ONE OCEAN Foundation

Ocean Disclosure Initiative

CHEMICAL AND PHARMACEUTICAL INDUSTRY REVIEW

SDA Bocconi SCHOOL OF MANAGEMENT
SUSTAINABILITY LAB

McKinsey & Company

CSIC
Consejo Superior de Investigaciones Científicas

Table of contents

About One Ocean Foundation

This research has been carried out by the One Ocean Foundation as part of its Ocean Disclosure Initiative project.

The mission of the Foundation is to accelerate solutions to ocean issues by inspiring international leaders, institutions, companies and people, promoting a blue economy, and enhancing ocean knowledge through ocean literacy. The Foundation intends to develop a leading platform, bringing together and strengthening the voices speaking out on behalf of the ocean around the world.

The distinctive feature of the One Ocean Foundation is its scientific scope and, at the same time, its strong educational drive, with the aim of increasing awareness and establishing constructive relationships between all stakeholders engaged in marine preservation at various levels.

Thanks to its extensive network of partners, the One Ocean Foundation is engaged in numerous unique, innovative, and high–value projects related to its mission of ocean protection in three main areas: education, environmental research, and the blue economy.

For information please contact the One Ocean Foundation at:
secretariat@1ocean.org
Tel: +39 02796145
Via Gesù 10, Milan - Italy

To see the latest One Ocean Foundation contents please visit:
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About the Ocean Disclosure Initiative

The Ocean Disclosure Initiative project is part of the multi-year research "Business for Ocean Sustainability" promoted by the One Ocean Foundation (OOF) in collaboration with SDA Bocconi School of Management Sustainability Lab, McKinsey & Company and CSIC (Consejo Superior de Investigaciones Científicas) and aimed at building knowledge about the relationship between business activities and the ocean.

The project commenced in 2019 with the goal of investigating the role of companies in addressing ocean challenges, focusing on the pressures on marine ecosystems, the level of awareness within the business community and the main responses (technological and organisational) implemented.

The Ocean Disclosure Initiative aims to provide a science-based framework and methodology with the objective of supporting businesses from all industries in taking action on ocean-related issues, promoting prevention and/or mitigation responses, and favouring disclosure and reporting.


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Introduction to the chemical and pharmaceutical industry

The chemical sector, the fifth-largest industry, is a key supplier of essential components across industries

The chemical and pharmaceutical sector is a vital contributor to the global economy, generating billions in annual revenue and producing essential daily-use products like medicines, fertilisers, and plastics. According to the European Chemical Industry Council, in 2022, the value of the chemical industry amounted to €5.43 trillion, making it the fifth-largest manufacturing sector in the world.[1] Europe plays a pivotal role in this global landscape, ranking as the second-largest chemical producer with annual sales exceeding €700 billion.[2] The industry serves as a cornerstone of global supply chains; in Italy, for instance, it provides essential components for 95% of all manufactured goods. These include everyday consumer products as well as advanced technologies vital for the ecological transition, such as batteries, wind turbines, and solar panels.[3]

In this framework, the pharmaceutical industry continues to exhibit remarkable growth and influence. In 2022, it contributed $755 billion to global GDP and supported 7.8 million jobs worldwide.[4] The growing market reflects the increasing global demand for healthcare solutions, driven by advancements in medical technology, and expanding access to treatments in emerging markets. The chemical and pharmaceutical sector continues to shape the global landscape, driving economic growth, employment, and innovation across industries.

1. Cefic-European Chemical Industry Council (2023) "Facts & figures 2023" [online] Available at: https://cefic.org/app/uploads/2023/12/2023_Facts_and_Figures_The_Leaflet.pdf

2. Ibidem

3. Federazione nazionale Industria Chimica (2024) "Situation and outlook for the chemical industry" [online] Available at: https://www.federchimica.it/docs/default-source/chemical-industry-in-italy/situation-and-outlook-chemical-industry_jul2020.pdf?sfvrsn=9c2d4793_18

4. WifOR Institute, International Federation of Pharmaceutical Manufacturers & Associations (IFPMA) (2024) "The economic impact of the global pharmaceutical industry" [online] Available at: https://www.ifpma.org/wp-content/uploads/2024/11/2024_WifOR_Economic_Impact_Global_Pharmaceutical_Industry_Report.pdf

From an environmental point of view, the chemical and pharmaceutical industry, while essential for global development, is among the largest consumers of energy and a major contributor to greenhouse gas (GHG) emissions.[5] A significant portion of these emissions arises from converting carbon-containing feedstocks — such as natural gas, coal, and oil — which are essential for producing a wide range of chemical products. Moreover, carbon, a fundamental building block in chemical processes, generates considerable CO_2 and methane emissions during its extraction, refining, and conversion. Additionally, the industry's energy-intensive operations, often requiring extreme temperatures and substantial power, amplify its environmental footprint through fuel combustion and electricity consumption.[6] Beyond GHG emissions, the sector has the potential to release toxic, bioaccumulative, and persistent chemicals into the environment, posing lasting risks to ecosystems and human health.[7] Tackling these challenges demands transformative innovation, coupled with investment in cleaner technologies and sustainable practices, to minimise the sector's carbon footprint and mitigate broader environmental impacts.

The industry is among the largest consumers of energy and contributors to GHG emissions

Given the magnitude and variety of products within the chemical and pharmaceutical sector, discussing its pressures on marine ecosystems as a whole is a complex task. In the framework of the Business for Ocean Sustainability research, the boundaries of the chemical and pharmaceutical sector are defined as all economic activities related to the production of basic chemicals, resins, synthetic rubber and fibres, pesticides, fertilisers, paints, coatings, adhesives, soaps, cleaning compounds and toiletries, as well as pharmaceutical and medicine manufacturing.

5. International Energy Agency (IEA) (2023) [online] Available at: https://www.iea.org/energy-system/industry/chemicals

6. ICIS, Carbon Minds (2024) "Pathways for the global chemical industry to climate neutrality" [online] Available at: https://icca-chem.org/wp-content/uploads/2024/11/Climate-Neutrality.pdf

7. Ibidem

Scientific literature often splits these production lines into four main sales areas to offer a more incisive business perspective.[8] These four areas consist of:

Basic chemicals:

Polymers that consist mainly of plastics (33%) (e.g. polypropylene, polyethylene, PET, PVC), bulk petrochemicals and intermediates, other derivatives and basic industrials, inorganic chemicals, and fertilisers. The major markets for plastics are packaging, followed by home construction, containers, appliances, pipes, transportation, toys, and games.

Speciality chemicals:

Electronic chemicals, industrial gases, adhesives, and sealants, as well as coatings, industrial and institutional cleaning chemicals, and catalysts. Coatings represent around 15% of all sales within speciality chemicals.

Life science chemicals:

Pharmaceuticals, diagnostics, animal health products, vitamins, and crop protection chemicals.

Consumer products:

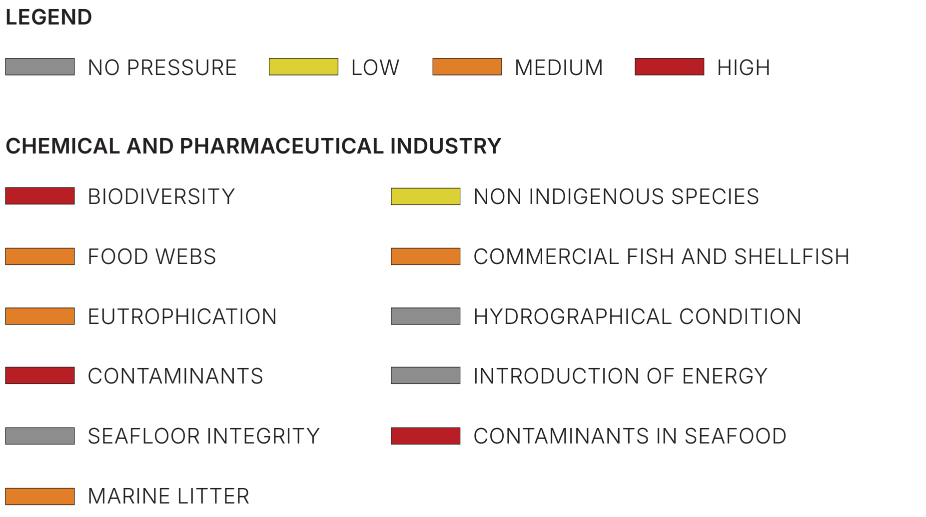
Direct product sale of chemicals such as soaps, detergents, and cosmetics. Consumer products represented around 14% of total chemical sales in the EU in 2023.

8. The essential chemical industry (N.D) The chemical industry [online] Available at: https://www.essentialchemicalindustry.org/the-chemical-industry/the-chemical-industry.html

The chemical and pharmaceutical industry exerts significant pressure on ocean ecosystems. Indeed, the complex processes of this kind of industry can lead to the release of various synthetic chemicals, plastic waste, and other by-products into the environment, leading to seawater contamination. As indicated in the table below (Figure 1) in red, the scientific assessment identified the industry's most significant pressures on the ocean as:

- **Loss of biodiversity**
- **Introduction of contaminants**
- **Introduction of contaminants in seafood**

FIGURE 1: Review of the negative pressures of the chemical and pharmaceutical industry*



***Pressures exerted on the eleven Good Environmental Status descriptors (GES) of EU marine waters, listed in the figure as identified in the Marine Strategy Framework Directive of the European Union.** https://environment.ec.europa.eu/topics/marine-and-coastal-environment_en

Source: Author's elaboration

Furthermore, the industry review examines additional pressures exerted by the industry on various indicators, including the introduction of marine litter — primarily in the form of plastics; the increase in seawater eutrophication caused by the release of certain chemicals; and the reduction in the availability of commercial fish and shellfish due to the increased mortality of marine species due to potentially toxic substances entering the ocean.

The main pressures exerted by the chemical and pharmaceutical industry

The adoption of sustainable processes in the sector presents significant challenges due to the diversity of products, intricate regulatory frameworks, and the complexity of supply chains

One of the biggest challenges the chemical and pharmaceutical industry faces in achieving sustainability is the complex nature of the sector itself. **The number of chemical and pharmaceutical products manufactured each year can range from thousands to millions**, depending on the criteria used to define an individual product. In general, the more complex the sector, the slower the transition towards sustainability may be. The reason for the sector's complexity is partly due to the following factors:

Diverse applications:

Chemicals are essential for a wide range of industries and applications, including agriculture, healthcare, construction, automotive, electronics, and consumer goods. Each industry has its own set of requirements, which demand the creation of customised chemical products to fulfil their distinct needs.

Complexity of regulatory frameworks:

The chemical and pharmaceutical industry operates within a complicated web of regulations and standards that vary greatly across countries and regions, resulting in geographical disparities in environmental impact. For instance, less regulated regions often experience higher levels of marine pollution due to inadequate chemical waste disposal and management practices.

International and regional organisations such as the European Union and the United Nations have attempted to mitigate this issue through several initiatives. At the EU level, it is important to mention the Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH) initiative and the Plant Protection Products (PPP) Regulation, which ensure that chemicals undergo rigorous assessment for their environmental and human health impacts before they are placed on the market. At the UN level, the UNEP has been working efficiently in developing mainstream solutions for the sound management of chemicals and waste along with uniform regulatory harmonisation across the industry to drive sustainable practices. In turn, complying with regulations often leads to the formulation of alternative chemical products and processes.

Complex supply chain:
While every sector has a unique and complex supply chain, the chemical sector's intricacy relies on managing global operations and extensive transportation networks. Chemical products are often sourced from different regions, with raw materials and intermediates transported across countries and continents. For instance, the Chemicals Trends 2019 report by McKinsey & Company highlighted that the chemical industry accounted for approximately 16% of global seaborne trade.[9]

Our analysis attempts to break down the complexity of the chemical and pharmaceutical sector by examining the production lines that contribute to the pressures mentioned above.

Basic chemicals

Basic chemicals, also known as commodity or bulk chemicals, are chemical substances produced in massive quantities which serve as raw materials or intermediates in manufacturing numerous products.

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9. McKinsey & Company (2019) "Chemicals Trends 2019: Finding Opportunities in a Changing Landscape" [online] Available at: https://www.mckinsey.com/industries/chemicals/our-insights/chemicals-trends-2019-finding-opportunities-in-a-changing-landscape

It is important to note that basic chemicals are the building blocks of all other chemical products. Raw materials are processed and refined to produce basic chemicals — polymers, petrochemicals, inorganic chemicals, and industrial chemicals, which are then devoted to the production of speciality chemicals, consumer products or life science chemicals. For this research, we touch upon a selection of basic chemicals that have the potential to be especially threatening to ocean biodiversity and could cause contamination of marine ecosystems. These primarily include **polymers**, especially **plastics**, and **Polycyclic Aromatic Hydrocarbons (PAHs)**.

Plastics have been a heavily debated topic in recent years. While many studies have focused on plastic recycling and repurposing, this review shifts the focus to their production processes. It addresses the negative impact of plastics on biodiversity and explores good practices for producing and using them in the chemical industry to create other chemicals.

Among basic chemicals, plastics are especially susceptible to entering waterways, contaminating marine ecosystems and threatening seafood

Plastics are a diverse group of materials produced through the chemical processing of polymers derived from fossil fuels.[10] As a result, the petrochemical industry is crucial in supplying raw materials for plastic production. Specifically, the polymerisation process involves converting raw materials into plastic resins through chemical reactions. Various chemical additives, such as plasticisers, flame retardants, and colourants, are incorporated into the plastic matrix during this stage. Improper handling and disposal of these chemicals can release them into waterways, where they can accumulate and contaminate marine ecosystems and seafood.[11]

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10. Ellen MacArthur Foundation (N.D) The new plastic economy: rethinking the future of plastic [online]. Available at: https://ellenmacarthurfoundation.org/the-new-plastics-economy-rethinking-the-future-of-plastics

11. Thushari, G.G.G., & Senevirathana, J.D.M. (2020) "Plastic pollution in the marine environment" [online]. Available at: https://doi.org/10.1016/j.heliyon.2020.e04709

For instance, flame retardants are added to plastics to reduce their flammability.[12] However, some flame retardants, such as polybrominated diphenyl ethers (PBDEs), are persistent organic pollutants (POPs) that can accumulate in seawater and, consequently, bioaccumulate in marine organisms. Similarly, stabilisers are added to plastics to prevent degradation caused by heat, light, or oxidation. Certain stabilisers, such as some halogenated or heavy metal-based compounds, are also persistent, bio-accumulative, and toxic to marine biodiversity.[13]

PAHs can be defined as a group of organic compounds released into the environment through the combustion of fossil fuels, oil spills, and incomplete combustion of organic materials.[14] PAHs can also be used to produce plastics and can enter the ocean through runoff from land, atmospheric deposition, and direct discharges. They can cause adverse effects on fish in terms of reproduction, development, immune system, and behaviour. Certain PAHs, such as benzo[a]pyrene, are classified as carcinogens and have the potential to cause cancer in aquatic organisms.[15]

Good practices

The chemical industry is generally heavily regulated by national and international legislation and regulations. In addition to these regulations, most chemical firms usually follow the UNEP's "responsible chemical management" approach. In plastics production, this entails implementing practices and strategies to ensure the safe handling, usage, storage, and disposal of chemicals involved in the production process.[16]

Implementing strategies for the safe handling, storage, and disposal of plastics during production can potentially reduce contamination

12. Hale, R. C., et al. (2001) "Polybrominated diphenyl ether flame retardants in Virginia freshwater and estuarine fishes" [online]. Available at: doi: 10.1021/es010845q. PMID: 11770759

13. United Nations Environment Programme (2012) "State of the Science of Endocrine-Disrupting Chemicals 2012"

14. Agency for Toxic Substances and Disease Registry (2021) "Polycyclic Aromatic Hydrocarbons (PAHs)" [online] Available at: https://www.atsdr.cdc.gov/ToxProfiles/tp69-c1-b.pdf

Specifically, this approach includes:

Chemical inventory and risk assessment:

Maintaining a comprehensive inventory of chemicals used in plastics production and conducting risk assessments to identify potential hazards and guide appropriate safety measures. This involves understanding the properties, toxicity, and environmental impacts of plastics in order to manage their risks effectively.

Hazard communication and labelling:

Communicating the hazards associated with plastic production through proper labelling, safety data sheets (SDS), and instructions for safe handling is essential to ensure that workers and relevant stakeholders are aware of the potential risks, necessary precautions, and emergency response procedures to reduce the impact on the environment.[17]

Safe handling and storage:

Establishing protocols and training programmes for safely handling, storing, and transporting plastics to avoid disposal and release into the environment. This includes providing appropriate personal protective equipment (PPE), implementing spill containment measures, and ensuring proper ventilation and segregation of incompatible chemicals.

Waste management and disposal:

Proper segregation, containment, and disposal of chemical waste according to local regulations and good practices to prevent the release of harmful chemicals into the environment. Recycling and reuse of chemicals can also be considered to minimise waste generation.

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15. Agency for Toxic Substances and Disease Registry (2021) "Polycyclic Aromatic Hydrocarbons (PAHs)" [online] Available at: https://www.atsdr.cdc.gov/ToxProfiles/tp69-c1-b.pdf

16. UNEP (2007) "Strategic approach to international chemical management"

17. International Labour Organization (2014) "Chemical Control Toolkit: A Guide for Managing Chemicals in the Workplace" [online] Available at: https://www.ilo.org/static/english/protection/safework/ctrl_banding/toolkit/icct/

Environmental monitoring and compliance:
Regular monitoring of air, water, and soil quality can help assess the effectiveness of chemical management practices and identify any potential impacts.

While the same management approach applies to all basic chemicals, PAH's good management practices usually include stricter regulations concerning industrial discharges in the petroleum industry, as well as spill prevention measures. These measures have been intensified as a result of the Deepwater Horizon oil spill in 2010, which released a significant amount of PAHs into the Gulf of Mexico, resulting in widespread ecological damage.[18] In general, strict compliance with local environmental regulations, permits, and reporting requirements is especially important to ensure legal and responsible chemical management.

Speciality chemicals

Speciality chemicals comprise a wide range of chemicals with unique properties and applications. These chemicals are typically produced in smaller quantities compared to basic chemicals and are often tailored to meet specific customer requirements. They are characterised by **their high value, performance-enhancing properties, and specialised applications** across various industries, such as electronics, agrochemicals, industrials, aerospace and even pharmaceuticals. To provide a comprehensive but not exhaustive overview of speciality chemicals, this section will focus on some of the most potentially ocean-polluting chemicals categorised by industry segments which include:

- **Pesticides** produced in the agrochemical industry;

18. Reddy, C. M., et al. (2012) "Composition and fate of gas and oil released to the water column during the Deepwater Horizon oil spill" [online]. Available at: https://doi.org/10.1073/pnas.1101242108

- **Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs)** used as foam-blowing agents and solvents for refrigerants and electrical appliances;
- **Per- and poly-fluoroalkyl substances (PFAS)** used for aerospace and defence, automotive, aviation, household products and food contact materials industries.

Pesticides play a crucial role in agriculture by controlling pests and diseases to ensure food security and crop productivity. However, according to the UNEP, it is estimated that around 60% of herbicides, 90% of fungicides, and 30% of insecticides used in agriculture can be lost through runoff.[19] Water contamination leads to the creation of a toxic environment that endangers marine organisms such as fish, shellfish, and marine mammals. Exposure to these chemicals can lead to reproductive issues, developmental abnormalities, and even death.[20] In addition to the need for the agriculture industry to reduce the use of potentially dangerous pesticides, the production process must also become more sustainable. This is particularly important because the production of pesticides involves the synthesis and formulation of various chemical compounds that generate waste materials, including solvents, reactants, and by-products, which require careful management.

Similarly, CFCs and HCFCs — greenhouse gases containing carbon, hydrogen, and fluorine — have been widely used in the production of refrigerants, propellants in aerosol products, foam-blowing agents, and solvents.[21] These are essential for their non-flammability and chemical stability but are extremely harmful to the ozone layer as well as marine biodiversity. In the presence of sunlight, CFCs and HCFCs can break down and release chlorine and bromine atoms.

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19. UNEP (2017) "Frontiers 2017: Emerging Issues of Environmental Concern".

20. Helfrich, L. et al. (2009) "Pesticides and Aquatic Animals: A guide to reducing impacts on Aquatic systems" [online]. Available at: https://vtechworks.lib.vt.edu/bitstream/handle/10919/48060/420013_pdf.pdf?sequence=1&isAllowed=y

21. Environmental Protection Agency (2019) "Class I Ozone-Depleting Substances: Regulatory Programs" [online]. Available at: https://www.epa.gov/ods-phaseout/phaseout-class-i-ozone-depleting-substances

These atoms can catalytically destroy ozone molecules in the stratosphere, contributing to ozone depletion and consequent formation of hydrochloric acid (HCl) and hydrobromic acid (HBr), which enter ocean waters through atmospheric deposition.[22]

Finally, PFAS — similarly to CFCs and HCFCs — are widely used because of their unique, desirable properties, such as stability under intense heat, and many are also surfactants.[23] PFAS comprise a large class of thousands of synthetic chemicals used in several industries, ranging from aviation to household products. PFAS can be found in everyday products,[24] such as:

PFAS, chemicals widely used from aviation to household products, pose significant risks to ocean health due to their long-lasting persistence in the environment

- **Cleaning products**
- **Water-resistant fabrics,** such as rain jackets, umbrellas, tents, ski clothing
- **Grease-resistant paper**
- **Non-stick cookware**
- **Personal care products,** like shampoo, dental floss, nail polish, and eye makeup
- **Stain-resistant coatings** used on carpets, upholstery, and other fabrics.

PFAS are released into the environment directly from professional and industrial facilities and indirectly through the use of consumer products and they have been found to be extremely harmful because of their prolonged persistence in the environment.

Good practices

As mentioned above, chemical firms must adhere to stringent regulations and guidelines regarding production.

22. United Nations Environment Programme (2018). Scientific Assessment of Ozone Depletion: 2018

23. European Chemicals Agency (N.D) "Per- and polyfluoroalkyl substances (PFAS)" [online]. Available at: https://echa.europa.eu/hot-topics/perfluoroalkyl-chemicals-pfas

24. Ibidem

The adoption of sustainable alternatives, such as biopesticides and "green" solvents, can reduce reliance on harmful chemicals

With regard to the agrochemical industry, most of the recent efforts have focused on the **development of reduced-risk pesticides and biopesticides**, which aim at minimising potential contamination and harm to biodiversity. These pesticides are designed to have reduced environmental persistence and target specific pests more effectively, thereby reducing the overall impact on non-target organisms. In terms of biopesticides, an interesting example of what should have been a good practice, but turned out to have unexpected consequences, is related to the use of *Bacillus thuringiensis (Bt)* — a natural soil bacterium — used in the production process as an alternative to other chemicals for synthetic insecticides. Bt has been successfully used to control certain pests, such as caterpillars and mosquitoes, thanks to its "Cry" toxins, which are toxic to some insects when ingested. Nevertheless, recent controversies have emerged following the discovery of biodiversity loss due to the long-term and intensive use of *Bt*.[25] Indeed, *Bt* strains can affect indigenous microorganisms — bacteria and fungi — and further establish complex relationships with local plants, ranging from a mostly beneficial demeanour to pathogenesis-like plant colonisation. By exerting a direct effect on target insects, *Bt* can indirectly affect other organisms in the food chain, thereby encouraging the proliferation of non-indigenous species and a general alteration of ecosystems.

Regarding CFCs and HFCFs, more sustainable alternative chemicals are often used to prevent the loss of biodiversity. For instance, hydrofluoroolefins (HFOs) are a new generation of refrigerants and blowing agents that have been developed as more ocean-friendly alternatives to CFCs and HCFCs. New refrigerants based on HFO technology act as replacements for high Global Warming Potential (GWP) HFCs.

25. Belousova, M.E., et al (2021) "Dissecting the Environmental Consequences of Bacillus thuringiensis Application for Natural Ecosystems" [online]. Available at: https://doi.org/10.3390/toxins13050355

These technologies have GWPs that are 99% lower than many commonly used HFCs and optimise energy efficiency, thereby lowering operational costs and energy consumption overall. In addition, in recent years, the industry has shifted towards "green" solvents, which are designed to be non-toxic, biodegradable, and have low volatility. Many chemical companies have chosen this course as green solvents are readily biodegradable, allowing them to break down more easily in the environment compared to traditional solvents. Simultaneously, the use of green solvents contributes to lower emissions of volatile organic compounds (VOCs), which are known to pose risks to living organisms through bioaccumulation and physiological impacts.[26]

On a similar note, over recent decades, global manufacturers have started to replace certain PFAS with fluorine-free substances. Given the magnitude and variety of PFAS, each chemical has to be analysed individually and its negative effects weighed to determine whether it should remain in use, be banned, or be replaced. This is in fact the aim declared by the European Commission when outlining the above-mentioned REACH initiative. For instance, in 2009, perfluorooctanesulfonic acid and its derivatives (PFOS) were included in the International Stockholm Convention on Persistent Organic Pollutants to eliminate their use. Recent developments in the REACH initiative have been even more promising, with Germany, Denmark, the Netherlands, Norway, and Sweden proposing a restriction covering a wide range of PFAS uses.[27] Finally, the European Chemical Agency (ECHA) introduced a restriction proposal for PFAS used in firefighting foams in January 2022.

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26. Mangotra, A., & Singh, S. K. (2024) "Volatile organic compounds: A threat to the environment and health hazards to living organisms – A review" [online]. Available at: https://www.sciencedirect.com/science/article/pii/S0168165623002304

27. European Chemicals Agency (N.d) "Registry of restrictions intentions until outcomes" [online]. Available at: https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b

Life science chemicals

Life science chemicals are vital to the chemical industry, contributing to advancements in healthcare, agriculture, and environmental sciences. The life sciences sector encompasses the production of pharmaceuticals, pesticides, and other speciality chemicals. The pharmaceutical industry alone is a significant contributor to the global economy, the world pharmaceutical (prescription) market was worth an estimated €1,288,299 million in 2023.[28] The development and production of life science chemicals are essential for human well-being, addressing medical needs, improving crop yields, and protecting public health. For the purpose of clarity, this review will discuss life sciences by considering the pharmaceutical sector and persistent organic pollutants (POPs). Hence, this review groups pharmaceuticals with life sciences and personal care products with consumer products. Generally, both are part of the broader category of pharmaceutical and personal care products (PPCPs). Persistent organic pollutants are used in many other industries, such as agriculture and industrial equipment and include polychlorinated biphenyls (PCBs). PCBs are POPs that were heavily used in the production of electrical appliances between the 1920s and 1979, when the US officially banned their use. PCBs can be carried for long distances and have been found in snow and seawater in areas far from where they were released into the environment, as well as in the bodies of small organisms and fish.[29] The lighter the form of PCB, the further it can be transported from the source of contamination. In addition, their persistence in the environment, coupled with their potential for bioaccumulation can lead to eutrophication[30] of surrounding bodies of water in the long term.

28. European Federation of Pharmaceutical Industries and Associations (Efpia) (2024): "The Pharmaceutical Industry in Figures" [online]. Available at: https://efpia.eu/media/2rxdkn43/the-pharmaceutical-industry-in-figures-2024.pdf

29. EPA (N.D) "Learn about Polychlorinated Biphenyls" Available at: https://www.epa.gov/pcbs/learn-about-polychlorinated-biphenyls#:~:text=Although%20no%20longer%20commercially%20produced,%2Dclosers%2C%20bushings%2C%20and%20electromagnets

30. Liyuan, L. et al. (2021) "Excessive application of chemical fertiliser and organophosphorus pesticides induced total phosphorus loss from planting causing surface water eutrophication" [online]. Available at: https://doi.org/10.1038/s41598-021-02521-7

Generally, though, all POPs are by definition highly persistent. If released into the ocean, they can be absorbed by phytoplankton and zooplankton, entering the food chain. As they move up the food chain, the concentrations of POPs increase, resulting in biomagnification. This process can have severe consequences for marine life, including fish, marine mammals, and seabirds.[31]

As mentioned, the life sciences sector also includes pharmaceuticals. These refer to a diverse range of chemicals used in healthcare and personal hygiene products, including, among others, prescription and over-the-counter drugs, fragrances, and disinfectants. The production of pharmaceuticals can lead to environmental contamination during various stages, such as synthesis, formulation, and packaging. For instance, agricultural runoffs as well as improper disposal or inadequate treatment of wastewater from pharmaceutical manufacturing facilities or healthcare settings can result in the release of pharmaceuticals, including hormones (e.g. endocrine disruptors like oestrogens) and antidepressants (e.g. fluoxetine) into aquatic systems. These chemicals can persist, accumulate, and have adverse effects on marine organisms, ranging from endocrine disruption to reproductive impairment, alteration of feeding patterns in fish, disturbed energy balance and food webs, alterations in behaviour and development leading to increased mortality, right up to near-collapse of local fish populations.[32] [33] [34]

Pharmaceuticals, including hormones and antibiotics, can enter the ocean, accumulate in marine ecosystems, and disrupt the endocrine systems of marine organisms

In addition, the production of antibiotics as pharmaceuticals can contribute to the emergence and spread of antibiotic-resistant bacteria. This is because when these compounds enter aquatic systems through production-related discharges or improper disposal, they can exert selective pressure on bacteria, leading to the development of resistant strains and major disruption in the functioning of the ecosystem.[35]

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31. Gobas, F., & Morrison, H. (2000) "Bioaccumulation and biomagnification in the aquatic environment" [online]. Available at: DOI:10.1201/9781420026283.ch9

32. EPA (2013) "Contaminants of Emerging Concern (CECs) in Fish: Pharmaceutical and Personal Care Products (PPCPs)"

33. Kidd, K. A., Blanchfield, P. J., Mills, K. H., Palace, V. P., Evans, R. E., Lazorchak, J. M., & Flick, R. W. (2007). Collapse of a fish population after exposure to a synthetic estrogen. Proceedings of the national academy of sciences, 104(21), 8897-8901.

Indeed, a study conducted in the Baltic Sea examined the presence of tetracycline-resistant bacteria in coastal waters influenced by chemical treatment discharge. The research found that the dispersion of wastewater containing pharmaceuticals, including antibiotics, contributed to the proliferation of tetracycline-resistant bacteria in the marine environment.[36]

Good practices

Integration of green chemistry principles and LCA could help reduce environmental impact and enhance resource efficiency

Best practices in the life science chemical sector often include ameliorating wastewater treatment to avoid dispersion in marine ecosystems. Employing advanced water management techniques, such as closed-loop systems, to remove or degrade pharmaceuticals before discharging them into the environment is crucial to avoid biodiversity loss. These processes are often part of a broader practice of life cycle assessment (LCA) and eco-design. LCAs are often used to perform a systematic and quantitative evaluation of the potential environmental impacts of a product, service, or activity across all of its life cycle stages. This process identifies key areas of improvement and builds on those to ensure the sustainability of the process.

Furthermore, in line with the UNEP's green economy project, "green chemistry principles" entail designing safer and more sustainable chemical processes, reducing or eliminating hazardous substances, optimising resource efficiency, and considering the entire life cycle of products.[37] For instance, a leading pharmaceutical company implemented a green chemistry initiative that resulted in a significant reduction in waste generation during the synthesis of an active pharmaceutical ingredient.

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34. Fong, P. P., & Ford, A. T. (2014). The biological effects of antidepressants on the molluscs and crustaceans: a review. Aquatic toxicology, 151, 4-13.

35. Kolpin, D. W., et al. (2002) "Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999-2000: a national reconnaissance" [online]. Available at: doi:10.1021/es011055j. PMID: 11944670

36. Björklund, H., et al. (2009) "Tetracycline resistance genes persist at aquaculture farms in the absence of selection pressure" [online]. Available at: doi:10.3389/fmicb.2020.01764

37. United Nations Environment Programme (UNEP). (2017). Guidance on the Environmentally Sound Management of Unused Pharmaceuticals in Health Care Facilities. Geneva.

By modifying the reaction conditions and optimising the process, they achieved a 90% reduction in waste generation and improved the overall environmental profile of the manufacturing process.[38] Finally, the pharmaceutical industry adheres to good manufacturing practices (GMP) guidelines, which are provisions for quality assurance, risk management, and environmental protection. Enhanced by international regulations backed by the European Medicines Agency (EMA) and the United States Environmental Protection Agency (EPA), these regulations aim to ensure safe and responsible production of pharmaceuticals.

Consumer products

Consumer products in the chemical industry refer to the wide range of goods that are manufactured for personal use, household purposes, or general consumption by individuals. These products can include cosmetics, cleaning agents, detergents, and paints. As mentioned above, there can often be an overlap with the life sciences sector with regard to PPCPs, especially regarding personal care products. However, this review will mainly focus on chemicals used in personal care products such as cosmetics, sunscreen agents, soaps and toothpaste. Specifically, some of the most potentially polluting chemical agents used in the production of those products are:

Harmful components in common products like cosmetics, cleaners, detergents, and paints can threaten marine biodiversity when reaching the ocean

Parabens and phthalates:

Both chemicals are used in the cosmetics industry. Parabens are a group of preservatives used in cosmetics to prevent microbial growth. They have been detected in marine environments and can bioaccumulate in marine organisms, potentially disrupting their hormone systems.

38. Clark, J. H., & Macquarrie, D. J. (2007). Handbook of Green Chemistry and Technology. Wiley-VCH

39. Agency for Toxic Substances and Disease Registry (2021) "Polycyclic Aromatic Hydrocarbons (PAHs)" [online] Available at: https://www.atsdr.cdc.gov/ToxProfiles/tp69-c1-b.pdf

40. European Chemicals Agency (2018) "Phthalates – Information" [online]. Available at: https://echa.europa.eu/en/hot-topics/phthalates

41. Perron, M., et al. (2012) Effects of triclosan on marine benthic and epibenthic organisms" [online]. Available at: https://pubmed.ncbi.nlm.nih.gov/22605471/

The production of parabens involves several steps, including the synthesis of esters from para-hydroxybenzoic acid and alcohol, a process which can be hazardous if not effectively managed. Phthalates, on the other hand, are plasticisers used in cosmetics to improve texture and fragrance. Both these products are heavily persistent and are often the cause of contamination in seafood. For instance, studies suggest that phthalates can cause endocrine disruption, reproductive abnormalities, and developmental issues in marine organisms[39]. The production of phthalates also involves the use of precursor chemicals and high-temperature processes, which can result in the emission of air pollutants and the potential release of contaminants into the surrounding environment[40].

Triclosan:

An antimicrobial agent commonly used in antibacterial soaps and toothpaste. It has been detected in aquatic environments and can have toxic effects on aquatic organisms.[41] It is precisely the persistence of this component that raises questions on the sustainability of products that use it. Triclosan is known to be resistant to conventional wastewater treatment processes, leading to incomplete removal during treatment. This can result in the discharge of triclosan into aquatic environments, where it can have detrimental effects on aquatic organisms and ecosystems.[42]

Oxybenzone and octinoxate:

Along with other chemicals,[43] are typically found in sunscreens. It has been estimated that up to 14,000 tons of sunscreen end up in the ocean every year,[44] potentially harming marine ecosystems and organisms, including corals, green algae, mussels, sea urchins and dolphins (see Figure 2 below).[45]

42. Heidler, J., & Halden, R. U (2009) "Mass balance assessment of triclosan removal during conventional sewage treatment. Chemosphere" [online]. Available at: https://pubmed.ncbi.nlm.nih.gov/16766013/

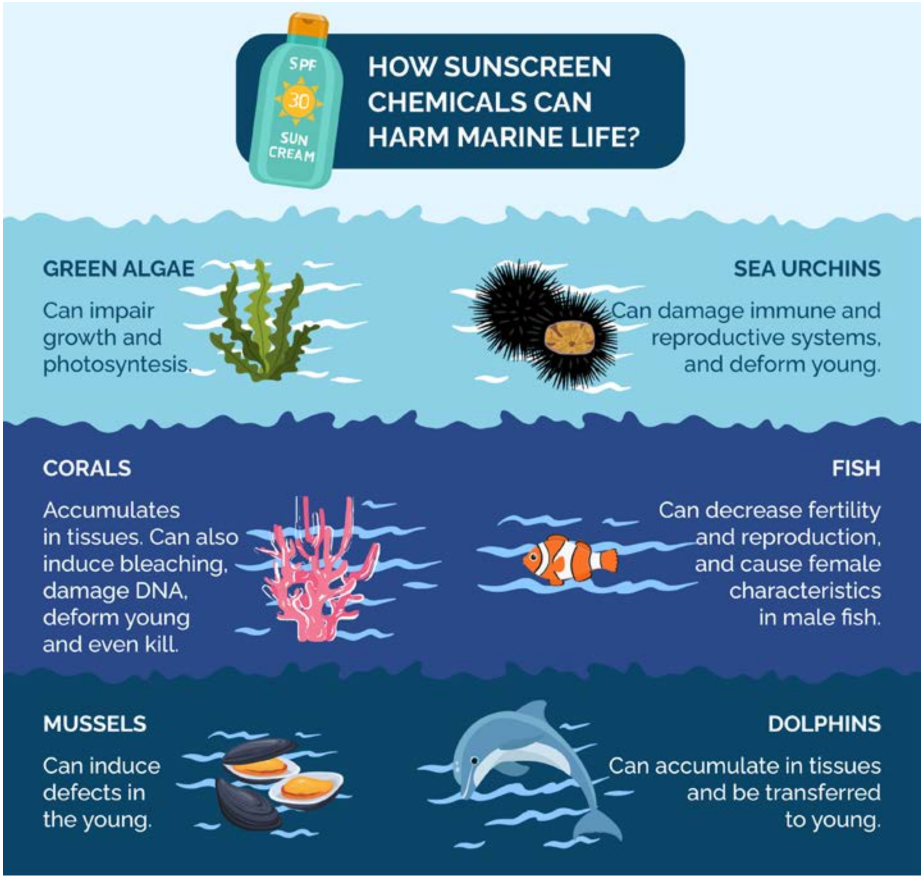
43. Other chemicals found in sunscreen that could harm marine environments are 3-Benzylidene camphor, 4-Methylbenzylidene camphor, Octocrylene, Benzophenone-1, Benzophenone-8, OD-PABA, nano-Titanium dioxide, and nano-Zinc oxide

44. American Chemical Society (2019). "Sunscreen and cosmetics compounds may harm coral by altering fatty acids" [online]. Available at: www.sciencedaily.com/releases/2019/01/190109110048.htm

45. American Chemical Society (2019). "Sunscreen and cosmetics compounds may harm coral by altering fatty acids" [online]. Available at: www.sciencedaily.com/releases/2019/01/190109110048.htm

Recent research conducted on coral reefs has revealed that substances like oxybenzone can lead to deformities in coral larvae and baby corals, causing damage to coral DNA and disrupting normal skeletal growth.[46] For example, anemones, which are a group of predatory marine invertebrates, have the ability to detect oxybenzone when exposed to sunlight. They try to eliminate the chemical by making minor changes to their chemical composition, but this results in the creation of a deadly toxin. The toxin accumulates in both the anemone tissue and the algae that live symbiotically with the anemone, causing damage and bleaching the anemone.[47]

FIGURE 2: Potential impacts of sunscreen chemicals on marine ecosystems



Source: Author's elaboration from National Oceanic and Atmospheric Administration (NOAA) "Sunscreen chemicals and coral reefs"

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46. Hall, D. (2022) "The truth about corals and sunscreen" [online]. Available at: https://ocean.si.edu/ecosystems/coral-reefs/truth-about-corals-and-sunscreen

47. Ibidem

Good practices

The use of plant-based extracts, natural antimicrobial agents, and "reef-safe" sunscreens can potentially reduce ecological risks to the ocean

Significant attention has been devoted, especially at the international level, to mitigating the effects of these hazardous chemicals. Nevertheless, in many cases, sustainable alternatives that guarantee the same efficacy have yet to be found. Some cosmetic manufacturers opt for paraben-free formulations, replacing parabens with alternative preservatives with a lower environmental impact, such as plant-based extracts or natural antimicrobial agents. This shift aims to reduce the potential ecological risks associated with parabens while maintaining product safety and stability.[48] In relation to phthalates, many REACH restrictions have come into play in the last few years. Regulatory actions have been implemented to restrict or ban certain phthalates in cosmetic and personal care products, such as di(2-ethylhexyl) phthalate (DEHP) and dibutyl phthalate (DBP).[49] Furthermore, due to their EU-wide classification as toxic to reproduction, several phthalates have also been restricted since November 2020 in consumer clothing or related accessories, as well as in other textiles that come into contact with the skin. However, old plastic items can still contain some of the phthalates that are no longer allowed to be used. This is a challenge for the circular economy as these chemicals first need to be detected and removed before the material can safely be recycled or reused. In 2021, to remedy this, the EU Waste Framework Directive[50] started requiring manufacturers, importers and distributors of products containing substances of very high concern to notify these products to the ECHA's databases. With regard to triclosan, the substance is registered under the REACH Regulation as not currently being manufactured in and/or imported to the European Economic Area.[51]

48. Darbre, P. (2021) Endocrine disruption and human health.

49. European Chemicals Agency (2018) "Phthalates – Information" [online]. Available at: https://echa.europa.eu/en/hot-topics/phthalates

50. European Chemicals Agency (N.D.) "Waste Framework Directive" [online]. Available at: https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en

51. European Chemicals Agency (N.D.) "Consultations" [online]. Available at: https://echa.europa.eu/it/substance-information/-/substanceinfo/100.020.167

The U.S. Food and Drug Administration (FDA) also banned the use of triclosan in over-the-counter consumer antiseptic wash products, including some soaps, in 2016.[52] Nevertheless, given its persistence, efforts are still being made to recover and recycle materials that contain traces of triclosan. Finally, some sunscreen manufacturers are developing and promoting "reef-safe" sunscreens, free from oxybenzone and other potentially harmful chemicals. These use alternative UV filters, such as zinc oxide or titanium dioxide, which have minimal impact on marine ecosystems. Campaigning efforts have resulted in greater awareness and adoption of safer sunscreens, though production has not fully shifted towards greener sustainable options.

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52. FDA (2016) “FDA issues final rule on safety and effectiveness of antibacterial soaps” [online]. Available at: https://www.fda.gov/news-events/press-announcements/fda-issues-final-rule-safety-and-effectiveness-antibacterial-soaps

Additional considerations: combined effects of nanoplastics and pharmaceuticals

Emerging contaminants often co-occur in marine environments, potentially exacerbating their impacts. Studies indicate a synergistic effect of nanoplastics and pharmaceutical residues.[53] Nanoplastics may act as vectors. They absorb pharmaceuticals, heavy metals, and organic pollutants, acting as carriers that enhance bioavailability and toxicity. Other highlighted environmental risks associated with the simultaneous exposure to micronanoplastics (MNPs) and pharmaceutical co-contaminants include a decrease in hatching rate, increase in mortality, developmental abnormalities, increase in reactive oxygen species, catalase, and lipid peroxidase, and decrease in total protein and superoxide dismutase.[54]

53. Arienzo, M., & Donadio, C. (2023) "Microplastic–Pharmaceuticals Interaction in Water Systems" [online]. Available at: https://doi.org/10.3390/jmse11071437

54. Rajendran, D., Kamalakannan, M., Doss, G. P., & Chandrasekaran, N. (2024) "Surface functionalization, particle size and pharmaceutical co-contaminant dependent impact of nanoplastics on marine crustacean–Artemia salina" [online]. Available at: https://pubs.rsc.org/en/content/articlelanding/2024/em/d4em00010b

In Depth: The use of algae in cosmetics

The use of algae has immense potential for the blue economy, serving as a versatile resource with applications across various industries while contributing to environmental sustainability. Algae could represent a healthy and low-calorie food, low in fat and rich in dietary fibre. They are also a valuable material for other commercial applications, including animal/fish feed; pharmaceuticals; plant biofertilisers; bio-based packaging; cosmetics or biofuels; and could provide services in wastewater treatment and the removal of carbon and nutrients from aquatic ecosystems.[55]

They are also a valuable material for other commercial applications, including animal/fish feed; pharmaceuticals; plant biofertilisers; bio-based packaging; cosmetics or biofuels; and could provide services in wastewater treatment and the removal of carbon and nutrients from aquatic ecosystems.

Macroalgae, or seaweed, could be found in coastal areas, they are simple in structure but rich in essential nutrients including fibre, protein, amino acids, minerals, and trace elements. Macroalgae also provide polyunsaturated fatty acids (PUFAs), such as omega-3 fatty acids (eicosapentaenoic acid, EPA), and liposoluble vitamins like β-carotene and vitamin E.

55. AGRINFO (2023) "Towards a strong and sustainable EU algae sector" [online]. Available at: https://agrinfo.eu/book-of-reports/towards-a-strong-and-sustainable-eu-algae-sector/

Macroalgae are classified into three groups based on their dominant pigments — green, brown, and red — which have diverse applications in cosmetics:

- **Red algae** are used as colourants in lipsticks, makeup, and eye shadows due to their biological elements, including vitamins, minerals, sugars, and lipids.

- **Brown and green algae** are both valuable for their moisturising and anti-inflammatory properties. Brown algae contain fucoxanthin, a pigment that helps reduce pigmentation, boosts collagen production, and minimises wrinkles. Green algae, abundant in chlorophyll, enhance hydration and soothe the skin.[56]

Microalgae, a diverse group of unicellular prokaryotic and eukaryotic microorganisms, are capable of thriving in environmental conditions such as high heat, salinity, and UV radiation. Their resilience and rich composition of bioactive compounds have made them invaluable in the cosmetic industry. The global market for microalgae is estimated to reach over 18 billion US dollars by 2028,[57] especially for two specific genera: *Spirulina* and *Chlorella*.

Microalgae are an excellent source of amino acids and proteins, which offer natural moisturising properties that hydrate the skin and prevent dryness. Additionally, microalgal metabolites such as carotenoids and sterols provide powerful anti-inflammatory and antioxidant benefits, helping to calm irritation and protect the skin from physical damage.[58] Pigments like phycocyanin further enhance antioxidant activity.

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56. Singh, S., & Purwar, V. (2022). "Role of algae in cosmetics. International Journal of Creative Research Thoughts [online]. Available at: https://ijcrt.org/papers/IJCRT22A6744.pdf

57. International Affairs Institute (IAI) (2022) "Blue Economy and the Role of Sustainable Practices" [online]. Available at: https://www.iai.it/sites/default/files/iaip2222.pdf

58. Malakar, B., & Mohanty, K. (2020). "The budding potential of algae in cosmetics." [online]. Available at: https://link-springer-com.pros2.lib.unimi.it/chapter/10.1007/978-981-15-7518-1_8

Microalgae are particularly celebrated for their role in photoprotection, thanks to their ability to produce compounds with UV-absorbing properties. These compounds are used in sunscreens and anti-ageing products to combat oxidative stress, maintain skin resilience, and promote a youthful appearance.

Algae have redefined the landscape of cosmetics, transforming the industry with their exceptional versatility and unparalleled benefits. As consumer preferences continue to shift toward sustainability and eco-consciousness, algae stand poised to play an even greater role in shaping the future of beauty products.

The importance of disclosing business pressures on the ocean

The industry-specific edition of the Ocean Disclosure Initiative tool dedicated to the chemical and pharmaceutical sector, developed by One Ocean Foundation in collaboration with its partners, reflects the main pressures exerted by this sector with the aim of helping companies to become aware of their impacts on marine ecosystems, assess the related risks, and disclose key information and strategic responses on the significant issues related to the chemical and pharmaceutical industry. As identified in our research and reflected in the industry-specific tool, these pressures include:

- **Loss of biodiversity;**
- **Introduction of contaminants into seawater and seafood**

The importance of the Ocean Disclosure Initiative lies in the fact that, for the first time, companies, scientific and financial communities, and civil society can rely on a common language to measure, address, and mitigate the most relevant pressures that humanity exerts on the marine environment, sector by sector, with significant advantages for the health of the ocean.

ONE OCEAN Foundation

secretariat@1ocean.org
1ocean.org