Environmental Chemistry Innovations

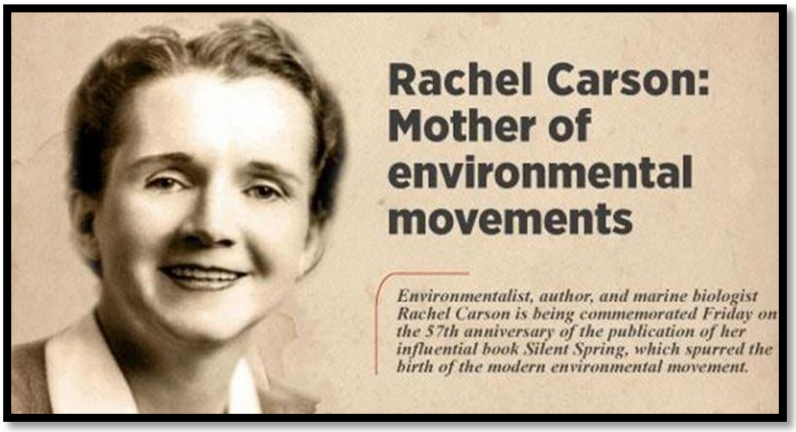
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1.1. Introduction

What exactly is "environmental chemistry"? The term 'environmental chemistry' may not have a specific definition, as its meaning varies among individuals. Nevertheless, ecological chemists play a very significant role in solving different global challenges such as ozone layer depletion and climate change, as well as also follow some local or regional issues such as acid rain, water pollution, and air pollution, etc *(Andrews et al., 2009).*



An old Chinese proverb states, "If we don't change our path, we'll end up exactly where we're going." This concept is significant today for humanity. The tiny part of the universe that supports all life is Earth, but human is on a dangerous pathway that could destroy their own homes. Almost 2 billion years ago, oxygen that was produced by sunlight altered the Earth as many photosynthetic organisms, such as cyanobacteria. Since no other life is such the most important on Earth, particularly its atmosphere. At present, humans can create significant changes by utilizing fossil fuels to produce energy.



Some concerned citizens have started to take action for the security of Earth’s future as risks to the planet mount and for humanity. Various efforts have been made for decades to

maintain the important ecosystem, such as in the early 1900s, when soil erosion was caused by farming in the United States. The Dust Bowl in the 1930s forced the government to take action for soil preservation according to climate change. In 1962, Rachel Carson's Silent Spring prompted global environmental change and mentioned the danger of pesticides in the environment (Manahan, 2011).

1.2. What is environmental chemistry

Environmental chemistry is the scientific study of biological and chemical processes found in natural settings such as water, soil, air, and living organisms. Its main purpose is to pay attention to pollution from industry, farming, and transportation. Since the revolution in the industrial field, human activities have significantly changed these natural systems, which has caused issues like water pollution and air pollution. Many fields have to work to find solutions that decreases the harm to living organisms and support eco-friendly practices (Enneboog, 2025). Environmental chemistry examines very carefully the risk characteristics of all the chemical compounds present in the environment. It plays a vital role in assessing the new significant products and their environmental impact. This field of science also safeguards the groundwater from the dust, soil, and various waste particles. It also prevents the water surface from sedimentation, pollutants, and radioactive microbiological parameters (Gooijer, 2022).



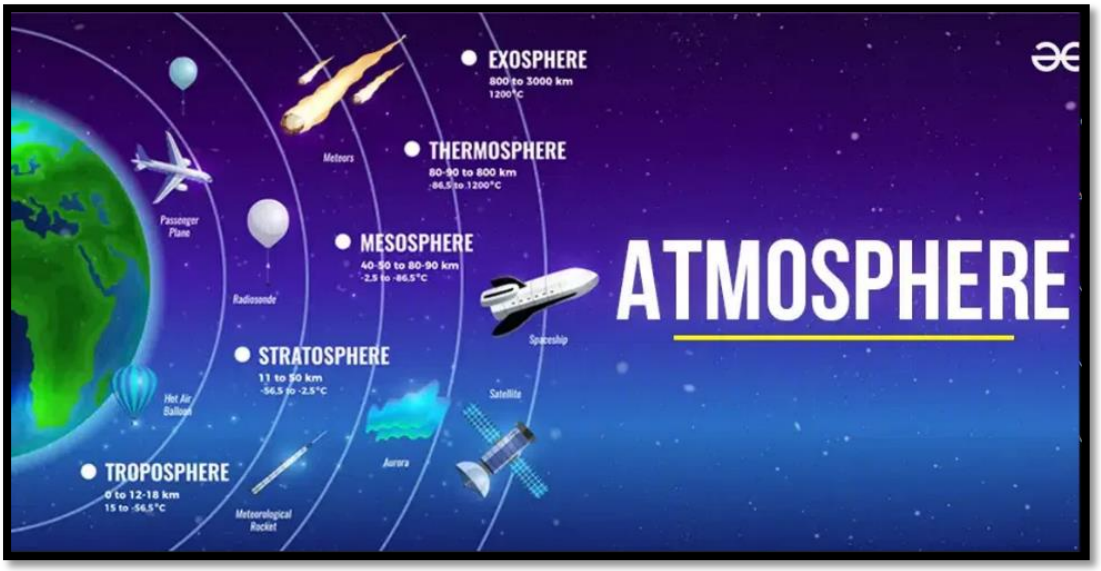
1.3. Essential role of Chemistry

Our lives are inescapably linked to Chemistry. Everything we eat, the environment where we live, and our bodies are all made up of chemicals. This is according to the concept that chemistry is the study of matter, and all matter is fundamentally chemical. Moreover, it controls the agricultural land that produces the food, the drinking water, and the atmosphere where we breathe. The human body has complex chemical reactions that carry out countless chemical mechanisms significant for life, and also a lot of chemical components present within us.

However, the different environmental chemical techniques, for example, the use of ecotoxicants and chemical indicators, are utilized to improve the soil quality. Out of this, some unwanted contaminants such as gasoline, motor oil. Sediments, carbon compounds, hydrocarbons, and metals can accumulate on roadways, roofs, impermeable surfaces of parking lots, and inside cities. Different fields were working on the management of waste, and cleaner production can be used in environmental chemistry.

1.4. Study of chemical processes in nature and how human activities affect them

There are various multidisciplinary scientific areas of chemical and biological processes that take place in the natural world, and studies that examine how human activity affects the natural ecosystem. It investigates the different long-term fates of natural and man-made chemicals that are present on the Earth, chemical and biological changes, origin, ecological impact, and their distribution. By fusing the concept with chemistry, the hydrosphere, lithosphere, biosphere, and atmosphere were all collected under a single umbrella (Team, 2024).



Different types of chemical reactions, such as organic and inorganic reactions that take part in changing the environmental condition; besides this, physical chemistry take an important part in contaminating the environmental chemistry. When the different chemicals enter the environment, they interact with the living organisms, water, soil, and the air, and can be categorized into ecosystems for plants and animals, also including humans. However, the final location of chemical impact is determined by the physical process, such as adsorption, sedimentation, and volatilization. Once the chemical dispread, it can decompose by biological or chemical mechanisms. The initial chemical degradation in water or oxidation in air, reduction, and hydrolysis (Speight, 2018).

Most of the reactive gases containing chlorine and bromine destroy the stratospheric ozone layer through a catalytic cycle, which includes two or more independent chemical reactions.

Therefore, a single chlorine and bromine atom can destroy hundreds of ozone molecules before they expel into the stratospheric layer. This means that the tiny amount of chlorine and bromine can have a huge effect on the ozone layer. A very unique fact arises in the early spring or late winter season, which is known as the polar region, when a significant increase of chlorine monoxide, which is the most reactive gas that leads to substantial ozone depletion. In the given figures, the ozone destruction cycle is discussed (https://csl.noaa.gov/assessments/ozone/2006/chapters/Q9.pdf).

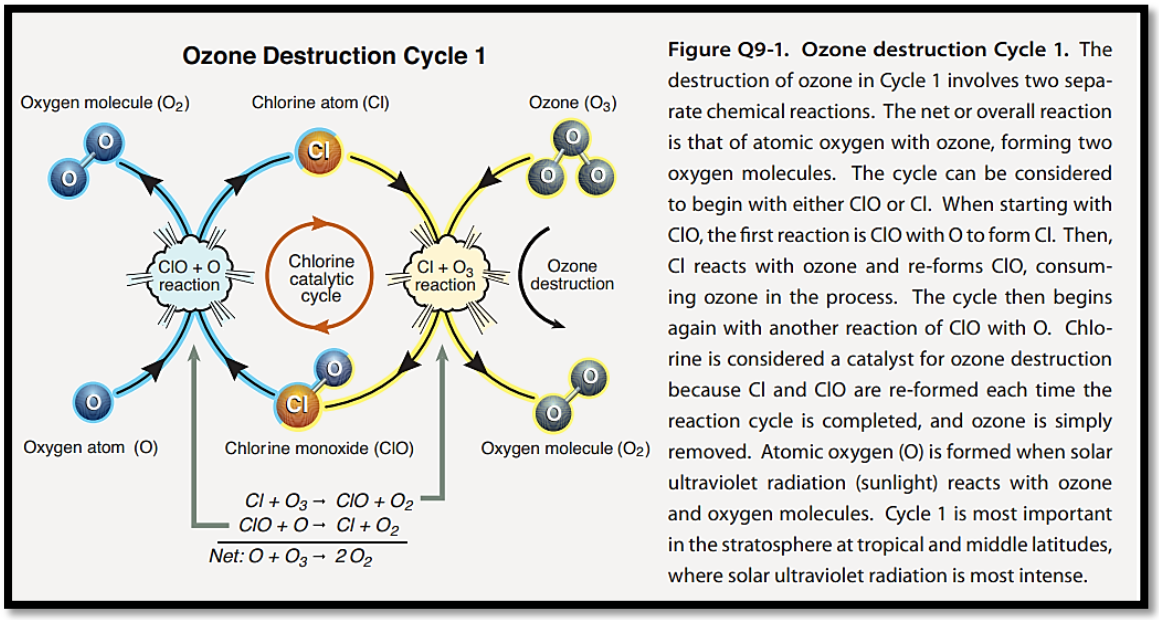


Figure Q9-1. Ozone destruction Cycle 1. The destruction of ozone in Cycle 1 involves two separate chemical reactions. The net or overall reaction is that of atomic oxygen with ozone, forming two oxygen molecules. The cycle can be considered to begin with either ClO or Cl. When starting with ClO, the first reaction is ClO with O to form Cl. Then, Cl reacts with ozone and re-forms ClO, consuming ozone in the process. The cycle then begins again with another reaction of ClO with O. Chlorine is considered a catalyst for ozone destruction because Cl and ClO are re-formed each time the reaction cycle is completed, and ozone is simply removed. Atomic oxygen (O) is formed when solar ultraviolet radiation (sunlight) reacts with ozone and oxygen molecules. Cycle 1 is most important in the stratosphere at tropical and middle latitudes, where solar ultraviolet radiation is most intense.

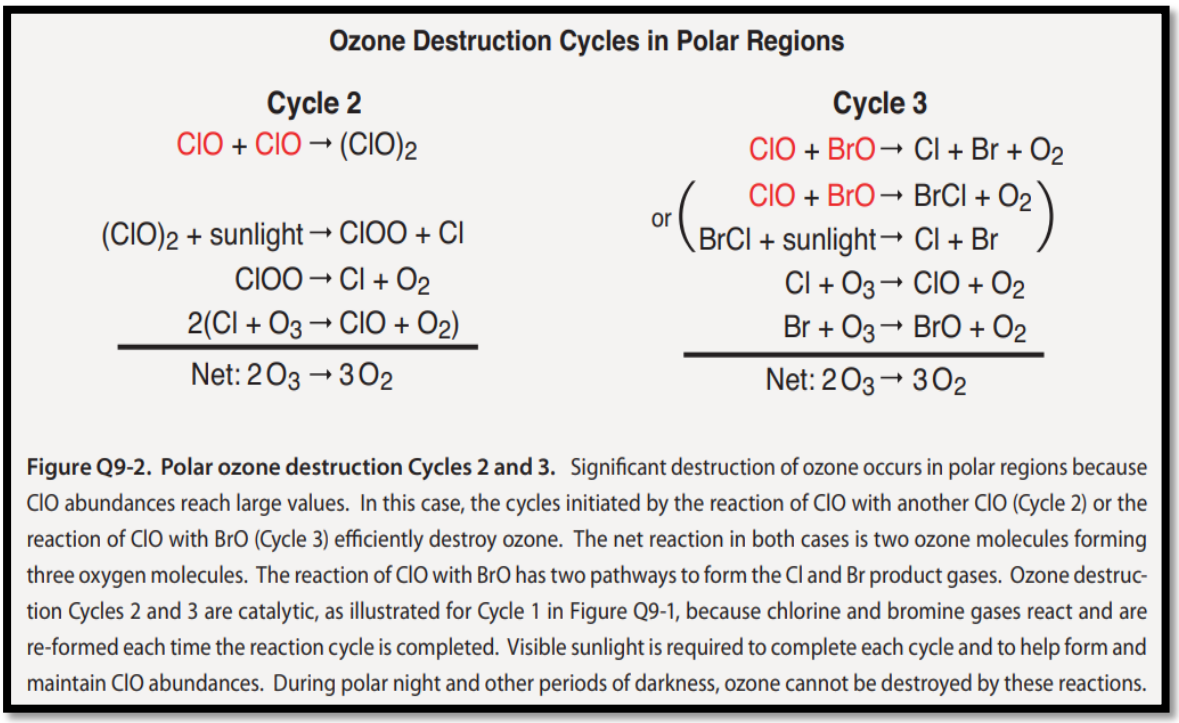
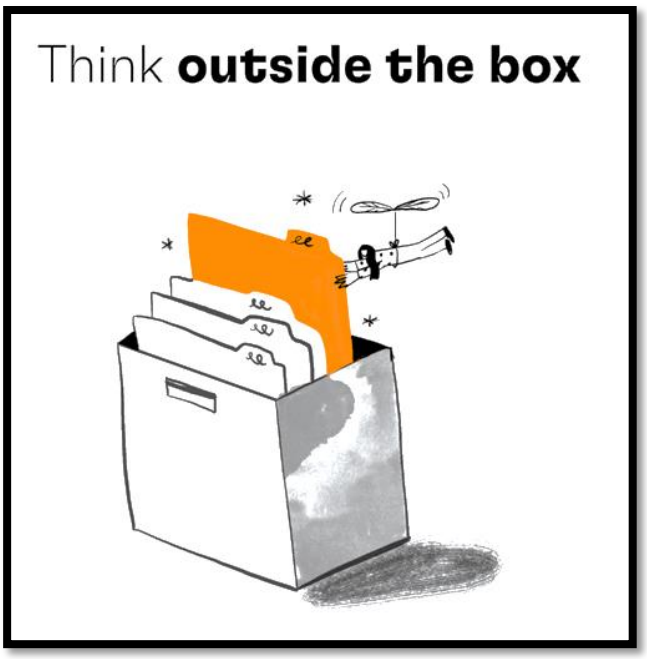


Figure Q9-2. Polar ozone destruction Cycles 2 and 3. Significant destruction of ozone occurs in polar regions because ClO abundances reach large values. In this case, the cycles initiated by the reaction of ClO with another ClO (Cycle 2) or the reaction of ClO with BrO (Cycle 3) efficiently destroy ozone. The net reaction in both cases is two ozone molecules forming three oxygen molecules. The reaction of ClO with BrO has two pathways to form the Cl and Br product gases. Ozone destruction Cycles 2 and 3 are catalytic, as illustrated for Cycle 1 in Figure Q9-1, because chlorine and bromine gases react and are re-formed each time the reaction cycle is completed. Visible sunlight is required to complete each cycle and to help form and maintain ClO abundances. During polar night and other periods of darkness, ozone cannot be destroyed by these reactions.

‘‘A nation destroy its soil destroy itself.’’ The primary reason for environmental destruction is Humans. Since the time when the ancient civilization began altering the land according to their survival. Various our activities such as spreading pollution, overconsumption, and deforestation have all led to major irreversible damage. In the current scenario, we are losing the most important natural resources, such as fertile soil, clean water, and biodiversity, very quickly. We have no more society if we destroy the environment. Leonardo DiCaprio said ‘‘Our planet’s alarm is going off, and it is time to wake up and take action’’

1.5. Why does innovation matter?

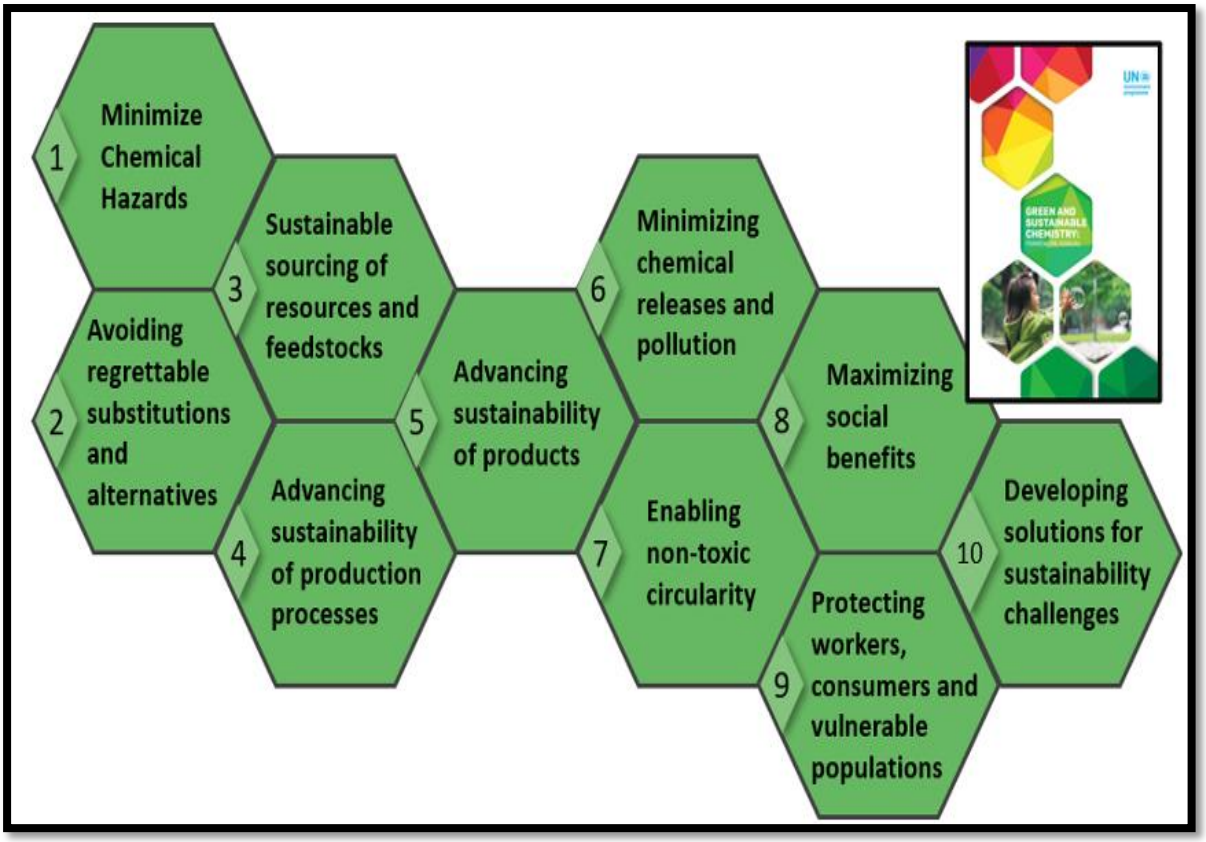


The innovation in environmental chemistry is very significant for the protection of living life, especially human health. And also to detect and eliminate the new toxic pollutants before they come across the environment and make pollution. Various interventions have been made possible, such as modern tools that can now able to detect tiny particles in drugs, pesticides, industrial chemical waste, and pharmaceuticals in water sources to help clean up all. Moreover, intelligent material and modern catalytic techniques are also more effective for the degradation of toxic pollutants faster, preventing long-term damage to the ecosystem. various example of innovation that provides real-time data to government and corporations to make quick or smart actions include lab-on-a-chip devices and AI-powered tools for monitoring environmental pollution. Today, after continuous hard work and efforts in research and technology, environmental chemists are not only able to solve the current issues but also predict the upcoming possible risks and ensure economic growth doesn’t come at any cost to damage our Earth.

1.6. Key Areas of Environmental Chemistry Innovations

Many of the scientists are creating more effective methods to detect and remove the pollutants and fight climate change. The all-new innovative solutions help to promote the cleanliness of our planet’s air, water, soil, and most importantly, they improve human health.

1.6.1. Green & Sustainable Chemistry



According to the Environmental Protection Agency (EPA), green chemistry involves the production of chemical products and processes that are environmentally safe, hence preventing pollution. It maximum chemical products were made in such a way that they break down into environmentally safe components that have no longer in the environment to create pollution and cause harm to the environment. Rather than considering a separate branch of science, green chemistry is responsible multidisciplinary approach to science founded on social, ecological, and chemical. Green chemistry inspires the innovation and development of novel research (Ivanković, 2017). In order to accomplish the global sustainable development targets, there have ten objectives shown in the given figure to seeks the progress in chemistry and foster the innovation. The UNEP work with more than 100 expert stakeholders to develop the main objectives and considerations for the green and sustainable chemistry. These objectives or goals add to traditional chemistry by focusing what we want to show and the sustainability. In the current situations after ensuring that chemistry is fully compatible with the global goals and to encourage the new ideas and they fully connect to potential of chemistry with the 2030 sustainable development agenda (https://www.unep.org/).

1.6.2. Principles of green chemistry

Paul Anastas and John warner in 1998 formulated 12 principles of "Green Chemistry''. They encourage the industrialists, government officials and scientist to adopt their activities that decrease or reduce the usage of hazardous material. These 12 principles have made significant contribution to the formation of new philosophy on the bases of their usefulness, specificity, and their relevance. These 12 principle are given below as



1. **Atom efficiency:** modified the synthesis methods to incorporate the raw material into its final product and decrease the waste of it.
2. **Prevention of waste:** Design the chemical methods as the minimum waste and the maximum usage into products.
3. **Safe chemical synthesis:** Developing the chemicals that are less dangerous or zero toxicity to human life as well to environment.
4. **Safe reaction condition and solvents:** Select that route of reaction which is safe for environment and the solvent used during the reaction also non hazardous
5. **Renewable stock material:** The raw material used is derived from sustainable sources such as crop and waste.
6. **Catalytic reaction:** Select the catalytic chemical reaction over the stoichiometric reagents to decrease the waste.
7. **Degradable substances:** At the end of chemical reaction the remaining chemical will convert into harmless components.
8. **Real time pollution monitoring:** The by-products during the synthesis regulating to avoid the waste production.
9. **Derivative reduction:** If possible to avoid the use of blocking or protective groups or any other temporary change.
10. **Prevention of accidents:** Select those type of chemicals and their routes to reduce the risk of explosion.

11. Energy efficient process: For ideal chemical reaction conducted at ambient temperature and pressure. If the chemical reaction takes place at low temperature and pressure.

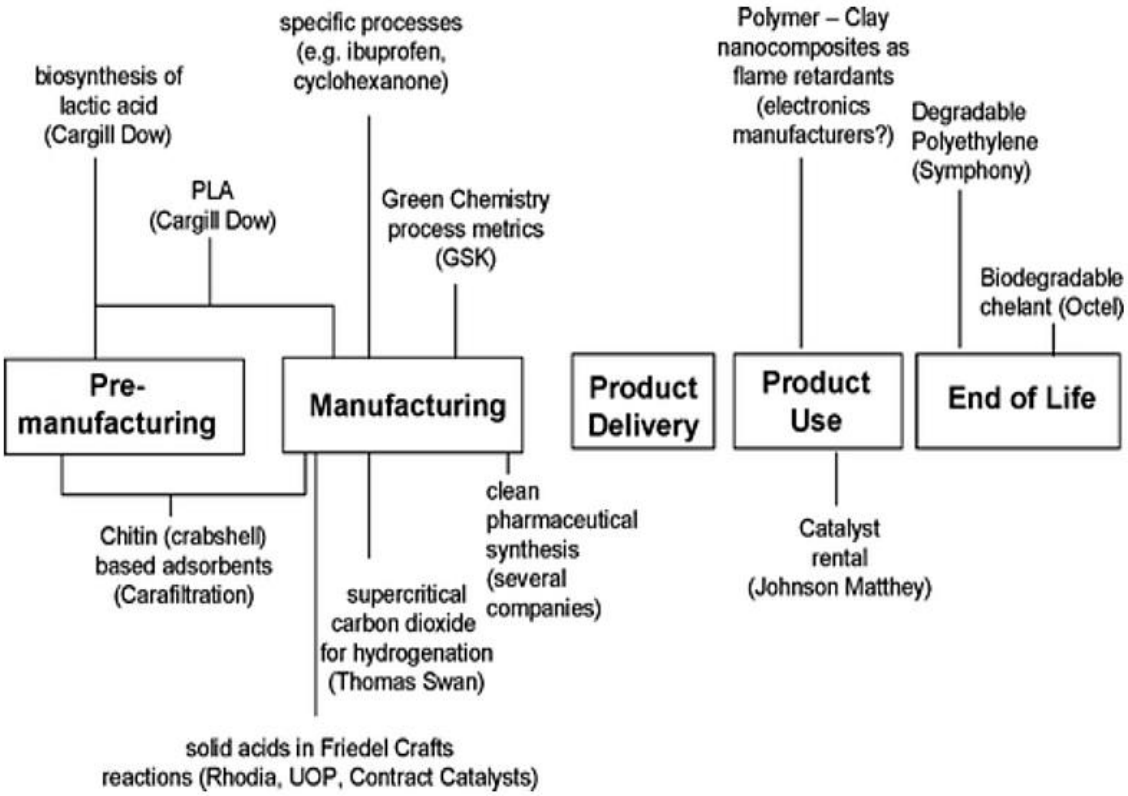
12. Safe route of route of reaction: Design the safe chemicals that are effective and non-toxic at all (Soltys et al., 2021).

Examples of green chemistry

1.6.3. Pollution Remediation Technologies

There are a number of various technologies discovered for pollution remediation, such as:

- Activated carbon-based technology
- Air sparging
- Bioremediation
- Groundwater circulating wells
- Nanoscale material for environmental site remediation
- Soil vapour extraction



1.6.4. Renewable Energy & Carbon Capture

The efficiency and cost of switching to 2050 clean energy of wind-water solar (WWS) could bring large significant values. The renewable systems are much more useful than fossil fuels, that why they cut global energy usage, which is more than half of the total usage. Around

60% of would save households by producing electricity cheaper, which affects the energy bills. Due to the burning of fossil fuels, which causes air pollution in the current time, the death rate is decreasing which has about 5 million usages of coal, oil, and gas is reduced (https://environmentamerica.org/center/). Since 2010 scalability of solar and wind has decreased from 89% to 69%, but enhancing the competitiveness of renewable energy sources without involving carbon capture (Bennett, et al., 2025).

1.7. Challenges & Future

- One of the main challenges is climate change, global warming, ozone layer depletion, deforestation, and solid waste management out Among all these issues, the most important challenge is the economic barriers.
- In the future, environmental chemistry depends on the interdisciplinary innovation that combines with artificial intelligence, biotechnology, chemistry, and the various rules that follow a low-carbon, minimum waste economy. For success in this field, we need Global collaborations, funding, as well as raising public awareness to increase the essentials.

1.8. Conclusion

Environmental chemistry has the main goal of detecting, preventing, and resolving the different types of pollution to make the environment clean and safe for living purposes. It gives an idea to understand the behaviour of chemicals in nature and analyse the new routes that are non-hazardous. Due to the cleaning project, it protects the groundwater, soil, and air from sediments and toxins also observes the harm, such as microbes and radiation.

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