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Green Catalyst For Sustainable Development

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Abstract:

Green catalysts, with their beneficial ecological qualities, have revolutionized chemical processes and become key players in sustainable development. This abstract offers an overview of how green catalysts support sustainability in a range of sectors. The move toward more resource and environmentally conscious catalytic processes is represented by the use of green catalysts. The many approaches used in green catalysis such as photocatalysis, biocatalysis, and nanocatalysis are examined in this review. Each of these approaches offers a special benefit to sustainable chemistry. High surface area and reactivity nanocatalysts hold potential for improving catalytic efficiency with the least amount of negative environmental effects. Green chemistry concepts are in line with biocatalysis, which uses naturally occurring catalysts such as enzymes to provide high selectivity and gentle reaction conditions. Utilizing sun energy, photocatalysis offers a sustainable method of achieving many kinds of chemical reactions. Green catalysis has consequences for pharmaceutical synthesis as well. Here, new and sustainable catalytic methodology can be designed to eliminate waste, expedite operations, and ensure strict regulatory compliance. The review deliver deeper into the cutting-edge developments and uncharted territory in green catalysis, with a focus on photocatalysis, biocatalysis, and nanocatalysis and its uses in sustainable energy conversion and pharmaceuticals. Green catalysts in pharmacy promise sustainable medication manufacturing in the future, along with regulatory compliance, innovation, and advancement in the field of green chemistry. Green catalysts are emerging as change-catalysts, guiding chemical processes towards a more sustainable and environmentally friendly future as industries realize the necessity of environmentally responsible practices.

Key words: green chemistry, green catalysis, nanocatalyst, Environmentally sustainable.

I. Introduction:

A. Background on Green Catalysts:

The idea of "green chemistry" was first put forth in the early 1990s. The Green Chemistry Institute was established in 1997, and the first volume of the known green chemistry journal of the Royal Society of Chemistry was published in 1999. Almost every aspect of chemistry is covered by green chemistry processes, including environmental, toxicity, polymer, biochemistry, inorganic, and organic chemistry. A number of popular green program trends, including bio and catalysis and the use of safety alternatives, can help achieve the objectives of environmental protection and economic gain. These trends include the use of renewable feedstocks (biomass), reaction solutions (such as water, ionic liquids, and supercritical liquids), reaction conditions (microwave irradiation), and new synthetic pathways (photo catalytic reaction). [(1)]Green catalysts, which support sustainable development and are in line with the ideas of green chemistry, mark an important change in the field of catalysis. In-depth discussion of the meaning, importance, and broad application of "green catalysts" is given in this section, with a focus on how they can reduce environmental impact and advance a more sustainable future. By supporting chemical reactions with less of an impact on the environment, green catalysts are essential for the advancement of sustainable development. With an eye toward reducing waste, energy use, and the usage of hazardous materials, these catalysts follow the guidelines of green chemistry. Reviewing green catalysts in the context of sustainable development, this paper examines their definition, importance, and reach[(2)]

What are Green Catalyst?

Green catalysts are catalysts that are made with a primary goal of reducing their ecological footprint. They are also referred to as sustainable or environmentally safe catalysts. They follow the fundamentals of green chemistry, which is an all-encompassing strategy aimed at creating chemical processes that are more ecologically friendly and sustainable by nature.[(3)] Green catalysts are essential for speeding up chemical reactions while lowering the amount of energy, hazardous materials, and unwanted by products that are produced. Green catalysts differentiate themselves mainly by their capacity to function in mild reaction conditions, which enhances energy efficiency and reduces the requirement for hard reaction environments. With their high catalytic activity, selectivity, and preference for renewable resources, these catalysts help produce desired products with the least amount of adverse reactions. The ultimate objective is to switch from traditional catalytic processes which frequently require hazardous reagents and produce large amounts of waste to more environmentally friendly ones that adhere to the fundamentals of sustainable chemistry. Green catalysts' importance for sustainable development, Green catalysts are important because they have the power to completely transform chemical reactions, which would greatly advance the concept of sustainable development.

II. Fundamentals of Green Catalysts:

Conventional catalytic techniques frequently require the use of dangerous chemicals, high-powered materials, and produce a significant amount of waste, all of which increase the environment. Green catalysts, on the other hand, address these problems with their applications and design principles, providing a more sustainable solution. This concept is embodied in the 12 Principles of Green Chemistry which can be paraphrased as[4]

1. Waste prevention instead of remediation

2. Atom efficiency

3. Less hazardous/toxic chemicals

4. Safer products by design

5. Innocuous solvents and auxiliaries

6. Energy efficient by design

7. Preferably renewable raw materials

8. Shorter syntheses (avoid derivatization)

9. Catalytic rather than stoichiometric reagents

10. Design products for degradation

11. Analytical methodologies for pollution prevention

12. Inherently safer processes

In chemistry, the process of changing the rate of a process by adding a substance which is not used by the reaction is known as catalysis. Catalysts that maximize chemical reactions with minimal environmental impact are referred to as green catalysts, or environmentally friendly catalysts.[5] By offering more environmentally friendly substitutes for traditional catalysts, which frequently entail the use of toxic or dangerous materials, they play a critical role in sustainable chemistry. Three main principles comprise the foundation of green catalysts: sustainability, selectivity, and efficiency.[6] Effectiveness the goals of green catalysts are to increase efficiency overall and reaction rates. High activity catalysts and reaction condition optimization can help achieve this. For example, adding nanoparticles to catalysts can increase their surface area and speed up reactions.[7] Selectivity With the goal to reduce the production of waste and undesired by products, green catalysts concentrate on facilitating selective reactions. Reaction yields can be optimized overall by increasing selectivity. Selectivity can be increased by creating catalysts with particular active sites or by changing the surface structure of the catalysts.[8] Sustainability the use of toxic or harmful substances is minimized or eliminated with the help of green catalysts. This can be accomplished in a few ways, such as using renewable resources as raw materials, substituting non-toxic or earthly alternatives for toxic metals, or creating catalysts that are simple to recover and reuse.[9] Prevention by Creating procedures to stop waste from being produced and the use of dangerous materials. Atom Economy of Reducing waste production by maximizing the incorporation of reactant atoms into the final product. Reduced Hazardous The process of synthesis Employing techniques that incorporate fewer toxic solvents and hazardous substances. Design for Energy Efficiency is the use of energy-saving techniques to lower total energy usage. Reducing dependency on non-renewable resources can be achieved through the use of renewable feedstock.

II. Types of Green Catalysts:

Green catalysts are available in a variety of forms, each intended for dealing with particular issues in an eco-friendly and long-lasting way. This section examines the overviews, traits, and applications of the two main categories of catalysts: heterogeneous and homogeneous catalysts.[10]

1. Homogeneous Catalysts:

The molecules of homogeneous catalysts are distributed in the same phase as the reactants. Their distinctive qualities render them valuable in advancing environmentally friendly and sustainable chemical processes. Organic compounds or transition metal complexes that promote reactions in solution are frequently used as homogeneous catalysts.

Homogeneous catalysts are known for their these are the further differ in the three types according to their activity.[11]

High Catalytic Activity: These catalysts usually show a high degree of effectiveness in initiating chemical reactions, enabling higher rates and more selective reactions.

Mild Reaction Conditions: Because they can work in comparatively mild environments, they don't require as much extreme heat or pressure, which helps to save energy.

Selectivity: By facilitating particular transformations, homogeneous catalysts reduce the production of undesirable by products.

In Pharmaceutical Synthesis Given that of their accuracy and effectiveness, homogeneous catalysts are used extensively in pharmaceutical synthesis. They are essential to the manufacture of pharmaceuticals because they support sustainable and environmentally friendly drug manufacturing techniques. Examples of applications are:

Asymmetric Synthesis: Asymmetric synthesis relies on homogeneous catalysts to produce chiral compounds with high enantiomeric purity, which is essential for the pharmaceutical industry.[12]

Carbon-Carbon and Carbon-Heteroatom Bond Formation: These catalysts offer environmentally safe pathways to intricate molecular structures by facilitating important bond-forming reactions in pharmaceutical synthesis.[13]

2. Heterogeneous Catalysts:

When compared to the reactants, heterogeneous catalysts have special benefits like ease of separation and the possibility of catalyst recycling. They also function in a different phase. Solid substances with active sites that promote the intended chemical reactions are frequently used as catalysts.[14] These qualities define heterogeneous catalysts which are estimated by the catalysts techniques.[15]

Simplicity of Separation: The catalyst and reaction mixture are in distinct phases, which makes the catalyst-product separation process easier.

Recycling of catalysts: Heterogeneous catalysts are a sustainable material because they can be recovered and used again in various reaction cycles.

Versatile : Heterogeneous catalysts are can be used in a variety of industries because they can catalyze a broad range of reactions.

In result, catalysts, both homogeneous and heterogeneous, are essential to the development of sustainable and green chemistry. Their unique qualities and uses make them essential elements in the creation of ecologically friendly synthetic pathways, especially in the synthesis of pharmaceuticals. The thoughtful application of these green catalysts will surely lead to more environmentally friendly and sustainable chemical processes as the field develops.

III. Green Catalysts in Drug Synthesis:

By providing a more environmentally friendly and sustainable method for drug synthesis, green catalysts also referred to as eco-friendly or sustainable catalysts play a critical role in the process. The purpose of these catalysts is to reduce or completely do away with the use of dangerous or toxic materials that are typically used in pharmaceutical synthesis procedures. In addition to decreasing the impact on the environment, using green catalysts in the synthesis of drugs improves the efficiency and selectivity of the reactions, producing higher yields and fewer undesirable by products. Green catalysts can be used for a variety of chemical reactions, such as asymmetric transformations, hydrogenation reactions, oxidation reactions, and cross-coupling reactions.[16] Different kinds of green catalysts are used in the synthesis of drugs. For example, the use of biocatalysts enzymes and whole cells is growing because of their high selectivity, high efficiency, and harmless reaction conditions. In the production of pharmaceuticals, enzymes such as lipases, proteases, and cytochrome P450s have been effectively used as green catalysts. Environmentally friendly metals including iron, copper, silver, and gold are another class of green catalysts. These metals are appealing substitutes for conventionally hazardous metals like mercury or palladium because of their great abundance and low toxicity. These metals' ease of recovery and recycling also contributes to their sustainability. The pharmaceutical industry is undergoing a change in direction with the introduction of green catalysts in drug synthesis, which promotes environmental consciousness and sustainability. Enzymatic and organocatalysts are two important classes of green catalysts that are examined in this section along with their properties, uses, and contributions to the synthesis of green drugs.[17]

A. Enzymatic Catalysts :

The foundation of biocatalysis, enzymatic catalysts, have become well-known for their unmatched efficiency and selectivity in accelerating complicated reactions necessary for the synthesis of pharmaceuticals. Enzymes' ability to precisely interact with substrates is facilitated by their active sites and three-dimensional structures. Because of their high specificity, enzymes can selectively convert substrates into the desired products.[18] This quality is especially useful in pharmaceutical synthesis, as enantiopure compound production is frequently a crucial prerequisite for the safety and efficacy of drugs. By avoiding the use of harsh reagents and extremely high temperatures, enzymatic processes have mild reaction conditions that support green chemistry principles and increase energy efficiency. Enzymatic catalysis's environmentally friendly practices is further highlighted by the use of water as a reaction medium, which reduces the need for organic solvents and its negative effects on the environment. This method satisfies the growing demand for greener manufacturing practices while simultaneously improving the sustainability of pharmaceutical processes.[19] Numerous case studies have proven the effectiveness of enzymatic catalysts, highlighting their use in pharmaceutical synthesis in a range of situations. Lipases have demonstrated a crucial role in the enzymatic resolution of chiral intermediates. Racemic esters are hydrolyzed selectively by lipases, like Candida antarctica lipase B (CALB), yielding compounds that are enantiomerically pure. In order to create enantiopure medications and ensure the best possible therapeutic outcomes, this biocatalytic resolution is essential. An additional application of enzymatic catalysis is demonstrated by glycosylation reactions.[20] An essential step in the production of glycosylated pharmaceuticals is the regioselective attachment of sugar moieties to drug candidates, which is facilitated by enzymes. Notably, the efficiency and environmental impact of these enzymatic glycosylation processes are frequently higher than those of conventional chemical methods.[21]

B. Organocatalysts:

Developments in Organocatalysis by Using small organic molecules as catalysts, organocatalysis has become a flexible and sustainable method for synthesizing drugs. Organocatalysts' special qualities add to their effectiveness and environmental friendliness. Organocatalysts are highly selective reaction facilitators that work in mild environments, frequently at room temperature.[22] This mildness in the reaction conditions is consistent with green chemistry principles and helps to minimize energy consumption. Due to their adaptability, organic catalysts can be used in a variety of reactions and are therefore useful tools in the synthesis of various pharmaceutical compounds. The fact that a large number of organic catalysts come from renewable resources highlights the sustainability of organocatalysis even more. This is in line with the main objective of creating more environmentally friendly and sustainable procedures within lowering reliance on non-renewable resources in the pharmaceutical sector.[23]

C. Green Routes to Active Pharmaceutical Ingredients (APIs):

Organocatalysis offers environmentally friendly and sustainable ways to synthesize active pharmaceutical ingredients (APIs), substituting conventional techniques. One important use is in aldol reactions, where important carbon–carbon bond formation is mediated by organocatalysts. An important stage in the synthesis of different APIs and pharmaceutical intermediates is represented by this procedure. [24]Another essential property of organocatalysts is their capacity to support asymmetric transformations, which makes it possible to synthesize chiral molecules with excellent enantioselectivity. The environmentally harmful effects of drug synthesis are lessened by the green pathways created by organocatalysis. The use of renewable starting materials is consistent with sustainable practices, and these catalytic processes frequently take place in the absence of hazardous heavy metals. Furthermore, the mild environments used in organocatalytic processes help save energy and are consistent with the larger a sustainable and environmentally friendly drug manufacturing goal.[25]

IV. Environmental Impact Assessment in Catalysis:

Environmental impact assessments, are essential for evaluating the possible effects of catalysts on the environment. In many different industries, including chemical production, petroleum refining, and the automotive industry, catalysts are utilized extensively to speed up and ease chemical reactions. An EIA for catalysts takes into account a number of important factors. The catalyst's composition and nature, its methods of manufacture and delivery, its use and disposal procedures, and any possible emissions or waste produced during its lifetime are some of these variables. Pollutant releases during catalyst production or use are a major concern when evaluating the environmental impact of catalysts. During their manufacturing process, certain catalysts have the potential to release harmful substances or greenhouse gases.[26] These emissions may have a negative impact on ecosystems, human health, and air quality in addition to causing climate change. Various measures have been implemented by regulatory bodies and industry to mitigate the environmental impacts of catalysts. Using greener synthesis routes and more sustainable energy sources during production are two examples of cleaner production techniques. Furthermore, it's critical to recycle catalysts and dispose of them properly to reduce their overall environmental impact.[27]

A. Life Cycle Assessment of Green Catalyst:

A change in focus is occurring in catalysis, a fundamental component of many industrial processes, with an increasing emphasis on sustainability. Catalysis's Environmental Impact Assessment (EIA), which employs Life Cycle Assessment (LCA) in particular, offers a comprehensive viewpoint on the environmental effects of various catalytic processes.

Characteristics of Green Catalysts In addition in LCA

Sustainable Sourcing: Compared to conventional catalysts that might depend on non-renewable resources, green catalysts frequently use renewable feedstocks, which helps to reduce their environmental impact.[28]

Decreased Energy Consumption: Green catalysts' selectivity and efficiency translate into reduced energy consumption during catalytic processes. This element has a major impact on the overall environmental impact.[29]

Minimized Waste Generation: Selectivity is given priority in the design of green catalysts, which leads to fewer by products and less waste production. In order to reduce the environmental impact of catalytic processes, this factor is essential.[30]

B. Comparative Analysis with Conventional Catalysts:

While conventional catalysts are necessary for many industrial processes, there are environmental issues that need to be carefully considered. Knowing these obstacles is essential to creating more environmentally friendly substitutes for catalysis.[31]

Depletion of Resources: Problem Precious or rare metals like platinum, palladium, and rhodium are frequently used in conventional catalysts, which depletes resources. These metals extraction and processing lead to habitat disruption and environmental deterioration. One major environmental issue related to catalytic processes especially those that use conventional catalysts is resource depletion.[32] This problem stems from the catalyst manufacturing process's reliance on rare or non-renewable metals, which adds to the depletion of vital resources. These use in catalytic applications have a significant impact on environmental sustainability.[33]

Energy intensity: Problem Energy-intensive procedures are frequently used in the production of conventional catalysts, which has a substantial negative environmental impact. Complex purification procedures and high-temperature synthesis processes raise the total energy consumption.[34]

Generation of Waste: Problem Using traditional catalysts could encourage unfavorable side reactions that produce waste and unwanted by products. The proper disposal of these by products presents environmental pollution challenges.[35]

Comparative Analysis with Conventional Catalysts:

Green catalysts show great promise as a substitute for conventional catalysts, providing a way around traditional catalytic processes' resource depletion issues. The creation and application of green catalysts solve major issues brought on by the depletion of valuable resources in a way that is consistent with sustainability and environmental responsibility.[36]

Sustainable and renewable feedstocks: are frequently used in the design of green catalysts, which lessens the need for rare metals. By doing this, the negative effects of resource extraction on the environment are lessened.[37]

Earth-Abundant Elements: By using earth-abundant elements, some green catalysts reduce the demand on finite resources. Green chemistry is in line with this approach, which emphasizes the use of readily available and environmentally benign materials[38]

Recycling of Catalysts: Recyclability is frequently given top priority in the design of green catalysts, which increases their longevity and lowers the overall need for the production of new catalysts. This is consistent with the circular economy principles and helps conserve resources.[39]

Understanding the problems with traditional catalysts such as waste production, energy intensity, and resource depletion makes the shift to more environmentally friendly substitutes crucial. With their emphasis on eco-friendly ideas, green catalysts provide a means of addressing these issues and open the door to a more sustainable catalysis in the future. By addressing resource depletion issues with the use of renewable feedstocks, earth-abundant elements, and effective catalyst recycling, green catalysts offer a promising substitute. By supporting ecologically responsible catalytic processes, these sustainable practices help to create a more sustainable and environmentally friendly future.[40]

V. Mechanistic Understanding and Enhancement in Green Catalysis:

At the interface of efficiency and sustainability, green catalysis strongly emphasizes elucidating reaction mechanisms and maximizing catalyst performance. The development of efficient and environmentally friendly chemical transformations is largely driven by a strategic improvement of the performance of green catalysts and a thorough understanding of the complexities of catalytic processes.[41] The Significance of Mechanistic Knowledge a major obstacle to the development of effective green catalysts is the incomplete understanding of reaction mechanisms. Mechanistic understanding is essential for directing the logical design of catalysts with increased activity and selectivity.[42]Comprehensive mechanistic understanding aids in the intelligent design of green catalysts, ensuring their efficacy in specific reactions and promoting the principles of sustainable chemistry.

The techniques for Mechanistic Research are further proceed:

In situ spectroscopy: The identification of active species and intermediates is made possible by the real-time monitoring of catalytic reactions using methods such as mass spectrometry or NMR.[43]

Computational modeling: A theoretical framework for understanding reaction pathways, energetics, and the overall catalytic mechanism is provided by theoretical calculations, such as density functional theory (DFT).[44]

A. Methods for Enhancing the Performance of Green Catalysts:

The field of green chemistry is concerned with finding and applying environmentally friendly substances and procedures. One essential element of green chemistry is catalysis. Green chemistry, sometimes referred to as sustainable or environmentally friendly chemistry minimizes toxicity through chemistry.[45] Its goal is to plan and carry out pollution avoidance alternatives to waste management that lower natural gas emissions, conserve energy, and minimize waste exhaustion of resources. Green chemistry is regarded as being beneficial to the environment because it is believed to lessen pollution and carbon emissions. Catalysis has contributed to the decrease in contamination of the surroundings.[46] By eliminating and using catalysts, air quality has been improved. lowering the usage of volatile organic compounds (VOC), regulating NO emissions, creating alternative catalytic technology to minimize waste and replace the use of chlorine or intermediates based on chlorine in chemical synthesis. By facilitating more effective and focused reactions, catalysis helps to eliminate large amounts of waste chemicals and by products.[47]

1. Catalyst Design Principles:

One of the most important ways to improve the performance of green catalysts is to customise their design. To maximize the catalyst's activity and selectivity, this entails adjusting its chemical and structural characteristics. Among the design tenets are:

A. Ligand Modification: By adjusting the ligands, a catalyst's electronic and steric characteristics can be optimized, impacting how reactants interact with it and encouraging the desired results.[48]

B. Active Site Engineering: Increasing catalytic efficiency and specificity requires designing catalysts with clearly defined active sites. This boost the reaction by making and more effective and improvement of the product which beneficial for yield product.[49]

2. Immobilization Methods:

Green catalysts perform better overall and are more stable and recyclable when they are immobilized effectively. Techniques for immobilization consist of:

A. Supported Catalysts: Catalysts can be more easily accessed, recovered from, and reused several times when they are rested on to solid supports[50]

B. Enzyme immobilization: Enzymes can be made more stable and used continuously in biocatalyst by immobilizing them on carriers or in matrices.[51]

3. Reaction Condition Optimization:

To maximize the effectiveness of green catalysts, reaction conditions must be optimized. Among the strategies are:

A. **Solvent Selection:** Selecting solvents that are safe for the environment helps catalytic processes become more environmentally friendly.[52]

B. **Temperature and Pressure Control:** Modifying reaction parameters reduces environmental impact while influencing catalyst activity.[53]

By combining these techniques, a comprehensive strategy is created to improve the efficiency of green catalysts. Researchers can realize the full potential of green catalysis by fusing creative catalyst design, effective immobilization, cutting-edge characterization methods, and optimized reaction conditions. This comprehensive approach facilitates the wider implementation of ecologically responsible and sustainable catalytic processes in diverse industries.[54]

VI .Industrial Applications and Challenges of Green Catalysts:

The goal of the field of "green chemistry" is to create environmentally friendly and sustainable chemical processes. A key component of green chemistry is the use of green catalysts, which are vital in fostering effective and environmentally responsible industrial applications.[55] Green catalysts have a number of benefits, including improved selectivity, decreased waste production, and lower energy consumption. Nevertheless, there are certain issues with their application in industrial settings that must be resolved. The creation of green catalysts with high activity and selectivity and stability in challenging industrial environments is a major challenge. The demanding conditions of large-scale production, which include higher temperatures, pressures, and corrosive environments, may cause catalysts that work well in laboratory-scale studies to fail.[56] As a result, significant research and development work is required to create catalysts that perform at their best under such circumstances. An additional important factor to consider is the economic feasibility of green catalysis. Green catalysts can be more expensive than conventional catalysts, even though they might provide better environmental benefits. The overall economics of industrial processes that use catalysts can be greatly impacted by this cost difference[57]. It is vital to investigate methods for increasing the cost-effectiveness of green catalysts, such as catalyst recovery and recycling or the creation of substitute, inexpensive catalyst materials. One of the biggest obstacles to the widespread use of green catalysts is the scaling up of catalytic processes from the laboratory to the industrial level.[58]To guarantee effective and successful manufacturing processes, factors including reactor design, mass transfer restrictions, catalyst deactivation, and product separation and purification must be carefully considered. In order to maximize the scalability of green catalytic processes and develop novel solutions, cooperation between chemists, engineers, and other stakeholders is necessary.[59] Green catalysts are being used in industrial processes more frequently. They are made to adhere to environmental responsibility and sustainability principles. When used in large-scale production, they could have positive effects on the economy, the environment, and different industries. However, in order to enable their widespread adoption, issues must be resolved, just like with any transformative technology.[60]

A. Implementation of Green Catalysts in Large-Scale Production:

Potential for Large-Scale Production When used on an industrial scale, green catalysts which are environmentally friendly offer a number of benefits. These catalysts have the potential to save a lot of money. They frequently reduce waste, improve overall process efficiency, and make use of easily accessible and reasonably priced materials.[61] A smaller environmental footprint can be achieved by using solvents that are safe for the environment and reducing the production of hazardous by products. The production of pharmaceuticals and renewable energy are two noteworthy industries that highlight the industrial applications of green catalysts. These catalysts are essential to the renewable energy sector because they help produce biofuels from biomass, which advances the creation of sustainable energy sources.[(62)] Additionally, in the production of pharmaceuticals, green Furthermore, the production of active pharmaceutical ingredients (APIs) in the pharmaceutical industry uses green catalysis, highlighting the adaptability and versatility of these catalysts in challenging chemical reactions.[(63)]

B. Dealing with Challenges in Expanding Green Catalysis:

Catalyst Stability and Duration: One of the biggest challenges in industrial operations is keeping green catalysts stable and long-lasting. Catalysts that can resist severe environments and maintain their activity over extended periods of time are necessary for the uninterrupted operation of industrial processes.[(64)] Prolonged catalyst lifetimes can be ensured by employing immobilization techniques and catalyst engineering, which emphasize stability enhancement Techniques for Immobilization Green catalysts can be made more stable and perform more consistently by immobilizing them on appropriate supports[(65)] The process is made more sustainable by this immobilization, which shields the catalyst from abrasive reaction conditions and makes it easier to recover and reuse.

Process Intensification and Efficiency: One of the biggest challenges in large-scale production is guaranteeing the effectiveness of green catalytic processes in high-throughput settings. Process intensification techniques, like advanced reactor designs and continuous flow processes, are essential for improving green catalysis's industrial efficiency.[(66)] These tactics lead to enhanced process performance overall and provide greater control over reaction conditions. Continuous Flow Processes Using continuous flow processes makes it possible to use green catalysts in a more managed and effective manner.[(67)] Better control over temperature and pressure is provided by these processes, which improves reaction efficiency. Furthermore, continuous flow reduces the requirement for large reaction volumes, which enhances resource efficiency and safety. Advanced Reactor Designs The intensification of green catalysis is greatly aided by developments in reactor design, such as membrane reactors and micro reactors .[(68)] The overall efficiency of the process is increased by these designs, which also enable improved heat management, enhanced mass transfer, and increased surface area for catalytic reactions.

Optimization of Selectivity and Yield:

Attaining optimal selectivity and yields in intricate chemical transformations on an industrial scale is an ongoing challenge. By using catalyst design principles and optimization techniques, green catalysts must be customized for particular reactions.[(69)] To optimize the advantages of green catalysis in large-scale production, it is crucial to understand the complex factors influencing selectivity and yields. Principles of Catalyst Design Selectivity and yield can be improved by customizing the design of green catalysts. To accomplish the intended results, this entails the meticulous selection of ligands, active sites, and reaction conditions. It's critical to comprehend the complex variables affecting selectivity and yields.[(70)] An All-encompassing Method for Optimization Taking into account the interactions between substrate characteristics, reaction conditions, and catalyst properties is part of a holistic approach. The goal of research is to gain a thorough understanding of the variables affecting the catalytic process so that green catalysts can be designed and optimized for use in industrial settings.[(71)] In general, although the industrial application of green catalysts presents many opportunities, it is critical to address issues like catalyst stability, process efficiency, and yield and selectivity optimization. Overcoming these obstacles and establishing green catalysis as a pillar of environmentally responsible and sustainable industrial processes will require constant research, innovation, and cooperation between academia and industry.[(72)]

VII. Regulatory Perspectives in Green Catalyst Implementation:

The development and application of green chemistry practices are heavily influenced by regulatory viewpoints. Green chemistry encourages the use of safer chemicals and environmentally friendly production techniques in an effort to lessen the impact that chemical processes and products have on the environment.[(73)]The following are some salient features of green chemistry regulatory perspectives:

1. International regulatory structures: A number of nations and areas have put laws and policies into place to encourage the use of green chemistry concepts. The Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) regulation of the European Union, for instance, promotes the replacement of dangerous substances with safer alternatives.[(74)]

2. Toxicity considerations: From a regulatory standpoint, the goal is to reduce the toxicity of catalysts and materials associated with them. Catalysts are usually subject to rigorous testing and evaluation under regulations in order to identify any possible hazards to the environment and public health. Regulatory frameworks facilitate the adoption of environmentally friendly alternatives by encouraging the use of less toxic or non-toxic catalysts.[75]

3. Hazardous catalyst substitution: Regulation frequently encourages the use of more environmentally friendly catalysts in place of risky or damaging ones. Regulations may mandate that businesses phase out the use of specific catalysts, particularly those that are deemed dangerous or persistent, or they may offer incentives.[76]

4. Hazard communication: Catalyst-related hazards must be clearly identified and communicated according to regulatory viewpoints. This makes it possible for employees, clients, and other stakeholders to handle catalysts safely and make informed decisions. Regulations typically specify the necessary labeling, safety data sheets, and documentation.[77]

A. Compliance with Environmental Regulations:

Implementation of green catalysts in the modern industrial process landscape is determined by strict adherence to environmental regulations. Global regulatory agencies have stepped up their efforts to stop environmental deterioration by enforcing rules that require ethical and sustainable business practices in all sectors of the economy.[78] Sustainable Development Green catalysts are essential to achieving the objectives of sustainable development. Through the reduction of energy consumption, the elimination of waste generation, and the removal of hazardous chemical requirements, these catalysts aid in the development of sustainable and ecologically friendly chemical processes[79] Advantages for the Environment Using green catalysts has demonstrable positive effects. By reducing air pollutants, greenhouse gas emissions, and water resource contamination, these catalysts help the environment. Green catalysts actively contribute to the preservation and protection of the environment by reducing their ecological footprint. The commitment to compliance stimulates the development of innovative and efficient green catalysts. Companies that actively engage in meeting and exceeding environmental regulations position themselves as industry leaders in the burgeoning market for environmentally friendly technologies. This not only fosters a culture of innovation but also enhances a company's competitiveness in a market increasingly valuing sustainability.[80]

B. International Efforts to Encourage the Utilization of Green Catalysts:

The Sustainable Development Goals (SDGs) of the United Nations offer a global framework for tackling urgent problems, and two particular goals have a big impact on the use of green catalysts.[81] The development and application of sustainable industrial practices is encouraged by Goal 9, which focuses on Industry, Innovation, and Infrastructure. Target 12, which focuses on Responsible Consumption and Production, encourages environmentally friendly manufacturing practices that are in line with using green catalysts to lessen environmental impact[82]Collaborations and partnerships between government agencies, academic institutions, and business sectors help to accelerate the implementation of green catalysts. Advocacy, research funding, and knowledge exchange are all facilitated by initiatives such as the Green Chemistry Commitment in the United States and the Green Chemistry Initiative in Canada. This creates an atmosphere that is favorable to the broad use of green catalysts.[83]

VIII .Advancement in green catalysis technologies:

These days, catalysis is regarded as one of the most important instruments in organic synthesis and as the foundation of green chemistry. A new way of thinking about sustainable organic synthesis has been brought about by the incorporation of catalysis in organic processes. Catalysis has improved the sustainability of chemical transformations by creating novel possibilities for organic synthesis within the framework of Green Chemistry.

A. Nanocatalysts for Sustainable Drug Synthesis:

A rapidly expanding topic, nanocatalysis is an essential part of "sustainable technology and organic transformations," which apply to nearly all kinds of catalytic organic transformations. Many types of nanocatalysts have been used in catalytic applications, including magnetic nanocatalysts, nanomixed metal oxides, core-shell nanocatalysts, nano-supported catalysts, and graphene-based nanocatalysts . Among this class of reusable nanocatalysts, magnetic nanocatalysts are unique because of their inexpensive production costs, outstanding activity, superior selectivity, high stability, effective recovery, and good recyclable nature.[84] The maximum levels of catalytic activity, selectivity, and stability can be attained by modifying the form, size, composition, and nature of the nanocatalyst structure of these adaptable, semi-heterogeneous, high surface area nanocatalysts. The remarkable benefits of nanocatalysts depend on the nanosize effect; in general, catalytic performance increases as nanostructure size decreases.[85]

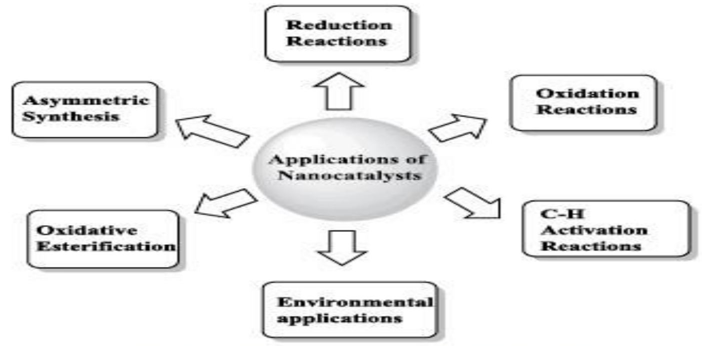


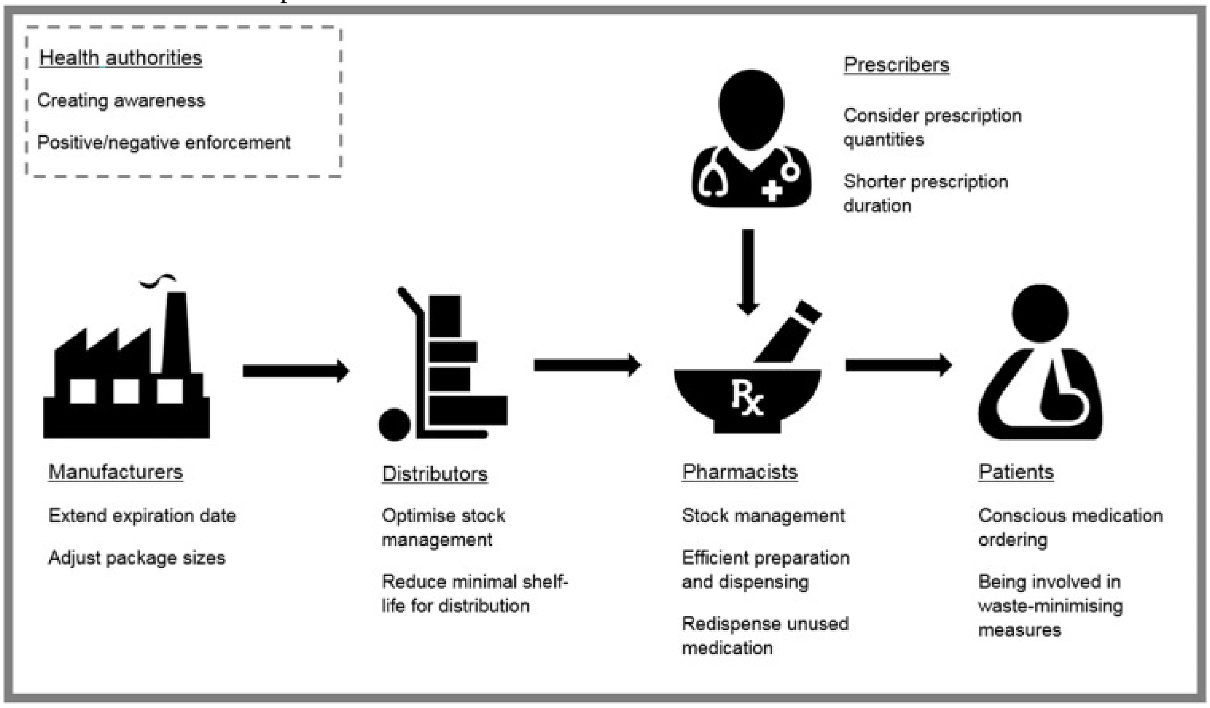
Figure 2: Applications of Nanocatalysts

B. Innovations in Flow Chemistry and Continuous Processing pharmaceutical chemistry:

A innovative technological platform that is gaining popularity in the pharmaceutical sector is continuous flow manufacturing. For pharmaceutical and fine chemical businesses, finding ways to integrate flow solutions into existing processes is essential to the success of this new technology Additionally, it is simple to integrate continuous flow synthetic techniques with other enabling technologies, which improves efficiency.[86] Microwave irradiation, supported reagents or catalysts, photochemistry, inductive heating, electrochemistry, novel solvent systems, 3D printing, or microreactor technology are examples of enabling technologies linked to flow chemistry. This combination might make it possible to create fully automated processes with higher throughput. They have provided a clear illustration of the significant and attractive characteristics that continuous flow technologies offer, which are utilized in industrial processes. It is therefore not surprising that pharmaceutical companies have recently focused on the application of flow chemistry in the production of APIs. It is an unstoppable trend that will only intensify in the future due to the ability to combine the synthesis of chemicals in flow with innovative analytical technologies for real-time process monitoring and with enabling technologies to expedite the isolation and purification stages.[87]

Waste Minimization and Management:

Medication waste has a negative influence on the environment and a significant financial impact on healthcare. Consequently, stopping medication from being wasted across the pharmaceutical chain is an intriguing strategy for achieving a sustainable supply and usage of medication.[88] In addition to addressing the issue of medicine waste, a goal of fully conserving resources and minimizing the environmental impact of the pharmaceutical industry should be set in order to create a sustainable pharmaceutical supply and use chain. The circular economy is a means of achieving a sustainable drug policy.[89] By raising awareness, offering recommendations for waste-minimization strategies, or encouraging partnerships and cooperation, health authorities could enforce waste-minimization.[90] Medication disposal is a concerning topic that is becoming more and more recognized by consumers and healthcare professionals. Today, medication disposal is a concerning topic that consumers and healthcare professionals are becoming more and more aware. The government, non-governmental organizations, medical professionals, pharmacists, patients, and the general public should collaborate to lessen the impact of out dated and unneeded medications on the environment.[91]e



The goal of green chemistry is to reduce the environmental impact of pharmaceutical product reuse and recycling. This entails creating procedures that minimize waste, promote raw material reuse, and make use of environmentally friendly production techniques.[92]Adopting sustainable methods in the pharmaceutical manufacturing sector can help make the sector more ecologically aware. Green chemistry promotes the use of catalytic processes because they can minimize waste production, lower the need for high temperatures and pressures, and boost reaction efficiency. Continuous Flow Chemistry Making the switch from batch to continuous flow systems can increase productivity, cut lower resource usage, and make some reactants recyclable.[93]

IX. Future Directions and Research Opportunities:

Green catalysis, which has its roots in environmentally friendly and sustainable methods, is a field that is always developing and offers exciting prospects for new developments and research. This field includes novel approaches and uncharted territory that have enormous potential to transform the field of sustainable chemistry.[94]

A. New Directions in Ecological Catalysis:

The process of nanocatalysis green chemistry, the subject of nanocatalysis which is defined by the use of nanomaterials as catalysts is rapidly expanding. High surface areas and distinct catalytic characteristics of nanoparticles allow for increased selectivity and reactivity.[95] Green nanocatalysts have the ability to catalyze a wide range of reactions with increased efficiency and less environmental effect. Of particular, metal nanoparticles based on eco-friendly materials show considerable promise in this regard.[96] The fields of biocatalysis and enzymatic catalysis are quickly developing. Biocatalysis uses natural catalysts, such as enzymes. High selectivity, benign reaction conditions, and minimal environmental impact are provided by enzymatic catalysis. The utilization of enzymes in green catalysis is enhanced by the progress made in protein engineering and immobilization methods, opening up new possibilities for sustainable transformations.[97] Photocatalysis is the integration of light-driven catalysis that is becoming more and more popular in green chemistry. Utilizing sun energy, photocatalysts propel chemical changes, providing a sustainable method for a range of processes. There is potential here for the creation of catalytic processes that are both energy- and cleaner-efficient.[98]

B. Unexplored Areas and Potential Applications:

Investigating the application of green catalysis in pharmaceutical synthesis is still largely unexplored. Creating innovative, environmentally friendly catalytic processes offers a chance to produce pharmaceuticals efficiently while causing the least amount of environmental damage. Pharmaceutical companies must develop scalable and environmentally friendly processes to comply with strict environmental laws.[99] The field of sustainable energy conversion gives an intriguing opportunity to investigate green catalysis. Energy conversion, storage, and usage are all greatly aided by catalysts. There is a lot of promise for developing renewable energy technologies in the process of dissecting novel catalytic materials and procedures for clean energy applications, including as fuel production and energy storage systems.[100] New developments in the fields of nanocatalysis, biocatalysis, and photocatalysis will greatly influence the direction of green catalysis in the future by providing unmatched chances for more effective and clean chemical reactions. Furthermore, there are promising opportunities for catalytic breakthroughs in search for a sustainable future in uncharted territory such as medicinal synthesis and sustainable energy conversion.

XI. Conclusion:

The field of green catalysis has yielded a wealth of important discoveries that shed light on the enormous potential and importance of environmentally friendly catalytic techniques in changing the face of pharmaceutical manufacture. Since the sustainability paradigm is based on ideas like atom economy, using renewable feedstocks, and pursuing energy efficiency, the development of green catalysis makes perfect sense. Green catalysis encompasses a variety of techniques, each with its own advantages. These include photocatalysis, biocatalysis, and nanocatalysis. Greener and more sustainable chemical transformations are promoted by these, which range from increased efficiency and selectivity to a smaller environmental impact. Green catalysis in pharmacy has the potential to make revolutionary strides in the future. The field is moving toward a more sustainable and ecologically sensitive future through the integration of sustainable catalytic techniques, which also promote innovation and competitiveness and comply with regulatory norms. Green catalysis is emerging as a scientific field as well as a key component in the transformation of pharmaceutical manufacture into a more sustainable and environmentally friendly industry.

Reference:-

[1] Saraswati.M.Pawar, Rasika.P.Devale Review On General Purpose Of Catalysis In Green Chemistryhttps://ijcrt.org/papers/IJCRT22A6527.pdf?shem=ssusxt

[2] Anastas, P. T., & Warner, J. C. (1998). Green Chemistry: Theory and Practice. Oxford University Press.

[3] Sheldon, R. A. (2007). The E factor 25 years on: The rise of green chemistry and sustainability. Green Chemistry, 9(12), 1273-1283.

[4] Clark, J. H., & Macquarrie, D. J. (2002). Handbook of Green Chemistry and Technology. Blackwell Science.

[5] P.T. Anastas, M.M. Kirchhoff, Acc. Chem. Res. 2002, 35, 686-693.

[6] Vajvodic , (v.2009) : environmental protection : green manufacturing in pharmaceuticals

[7] industry and cost reduction , Kem IND 58 (1): 32-33. In Croatian

[8] C. J. Li, Green Chem. 2010, 12, 1215-1217)

[9] P. Anastas, N. Eghbali, Chem. Soc. Rev. 2010, 39, 301-312

[10] M. Appel, D. L. DuBois, J. Am. Chem. Soc. 2010, 132, 13162-13163; Y. Shiraishi, Bull. Chem. Soc. Jpn. 2010, 83, 1-15

[11] R. A. Sheldon, Chem. Commun. 2010, 46, 8526-8536

[12] Sheldon, R. A., & Kochi, J. K. (1981). Metal-catalyzed oxidation of organic compounds in homogeneous solution. Chemical Reviews, 81(3), 263-276.

[13] Polshettiwar, V., Baruwati, B., & Varma, R. S. (2009). Self-assembly of metal oxides into three-dimensional nanostructures: Synthesis and application in catalysis. ACS Nano, 3(3), 728-736.

[14] The evolution of life cycle assessment in pharmaceutical and chemical applications – a perspectiveConcepción Jiménez-González*a and Michael R. Overcashb Issue 7, 2014

[15] De Vos, D. E., Dams, M., Sels, B. F., & Jacobs, P. A. (2002). Design of zeolite-based green catalysts. Chemical Reviews, 102(10), 3615-3640.

[16] Thomas, J. M., & Raja, R. (2005). In pursuit of sustainable catalysis. Science, 309(5735), 1193-1194.

[17] Corma, A. (1995). From Microporous to Mesoporous Molecular Sieve Materials and Their Use in Catalysis. Chemical Reviews, 95(3), 559-614.

[18] Green Chemistry in Pharmaceutical Industry" authored by Yen-Ho Chu and Chi-Huey Wong (DOI: 10.1021/jo960807u), published in the Journal of Organic Chemistry.

[19] Maruoka, K., & Ooi, T. (2007). Enantioselective organocatalysis. Chemical Reviews, 107(2), 599-615.

[20] Liese, A., & Hilterhaus, L. (2013). Evaluation of immobilized enzymes for industrial applications. Chemical Society Reviews, 42(15), 6236-6249.

[21] Adlercreutz, P. (2017). Immobilisation and application of lipases in organic media. Chemical Society Reviews, 46(24), 7617-7632.

[22] Reetz, M. T., & Maugeri, Z. (2008). Directed evolution of enantioselective enzymes: Iterative cycles of CASTing for probing protein-sequence space. Angewandte Chemie International Edition, 47(38), 7110-7121.

[23] List, B. (2007). Organocatalysis in Asymmetric Synthesis. Synthesis, 13, 1979-1993.

[24] MacMillan, D. W. (2008). The advent and development of organocatalysis. Nature, 455(7211), 304-308.

[25] Sheldon, R. A., & Brady, D. (2019). Chemicals from Biobased Feedstocks: Catalysis for a Sustainable Future. Royal Society of Chemistry.

[26] De Vos, D. E., Dams, M., Sels, B. F., & Jacobs, P. A. (2002). Design of zeolite-based green catalysts. Chemical Reviews, 102(10), 3615-3640.

[27] Thomas, J. M., & Raja, R. (2005). In pursuit of sustainable catalysis. Science, 309(5735), 1193-1194.

[28] Corma, A. (1995). From Microporous to Mesoporous Molecular Sieve Materials and Their Use in Catalysis. Chemical Reviews, 95(3), 559-614.

[29] Green Chemistry in Pharmaceutical Industry" authored by Yen-Ho Chu and Chi-Huey Wong (DOI: 10.1021/jo960807u), published in the Journal of Organic Chemistry.

[30] Maruoka, K., & Ooi, T. (2007). Enantioselective organocatalysis. Chemical Reviews, 107(2), 599-615.

[31] Liese, A., & Hilterhaus, L. (2013). Evaluation of immobilized enzymes for industrial applications. Chemical Society Reviews, 42(15), 6236-6249.

[32] Adlercreutz, P. (2017). Immobilisation and application of lipases in organic media. Chemical Society Reviews, 46(24), 7617-7632.

[33] Reetz, M. T., & Maugeri, Z. (2008). Directed evolution of enantioselective enzymes: Iterative cycles of CASTing for probing protein-sequence space. Angewandte Chemie International Edition, 47(38), 7110-7121.

[34] List, B. (2007). Organocatalysis in Asymmetric Synthesis. Synthesis, 13, 1979-1993.

[35] MacMillan, D. W. (2008). The advent and development of organocatalysis. Nature, 455(7211), 304-308.

[36] Enders, D., & Grondal, C. (2007). Organocatalytic cascade reactions as a new tool in total synthesis. Chemistry—A European Journal, 13(16), 4510-4522.

[37] Maruoka, K., & Ooi, T. (2007). Enantioselective organocatalysis. Chemical Reviews, 107(2), 599-615.

[38] Manzie, M., Mellon, N., & Barton, C. (2017). Environmental impact assessment of catalysts. In Catalysts for Upgrading Heavy Petroleum Feeds (pp. 359-372). Elsevier.

[39] Kocak, D., Tekkaya, E. E., and Bayramoglu, M. (2018). Environmental impact assessment of catalyst production by material flow analysis. Journal of Cleaner Production, 196, 979-990. doi:10.1016/j.jclepro.2018.06.187

[40] Curzons, A. D., & Mannan, M. S. (2008). Life cycle impact assessment: a review of the environmental impact assessment of industrial processes. Process Safety and Environmental Protection, 86(4), 221-232.

[41] Pizzol, M., Weidema, B., Brandão, M., Osset, P., & Lonza, L. (2017). Life cycle assessment: A guide to approaches, experiences, and information sources. Environmental Development, 23, 69-85.

[42] Brent, A. C., & Rogers, D. E. (2010). Life cycle sustainability assessment in the chemical process industry. Computers & Chemical Engineering, 34(9), 1395-1403.

[43] Anastas, P., & Warner, J. (1998). Green Chemistry: Theory and Practice. Oxford University Press.

[44] Sheldon, R. A., & Kochi, J. K. (1981). Metal-Catalyzed Oxidations of Organic Compounds. Academic Press.

[45] Trost, B. M. (1995). Transition Metal Catalysis: A Gentle Art. Science, 269(5225), 1849-1851.

[46] Poliakoff, M., Fitzpatrick, J. M., Farren, T. R., & Anastas, P. T. (2002). Green chemistry: science and politics of change. Science, 297(5582), 807-810.

[47] Anastas, P., & Warner, J. (1998). Green Chemistry: Theory and Practice. Oxford University Press.

[48] Trost, B. M. (1995). Transition Metal Catalysis: A Gentle Art. Science, 269(5225), 1849-1851.

[49] Zamagni, A., Guinée, J., Heijungs, R., Masoni, P., Raggi, A., & Rinaldi, S. (2012). Calculation of normalisation references for impact categories of the ReCiPe 2008 life cycle impact assessment method. The International Journal of Life Cycle Assessment, 17(6), 744-753.

[50] The evolution of life cycle assessment in pharmaceutical and chemical applications – a perspectiveConcepción Jiménez-González*a and Michael R. Overcashb Issue 7, 2014

[51] Sheldon, R. A., & Woodley, J. M. (2018). Role of Biocatalysis in Sustainable Chemistry. Chemical Reviews, 118(2), 801-838.

[52] Corma, A., & Garcia, H. (2003). Lewis acids as catalysts in oxidation reactions with hydrogen peroxide. Chemical Reviews, 103(11), 4307-4366.

[53] Sheldon, R. A. (2012). Green and sustainable manufacture of chemicals from biomass: state of the art. Green Chemistry, 14(10), 2841-2847.

[54] Mascal, M., & Nikitin, E. B. (2008). Direct, High-Yield Conversion of Cellulose into Biofuel. Angewandte Chemie International Edition, 47(42), 7924–7926.

[55] Allison L.B. (2005) “Green Careers, Case Study: Green Chemists and Pain Killers”. The Magazine For ACS, Green Chemistry Generating Reactions, 14(4):15.

[56] Cavani F, Centi G, Parathoner S, Trifino F (Eds). Sustainable Industrial Chemistry. WileyVCH, Chichester, West Sussex, UK, 2009.

[57] Bruijnincx, P. C., & Weckhuysen, B. M. (2013). Shale gas revolution: an opportunity for advanced catalysis. Angewandte Chemie International Edition, 52(42), 11457-11461.

[58] Ye, Z., & Zhou, Y. (2011). Design of chiral ligands for asymmetric catalysis: From C2-symmetric P, N-ligands to chiral ionic liquids. Chemical Reviews, 111(1), 1215-1232.

[59] Corma, A., & Garcia, H. (2003). Lewis acids as catalysts in oxidation reactions with hydrogen peroxide. Chemical Reviews, 103(11), 4307-4366.

[60] Sheldon, R. A., & Woodley, J. M. (2018). Role of Biocatalysis in Sustainable Chemistry. Chemical Reviews, 118(2), 801-838.

[61] Lu, Y., Mei, Y., Drechsler, U., Ballauff, M., & Brinker, C. J. (2006). Enzyme immobilization in hierarchically organized mesocellular mesoporous silica. Chemistry of Materials, 18(18), 5170-5175.

[62] Anastas, P., & Warner, J. (1998). Green Chemistry: Theory and Practice. Oxford University Press.

[63] Zhang, Y., Riisager, A., & Lipshutz, B. H. (2017). Catalysis using Aqueous Micellar Catalysis. Chemical Reviews, 117(11), 8860-8891.

[64] Cusumano J.A. (1992) In: Perspective in Catalysis; Thomas J.M., Zamaraev K.I. Eds; Blackwell Scientific Publications: Oxford, 542

[65] Anastas, P. T., Williamson, T. C. (Eds.). (2018). Green Chemistry: Concepts and Applications. Oxford University Press

[66] Sheldon, R. A., Arends, I. W., & Hanefeld, U. (2007). Green Chemistry and Catalysis. Wiley-VCH.

[67] Beller, M., Renken, A., & Tillack, A. (Eds.). (2012). Catalysis in Sustainable Energy Production. Wiley-VCH.

[68] Werner, S., & Rosenthal, U. (2014). Green Chemistry in the Pharmaceutical Industry. Wiley-VCH.

[69] Poliakoff, M., Fitzpatrick, J.M., Farren, T.R. & Anastas, P. (2002). Green Chemistry: Science and Politics of Change. Science, 297(5582), 807-810.

[70] Anastas PT, Williamson TC (1998) Green chemistry: frontiers inbenign chemical syntheses and processes. Oxford UniversityPress, Oxford.

[71] Corma, A., & Garcia, H. (2003). Lewis acids as catalysts in oxidation reactions with hydrogen peroxide. Chemical Reviews, 103(11), 4307-4366.

[72] Sheldon, R. A. (2012). Green and sustainable manufacture of chemicals from biomass: state of the art. Green Chemistry, 14(10), 2841-2847.

[73] Sheldon, R. A., & Woodley, J. M. (2018). Role of Biocatalysis in Sustainable Chemistry. Chemical Reviews, 118(2), 801-838.

[74] Lu, Y., Mei, Y., Drechsler, U., Ballauff, M., & Brinker, C. J. (2006). Enzyme immobilization in hierarchically organized mesocellular mesoporous silica. Chemistry of Materials, 18(18), 5170-5175.

[75] Sheldon, R. A. (2012). Green and sustainable manufacture of chemicals from biomass: state of the art. Green Chemistry, 14(10), 2841-2847.

[76] Trost, B. M. (1995). Transition Metal Catalysis: A Gentle Art. Science, 269(5225), 1849-1851.

[77] Zhang, Y., Riisager, A., & Lipshutz, B. H. (2017). Catalysis using Aqueous Micellar Catalysis. Chemical Reviews, 117(11), 8860-8891.

[78] Ye, Z., & Zhou, Y. (2011). Design of chiral ligands for asymmetric catalysis: From C2-symmetric P, N-ligands to chiral ionic liquids. Chemical Reviews, 111(1), 1215-1232.

[79] Corma, A., & Garcia, H. (2003). Lewis acids as catalysts in oxidation reactions with hydrogen peroxide. Chemical Reviews, 103(11), 4307-4366.

[80] Clark JH. Green chemistry: challenges and opportunities. Green Chemistry. 1999;1(1):1-8.

[81] Newman, S. G., & Jensen, K. F. (2013). The role of flow in green chemistry and engineering. Green Chemistry, 15(6), 1456-1472.

[82] Noël, T., & Hessel, V. (2017). Fine Chemicals by Heterogeneous Catalysis. In Sustainable Flow Chemistry: Methods and Applications (pp. 135-170). Wiley-VCH. doi: 10.1002/9783527699259.ch6

[83] Morikawa, M. (2015). Introduction: The Importance of Catalysis for a Sustainable Society. In Catalysis for Sustainability: Goals, Challenges, and Impacts (pp. 1-19). Springer. doi: 10.1007/978-3-319-10458-8_1

[84] European Chemicals Agency. (2021). REACH Regulation. Retrieved from https://echa.europa.eu/regulations/reach

[85] Anastas, P. T., & Zimmerman, J. B. (2016). Design through the 12 principles of green engineering. In Green Engineering: Environmentally Conscious Design of Chemical Processes (pp. 43-74). Pearson.

[86] Occupational Safety and Health Administration. (2021). Hazard Communication Standard (HCS). Retrieved from https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.1200

[87] Sheldon, R. A. (2012). Green and sustainable manufacture of chemicals from biomass: state of the art. Green Chemistry, 14(10), 2841-2847.

[88] Tucker, J. L., et al. (2018). Driving sustainability in chemical manufacturing: A perspective from pharmaceuticals. Science, 362(6412), 220-225.

[89] United Nations. (2015). Transforming our world: the 2030 Agenda for Sustainable Development. Retrieved from https://sdgs.un.org/

[90] Anastas, P., & Zimmerman, J. (2018). Through the 12 principles of green engineering. Environmental Science & Technology, 52(3), 1357-1361.

[91] Gawande MB (2014) Sustainable Nanocatalysts for Organic Synthetic Transformations. Organic Chem Curr Res 1:e137. doi: 10.4172/2161-0401.1000e137Page 2 of

[92] Chng LL, Erathodiyil N, Ying JY. Nanostructured catalysts for organic transformations. Acc Chem Res. 2013 Aug 20;46(8):1825-37. doi: 10.1021/ar300197s. Epub 2013 Jan 25. PMID: 23350747.

[93] The evolution of life cycle assessment in pharmaceutical and chemical applications – a perspectiveConcepción Jiménez-González*a and Michael R. Overcashb Issue 7, 2014

[94] Darvas F, Dormán G, Hessel V, Ley SV, editors. Flow chemistry. Berlin: de Gruyter; 2014. Wiles, C., & Watts, P. (2011). Recent advances in micro reaction technology. Chemical communications, 47(23), 6512-6535.

[95] Abbasi, G., & Gay, E. (2017). Impact of sterile compounding batch frequency on pharmaceutical waste. Hospital Pharmacy, 52(1), 60-64.

[96] Amster, E. D. (2016). Mitigating pharmaceutical waste exposures: policy and program considerations. Israel Journal of Health Policy Research, 5, 1-4.

[97] Fram MS, Kenneth B. Occurrence and concentrations of pharmaceutical compounds in groundwater used for public drinking-water supply in California. Science of The Total Environment. 2011;409(18):3409-17.

[98] Pratyusha K, Nikita M, Gaikwad AA, Phatak PD, Chaudhari. Review On: Waste Material Management In Pharmaceutical Industry. Int. J Pharm. Sci. Rev. Res.2012; 16(2):n° 27, 121-129

[99] Afanasjeva, J., & Gruenberg, K. (2019). Pharmacists as environmental stewards: Strategies for minimizing and managing drug waste. Sustainable Chemistry and Pharmacy, 13, 100164

[100] Xiang, Q., Yu, J., & Jaroniec, M. (2012). Graphene-based semiconductor photocatalysts. Chemical Society Reviews, 41(2), 782-796.