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Role of Catalysis in Controlling Air and Water Pollution: A Chemical Perspective

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ABSTRACT

One of the most serious and problematic issues in the 21st century is air and water pollution, which creates significant threats to the ecosystem, human health, and the global economy. Industrial effluents, runoff from farms, and waste in urban areas are also to blame for the poor quality of air and water, and in most cases, they require intricate cleaning measures. Physical filtration, chemical precipitation, and adsorption are examples of traditional methods that have been in high demand. However, they are often energy-intensive, expensive, and likely to form secondary pollutants, which impose additional environmental costs. Quite to the contrary, catalysis has also emerged as an attractive and renewable alternative, promising higher potential efficiency, superior selectivity, and lower energy demands. This review broadly applied a chemical approach to detailing how catalytic processes reduce pollution in air and water systems. It covers various types of catalysis, including heterogeneous, homogeneous, biocatalysis, and photocatalysis, as well as the methods used for each, along with the materials that can be employed. The consequences of various innovative features in the handling of wastewater generated by cooking industries, the purification of flue gas, and the testing of pollutants in an environmentally friendly environment are elaborated further in the case studies. Additional common problems (catalyst deactivation, scalability, and economic sustainability) are discussed. In addition, nano-catalysis and engineered enzymes, as well as catalytic design using artificial intelligence, are explored as potential solutions for the next generation of pollution management. Ultimately, as this review underscores, catalysis is not merely a technological Band-Aid, but a groundbreaking pillar of sustainable development that aligns with the principles of green chemistry, offering a path to healthier and more sustainable ecosystems worldwide.

Keywords- Catalysis, Air Pollution, Water Pollution, Heterogeneous Catalysis, Photocatalysis, Biocatalysis, Environmental Chemistry.

I. INTRODUCTION

The inherited effects of high industrialisation rates, urbanisation, and population growth realised over the recent several decades have resulted in a decline that puts enormous pressure on the environment, leading to both air and water pollution. According to the World Health Organisation (2022), air pollution causes approximately 7 million premature deaths annually, disproportionately affecting vulnerable populations more than others, particularly in both developed and emerging economies (Kumar et al., 2022). Industrial gases, motor emissions, and the burning of fossil fuels are significant contributors to air pollution, making them key elements in the issue. Meanwhile, the nation remains polluted by raw household, industrial, and agricultural wastewater, which is discharged into rivers, lakes, or oceans, resulting in severe repercussions. Government reports issued by the United Nations indicate that most of the wastewater deposited into water bodies worldwide is not being treated, leading to the production of toxic and eutrophic water bodies, which results in the loss of usable biodiversity. These statistics highlight the importance of effective, efficient, and sustainable methods for pollution control (Dutta et al., 2021).

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The conventional techniques used in pollution mitigation, such as scrubbers, filters, chlorination, and sedimentation, have been widely adopted due to their simplicity and low installation costs. These methods, however, tend to create secondary waste issues rather than destroying pollutants. For example, the desulfurization of flue gas, which removes sulfur dioxide (SO2) from industrial exhausts, produces a large amount of gypsum waste, making the disposal of this waste challenging and a land-use issue. Similarly, in the case of wastewater treatment, methods for coagulation-flocculation leave behind a sludge that requires handling, transportation, and disposal, thereby increasing the operational cost and posing environmental hazards. These constraints underscore the need for pollution control approaches that not only eliminate pollutants but also minimise waste generation and energy usage (Parameswari et al., 2021; Töre & Can, 2023).

In this regard, catalysis offers a transformative solution that differs from traditional approaches. The oxidation, reduction, or degradation of different types of substances, in the presence of catalysts, can be transformed into non-toxic or even beneficial substances without destroying or consuming the catalyst itself. This substance, which accelerates the chemical reaction, is not consumed in the process. As an alternative, the carbon monoxide (CO) and hydrocarbons (volatile organic compounds or VOCs) can be oxidised with the help of catalysts installed in automotive catalytic converters into less harmful carbon dioxide (CO2) and water. Likewise, the degradation of organic dyes, pharmaceutical residues, and pesticides in wastewater fields by advanced oxidation processes with catalysts is possible, thereby reducing complex molecules to biodegradable ones (Ameta et al., 2012).

The catalytic methodology aligns well with the tenets of Green Chemistry, promoting waste prevention, energy conservation, and the use of less harmful chemicals. Catalytic reactions generate low-temperature and low-pressure reactions, resulting in reduced energy requirements and lower greenhouse gas emissions. Additionally, the use of catalysts may enhance selectivity, reducing the creation of unwanted by-products and promoting the formation of environmentally friendly pathways. These benefits make catalysis a key enabler of achieving the Sustainable Development Goals (SDGs), specifically clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), and climate action (SDG 13) (Pham & Park, 2024).

With such possible advantages in place, the applications of catalytic technologies in research and industry have been on the rise. Nevertheless, there are still problems with process scaling, catalyst stability, and the avoidance of deactivation by fouling or poisoning. Cost-effective catalyst design and the establishment of materials based on nontoxic, renewable, and abundant sources are also required (Lakhani et al., 2024).

This review, thus, aims to present an overview of catalytic process mechanisms in pollution control applications, with a special focus on air pollution reduction, including the reduction of CO, NOx, carbon monoxide volume, SOx, and water pollution, such as dyes, heavy metals, pharmaceuticals, and pesticides. It will also provide case studies on industrial applications and comment on the current state of disinhibitors, as well as prospects for catalytic environmental technologies. This review aims to contribute to the development of scalable and sustainable approaches to protect air and water resources from pollution contamination by exploring the chemical principles, materials science, and engineering strategies behind catalytic solutions to the problem (Pham & Park, 2024).

II. FUNDAMENTALS OF CATALYSIS IN ENVIRONMENTAL CHEMISTRY

Catalysis is considered an important environmental chemistry process because it promotes reactions in which pollutants are controlled, transformed, or destroyed without destroying the catalyst. In its simplest form, catalysis works by lowering the energy barrier required to make a chemical reaction occur - this means that needed chemical reactions can occur under more gentle conditions, in other words, at lower temperatures and pressures - something that is excellent news in situations where you are trying to treat pollution, because energy efficiency and cost-effectiveness are of the utmost importance. Catalysts are also utilised in the environmental context to either break down hazardous pollutants, convert them into less toxic forms, or trap the contamination in fluid air or water systems (Raheel et al., 2024).

The various forms of catalysis used vary with the character of the pollutants and the chemical reactions sought. Air pollution mitigation is commonly achieved through the use of heterogeneous catalysis, in which the reactants and catalyst are in different phases. Notably, manganese oxide (MnO2) and copper oxide (CuO) are utilised as metal oxides in the catalytic oxidation of volatile organic compounds (VOCs), a significant source of smog and respiratory ailments. High surface area contact between the gas-solid interface increases reaction rates, and easy separation of the catalyst and reaction products is easy (Delimaris & Ioannides, 2009).

However, homogeneous catalysis, where both the reactants and the catalyst exist in the same phase, is commonly applied to water treatment processes. The most famous is the Fenton reaction, in which ferrous ions (Fe 2) and hydrogen peroxide (H 2 O 2) produce highly reactive hydroxyl radicals (HO), which can destroy organic pollutants such as dyes and pharmaceuticals. The method is very efficient in breaking down stubborn pollutants; however, the reuse and recovery of the catalysts pose a viable challenge (Furia et al., 2021).

Biocatalysis is a green and environmentally friendly method that utilises enzymes or microorganisms to accelerate the degradation of pollutants. Phenolic compounds in industrial effluents and wastewater streams can be effectively degraded by enzymes such as laccase, which are produced by fungi. These biocatalysts operate at low temperatures and mild pH conditions, with significantly lower energy consumption compared to severe chemical treatment, and secondary pollution is reduced (Benavides et al., 2024).

The other promising field is that of photocatalysis, in which light energy, usually in the form of ultraviolet or visible light waves, is utilised to catalyse chemical reactions. A wide variety of semiconductors are being investigated for photocatalytic degradation of air and water contaminants, notably titanium dioxide (TiO2) and zinc oxide (ZnO). These materials, when irradiated, form electron-hole pairs that react with oxygen or water solute parts to form reactive species, such as superoxide radicals. Input"("O("2-) and hydroxyl radicals, which oxidise organic contaminants to benign products, which can be left to CO 2 and water. Of particular interest is photocatalysis (using the potential of solar energy) and reduced chemical consumption (Marín-Marín et al., 2023).

All these catalytic strategies constitute an extensive toolkit for addressing pollution issues in industries. One of the variables varies based on the particular pollutant, the reaction environment, and the cost-effectiveness of the chosen catalytic system. The integration of heterogeneous, homogeneous, biological, and photocatalytic systems is one concept that scientists and technologists have been working on to establish tailored systems that provide optimum efficiency while being sustainable. Continuous progress in material science, reuse, and reaction robotics fields is facilitating the development of such catalysis technologies, and environmental pollution can significantly contribute to reducing the global burden on air and water quality, thereby improving the ecosystem (Kong et al., 2023).

Table 1: Comparison of Catalysis Types in Environmental Applications

Type of Catalysis	Example Catalyst	Target Pollutant	Key Advantages	Limitations
Heterogeneous	Pt/Rh, TiO_2, zeolites	NOx, VOCs, dyes	Reusable, stable, selective	High cost, deactivation
Homogeneous	Fe^{2+} (Fenton's reagent)	Organic dyes, phenols	High efficiency	Sludge generation
Biocatalysis	Laccase, peroxidase	Aromatics, pesticides	Eco-friendly, mild	Sensitive to pH/temp
Photocatalysis	TiO_2, ZnO	Pharmaceuticals, NOx	Solar-driven, mineralisation	Low quantum yield

III. CATALYSIS IN AIR POLLUTION CONTROL

Catalysis is also a key element in reducing air pollution through chemical reactions that convert atmospheric pollutants into harmless compounds under controlled and energy-efficient processes. Catalytic reactions on carbon monoxide (CO) and nitrogen oxides (NOx) are among the key strategies for regulating industrial emissions, automotive emissions, and the emissions from combustion engines. They are particularly detrimental because these pollutants are toxic in nature and contribute to the development of smog, while also hurting human health and the environment (Maizak et al., 2020).

3.1 Catalytic Oxidation of Carbon Monoxide (CO)

Carbon monoxide is a colourless and odourless gas that is highly toxic and is formed mainly by improper combustion of fossils, biomass and industrialisation. Having a high concentration of CO can cause headaches, dizziness and in extreme situations, can cause death by blocking the transportation of oxygen in the blood. Catalytic oxidation of CO to carbon dioxide (CO2) is a straightforward solution to the problem, as it can be converted into a less hazardous form (Pati & Jangam, 2024).

In general, the most common catalysts used for this purpose are supported by metal oxides (e.g., alumina, ceria, or titania), which are typically platinum (Pt), palladium (Pd), and gold (Au). These catalysts provide active sites where CO molecules adsorb and react with oxygen at relatively low temperatures; therefore, they can be utilised in a wide range of applications, including residential heating units, automotive exhaust systems, and industrial burners. The overall reaction is straightforward:

$$\mathbf{CO + \tfrac{1}{2} O_2 \rightarrow CO_2}.$$

Nevertheless, there is a strong challenge to develop catalysts that can work at lower temperatures and are not poisoned by impurities such as sulfur compounds. Researchers have focused on enhancing the catalyst surface area, adjusting metal-support interactions, and introducing promoters to improve efficiency. The latest developments involve the application of ceria-based supports, which promote oxygen flow and regeneration, thereby increasing catalytic activity. Having a high activity in changing temperatures and concentrations extends the practical applications of catalytic CO oxidation even further.

3.2 NOx Abatement via Selective Catalytic Reduction (SCR)

NOx can be considered one of the primary sources of environmental issues, including smog formation, acid rain, and the formation of ground-level ozone. The sources of emission for these reactive gases are primarily power plants,

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diesel engines, and industrial combustion units. The harmful impact has led regulatory authorities worldwide to enforce strict regulations on emissions, making catalytic technologies unavoidable.

One of the most effective techniques for reducing NOx is selective catalytic reduction (SCR). During the process, a reductant, in most cases ammonia (NH 3), is used to convert NOx selectively to harmless nitrogen gas (N 2) and water (H 2 O) in the presence of a catalyst. Vanadium pentoxide (V2O5), tungsten trioxide (WO3), and titanium dioxide (TiO2) supports are the most common catalysts in SCR and have demonstrated high activity, stability, and longevity in adverse working conditions.

The fundamental reaction can be represented as:

$$4\,NO + 4\,NH_3 + O_2 \rightarrow 4\,N_2 + 6\,H_2O$$

or

$$2\,NO_2 + 4\,NH_3 + O_2 \rightarrow 3\,N_2 + 6\,H_2O.$$

Some of the factors that determine the efficiency of SCR catalysts include the temperature window, the dosing of NH3, and the presence of competing species such as SO2 and particulates. The optimisation of these parameters has resulted in the widespread use of SCR systems in coal-fired power plants, as well as in industrial and modern diesel engines. In addition to achieving high levels of NOx reduction, SCR can also help industries meet environmental standards, enhance fuel efficiency, and reduce operational costs.

Recent trends in explosive activities in catalysts used in SCR have focused on developing catalysts with broader temperature functionality and reduced vulnerability to poisoning. SCR systems have been offered a new opportunity to enhance their catalytic activity and lifetime with the introduction of new materials, including zeolites, water-based metal-organic frameworks (MOFs), and nanostructured supports (Li, 2023).

Table 2: Catalytic Methods for NOx Removal

Method	Catalyst	Reaction Pathway	Application
SCR	V_2O_5–WO_3/TiO_2	$NOx + NH_3 \rightarrow N_2 + H_2O$	Power plants
NSCR	Rh, Pd	$NOx + CO/HC \rightarrow N_2 + CO_2$	Automobiles
Photocatalysis	TiO_2	$NOx \rightarrow$ Nitrate	Building coatings

3.3 VOC and Hydrocarbon Oxidation

VOCs, such as toluene and benzene, are significant air pollutants that lead to the development of smog and ground-level ozone, which can be life-threatening. Catalytic oxidation of VOCs is one of the established and efficient techniques for minimising these damaging emissions. Manganese dioxide (MnO2), cobalt oxide (Co3O4), and cerium oxide (CeO2) are widely recognised catalysts, particularly in the treatment of industrial exhaust, which facilitates oxidation reactions at lower temperatures. The use of these catalysts enables VOCs to be converted into relatively harmless substances, such as carbon dioxide and water, thereby reducing their contribution to ozone formation and air toxicity. They are stable, highly surface-available, and reductive, and thus can be considered for ongoing use in severe industrial environments (Chen et al., 2021).

3.4 SO_2 and Particulate Matter Control

Similarly, another significant pollutant, sulfur dioxide (SO2), which is commonly emitted mainly through fossil fuel combustion, leads to respiratory infections and causes acid rain. Conversion of SO2 to sulfuric acid (or elemental sulfur) can be catalystically carried out using desulfurization methods, which are safe to store, or utilised as further oxidants in the industrial process. This is to prevent the direct release of SO2 into the air, as this will significantly reduce its adverse effects on the air.

Other atmospheric risks that penetrate the respiratory system and have long-term health effects are particulate matter, which are tiny particles under 2.5 micrometres. Catalytic filters, typically coated with metal oxides or anchored with noble metals, effectively capture and neutralise fine particulates before they enter air and water systems (Tran et al., 2017).

IV. CATALYSIS IN WATER POLLUTION CONTROL

Catalysis is also a relevant consideration in the water pollution control process because it offers sustainable, feasible, and low-cost methods for degrading and eliminating hazardous contaminants. The leakage of industrial effluents, agricultural runoff, and domestic waste into water bodies is steadily increasing, resulting in an extensive reservoir of organic pollutants, pharmaceuticals, dyes, pesticides, and metals in the aquatic environment. The candid solutions to addressing complex water matrices and the quality of drinking and wastewater will be achieved through improved reaction rates and selectivity at milder conditions, which are made possible by catalytic processes.

4.1 Advanced Oxidation Processes (AOPs)

Advanced oxidation processes are among the most promising catalytic methods for treating water. These strong oxidising substances that are employed by AOPs include those that form hydroxyl radicals (OH). Another widely used system is the Fenton system, in which the catalytic breakdown of hydrogen peroxide (H2O2) proceeds with the assistance of ferrous ions (Fe2+). The resultant reaction produces the hydroxyl radical, which is capable of breaking up complex organic compounds, such as dyes, drugs, and endocrine disruptors, that are otherwise difficult to break down by other treatment modes. Moreover, photocatalysis, especially when using TiO2 catalysts under UV or visible light, has also proven highly effective in mineralising pollutants into non-toxic compounds such as carbon dioxide (CO2) and/or water (H2O), and thus is safer to discharge (Khan et al., 2020).

4.2 Heterogeneous Catalysis in Water Treatment

The reasons for using heterogeneous catalytic systems in large-scale form are their ease of recovery, reusability, and structural stability. TiO2 photocatalysis is an example of photocatalysis in which titanium dioxide is used to catalyse the formation of reactive oxygen species that react and mineralise organic pollutants. Other catalysts that have been employed to reduce toxicity, such as nitroaromatics and chlorinated organic compounds, include metal catalysts, such as palladium or platinum, on carbon. These catalysts not only eliminate contaminants but also help transform the harmful byproducts of water treatment processes into less toxic components.

4.3 Biocatalysis and Enzyme-Based Remediation

The enzymes and microorganisms that produce these compounds in an environmentally friendly manner for purifying polluted water are referred to as biocatalysis. This way, there has been a strong focus on enzymes like laccase and peroxidase to degrade phenolic compounds and pesticides, as well as other toxic organics. Such enzymes are high-performance and can be used in low-heat conditions, which negates the need for energy and eliminates waste buildup. Moreover, in wastewater bioreactors, microbial consortia have the potential to degrade pollutants at their optimal degradation level through their synergistic metabolic pathways, which offer scalable and adaptive wastewater treatment approaches in industrial and municipal wastewater treatment systems (Yin et al., 2024).

4.4 Catalytic Removal of Heavy Metals

Two harmful heavy metals that pose a danger to human health and the environment include chromium and arsenic. Catalytic methods can successfully remove them. One of these is the decontamination of hexavalent chromium (Cr(VI)). Render trivalent chromium (Cr(III)) with the assistance of iron nanoparticles to store the metal in a less toxic and insoluble form so that it can be disposed of. There have also been catalytic precipitation designs to remove arsenic species in water into insoluble precipitates, which are then filtered off. The procedures are essential, particularly when dealing with the discharge of industrial waste in effluents or contaminated groundwater sources (Pio et al., 2015).

Table 3: Catalytic Approaches in Water Pollution Control

Pollutant	**Catalyst**	**Mechanism**	**Outcome**
Dyes (Methylene blue, Rhodamine B)	TiO_2, ZnO	Photocatalysis	Mineralization to CO_2, H_2O
Pharmaceuticals (Ibuprofen, Diclofenac)	Fe/TiO_2	Hydroxyl radical attack	Degradation
Heavy metals (Cr, As)	Fe^0, MnO_2	Redox reactions	Detoxification
Phenols & Aromatics	Laccase, peroxidase	Enzymatic oxidation	Biodegradation

V. CASE STUDIES OF CATALYSIS IN ENVIRONMENTAL APPLICATIONS

The catalysis process is central to controlling air and water pollution, offering efficient, cost-effective, and environmentally friendly solutions across a wide variety of industries. The following section presents two case studies that demonstrate the successful implementation of catalytic technologies to minimise pollutants and enhance the health of the ecosystem, supporting the chemical perspective on pollution reduction.

The catalytic system is most famously known as the automotive catalytic converter, which was introduced in 1975. These are designed to reduce the harmful emissions of carbon monoxide (CO), nitrogen oxides (NOx), and uncombusted hydrocarbons by cars, in a way that unleashes cleaner gases such as carbon dioxide (CO2), nitrogen (N2), and water (H2O) into the atmosphere. It has been demonstrated that catalytic converters can reduce CO, NOx, and hydrocarbons by more than 90 per cent, thereby lowering the level of air contamination in densely populated cities (Mokhtar et al., 2021).

The other novel remedy is the introduction of titanium dioxide (TiO2) photocatalytic surface on the exterior of structures. In Japan and select European cities, the technology has gained popularity, with an effort to reduce nitrogen oxide emissions caused by road traffic and industrial emissions. The ultraviolet light on TiO2 generates reactive oxygen species, which oxidise the NOx in the presence of defined micro-emulsions of TiO2 to clarify the contents of NOx, which are lost in the rain. Such a non-pollutant control technique demonstrates that a type of catalysis can be incorporated into an architectural design to continuously provide clean air.

The Fenton-based process of catalytic oxidation has been extensively used in the Indian textile industry to treat effluents containing complex azo dyes and organic pollutants. The Fenton process, an optimised process that employs a mixture of iron salts and hydrogen peroxide in acidic conditions, is used to generate hydroxyl radicals, which in turn oxidise and decompose recalcitrant contaminants. This initiative has been highly successful, as it reduces the colour and chemical oxygen demand (COD) and toxicity of the wastewater streams, encouraging textile mills to meet increasingly demanding environmental standards (Hassaan & Nemr, 2017).

VI. CHALLENGES IN CATALYTIC POLLUTION CONTROL

Catalysis has been vital in the current efforts to address air and water pollution, providing channels for effective breakdown, minimisation of emissions, and transformation of both detrimental pollutants. However, with respect to the vast potential of catalytic processes, there are a few challenges that hinder their overall usage and efficiency, at least on a scale comparable to those achieved at the industrial level. One of the most important issues is catalyst deactivation, which can be attributed to sintering, fouling, and poisoning. In poisoning (inactivation of active sites by specific molecules that contain sulfur, phosphorus, or chlorine), these molecules are irreversibly bound to the active sites, thereby inactivating or deactivating them. Treatment of water is likely to foul owing to the accumulation of organic material or particulates that obscure access to active sites on the catalyst material. Erosion can increase sintering of catalytic nanoparticles, which can impair surface area and reactivity, making high-temperature industrial applications a significant drawback. The other challenge is the high price of noble metals, such as platinum (Pt), palladium (Pd), and rhodium (Rh), which are extensively used in automotive catalyst converters. They are commonly employed in photocatalytic oxidation and water conversion. Their rarity and response to prices make them constitute a substantial portion of the operational costs, and this limitation restricts their application on a large scale, particularly in developing regions where pollution from industrial activities is very high. Attempts to replace these metals with transition metal oxides, or bimetallic systems, have been enticing; however, they tend to lead to a trade-off between productivity and stability (Vignesh et al., 2017).

The energy requirements of photocatalysis present extra hardships. Conventional photocatalysts, such as titanium dioxide (TiO_2), require ultraviolet (UV) light to excite electrons and generate active species. Since UV light is a small portion of the solar spectrum, exceptionally high energy inputs are required before reactions begin to occur efficiently. The visibility of light-active catalysts has not been neglected, but developing catalysts with which photocatalytic efficiencies and long-term stability can be measured in real-world conditions has been a concern. In the case of homogeneous catalysis, which is highly exploited in water remediation, yet another problem arises from the production of sludge. Both the extraction of the catalysts and the treatment of water might also prove challenging, and secondary pollution in the form of sludge with high levels of metals will also be produced, requiring further treatment. The options under investigation include immobilised catalysts as well as magnetic separation methods, although they are still at the optimisation stage. Finally, a significant downside is that lab-scale nanocatalysts cannot be scaled up. In the laboratory, nanostructured catalysts have been demonstrated to exhibit increased surface area, controllable reactivity, and selective degradation of pollutants. The difficulty of these successes being translated into industry-scale initiatives, however, is a challenge related to the reproducibility of synthesis to agglomeration, handling safety, and cost. Another topic of interest is the continuity of the structural integrity and catalytic functionality of nanomaterials during an extended period of use in complicated environmental matrices (Akther et al., 2019).

VII. CONCLUSION

Catalysis has taken the lead in addressing environmental pollution control by providing revolutionary methods for controlling air and water pollutants. Catalytic chemical processes are highly effective chemical treatment methods compared to traditional ones because they enable chemical reactions to convert toxic chemical pollutants into less toxic, or even beneficial, chemicals. Key advances in heterogeneous, homogeneous, photocatalytic, and biocatalytic systems are discussed, with varying merits: the robustness and recyclability of heterogeneous systems, the selectivity of homogeneous systems, the selective degradation of pollution by light energy in photocatalysts, and the selectivity and specificity of biocatalysts in biomolecule transformation systems, which are facilitated by enzymes. In combination, these systems have been used to achieve success in treating industrial effluent, purifying air, and remedying urban water. Such successes have their share of trouble. The most apparent limitations to large-scale usage are high costs, scale, and challenges to catalyst stability, particularly in large-scale applications. The ongoing research is also increasingly addressing how such limitations can be overcome through nanotechnology (by covering a wider surface area and possibly adopting a more environmentally friendly, selective approach in catalysis) and biotechnology (with increased eco-friendliness and selectivity in catalysis processes). Beyond this, artificial intelligence (AI) is increasingly taking centre stage in optimising reaction conditions and evaluating catalyst performance, thereby reducing measures of trial and error in research. Finally, catalysis is the narrative about the intersection of new technology in the chemistry space with ecological responsibility; a potent case it makes that scientifically engineered options could be directly translated to finding ways to reduce the pollution footprint. By constantly introducing and integrating optimal systems of a catalytic character, researchers and industries can bring themselves to a state of equilibrium, where the industrial world can become resourceful. The surrounding integrity of aspects considers the resources that constitute the environment, where, instead of being mutually exclusive, industrial endeavours and eco-protection can become coexistent. Catalysis can therefore bring about more than just an escape route from the chaos of pollution that surrounds us, which we can barely escape these days; it can also give us a cleaner and stronger tomorrow.

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