightforward. There are massive gaps in the data," he says. "But when we can point to places where natural capital has depleted at the greatest rate, and the risk is highest, we start to see a much wider group of people from within financial institutions pay attention. That's been a game-changer."

Has the transition begun?

A large-scale, system-wide transition to a zero-pollution ocean is, at this point, an ambition. But this does not necessarily mean that transition risks to the chemicals sector are hypothetical. Already, several examples demonstrate of the future risks that industry players may face:

Regulatory risk:

- UK company Southern Water was fined GBP90m in 2021 after admitting to 6,971 illegal pollution incidents, including releasing untreated sewage into the sea. Southern Water is not alone. It is ranked only the *second-worst* water company in the UK after South West Water.[48] Yet proving that risk and opportunity are often two sides of the one coin, Australian investor Macquarie Group soon acquired a controlling share in the utility, committing more than GBP1bn to improve the company's sustainability record.[49]
- In October 2021, lawmakers in Belgium threatened to shut down a 3M facility producing PFAS over concerns that residents had been exposed to chemicals emissions.

Legal risk:

US courts have ordered several prominent chemicals companies to pay substantial damages for pollution.

- DuPont and two of its spin-off companies reached a US$4bn settlement deal in 2021 for several legal proceedings relating to its historical use of PFAS.[50] Yet just months later, the company again faced fines over pollution from the same type of chemical.[51]
- Texas-based petrochemical manufacturer Formosa was ordered to pay US$50m in damages in 2019 after it was found guilty of illegally releasing plastic pellets and other pollutants into coastal waterways.[52]
- DuPont and 3M face the prospect of further fines over the use of PFAS in the US state of Georgia.[53]
- In 2015 the Chinese government said it encourages NGOs to sue companies that breach pollution rules, and several chemicals companies have faced lawsuits since.[54] In 2018, three chemicals companies that polluted soil near a school in Jiangsu province were ordered to apologise and pay compensation.[55]

Financial risk:

- In December 2021, 23 investors managing US$4.1 trillion in assets, wrote to the 50 chemicals companies assessed by ChemScore calling for them to be more transparent about the volume of "substances of high concern" that they produce.[56]
- UK hedge fund Bluebell Capital Investors has targeted Belgian chemical manufacturer Solvay over its dumping of waste containing mercury, arsenic, ammonia, nitrogen and boron into Italian coastal waters adjacent to its factory at Rosignano. Solvay maintains that it is acting within Italian environmental regulations, but Bluebell claims that the practice does not align with Solvay's ESG commitments.[57]

Environmental impact and controversies are becoming an increasingly critical risk for Solvay

Criticality*	Stakeholders	Risk	Trend
Very High	Employees Local Communities Customers	Security	↗
	Suppliers Employees Planet Investors	Compliance and business integrity	→
	Planet Local Communities	Environment impact & Controversies	↗
	Employees Local Communities Suppliers	Operations safety	↘
High	Customers Local Communities Employees Planet Investors	Climate change	→
Emerging risks**			
	Customers Local Communities Employees Planet Investors	Regulatory framework for chemicals sustainability	Emerging

* The criticality level is determined by combining the risk's two ratings (impact and level of control) at the time of the assessment
** Emerging risks: newly developing or changing risk that may have, on the long term, a significant impact which will need to be assessed in the future

Source: Solvay Integrated Report 2020[58]

The opportunities that will arise from the transition to a low-carbon economy provide a valuable template to understand those that will underpin the transition to a zero-pollution ocean

Seizing potential reward

While risk management is essential, interviewees from the finance sector invariably highlighted the other side of the coin: opportunity. The opportunities that will arise from the transition to a low-carbon economy provide a valuable template to understand those that will underpin the transition to a zero-pollution ocean. Transition finance is a rapidly emerging segment, and while the current focus is on climate, there is a significant opportunity to finance the transition to a zero-pollution ocean.[59]

Again, the World Business Council on Sustainable Development's work on the chemicals sector's readiness for TCFD is instructive. The five chemicals companies the WBCSD collaborated with (AkzoNobel, BASF, DSM, Solvay, Sumitomo Chemical) expect that the transition to a low-carbon economy will create opportunities to profit from the more efficient use of resources, the development of new products and services, access to new markets and through diversification and substitution which will improve companies' resilience. A system-wide transition to address marine chemical pollution is likely to create similar opportunities.

The discussion about climate finance has moved beyond just risk and opportunity, says Eric Usher of the UNEP FI. "It's about having the overall portfolio aligned with the transition to a net-zero economy, a perspective which captures both risk and opportunity. Banks see that most industries are going through radical disruption."

Chemicals companies have highlighted significant opportunities to profit from the transition to a low-carbon economy

Climate-related opportunities for the chemical sector based on a review of Forum members' disclosures

Climate-related opportunities

Resource efficiency

- Use of more efficient modes of transport
- Use of more efficient production and distribution processes
- Use of recycling
- Move to more efficient buildings
- Reduced water usage and consumption

Energy source

- Use of lower emission sources of energy
- Use of supportive policy incentives
- Use of new technologies
- Participation in carbon markets
- Shift toward decentralized energy generation

Products and services

- Development and/or expansion of low emission goods and services
- Development of climate adaption and insurance risk solutions
- Development of new products or services through R&D and innovation
- Ability to diversify business activities
- Shift in consumer preferences

Markets

- Access to new markets
- Use of public-sector incentives
- Resource substitutes/diversification

Resilience

- Participation in renewable energy programs and adoption of energy efficiency measures
- Access to new assets and locations needing insurance coverage

Source: WBCSD TCFD Chemical Sector Preparer Forum. Climate-related financial disclosure by chemical sector companies: Implementing the TCFD recommendations

For meaningful opportunities to materialise, scale will be critical. Investment into significant new capital works projects, R&D into new technologies and reshaping entire supply chains will be required. For context, the average M&A deal size in the chemicals sector in the first half of 2021 was US$252m—a figure that has grown in the past few years despite the pandemic.[60] One thing is clear: the transition to a zero-pollution ocean will be capital-intensive.

The opportunities will arise, says Mr Thiele, from identifying polluting products or processes that will still be required in the future—desalination or antibiotics, perhaps. The commercial prize lies in designing technology that allows these to be used in a less polluting or non-polluting way and financing the transition to that new technology. "The opportunity will be in spotting future needs and then filling the finance gap," he says.

"A lot of the excitement on the investor front comes from the opportunities," says Dennis Fritsch, head of Sustainable Blue Economy Finance at the UNEP Finance Initiative. "It's not because of the high risks of business as usual. It's because they want to offer their clients exciting, sustainable products."

These opportunities do not yet exist at scale. "Currently there is still a significant disconnect between the opportunities, the size and volume of the demand and the supply of investable blue products," says Valeria Ramundo Orlando, co-founder of Greensquare Ventures. "There is huge variation between supply and demand. In the sustainable blue economy, there are fantastic investments in the range of US$10m-15m, with proven returns. Unfortunately, the large institutional investors as well as family offices are looking for something that will make a greater impact in terms of volume and scale."

Innovation in more sustainable and less polluting chemicals will not only come from the big chemicals companies: the burgeoning green chemistry start-up scene could be a significant driver of the technology needed to transition to a zero-pollution ocean

As mentioned above, some opportunities exist in sustainability-linked credit for chemicals producers. But these remain few. For the transition to be meaningful, horizontal adoption across financial institutions will be critical. It is not enough to engage with the sustainable finance arms of asset managers, says Mr Thiele. Investment professionals across the sector must understand the scale of the opportunity.

PC, VC and blended finance

Innovation in more-sustainable and less-polluting chemicals will not only come from the big chemicals companies: the burgeoning green chemistry start-up scene could be a significant driver of the technology needed to transition to a zero-pollution ocean.

Private equity (PE) and venture capital (VC) funding will be critical, then, to ensure a robust pipeline of sustainable technology. There is already intense PE interest in the chemicals sector. In the year to June 2021, PE firms invested US$7.4bn in specialty chemicals alone.[61] These deals were not necessarily related to green chemistry, but the amount of activity indicates the potential of PE to help fund the sector's sustainability transition. PE investments into green chemicals are becoming more common: One promising example is Swedish Bank SEB's VC arm Greentech, which made its first investment in green chemicals production in 2021.[62]

Large chemicals companies also commonly look to acquire green chemistry start-ups as a cheaper alternative to in-house R&D, says Mr Tickner. The green chemistry sector should be an attractive proposition to PE and VC firms which often invest with an exit strategy already in mind.

Large scale, private sector-led finance will be critical to financing the transition to a zero-pollution ocean. However, marine chemical pollution is still relatively unknown and solutions, if they exist, are in their infancy. Instruments such as impact investing and blended finance, which have both sustainability goals and financial ones, will play an essential role for some time to come.

One salient example is the Reef Credit Scheme, an innovative financing mechanism that pays Australian farmers to change their land management practices to reduce nutrient, pesticide or sediment runoff into waters surrounding the Great Barrier Reef.[63] Sovereign, corporate and philanthropic investors—including global bank HSBC—have purchased the tradable credits.[64]

If investors are to play a credible role in financing the transition to a zero-pollution ocean, the first step must be awareness-raising. Few understand the risk to, and impacts of, the chemicals industry and other sectors along the chemicals value chain from marine pollution

"Blended finance lends itself quite well to the blue economy, partly because the marine space often has legal or governance issues which are not present on the land," says UNEP FI's Mr Fritsch. But, he cautions, do not expect this type of instrument to deliver widespread change: "Plain vanilla instruments still finance the majority of this sector."

A roadmap for investor-led change

If investors are to play a credible role in financing the transition to a zero-pollution ocean, the first step must be awareness-raising. Few understand the risk to, and impacts of, the chemicals industry and other sectors along the chemicals value chain from marine pollution.

ESG disclosure rules will play a crucial role in raising the issue's profile among the finance community. An emerging focus on nature-related impacts and risks, spearheaded by instruments such as the TNFD and EU Taxonomies, provide an important opportunity to catapult a zero-pollution ocean up investors' agenda.

A roadmap for investor-led action on marine chemical pollution

1. Develop **improved ESG guidance**, particularly around emerging nature-related frameworks such as TNFD.
2. Publish **more and better data**, particularly around companies' impacts on marine chemical pollution and exposure to transition risks.
3. The articulation of climate-related risks to investors can provide a template for **setting out the risks that investors may face** during the transition to a zero-pollution ocean.
4. **Industry and investors must work together to uncover opportunities** for transition financing and align the supply of and demand for large-scale deals.
5. **Private equity and M&A activity** can help drive innovation in the burgeoning green chemistry start-up scene.

As Chapter 6 set out, the chemicals sector urgently needs to address the environmental impact of its waste footprint and drastically reduce the GHG emissions associated with the production and consumption of its products. The scale and form of the transformation required for the sector to meet emissions reduction targets hints at what will be needed to transition to a zero-pollution ocean.

Investors, too, will face new risks—and also enjoy new opportunities. Industry and investors will need to work together to identify and profitably fill long-term funding gaps. The scale of the challenge is immense, and the capital required to meet it is just as significant. But, says Guy Bailey, head of intermediates and applications at Wood Mackenzie, "if the finance sector is persuaded that sustainable investments are the better long-term play, then capital will move in that direction".

Please see Notes for references

8: Civil society and consumers

This chapter examines the roles that civil society and consumers can play in curbing marine chemical pollution. It argues that, although public awareness of this issue is relatively low, previous successes by civil society groups map a way forward. This includes using visual, science-based storytelling to counter apathy, along with realistic, achievable solutions that people can implement in their daily lives.

8.1 Principal findings and recommendations

- **Civil society pressure on marine chemical pollution has proven effective, despite the barriers that NGOs face.**
  Industry and government are the stakeholders that can have the most direct impact on marine chemical pollution. Still, civil society groups have had some notable success in influencing decision-makers to act on marine chemical pollution. Campaigns by the environmental NGO Greenpeace led to the 1996 London Protocol, which banned radioactive dumping worldwide; community awareness and NGO pressure led to the Stockholm Convention on Persistent Organic Pollutants in 2001; and community action on lead paint, pesticides and other pollutants has led to regulatory change. Yet NGOs working to address chemical pollution typically struggle to access information and adequate funding, and often face legal and political impediments, which can at times undermine their effectiveness.

- **Popular awareness of the danger of marine chemical pollution is low. Emotive and visual storytelling—grounded in science – is the key to addressing apathy.**
  Community awareness about marine chemical pollution is low relative to other environmental issues such as plastic pollution or climate change. Knowledge-building is a critical first step. The most effective way to do this is by using emotive and visual storytelling. Blue Planet II, a BBC documentary series narrated by the naturalist Sir David Attenborough, has played an outsized role in raising public awareness about marine plastic pollution, for example. For storytelling to be effective, it must be deeply rooted in science.

- **Achievable actions by individuals, particularly the ability to make informed purchasing choices, are crucial.**
  Awareness-raising, while an important first step, is not effective unless it is accompanied by calls for achievable action. Ultimately, the most effective means available to individuals

to combat marine chemical pollution is to exert their power as consumers and voters. Campaigns that encourage small changes in behaviour, such as using fewer or slightly different products, can present achievable actions. Citizen science projects and education programmes can also play a role in giving communities a sense of agency over water quality in their local coastal areas. However, for individuals to make informed purchasing decisions, they must be able to access better information about the products they buy. Giving consumers the right to know will require better cooperation from industry and regulators.

- **NGOs can act as focuses of citizen power and as convenors of stakeholder groups with divergent interests.**
  NGOs play a crucial role in focusing and co-ordinating popular action: there are some illustrative examples of large multinational businesses and of governments responding directly to NGO campaigns or community pressure to address marine pollution. NGOs can also act as convenors, bringing together disparate stakeholder groups which might not otherwise act in concert. The Ellen MacArthur Foundation, for example, has acted as a catalyst for business sectors to address plastic waste. NGOs play a similar role in forging consensus among decision-makers on marine chemical pollution.

- **A consumer and NGO wish list: seven steps for civil society action on marine chemical pollution.**

  1. **Raise awareness:** make the invisible visible.
  2. Campaigns **should be based on science but appeal to emotion.**
  3. Provide individuals with **realistic and achievable solutions,** rather than dwelling on the problems.
  4. **Engage local communities.**
  5. **Provide consumers with** the **tools and information** to make informed purchasing decisions, including the **right to know** about chemicals in the products they buy.
  6. **NGOs can play a dual role,** engaging the community as well as convening and influencing decision-makers.
  7. To achieve these goals, NGOs should be able **to access data and information, be adequately funded, and enjoy legal protection.**

8.2 Current approaches: Low awareness, high potential

Policymakers, business leaders and investors must all play a role in tackling marine chemical pollution. Yet, individuals can play an important part too. Changing consumer preferences, citizens' advocacy and NGOs (ranging from small community groups to major global charities) will be necessary to transition to a zero-pollution ocean.

Civil society groups have had some notable successes in influencing decision-makers to act on marine chemical pollution. The environmental NGO Greenpeace, for example, waged a long campaign against dumping waste at sea, famously documenting a Russian Navy ship dumping radioactive material in the Sea of Japan in 1993. The footage sparked outrage from many countries and directly led to the 1996 London Protocol, which banned radioactive dumping worldwide.[1] NGOs have mobilised to tackle chemical pollution in Eastern Europe, the Caucasus and Central Asia, where stockpiles of toxic chemicals had often been poorly stored and managed following the collapse of the Soviet Union.[2]

"Local and national NGO campaigns in numerous countries across the world increased the pressure on governments to develop the Stockholm Convention on Persistent Organic Pollutants in 2001—both in record time for a UN Convention, and with a process for ongoing additions of new POPs. "This means many toxic marine pollutants have been added over the last 15 years," says Mariann Lloyd-Smith, Senior Advisor to the International Pollutants Elimination Network (IPEN).

"There is a similar story behind the Basel Action Network campaigns to use the Basel Convention to prevent the transfer of hazardous waste from developed to less-developed countries. There have been successful campaigns globally on the elimination of hazardous pesticides, lead paint and chemicals in plastics and products with an emphasis on children's toys," she says. "Civil society networks such as IPEN, Break Free from Plastics and the Pesticide Action Network involve hundreds of NGOs in over 100 countries, and underpin major global campaigns utilising community action and targeting local, national and international policy and management."

Even so, two decades on from the signing of the Stockholm Convention and regional commitments to eliminate hazardous substances such as the OSPAR Commission in the North-East Atlantic, POPs are still released into the marine environment, notes Rémi Parmentier, a former Greenpeace activist who was instrumental in the campaign to ban the dumping of waste at sea and is now a consultant advising other environmental movements and some governments. And despite these notable victories, more comprehensive awareness of and action to address marine chemical pollution remain elusive.

When asked why marine chemical pollution is not high on the public agenda, most experts interviewed for this report gave two variations of the same answer: visibility and complexity. It is hard to care much about something you do not understand and cannot see. "Out of sight is out of mind," says Mr Parmentier.

Alex Rogers, science director of REV Ocean, an independent marine research vessel, raises the same issue. "How does the consumer know what substances are in the products they buy? The sheer complexity of chemicals in everything from household goods to industry is a major challenge for consumers."

Greenwashing, a practice where businesses market their products as more sustainable than they are, complicates matters further. In many cases, businesses are not required by law to disclose the chemicals in their products—or, more commonly in the developing world, governments lack the capacity to effectively enforce disclosure rules. The challenge, in the words of Dune Ives, chief executive officer of Lonely Whale, an organisation that campaigns for ocean sustainability, is: "How do you make the invisible visible?"

The Blue Planet effect

The serene television narration of David Attenborough, arguably the most famous documentary-maker ever, has been a reassuring presence in living rooms worldwide for nearly seven decades. Over time, his messages have subtly shifted from being educational to activist: exhorting viewers to act to counter the increasingly urgent perils of climate change and other human-induced environmental threats.

If awareness is the aim, then this shift in focus has been remarkably successful. *Blue Planet II*, a 2017 documentary series that concluded with a six-minute segment on marine litter, has been credited with catapulting plastic pollution into the public consciousness.[3]

When asked why marine chemical pollution is not high on the public agenda, most experts interviewed for this report gave two variations of the same answer: visibility and complexity

Plastic is now a well-known issue. A 2019 survey found that more Americans are concerned about plastic waste in the ocean (65 percent) than worry about climate change (58 percent).[4] Some 97 percent of respondents to a 2020 survey in India said that plastic waste is a concern for human health and the environment.[5] The Stockholm Environment Institute, a non-profit, tracked 50 campaigns to tackle plastic waste in a 2021 study. Its list is far from exhaustive and was itself whittled down from an even longer list.[6] Business is on board too: Consumer brands from McDonald's to Adidas tout their low-plastic credentials.

8.3 Pathways to action: Reaching and empowering consumers

Slogans and science: How to build a campaign

How, then, could marine chemical pollution achieve the same level of awareness as its solid-waste counterpart? Chemical pollution, unlike plastic, is often unseen. It is relatively easy for a layperson to grasp the problems caused by plastic: they see it at their local beach, and media images of sea life tangled in plastic debris are emotive and visually arresting. It is hard to convey the same message with microscopic molecules.

Inevitably, emotions need to play a role. "You have to make people angry," Mr Parmentier says. "You can do that by focusing on the effect on the natural environment, the places that they care for. The ocean is associated with holidays and lifestyles. And you can also bring it back to their plates through the food chain."

"Pollution campaigns have been most successful when there is something visible," says Ms Lloyd-Smith. "Smokestacks, industrial effluent outlets and dying workers are what the general community think about when we talk about pollution. I know this sounds harsh, but visible effects are the first thing that the media ask for in a campaign around pollution."

In the campaign against plastic waste, Ms Ives points to the impact of a video posted to YouTube by Ms Christine Figgener, which shows the marine conservation biologist removing a plastic straw from a baby sea turtle's nose. "We would have never had such success with our plastic pollution campaigning work had she not posted that video," says Ms Ives. The video, which is a graphic and disturbing glimpse at the damage caused by plastic pollution, has been viewed more than 43 million times.[7]

Several interviewees raised the success of climate campaigners in adopting consistent and easy-to-understand messages. Climate change, like pollution, is a complex and multifaceted issue. Slogans such as "net zero" or "toxic-free future" enable ordinary people to understand it and feel that a solution is within their reach.

Slogans are perhaps necessary but are far from sufficient. An effective campaign needs thorough planning. "An effective environmental campaign looks much like any other kind of effective marketing campaign," says Richard Page, coordinator of the NGO RISE UP Blue Call to Action and a lifelong ocean campaigner who spent two decades at Greenpeace. This means defining objectives and strategy and doing a "power analysis" to assess which people and organisations can drive change. "You can't just start with a slogan and expect to change the world," he warns, "however good that slogan might be."

Chemical pollution, unlike plastic, is often unseen. It is relatively easy for a layperson to grasp the problems caused by plastic: they see it at their local beach and in visually arresting media images. It is hard to convey the same message with microscopic molecules

Credible campaigns must also be grounded in science. In the case of plastics, academic research has played a crucial role in galvanising the public. Two controversial academic studies, published in 2015 and 2017, have had a rousing effect on public sentiment towards plastic waste. The first, by Jambeck et al., found that four countries—China, Indonesia, the Philippines and Vietnam—account for more than half of all plastic waste that flows into the ocean.[8] The second, by Christian Schmidt, Tobias Krauth, and Stephan Wagner, was widely quoted as finding that ten rivers are the source of 90 percent of plastic waste in the sea.[9]

The findings of both studies were later questioned. The Jambeck research was criticised for not taking Western countries' export of plastic waste to Asia into account. The authors of the second study published a correction of their data. But this did little to change the impact of the pieces: the point had been made. Both studies continue to be cited regularly in the media.

This research, combined with the advocacy of NGOs such as the Basel Action Network, likely contributed to China's unprecedented 2017 decision to stop accepting plastic waste imports. Several South-East Asian countries subsequently changed their own policies, and in 2019 signatories of the Basel Convention agreed to ban the global trade of plastic waste.[10]

Data and knowledge to make informed purchasing decisions

Ultimately, the most potent way for individuals to influence marine chemical pollution is through purchasing decisions. Unfortunately, consumers do not always have access to the necessary information to make these decisions. NGOs have long campaigned for consumers' right-to-know about hazardous chemicals in the products they buy.

"The lack of information on chemical safety issues, including deficient labeling and inadequate information on hazardous chemicals in products is a significant challenge," says Aileen Lucero, national coordinator of The Ecowaste Coalition, a network of 150 community, church, school, environmental and health groups in The Philippines. "There is a lack of publicly accessible data on chemicals of concern that are discharged from pollution sources, their effects on public health and the environment. Legislation to protect the public's right to know is insufficient." The EcoWaste Coalition calls for national laws that require industry to disclose the chemical ingredients of their products.

Following lobbying by NGOs, the Stockholm Convention adopted a number of articles that protect the public's right to access information about the health and environmental effects of POPs. Other conventions and agreements have subsequently adopted similar clauses. Central to this, says Ms Lloyd-Smith, is that manufacturers cannot avoid disclosure of this information on the grounds that it is commercially sensitive or confidential information. "Right-to-know is essential to address marine pollution," she says.

Accessing information about chemical ingredients is particularly difficult in countries that rely heavily on imported products, says Griffins Ochieng, executive director of the Centre for Environmental

Effective civil society campaigns to prevent marine pollution

UK-based NGO Surfers Against Sewage publishes an annual water quality report and allows individuals to report pollution incidents. Its free-to-use Safer Seas & Rivers Service app allows swimmers and surfers to track water quality in their local rivers and seas.[11]

The Hawaii chapters of the NGO Surfrider Foundation claimed victory in 2018 after their years-long campaign to rid sunscreens of the chemicals oxybenzone and octinoxate to protect coral reefs led to a legislative ban.[12] Similar campaigns have emerged worldwide, with bans coming into effect in parts of the Caribbean and Pacific Islands. Sunscreen brands now increasingly market themselves as "reef-friendly".

Beat the Microbead, an app developed by an anti-plastic pollution NGO called the Plastic Soup Foundation, provides a searchable database of cosmetics to allow consumers to choose products that do not contain microplastics.[13]

Greenpeace's Detox My Fashion campaign has for ten years advocated halting the release of toxic chemicals into waterways released by the textile industry.[14] In 2021, outdoor clothing brand GORE-TEX announced it would stop using a number of harmful per- and polyfluorinated chemicals (PFCs) in its consumer clothing after coming under pressure from the campaign.[15]

Greenpeace also has a research laboratory based at the UK's University of Exeter, which provides scientific advice to support the NGO's campaigns. Some of its recent work has focused on marine chemical pollution as well as plastic and microplastic pollution.[16]

International Pellet Watch is a citizen-science project that allows individuals and groups to collect resin pellets from their local coastal areas and send them to Tokyo University of Agriculture and Technology, where scientists analyse the samples for the presence of harmful chemicals such as POPs.[17]

Justice and Development, a Kenyan NGO. Consumers, and the governments and NGOs that represent them, have very little influence over the way products are designed, manufactured and labelled in other parts of the world. The challenge is most acute for small and developing economies, which often have strong regulations and are signatories to the Basel, Rotterdam and Stockholm conventions, but lack the capacity to effectively enforce and monitor these obligations.

Shifting consumer preferences

Several large retail companies have radically changed how they use chemicals in their products in response to customer demand (some examples are listed in Chapter 7). These are not isolated actions: S&P, a ratings agency, believes that changing consumer preferences present a material financial risk to the chemicals sector: "social perception of chemical products and consumer preferences could pose important long-term challenges for companies."[18]

Technology giant Apple provides an instructive example. Apple is now working with the NGO ChemSec to develop a step-by-step approach to help its supply chain partners reduce their use of harmful chemicals.[19] It was not always so enlightened. In 2014, the company was subject to a campaign by the NGOs China Labor Watch and Green America called "Bad Apple", which called on consumers to boycott Apple over the use of the chemicals benzene and n-hexane in its production process. Both chemicals are potentially hazardous to the health of the workers on the assembly line.

The campaign received global media attention[20] and resulted in Apple agreeing to discontinue several toxic chemicals.[21] The company became a founding member of the Clean Electronics Production Network (CEPN), a multistakeholder network committed to reducing workers' exposure to harmful chemicals.[22] It is now considered to be an industry leader on toxic chemicals.

The cosmetics industry is another segment that has seen a rapid shift in consumer preferences, as customers become more concerned about chemicals used in skin creams and make-up. "Natural" and "green" cosmetic brands have become increasingly popular, driven by health and environmental concerns.[23] Websites such as the Campaign for Safe Cosmetics[24] and EWG (Environmental Working Group)[25] advise consumers how to read product labels to avoid products containing toxic chemicals. EWG's Skin Deep database allows consumers to search by brand, and producers can apply to include the "EWG Verified" mark on their product label.

Still, the example of the cosmetics industry also demonstrates the challenges that consumers face in making these purchasing decisions: a 2021 study found that despite growing consumer awareness, large cosmetics brands in the US and Canada still use PFAS widely in their products. A legislative loophole means that most products do not have to carry a warning label.[26] Consumers may wish to make certain purchasing decisions but do not always have the information that allows them to do so. In other cases, particularly in the developing world, customers may wish to make different purchasing decisions but are unable to do so due to financial constraints or a lack of alternative products.

It is crucial to remember that consumers do not only make purchases on behalf of themselves and their households, says Ms Ives. Businesses, schools and local governments all make procurement decisions that collectively can significantly impact marine chemical pollution.

"How do you convince commercial real estate developers to think about permeable pavements and roofing choices?" she says. "How do you convince local governments to plant with absorption in mind?" Green construction guides and standards are now common in many countries. "Is there a blue construction guide?"

Think global, act local

Local multi-stakeholder groups, sometimes funded by governments but heavily reliant on volunteers and community participation, can play an essential role in addressing marine chemical pollution in bays and coastal areas.

The Puget Sound Partnership in Washington State in the Northwest United States is government-run and funded but aims to "build issue awareness to increase public support for Puget Sound recovery and cultivate stewardship behaviours that benefit Puget Sound". Citizens can join one of several partnership boards to oversee different aspects of the environmental recovery and stewardship of Puget Sound.[27]

On the United States' East Coast, the Chesapeake Bay Program is a regional partnership that brings together federal, state and local government agencies, universities, businesses and NGOs to restore the bay and its rivers. The Toxic Contaminants Workgroup acts to reduce toxic chemicals in the bay that affect the health of fish and other wildlife. The group promotes the "safe catching, sharing, preparing and consumption of fish" caught in the bay.[28]

These two examples are well-funded and primarily government-led. At the other end of the spectrum, Friends of the Upper Wye in the United Kingdom is a volunteer organisation of around 300 members whose 100 citizen scientists regularly test water quality on the upper part of the River Wye. The group receives some funding from the UK's Environment Agency and collaborates with Cardiff University, but it is essentially a volunteer effort. Volunteers upload data from the samples they collect to an open-source platform for Cardiff University scientists to analyse. The national government's Environment Agency also plans to use the data to complement its monitoring.

In each of these examples, the motivation is to preserve and protect the local environment. "People are dismayed to find an ecological disaster on their doorstep and very motivated to play a role in turning the situation around," says Nicola Cutcher, a journalist who is a member of the Friends of the Upper Wye. "The citizen science enables people to test the water running through their garden or on their dog walk, and they want to know more about the water quality, especially if their children or pets are playing in that water or if they've observed a decline in wildlife over the last few years."

Give individuals a path to action

One of the most common mistakes that campaigners make is raising awareness without giving individuals a pathway to action. According to the Stockholm Environment Institute, the most successful consumer campaigns to tackle plastic pollution have offered individuals an achievable solution.[29] If the source of pollution can be pinpointed, it is surely easy for consumers to imagine a solution (even if the reality turns out to be somewhat more complex).

Strawless in Seattle, which Ms Ives and her colleagues at Lonely Whale led, is a good example of the powerful impact a campaign can have when it offers individuals an easy path to change. The premise is simple: customers should refuse a plastic straw offered in a café or shop. The initiative led to a city-level ban on plastic drinking straws and helped spark a worldwide movement that has seen local governments and businesses ban straws all over the world—as well as a boom in reusable and paper straws.[30]

"The way into consumers' hearts is to allow them to see a path to success that they can be a part of," says Ms Ives. In a campaign to address marine chemical pollution, "you might never say flame retardants or chemicals or pesticides. But you might talk about planting a million rain gardens [which reduce pollutant runoff in urban areas]. For an individual who doesn't know much about chemicals, that sounds lovely."

The aim of an environmental campaign, Ms Ives says, should be to encourage individuals to change their behaviour and convince their peers to do the same. "We knew straws were not the most important thing to focus on," she says. "But a straw can grab your attention. By saying 'no straw,' you start a conversation that you don't get by saying 'no PFAS' or 'no flame-retardants.' If we had just led with the science, we would have lost the opportunity to engage hearts and minds."

"If you want long-term influence, you somehow have to get people to engage with the issues on a deeper level with their peers," agrees Marianne Krasny, professor of natural resources and the environment at Cornell University. "The most effective way to spread complex behaviours is through peer-to-peer close or tight networks."

Beach cleanups, where groups of people get together to clear debris from their local beach, are an example of how social networks can drive awareness and individual action on marine pollution. Beach cleanups can be small, informal, neighbourhood affairs or part of an extensive national or global campaign.

The International Coastal Cleanup (ICC), running for 35 years, is one example. The 2019 cleanup involved more than one million volunteers[31] (although this number has since reduced due to the pandemic). Afroz Shah, an Indian lawyer and environmentalist, earned global recognition after spending every weekend cleaning Mumbai's Versova Beach and ultimately inspiring 200,000 volunteers to join him in what became known as the world's largest beach cleanup.[32] The "One Ocean One Voice" campaign has brought together more than 57,000 people to clean up Bali's beaches over five years.[33]

One important feature of beach cleanups is that they give participants a sense of agency. By participating, individuals can directly contribute to ocean health and may subsequently be more likely to make different purchasing choices or lobby their local government. Large-scale cleanups can have an impact beyond the immediate environmental benefit of the cleanup itself: attracting media attention and raising awareness among both the public and legislators about plastic pollution. Several beach cleanup organisers also act as advocates at the national or sub-national level,[34] harnessing the power of their communities to try to push for legislative change. Creating a sense of community can be a powerful way to persuade individuals to act on marine pollution, says Ms Ives. "You're working towards the same cause, and there is a sense of togetherness."

While picking up plastic waste from the beach is a relatively straightforward exercise, ridding the marine environment of chemical pollution (including microplastics and solid plastic in the open ocean) is somewhat trickier. This does not mean, however, that there is not a role for individuals. Citizen science initiatives allow individuals, communities and school groups to collect and test water samples. Technology means that local groups can feed into more extensive data-collection efforts.

Individuals or classroom teachers can order test kits from The EarthEco Water Challenge which enable them to monitor water quality in their local area. They can then upload their results to a global database. The organisation provides lesson plans and other resources for teachers.[35] The Marine Debris Tracker App allows individuals and grassroots groups to collect and share data on plastic waste. The International Coastal Cleanup has evolved into a dual role as both cleanup and a citizen science project: participants use an app to collect data on coastal pollution.[36]

Storm-drain stencilling is another grassroots movement that has emerged to address marine pollution. The premise is simple: an individual or group (or, often, a local government) spray-paints messages onto pavements and stormwater drains to remind passersby that pollutants entering the drain will end up in the ocean. Projects range from artfully painted ceramic tiles in Hong Kong[37] to DIY stencilling kits in New Jersey[38] and "save the platypus" themed graffiti installations in Melbourne, Australia.[39]

One crucial, if longer-term, strategy to raise awareness and drive citizen engagement on marine chemical pollution is to teach it in schools and universities. One recent study has found that teaching university students about climate change—at scale—could significantly reduce carbon emissions. Students tend to make different decisions in their personal and professional lives after taking such courses.[40]

Ms Krasny and her Civic Ecology Lab members teach massive open online courses (MOOCs) on climate and environment and say the course on marine plastic waste attracts the most engaged students (although she is unsure whether a course on marine chemical pollution would generate the same enthusiasm). The UN Environment Programme has run a similar MOOC in partnership with the Open University of the Netherlands.[42]

Several NGOs run programmes that aim to educate school-age children about ocean health, often focusing on plastic pollution. Others provide hands-on training for young activists. The Ocean Heroes Bootcamp, for example, teaches young people how to build successful grassroots campaigns to tackle marine plastic pollution.[43]

In Indonesia, the NGO ECOTON teaches youth volunteers to collect and analyse water samples from the Surabaya River to assess microplastic contamination. City-level regulations protect the river from pollution, but poor enforcement means the waterway remains highly polluted.[44] Community engagement in combating pollution is particularly important in developing countries, where governments often lack the capacity to enforce regulations, says Mr Ochieng of the Centre for Environmental Justice and Development in Kenya.

NGOs: Beyond consumer engagement

One theme that interviewees for this report raised repeatedly is the lack of engagement between stakeholder groups on marine chemical pollution: industry leaders do not talk to policymakers, who do not talk to investors, who do not talk to scientists.

In this context, NGOs play an essential role that goes well beyond public engagement and lobbying. Multi-stakeholder collaborations and initiatives to promote ocean health typically comprise industry and government members, but—behind the scenes—there are very often one or more NGOs working in a coordinating or catalysing role.

These NGO-led multi-stakeholder groups can have a profound impact on global policymaking and business strategy. One example is the Ellen MacArthur Foundation, which in 2012 launched what it says was the first-ever report to examine the economic potential of a circular economy at the World Economic Forum meeting in Davos. Four years later, it launched the first New Plastics Economy report at the same conference. The effect has been dramatic. More than 1,000 organisations, including global businesses and governments, have joined the Foundation's Plastic Pact Network or signed its Global Commitment.[45] The term "circular economy"

One theme that interviewees for this report raised repeatedly is the lack of engagement between stakeholder groups on marine chemical pollution: industry leaders do not talk to policymakers, who do not talk to investors, who do not talk to scientists

is now common parlance in boardrooms and government offices alike. The example demonstrates that a well-organised NGO-led campaign can have a profound impact in just a few years.

NGOs can sometimes develop deep collaborative relationships with individual businesses, too. The environmental charity WWF, for example, publishes a long list of its corporate partnerships.[46] The relationship between business and civil society is much more complex now than in the past, notes Mr Parmentier, with parts of the corporate sector aware of their responsibility to actively contribute to finding solutions. There is ample opportunity here. "How do we develop a relationship between these two elements to focus on the areas where we can agree? Can we push the envelope together?"

Still, NGOs often face barriers that limit their effectiveness. Low awareness about chemical pollution among policymakers means that there is a long process for NGOs to first educate before they can begin to have an impact, says Mr Ochieng. And resourcing remains an ongoing challenge. "Limited financial resources to build and expand NGO capacity to generate data, raise awareness and campaign for real solutions is a problem," says Ms Lucero of The Ecowaste Coalition in the Philippines. The businesses and governments that NGOs often campaign against are typically better resourced and more powerful. In some cases campaigners face legal action: in 2021, four Cambodian environmentalists were arrested and charged while collecting wastewater runoff in the Tonle Sap river, for example.[47]

8.4 A roadmap for civil society-led change

Industry and government are probably the two most important stakeholders on the journey to a zero-pollution ocean: real progress will remain elusive without both legislative change and business transformation. But individuals—as consumers and voters—can have a significant influence on these two groups. The role of civil society should not be overlooked.

A two-stage process will be needed. Public awareness about marine chemical pollution is low. The challenge is to make the invisible visible. Emotive storytelling, photography and documentary-making can bring the issue to life in a way that captures the public's imagination. Focusing on topics that individuals care about, such as the potential impact of chemical pollution on human health, will be crucial. Local community projects and education can engage and inspire the next generation of activists.

A roadmap for civil society-led action on marine chemical pollution

- **Raise awareness**: make the invisible visible.
- Campaigns **should be based on science but appeal to emotion**.
- Provide individuals with **realistic and achievable solutions**, rather than dwelling on the problems.
- **Engage local communities**.
- **Provide consumers with** the **tools and information** to make informed purchasing decisions.
- **NGOs can play a dual role**, engaging the community as well as convening and influencing decision-makers.
- To achieve these goals, NGOs should be able **to access data and information, be adequately funded, and enjoy legal protection**.

But awareness-raising alone is not enough. Information does not automatically lead to action. It will be important to provide easy-to-implement solutions that give individuals an opportunity to contribute personally to change. Product guides to inform better purchasing decisions and practical, positive steps individuals and communities can take are more effective than simply providing information about the problem. Small actions can lead to more extensive behaviour changes.

NGOs play a vital role in raising awareness among the community, but this is not their only role. Several large charities play an essential coordination role in bringing decision-makers together. International networks, comprising hundreds of national NGOs, work with all levels of government, particularly in the developing world, assisting with information, generating relevant data and policy research and advocacy. This work is often less headline-grabbing but is of fundamental importance in driving change.

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Case study: Quantifying the economic impact of dead zones - Notes

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Technical methodology note

The theory

In this study, we attempt to assess the economic impact of an increase in the size of the dead zone on the commercial fishing industry in the region.

The key variables we use to make this assessment are total fish catch, by weight and total revenue from the catch. We begin by first estimating the impact on the Gulf of Mexico fishery industry and then extrapolating this to the national fishery industry. We use a regression analysis to identify the relationship between fish catch and landing revenue.

The assumptions

We do not use hypoxia directly in the model as it is difficult to isolate the effect of hypoxia on the quantity of fish caught. However, there is enough evidence to prove that hypoxia will affect fish population negatively over time based on our literature review, either through a decline in biomass (weight of the fish) or a decline in the numbers of fish caught. Hence, we assume that landing weight will decline due to hypoxia. (Please refer to the research rationale for a detailed explanation.)

Variables and data:

Dependent variable

- **Landing revenue (real):** We aggregate the landing revenue from the commercial fish catch for five states in the Gulf of Mexico—Alabama, Florida (West), Louisiana, Mississippi and Texas—in US dollars. The nominal revenue is deflated using the CPI numbers for the South region* to obtain real revenue. The data is obtained from the NOAA and the technical description is as follows: "*The dollar value of our landings are ex-vessel (as paid to the fisherman at time of first sale) and are reported as nominal (current at the time of reporting) values*".

Data was obtained from the NOAA website and is available on an annual basis from 1950-2020.

Independent variables

- **Landing weight:** Sum of the landing weight of commercial fish catch for five states in the Gulf of Mexico—Alabama, Florida (West), Louisiana, Mississippi and Texas—in pounds. The data is obtained from the NOAA and the technical description is as follows: "*Landings are reported in pounds of round (live) weight for all species or groups except univalve and bivalve mollusks, such as clams, mussels, oysters and scallops, which are reported as pounds of meat (excludes shell weight).*

  Landings data do not indicate the physical location of harvest but the location at which the landings either first crossed the dock or were reported from."

Data was obtained from the NOAA website and is available on an annual basis from 1950-2020.

* The South region comprises Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia. https://www.bls.gov/regions/southeast/news-release/consumerpriceindex_south.htm

- **Aquaculture production:** According to FAOSTAT, "*Aquaculture is understood to mean the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc.*

  Aquaculture production specifically refers to output from aquaculture activities, which are designated for final harvest for consumption. At this time, harvest for ornamental purposes is not included."

Data was obtained from FAOSTAT and is available on an annual basis from 1950-2019.

- **CPI South:** Consumer price index for All Urban Consumers (CPI-U); All items in South urban, all urban consumers, not seasonally adjusted. (See footnote for description of the Southern region). The series is not used as a direct variable in the model, but rather to deflate the nominal revenue to obtain real revenue. Data was obtained from FRED and is available for the period 1967-2021.

- **Landing revenue (one-period lagged value):** We use a one-period lagged value of the dependent variable itself in a structural model.

Type	Variable Name	Units	Source	Frequency	Availability
Dependent	Landing revenue (real)	Dollars	NOAA	Annual	1950-2020
Independent	Landing weight	Pounds	NOAA	Annual	1950-2020
	Aquaculture production	Metric tons – live weight	FAOSTAT	Annual	1950-2019
	CPI South (Urban)	Index	FRED	Annual	1967-2021
	Landing revenue (one-period lagged value)	Dollars	NOAA	Annual	1950-2020

Model specification:

- To determine the relationship between landing weight and landing revenue, we run a structural ordinary least squares (OLS) regression model. The dependent variable is landing revenue and the independent variables are landing weight, aquaculture production and landing revenue one-period lagged value.

- To arrive at the real values of the dependent variable under study here—landing revenue—we used CPI South to deflate the nominal series. The real series is derived by dividing the nominal series by the CPI figures.

- Since CPI South data is available only from 1967 onwards, real values of the dependent variable are available only from 1967 onward. As we are using a one-period lag value of the independent variable, the model cannot be run for 1967. Based on available data for all variables, the regression model was run for the period 1968-2019.

- The model uses the natural log transformation (log to the base e) of both the regressand and the regressors. The model uses data from 1950-2020 and has a total of 52 variables after necessary adjustments.
- The regression model was run using the statistical software package EViews.

Regression results and interpretation

- The model yields a healthy adjusted Rsquared of 84.77%. The p-values of all regression coefficients (except the constant) are significant at the 5% significance level, hence we reject the null hypothesis of zero slope coefficient.
- The signs of the model parameters are consistent with theory:
    - **Landing weight:** an increase in landing weight should lead to a decline in total revenue due to the quantity effect. An increase in the quantity supplied leads to a decline in price as it is more abundantly available. The final effect on total revenue will depend on whether the price or the quantity effect dominates. A positive coefficient indicates that the % decline in price was greater than the % increase in quantity. A negative coefficient indicates that the % decline in price was larger than the % increase in quantity. The correlation coefficient between the landing revenue (real) and landing weight stands at 57.52%.
    - **Aquaculture production:** an increase in aquaculture production leads to an increase in the quantity of total fish available for consumption. It is akin to a perfect substitute as it results in a total increase in fish production. The final effect on total revenue will depend on whether the price or the quantity effect dominates. A positive coefficient indicates that the % decline in price was greater than the % increase in quantity. A negative coefficient indicates that the % decline in price was larger than the % increase in quantity. The correlation coefficient between the landing revenue (real) and aquaculture production stands at -60.01%.
- Model Robustness tests (see appendix for statistical results):
    - **Heteroscedasticity:** White's heteroscedasticity test accepts the null hypothesis of no heteroscedasticity in the residual terms.
    - **Serial correlation:** Breusch-Godfrey Serial Correlation LM Test accepts the null hypothesis of no serial correlation in the residual terms.
    - **Residual normality tests:** Jarque-Bera test for normality of residuals accepts the null hypothesis of normal distribution of the residuals.
- We use the model parameters to generate in-sample estimates for the revenue (real) series. The estimated series has a good fit with the actual series. The trend also matches well. (See appendix for chart).

The sensitivity analysis

- We use a sensitivity analysis model to understand the impact of a change in fish catch on the Gulf of Mexico and national fisheries revenue. The three scenarios are: a baseline, which will be based on a 10-year average of landing weight; an upside scenario, where we assume a 15 percent increase in fish catch on the 10-year average; and three downside scenarios, where we assume a 15 percent, 20 percent and 40 percent decline in fish catch in the Gulf of Mexico on the 10-year average.**

- We calculated a 10-year average of landing weight (2011-2020) and applied the 15 percent increase and the 15 percent, 20 percent and 40 percent decline on to that number

- Using the model parameters, we calculate the reduced landing revenue in the Gulf of Mexico under the four identified scenarios highlighted above.

From Gulf of Mexico to the national level

- To extrapolate the impact of a decline in Gulf of Mexico commercial fisheries revenue to the national commercial fisheries revenue, we calculate the share of Gulf of Mexico commercial fisheries revenue (real) in national commercial fisheries revenue (real). The Gulf of Mexico revenue is an aggregate of the revenue from the five states in the region: Alabama, Florida (West), Louisiana, Mississippi and Texas.

- We calculate a 10-year rolling average of the region's share of commercial fisheries revenue (real) as a % of total national commercial fishery revenue (real) for the period 1960-2020. Over 2011-2020, the Gulf of Mexico accounted for 16.52 percent of total national revenue. This figure is applied to the Gulf of Mexico revenue figures obtained from the sensitivity analysis results to calculate the corresponding national revenue under each scenario.

- In order to arrive at the commercial fisheries revenue (nominal), the real revenue figures under each scenario are reflated using the 10-year average (2011-2020) of CPI South. The figure of 16.52 percent obtained above is applied to these reflated figures to arrive at the national nominal revenue figures.

- See the table below for final model results:

Scenario description (changes to landing weight)	Gulf of Mexico revenue, nominal (USDm)	National revenue, nominal (USDm)	Net Change (USDm) nominal (national)	% Change from baseline, nominal (national)
Baseline: 10-year average (2011-2020)	864.66	5,387.18		
Scenario 1: Upside 15%	909.36	5,504.46	117.28	2.18%
Scenario 2: Downside -15%	832.25	5,037.71	-349.47	-6.49%
Scenario 3: Downside -20%	817.59	4,948.98	-438.21	-8.13%
Scenario 4: Downside -40%	751.47	4,548.75	-838.43	-15.56%

** To determine the quantum of decline in landing weight, we first analysed past data for fish landings along with the size of the dead zone. There is no significantly observable pattern in landing catch and dead zone size. We analyse only the decline in landing catch over the years. The range of decline varies from 0.76% to 27.27%. Since past data does not yield a clear trend, we rely on our literature review to finalise the thresholds.

Appendix: Statistical results

A1: Model results

**Dependent Variable:
LOG(DF1_RGC_SOUTH)**

Method: Least Squares

Date: 11/02/21 Time: 04:31

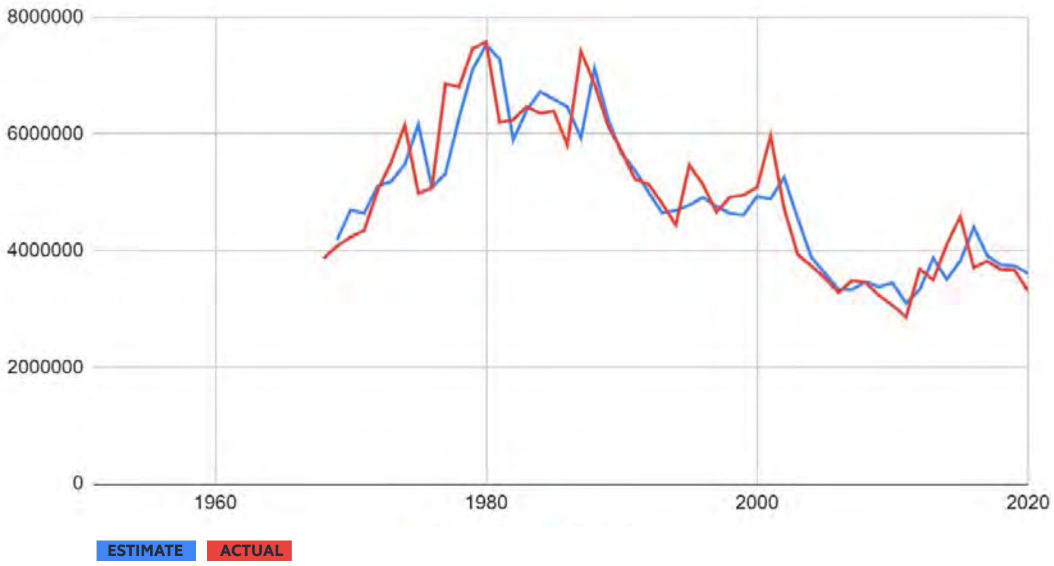
Sample (adjusted): 1968 2019

Included observations: 52 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG(WT_GOM_C)	0.2931	0.0959	3.0559	0.0037
LOG(AQUA_PRODN_TONNES)	-0.1046	0.0354	-2.9530	0.0049
LOG(DF1_RGC_SOUTH(-1))	0.6832	0.0785	8.7002	0.0000
C	-0.0305	1.7744	-0.0172	0.9864

R-squared	85.66%	Mean dependent var	15.37976733
Adjusted R-squared	84.77%	S.D. dependent var	0.2615443995
S.E. of regression	0.1020761765	Akaike info criterion	-1.65239132
Sum squared resid	0.5001381986	Schwarz criterion	-1.502295649
Log likelihood	46.96217432	Hannan-Quinn criter.	-1.594848182
F-statistic	95.60688399	Durbin-Watson stat	2.091613153
Prob(F-statistic)	2.96E-20		

C1: Estimated vs Actual



A2: Breusch-Godfrey Serial Correlation LM Test:

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	1.612625628	Prob. F(2,46)	0.2104299118
Obs*R-squared	3.407053514	Prob. Chi-Square(2)	0.1820403784

Test Equation:

Dependent Variable: RESID

Method: Least Squares

Date: 11/02/21 Time: 05:07

Sample: 1968 2019

Included observations: 52

Presample missing value lagged residuals set to zero.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG(WT_GOM_C)	-0.03389193677	0.1009600656	-0.3356964613	0.7386261185
LOG(AQUA_PRODN_TONNES)	0.008244527473	0.0355598601	0.2318492663	0.8176834256
LOG(DF1_RGC_SOUTH(-1))	0.0640045575	0.09240165805	0.6926775867	0.4919942377
C	-0.3682781187	1.7643298	-0.2087354182	0.8355763597
RESID(-1)	-0.1287289968	0.1677646596	-0.7673189164	0.446812656
RESID(-2)	-0.2630804728	0.1510551887	-1.741618246	0.0882595329

R-squared	0.06552025989	Mean dependent var	-2.82E-15
Adjusted R-squared	-0.03605362491	S.D. dependent var	0.09902843705
S.E. of regression	0.1007977974	Akaike info criterion	-1.643233575
Sum squared resid	0.4673690138	Schwarz criterion	-1.418090069
Log likelihood	48.72407296	Hannan-Quinn criter.	-1.556918869
F-statistic	0.6450502511	Durbin-Watson stat	1.983986624
Prob(F-statistic)	0.6665661899		

A3: Heteroscedasticity Test: White

Heteroskedasticity Test: White

F-statistic	0.3617098172	Prob. F(9,42)	0.9468207509
Obs*R-squared	3.740553348	Prob. Chi-Square(9)	0.9276440978
Scaled explained SS	3.548556563	Prob. Chi-Square(9)	0.9385417022

Test Equation:

Dependent Variable: RESID^2

Method: Least Squares

Date: 11/02/21 Time: 05:08

Sample: 1968 2019

Included observations: 52

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-15.83198628	26.82906099	-0.5901058665	0.558
LOG(WT_GOM_C)^2	-0.01886989591	0.09439570472	-0.1999020608	0.843
LOG(WT_GOM_C)*LOG(AQUA_PRODN_TONNES)	0.03399919226	0.04163984664	0.8165061835	0.419
LOG(WT_GOM_C)*LOG(DF1_RGC_SOUTH(-1))	0.02388063349	0.105224637	0.2269490699	0.822
LOG(WT_GOM_C)	0.01164790194	2.909065866	0.004004000762	0.997
LOG(AQUA_PRODN_TONNES)^2	-0.009047151607	0.01781045107	-0.5079686962	0.614
LOG(AQUA_PRODN_TONNES)*LOG(DF1_RGC_SOUTH(-1))	-0.03971124362	0.03367935837	-1.179097392	0.245
LOG(AQUA_PRODN_TONNES)	0.1112619661	0.8306370361	0.1339477549	0.8940836884
LOG(DF1_RGC_SOUTH(-1))^2	-0.06378273204	0.05207527708	-1.22481791	0.2274690896
LOG(DF1_RGC_SOUTH(-1))	1.95251079	2.255195143	0.8657835206	0.3915277312

R-squared	0.07193371824	Mean dependent var	0.009618042281
Adjusted R-squared	-0.1269376279	S.D. dependent var	0.01449233316
S.E. of regression	0.01538467227	Akaike info criterion	-5.339848794
Sum squared resid	0.009940901919	Schwarz criterion	-4.964609617
Log likelihood	148.8360686	Hannan-Quinn criter.	-5.195990949
F-statistic	0.3617098172	Durbin-Watson stat	1.986452797
Prob(F-statistic)	0.9468207509		

A4: Jarque-Bera normality test

Series: Residuals

Sample 1968 2019

Observations 52

Mean	-2.82E-15
Median	-0.018337
Maximum	0.254156
Minimum	-0.213336
Std. Dev.	0.099028
Skewness	0.442985
Kurtosis	3.226743
Jarque-Bera	1.812101
Probability	0.404117

Chapter 5 Notes

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Chapter 8 Notes

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