Green Chemistry Technology for Sustainable Development and Applications

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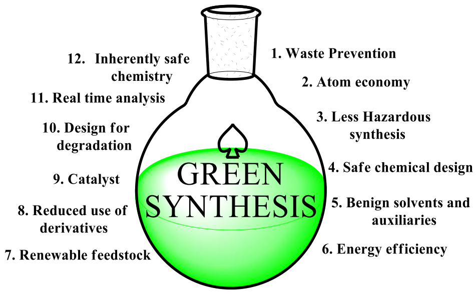
GRAPHICAL ABSTRACT

Abstract

Green chemistry (GC), or sustainable chemistry, aims, under greater social prospects, for a sustainable global future for the Earth, and for products that reduce the use of hazardous substances for humans and the environment.GC was initiated in the 1990s as a quick-rising advanced technique for providing environmentally suitable solutions for the sustainable development of future technology. GC offers enhanced chemical method economics, associated with a reduced environmental burden. GC can be applied to design environmentally compassionate synthetic methods, to form life-saving medicines, environmentally friendly agrochemicals, biocatalysts processes, renewable energy sources, energy efficiency synthesis, and innovative materials with low environmental impact. Directed progress created by biotechnological methods a great selection of enzymatic catalysts that are very efficient in catalyzing the synthesis of chemicals. Biocatalysts are used on a large scale to deliver low-cost and high-quality products and medicines. Biodegradable polymers and polymers from carbon dioxide have been advanced by many chemical companies. Organic photovoltaic solar cells have been used for low-energy production, photovoltaic solutions provide electricity at a lower cost than first- and second-generation solar techniques. This review highlights innovative green chemistry (GC) approaches that aim to create a sustainable future for technology and the development of novel chemical products.

Keyword: Green Chemistry, Sustainable Energy, Environmental Pollution, Hazardous Substances, Waste Products.



1. INTRODUCTION

The chemical industry plays an important role in sustaining the world economy and supporting upcoming techniques and scientific advances in new materials, less hazardous products, environmental safety, renewable energy sources, methods with energy efficiency, and renewable raw materials. Natural resources were rapidly being exploited due to environmental issues. To consider the recognized ways that materials were used, the design of chemical routes, the hazardous effects of products, energy utilization, and other factors involved in the preparation of products. Green Chemistry (GC) is "the development, design, and application of chemical products and methods to reduce or to eliminate the use and formation of hazardous substances for both workers and consumers". The definition of GC begins with the concept of development and design. This means we, as scientists, must take into consideration from the start what we are looking for, what kind of products, and how we are going to design, manufacture, and use them. Another aspect of GC is in the phrase "use and formation of hazardous substances" [1-5]. We must think earlier that the product's use will be dangerous or cause environmental pollution through its use or after its practical application (as waste) rather than focusing only on unwanted products that may be accidentally generated in a process. GC not only focuses on the production of safer products, less hazardous consequences to the environment, and saving energy and water but also includes wider issues that can be valuable in the end, like sustainable development. The quick development of new chemical techniques and a large number of new chemical products diverted the attention of ecologists to counteractive actions for the negative impacts (environmental pollution, reduction of pollutants, recycling, etc) [6-12]. The unique way to decrease the negative impacts is to design the novelty in the production techniques, taking into account energy, materials, atom economy, use and formation of secondary materials that are toxic, and finally the life cycle of the products and their realistic recycling into new materials. About 600-700 million tons of chemical products are formed per year (excluding fossil fuels, fertilizers, and medicines) from the chemical industries worldwide. More than 120,000 chemicals are in circulation for various uses, of which about 2500 are high-volume products. Some of these chemicals are studied for their toxicological and ecotoxicological effects. Despite strict environmental laws and regulations in developed countries, there are many environmental issues and adverse effects on sensitive ecosystems and habitats [13-16]. Scientists and chemists must start from the basics and design chemical products and methods that reduce or eliminate the use and formation of dangerous compounds. In the past, chemists reduced risks by controlling exposure to toxic chemicals. In return, GC attempts to reduce or eliminate the hazardous effects of products on the environment by designing and changing the process. Recently, GC has gained a firm grip on research and development in the chemical industry and academia, especially in developed countries. It is widely recognized that sustainable civilization requires both a healthy environment and a healthy economy. GC, with its applications, has confirmed that creative scientific design can help achieve both those goals concurrently and for societal benefit [17-19].

2. Twelve Principles of Green Chemistry

Twelve principles define the most crucial roles in green chemistry (GC). GC includes many ways to reduce or eliminate environmental pollution through devoted sustainable prevention programs. GC must focus on alternative, environmentally friendly chemicals in synthetic methods, as well as increase reaction rates and lower reaction temperatures to save energy. GC looks very cautiously at reaction effectiveness, the use of less hazardous solvents, the reduction of toxic products, and the reduction of waste. Anastas PT and Warner JC developed the "Twelve Principles of Green Chemistry" in 1991. These principles can be classified into "Reducing Risk" and "Minimizing the Environmental Footprint."

A. Green Chemistry's objectives to reduce risk in the laboratory

Use non-toxic chemicals, follow less dangerous synthesis procedures, use safer solvents, and prevent accidents (explosions, fires, etc.) in reaction conditions.

B. Reducing the environmental footprint

Waste Minimization and Prevention: Use of catalysts instead of stoichiometric quantities reduce, the use of chemical derivatives, synthetic efficiency (atom economy), taking advantage of chemicals designed for degradation, the establishment of in-process controls for pollution prevention, use of renewable feedstocks, support energy efficiency.

The twelve principles of GC in the following set

i. Prevention: Prevention is better than cure. *It is better to avoid producing toxic substances than to treat them later (waste or pollution). Defensive action can dramatically change numerous attitudes among scientists developed in the last decades. GC can prevent waste production and poisonous byproducts by manufacturing chemical substances, such as toxic byproducts, and making a novel change in the chemical process.*

ii. Maximize synthetic methods (Atom economy): *Until now, the maximum of synthetic techniques has been worthless, yielding between 70-90%. The GC has abolished the reuse of byproducts and supported synthetic methods to maximize the mixing of all reagents used in manufacturing the final product. Barry Trost developed the concept of Atom Economy, a method of expressing how efficiently a particular reaction uses the reactant atoms.*

iii. Less hazardous chemical synthesis: *GC must be responsible for designing safer and less toxic synthetic techniques, using fewer poisonous compounds and products. Less toxic material will be less dangerous to workers and less hazardous to the environment.*

iv. Designing safer chemicals: *Green Chemist's primary aim must be to ensure that chemical products possess the desired function and properties with minimum toxicity. Most of the compounds in the market are categorized based on their physiochemical properties and toxicities, but there is a lack of ecotoxicological data for most of them.*

v. Safer solvents and auxiliary substances: *Solvents, separating agents, and other supportive chemicals used in synthesis must be replaced or reduced with less poisonous chemicals. GC initiated significant changes in chemical laboratories, and there are fewer toxic chemicals and alternative techniques.*

vi. Design for energy efficiency: *Chemists must know that until now, there has been very little attention to energy necessities in synthetic processes. To reduce energy requirements, synthetic procedures must be conducted at room temperature and decreased pressure.*

vii. Use of renewable raw materials: Refined petrochemical products are usually the starting material for synthesis. Raw materials must be less toxic and, if possible, renewable rather than depleting. Finding renewable raw materials is a difficult task. Green chemists must design the synthetic process by discovering renewable chemicals. Development with depleting natural resources is a negative aspect of economic growth.

viii. Reduce intermediate derivatives: *Chemists must reduce unnecessary intermediate compounds (temporary modification of physical and chemical processes, use of blocking groups, protection/deprotection techniques in synthetic methods. These intermediates use additional reagents, are wasteful, and produce vast amounts of byproducts and waste. Designing new synthetic routes is desirable.*

ix. Catalysis, catalytic reagents: *The use of catalysts in synthesis procedures can dramatically improve the effectiveness of chemical reactions and the yield of products. Some selective catalytic reagents are even superior to stoichiometric reagents. New catalysts and more stress on catalytic processes are the future of GC techniques.*

x. Design products that degrade easily: *Various chemical compounds and products do not degrade very easily, thus affecting the environment. The main aim of GC is to design products with maximum benefits and break them down into nontoxic materials at the end of their life. Many consumer products (e.g., plastics) persist in the environment after being discarded, leading to an unhealthy atmosphere. This can be minimized by designing products that degrade in a very short time.*

xi. Real-time analysis for pollution prevention: *Synthetic techniques need to be further developed to allow for real-time, in-process monitoring, and control before the formation of toxic compounds.*

xii. Inherently safer chemistry for accident prevention. *Raw materials and chemical compounds used in the synthetic procedures should be completely safe, i.e. their properties and their by-products to be non-toxic and not hazardous (e.g. explode, flammable, allergic to humans, cause burns to skin, etc.).*

Figure 1. Green Chemistry Provided Essential Design Criteria for the Progress of Efficient Chemical Synthesis. The 12 Principles of GC Have Been Accepted as Basic Principles for Future Sustainable Chemistry.

3. Green Engineering Principles for Sustainable Technology

The 12 principles of green chemistry were later complemented with 12 principles of green engineering, which support and promote similar green and eco-friendly aspects of industrial processes, design features for recycling in products, energy efficiency, and renewable raw materials. The 12 principles of green engineering have been developed to provide a framework for scientists to use when designing new materials, products, processes, and systems that are benign to human health and the environment.

*i. **Designers must ensure that** all raw material and energy inputs and outputs are non-toxic.*

*ii. **It is better to prevent waste production** than to treat or clean up waste after it is formed.*

*iii. **Separation and purification operations** should be **designed to decrease energy and** material use.*

***iv. The design of the Products, processes**, and systems should maximize mass, energy, space, and time effectiveness.*

*v. When using energy and materials, products**, processes, and systems should be "output pulled**" rather than "input pushed."*

*vi. **Embedded entropy and complexity** must be viewed as a deal when making design choices on recycling, reuse, or valuable disposition.*

*vii. **The design goal should be durable rather than being immortal***

*viii. **Different designs must be made for different capacity or capability solution***

*ix. **Material diversity** in multicomponent products should be reduced to promote disassembly and value retention.*

*x. **The design of products,** processes, and systems must include combination and interconnectivity with the flow of available energy and materials.*

*xi. **Products, processes, and systems** should be designed to act in a commercial "afterlife."*

*xii. **Material and energy inputs** should be reusable rather than diminishing. These principles describe the enormous scale of business procedures as more sophisticated than lab-scale syntheses wherever value and social science become a drive. The health and safety of employees and environmental impacts are much higher since an outsized range of solvents, chemicals, and wastes are concerned. The main aim of Green Chemistry (GC) is to stop the use of hazardous substances for the health and safety of Workers and Consumers. It isn't easy to apply these principles to chemical processes. It is impressive to see many creative advances in various scientific and industrial techniques for GC initiatives and industrial applications. Exciting results have been achieved by the cooperation of chemists, material scientists, bioscientists, and technologists. The GC approach has expanded and produced excellent non-poisonous materials and feedstock savings in chemical industries [20-22].*

4. Green Chemistry and Sustainable Development

Chemistry has added advantages to our lives by making various valuable products and materials possible. However, this success has disadvantages over the environment and nonrenewable natural resources. Sustainability is at stake, and the quality of life is in danger. Several chemicals work their way up the food chain and circulate worldwide; pesticide residues were found in the tropics and the

Arctic; flame retardants from electronics are now usually found in aquatic organisms, particularly marine mammals. Green chemistry (GC) has been introduced to change all these adverse effects on the environment and human beings. Design, novelty, and green procedures will restore Earth's sustainable development. Fossil fuel is a typical example of nonrenewable natural resources. The chemical industry depends almost entirely on petroleum as the building block for creating chemicals. This chemical compound is very energy-intensive, inefficient, and toxic, resulting in significant energy use and the formation of hazardous waste. The use of renewable and alternative materials, including agricultural waste or biomass and non-food-related bioproducts, is one of the significant principles of Green Chemistry (GC) to be prioritized. The term "sustainable chemistry" introduced at the start was converted into "green" because it means fundamental change, novelty, and rejection of old attitudes and practices [23-25]. The GC primarily promoted safer chemicals and protection of the environment, but at the same time, established the principles of energy efficiency and atom economy in chemical methods with the reduction of waste. The chemical industries used the principle of Green Chemistry in their research and development and scored economic benefits. GC applications made financial sense in various product syntheses, green solvents, and renewable raw materials. Many other introduced green techniques, like the supercritical CO2 replacing volatile organic solvents, catalysis, and lower temperature reactions, showed excellent results with maximum yields. A decrease in waste in chemical methods is also part of the "green" changes in the industry due to higher ecological taxes. Some governments introduced lower taxes for industries that voluntarily applied alternative "greener" technologies. The research on GC, green solvents, catalysis alternative syntheses, and waste reduction has recently increased.GC principles provide excellent prominence to the scientific term "hazardous" for processes and the life cycle of chemical substances. GC may be a means of handling risk reduction and pollution turning away by addressing the intrinsic hazards of gear instead of handling the conditions of their use that may increase their risk (exposure within the operating setting or uses of the merchandise with exposure potential). In the past, all regular approaches to risk decline targeted reducing exposure to risky compounds, and laws usually needed to raise to-the-mark technologies and treatment technology. GC goes to the guts of risk turning away or decent reduction before the substance is formed or used. GC demands that products be designed and raw materials with lower risky properties be used as potential. GC describes the difficulties and sensible reflections within the process; however, place 1st turns away, then remedial action later. The definition of GC and its principles illustrate another essential purpose concerning employing the term "hazard." This term is not restricted to physical hazards like explosiveness, flammability, and corrodibility; however, it includes acute and chronic toxicity, carcinogenicity, environmental pollution to water, air, soil, and ecological toxicity [26-28].

5. Practical Applications of Green Chemistry

In the 1980s, new environmental laws and laws for worker's health and safety and environmental pollution were introduced; this led the chemical industries to alter their technologies and introduce new processes. Economic incentives and, therefore, the escape of litigations from the state, citizens, and environmental organizations were significant factors in the changes in many technological applications. However, in most business areas, new ways prevailed, such as the employment of fossil oil merchandise for feedstock, organic artificial routes, and organic chlorinated solvents for separation. However, the inexperienced chemistry concepts began to have many pronounced effects within the Industry. In 1998, the OECD, through programs like the "Risk Management Program" promoted new and innovative activities under the umbrella of "Sustainable Chemistry." The aim was to introduce new practices within the industry and promote environmental kindness. The areas planned for particular focus under the principles of green chemistry were the following: [29-36].

- ***a. Use of alternative feedstock**. Many new developments already exist in this field, but the focus on renewable raw materials and a shift from fossil fuels is necessary for sustainability. The raw materials for the chemical industry must be renewable and nonhazardous for workers and the environment.*
- ***b. Use of less hazardous reagents:** Sufficient data has been collected regarding the toxicological and ecotoxicological properties of many chemical compounds used in the Industry. Chemists and Scientists must put effort into using less toxic raw materials and reagents to synthesize chemical products. However, if there are main barriers, they must choose less poisonous compounds and change their technologies accordingly, for example, using green solvents, catalysts, and new synthetic techniques.*
- ***c. Use of natural processes (biocatalytic techniques):** In the last few years, new biocatalytic techniques have been developed that are more selective, consume less energy, are active at low temperatures, produce higher yields, and use less toxic raw materials. Research on GC in the last*

decade has replaced many old techniques and introduced some innovative catalytic methods with higher yields and lesser byproducts.

d.Use of alternative solvents Several *solvents, particularly polychlorinated and aromatic solvents, have been used for many years for extractions in artificial chemistry. Some solvents (e.g., carbon tetrachloride) were illegal, and others were restricted. Chemists currently use less nephrotoxic solvents, and their waste may be recycled or rotten at high temperatures. Under the gigacycle principles, the Industry is endowed with new solvents that are less nephrotoxic to employees and may disintegrate beyond environmental conditions.*

e. Design of safer chemicals and products*. Many new improvements in the techniques of toxicological tests have changed our considerations in terms of toxicity and the mechanisms of new chemicals and products. Quantitative structure-activity relationships (QSAR) can be used to estimate a new substance's carcinogenicity or other toxicological properties. This is one of the principles and applications of green chemistry, leading to the synthesis of many new chemical products with low toxicity and making them more benign to the environment.*

f. Developing alternative reaction conditions*. Numerous alternative or "greener" reaction techniques significantly improve product yield, save energy, and minimize waste. Chemicals are now being synthesized using various methods, such as microwave and ultrasound-assisted synthetic techniques, photochemical reactions, reactions using water as the solvent, and catalytic reactions.*

g. Minimizing energy consumption*. Energy savings and climate change have become environmental problems. The chemical industry continuously works to reduce energy demand with innovations and changes in synthetic reactions (lower temperatures, reducing reaction steps). GC looks forward to contributing through research to reduce energy consumption in various industrial processes. This brief description of the most critical changes in future industrial processes will improve efficiency, save energy, minimize waste, and produce safer products with less environmental impacts.*

6. Use of Alternative Basic Chemicals as Raw Material

According to the scientists, the coming scenario depicts that natural gas and petroleum production will "peak," plateau, and then decline. A hike in price in the last decades contributes to the uncertainty. These trends and, therefore, the unsure future inevitably influence different chemical industries that manufacture chemical merchandise. Within the report's Preface, we tend to scan, "Industrial chemistry has evolved from victimization of natural plant oils, coal tars, and wood tars to a trade that today produces merchandise from oil and natural gas. The modification in feedstock selection over the last century is because the oil and gas industry elements provide technologists with a meager combined price for raw materials and processes. The speedy increase with vital fluctuations resulted from various production trends, booming growth, short-run events, and the geopolitics of petroleum. These price hikes and fluctuations contribute to uncertainty in the near-term value of feedstock and burden chemical producers. Approaching the "peak" will be troubling, add significantly to produce and price pressures, and hasten the industry's move from fossil fuel and gas to less volatile "alternative" raw materials like coal or biomass. Different raw materials can consume energy and emit more dioxide per manufactured product unit. Biomass could also be an exception to higher energy and carbon dioxide emissions counting on however the dioxide is accounted for. Designing for and developing new technologies to ease the ultimate transition to alternatives and manage dioxide must be initiated by all industry stakeholders. The majority of raw chemicals and beginning materials not just for the trade industry} but conjointly for different industries and workshops were the products of the organic compound industry. This total responsibility to fossil fuels and their product (for chemicals and transport) had a good impact on resources, increment in costs, and slump in countries, and an unsure future for feedstock supply. Due to the cheap price and newly developed technologies, many chemicals rely on petrochemical feedstock. However, the longer term isn't promising. Green Chemistry (GC) is looking ahead to provide new strategies for sustainable development [46-55]. Their plans focus on:

a) Green chemistry must prioritize the use of renewable feedstocks and raw materials. The second most desired property of primary initial chemicals is their lower toxicity and reduced environmental impact. The health and safety of staff, as well as the environment, should be a top priority. GC proposes a shift towards biological starting materials. When using these materials, many challenges may arise; however, there are promising new prospects for large-scale production and use of various renewable materials.

b) ***Oleochemistry****.* ***New biological beginning materials:*** *Fats and oils as oleochemical raw materials can become a replacement supply of chemical feedstocks. Many raw materials exist within the market, with several applications in cosmetics, polymers, lubricating oils, and other merchandise.*

c) ***Photochemistry****: Green Chemistry stresses photochemical reactions in chemical processes. Light (UV and visible) can be a significant catalyst for numerous reactions by replacing deadly metals in* *several responses. Researchers assume that Photochemistry has vast potential, and multiple research innovations and applications have been introduced recently. Ultraviolet light is considered a renewable energy source, and through Photochemistry, it can contribute to GC applications.*

d) ***Photocatalytic artificial routes with Titanium dioxide(TiO2)****: Many researchers use TiO2 for photocatalytic industrial reactions beneath visible light. The use of energy is reduced, waste products are low, and therefore, the yields are abundant compared to Conventional reactions.*

e) Photocatalytic oxidations. *The TiO2 and alternative aluminous oxides (Fe2+) are often utilized in photocatalytic oxidations to decompose virulent and waste chemical materials. These decompositions, particularly for polychlorinated compounds, phenols, etc., will produce less toxic neutral substances. A helpful mixture is Fe2+/H2O2 (Fenton reagent), with the help of light, which can decompose virulent industrial waste. Different techniques have already been applied in industrial effluents, which have superb leads for environmental protection. These oxidations are called Advanced Oxidation Processes (AOP), a recently introduced technology for eliminating liquid waste in the Chemical Industry and destroying chemicals that pollute the atmosphere.*

f) Waste Biomass as feedstock, biomaterials, and biofuels: *The new technologies involved in using biomass to form varied materials are spectacular. It is known that biomass from agricultural processes is wasted. Researchers have studied numerous aspects of biomass and its effects for years. Biomass is measured as a significant sustainability problem with rising fuel costs. Recently, numerous new technologies have shown the application of biomass as biofuel, the raw material for forming biomaterials, polymers, and alternative uses.*

g) Biodegradation of biomass as biogas and biodiesel: *Biomass is known for biofuel, mainly from organic waste in landfills. Biomass can be used to produce biodiesel by chemical and physical procedures. Biomass offers the chance to create energy globally. Currently, it's calculable that four-dimensional of all fuel products in cars are made from biomass*

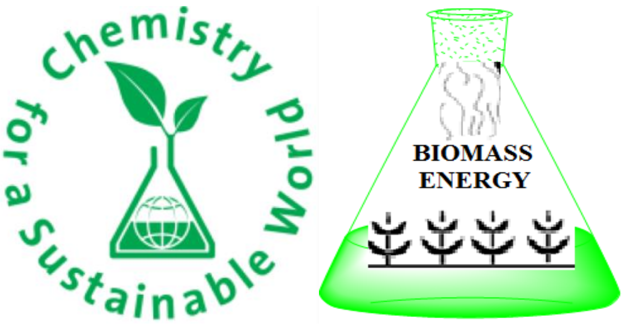


Figure 2. Biomass can be the Starting Material for the Making of Biofuel, Biomaterials, Biopolymers, and Engine Fuels.

h) Biocatalysis and biotransformations in the chemical industry: *Biocatalysis is valued in green technology because of its numerous applications, which are both benign for the environment and energy-efficient. The food and pharmaceutical industries use enzymes for various artificial routes, offering considerable advantages. Biocatalysts are at the interface of fermentation techniques and different industrial processes that utilize enzymes for higher yields and low energy consumption. Biotransformation occurs through biocatalysis, which is an excellent green technique for a variety of chemical industries and products.*

i) Capture or sequestration of carbon dioxide: *Green Chemistry (GC) is responsible for the reduction of carbon dioxide (CO_2) in chemical industries. Global climatic change and, therefore, the atmospheric phenomenon of the greenhouse effect are due to CO_2 discharges, leading to environmental pollution. Any step to inhibit CO2 emissions throughout the synthetic processes may be a critical goal for GC. Also, any plan within the chemical procedure that sequesters or captures or will use CO_2 is proper for GC objectives.*

7. Reduction of Solvent Toxicity and Use of Alternative Solvents

The use of hazardous solvents in synthetic and chemical processes disrupts Green Chemistry. One of the most important principles of GC is to reduce solvent utilization to the maximum possible, interchange it with a less toxic one, or use various solvent-free strategies. The chemical industry's use of solvents poses significant concerns for worker health and safety, as well as waste pollution. Techniques such as synthesis, cleaning, drying, product separation, analysis, and exercise involve the use of solvents. Changing solvents and methods is a complex task. There are many choices; however, they can be *more costly, time-consuming, or troublesome to use under established methodologies. Even though environmental pollution from solvents poses a significant issue for numerous chemical industries, solutions often involve either substituting solvents or limiting their usage. Some solvent area units were replaced. Recently under the influence of GC principles, and strategies were modified to advance techniques. These changes are in the area unit listed below [56-65].*

A) Oxidations under Green Chemistry Principles to Reduce Solvents

Green chemistry (GC) has changed several chemical oxidation methods. Many oxidations are performed in water, supercritical CO_2, less hazardous solvents, and at room temperatures. Hydrogen peroxide (H_2O_2) is a perfect oxidative reagent at average temperatures. There are various research efforts to apply oxidations with high selectivity and as byproducts only water. In combination with homogeneous and heterogeneous reactions, catalysts are used in several oxidations. Oxidations play a vital role in the pharmaceutical and petrochemical industries' processes. Oxygen and nitrogen oxides are oxidative agents with GC credentials that oxidize benzene, propylene, and cyclopentanone. In recent years, researchers have used catalytic methods with metallic complexes for oxidation. Some examples are metal photosystems, metal oxide clusters, polyoxometallates (POM), mainly Volfram (Tungsten, W), and heteroecious. Heterogeneous catalysis for oxidations with zeolitic materials is another method used.

***b) Catalytic Selectivity and Reduced Solvents in Synthesis:** Catalytic selectivity is another effort to minimize solvents within the synthesis with higher yields and lower waste. Many industrial processes depend on new catalysts, like heteropolyacid or inorganic polyacids that act as green catalysts in oxidations, in the hydration of butane mixtures, and in the chemical process of tetrahydrofuran. The heterogeneous catalytic procedure demonstrated a cleaner product, the lowest waste, and easy product separation. Many porous materials with minor pore diameters are catalytic surfaces that regulate the reactants (mesoporous solid acids). Selectivity and high yields are produced in this pattern of reaction. Polymer chemistry and plastics production have recently achieved green recommendations with new strategies. Renewable initial materials, higher yields with bio-catalyst procedures, lesser use of solvents, and less waste are some factors within the formation of well-known polymers.*

8. Applications of New Technologies in the Green Synthesis

We briefly report a few of the numerous changes within the synthesis below GC principles and alternative methods [66-70].

***a) Ionic liquids in organic synthesis:** Ionic liquids are used as another solvent in organic synthesis. These substances are liquid electrolytes, ionic fluids, ionic melts, liquid salts, fused salts, or ionic glasses. Ionic liquids have wide applications as potent solvents and electrically conducting fluids. Salts that are liquid at near-ambient temperatures are necessary for battery applications. Ionic liquids combine anions and cations, coalesced salts with a melting point lower than 100˚ C. Though ionic liquids don't fit the principles of GC, they are considered intelligent candidates for future advances that will offer "green" credentials for their use and application.*

***b) Organic synthesis in water:** For various decades, water was considered a medium to be avoided as a solvent for artificial chemistry. Water is a perfect solvent for various synthetic strategies. The most enticing example of water as a solvent is the Diels-Alder synthesis. Water is excellent for selectivity, even for reagents that are not soluble or insoluble in water.*

***c) Synthesis in polyfluorinated phases:** In these procedures, chemists use polyfluorinated two-phase systems of solvents that dissolve catalysts with an extended hyperfluorinated alcylo- or acyclic chain. Reagents are mixed in an organic solvent that is insoluble in the hyperfluorinated part. Warming up the mixture increases the reaction, which yields excellent products.*

***d) Supercritical carbon dioxide and supercritical water: S**upercritical fluid is named any liquid matter at a temperature and pressure on top of its critical point, where distinct liquid and gas phases do not exist. It can effuse through solids like gas and dissolve materials such as liquid. Near the crucial moment, little changes in pressure or temperature end in massive changes in density, permitting numerous properties of an essential fluid to be "fine-tuned." Supercritical fluids are acceptable as a substitute for organic solvents in various chemical reactions. Carbon dioxide and water are used for Supercritical fluid extraction (SFE).*

***e) Use of microwave techniques:** Microwaves (MW) are widely used for food warming and preparation. Their use in organic synthesis and success with "green criteria is incredibly well established. There are already various analyses and uses for MW organic synthesis with high yields, without solvents, lowest energy supplies, and low waste.*

f) ***Use of ultrasound (Sonochemistry):*** *Chemical synthesis can begin and be increased by sonic waves. Sonochemical reactions by ultrasound are the upcoming "green" ways with good yields. Sonochemical reactions are classified into 3 categories: solid sonochemistry of liquids, heterogeneous sonochemistry of liquid-liquid or solid-liquid systems, and, mixing with the previous methods, sonocatalysis. The chemical improvement of reactions by ultrasound has been explored and has valuable applications in mixed-phase synthesis, materials chemistry, and medicine uses. Many techniques advanced in organic synthesis, with stress on poisonous solvent minimization and thermoregulated systems, are soluble polymers as catalysts and enzymes. All these technologies have developed with GC principles in mind since the economic creation of chemical substances is the fundamental technology that produces environmental issues, waste material, and hazardous by-products.*

Green chemistry advanced*: The Principles of Green Chemistry (GC) have advanced considerably in the last few years. Analysis of numerous industrial applications has been successful and with a considerable reward for energy use, less poisonous material, and minimum waste. These advances have significantly contributed to the safety and sound health of the chemical industry staff, creating merchandise with basic materials workshops and different skilled individuals concerned with the transport and distribution of those products. Secondly, GC found other ways to chop energy, such as using different procedures or new catalytic routes to chop off energy. Energy use by the chemical industry is not solely an economic advancement but a necessary environmental issue—using different solvents like toluene than benzene, dichloromethane than chloroform, and cyclohexane than Carbon tetrachloride. GC has reduced environmental problems considerably. GC initiates advance for the economic merchandise throughout their use or after this helpful life cycle as waste. These are some essential variations for property development goals. GC is responsible for producing less toxic substances and cleaner production methods through various perfect designs. From pesticides, fertilizers, medicines, elastomers, plastics, analytical reagents, and different products, the foremost Researchers and Scientists are currently focusing on forming safer, healthier, and gentler products for the atmosphere. The chemical industry is continuously working on achieving its sustainability goal and preventing environmental damage, not only because technological advances provide alternate methods but also because they make some economic sense and turn away the long-run lack of resources for feedstocks and energy [71-74].*

9. 'Directed Evolution', Green Chemistry, and Biocatalysis

Biochemical Engineering copies the natural evolution to make new and high-efficiency proteins (enzymes for biocatalysis) in the laboratory. This technique has sorted out several critical artificial industrial issues, typically substituting less economical artificial strategies and sometimes dangerous techniques. Directed evolution, property development, and clean technology (biocatalysis) have become offered in several fields of the industry [75,76]. The directed evolution strategy solved various catalytic problems with the help of biology. Sustainable technology has been provided in many trade areas, and we need not depend on non-renewable raw materials. Modified genes are responsible for producing proteins with different structures and biological functions, from which the scientist can opt for the desired one, repeating the process until the action needed by the industry is achieved. Through the direct evolution of biotechnology, various enzymes can be produced in chemical industries. This technique has been adapted to the areas of GC and renewable energy. Directed evolution improves enzymes that convert polysaccharides (Cellulose) or different plant sugars to biofuels and chemicals. [77,78].

10. Enzymes Can Be Tailored By Directed Evolution for Optimal Performance

The most enticing technical success of directed development is designing tailored (rational design) industrial enzymes for biocatalysts. Many original examples can be derived from the Scientific literature in the last few years. The buildup of multiple mutations by Directed evolution allowed the vital development of the biocatalyst for reactions on substrates [79]. These innovations have revolutionized the slow and expensive methods of Protein alteration. These modified proteins replace processes in the production of prescribed drugs, fuels, paper merchandise, textiles, and agricultural chemicals [80,81]. The Cytochrome P450 (CYPs) constitutes the critical accelerator family capable of catalyzing xenobiotic metabolism, the aerobic metabolism of most medicines, and different lipophilic xenobiotics and are thus of specific connection for clinical pharmacology. New reactions are catalyzed by discovering enzymes, which is of utmost importance for the Chemical Industry and is extremely difficult for laboratory experimentalists. Scientists are investigating if CYP P450 enzymes are designed by directed evolution to catalyze Industrial artificial reactions. However, fascinating metabolisms are more *challenging to achieve. Recently, researchers discovered that P450-derived enzymes could also catalyze helpful reactions accessible solely to synthetic chemistry. The evolution and engineering of these enzymes present an excellent case study on how to genetically encrypt novel chemistry and develop biology's reaction Space [82], directed evolution achieved to alter these promiscuous generalist enzymes into specialists capable of mediating reactions of commercial interest with exquisite regio- and stereo- property. Progress has been created by changing the properties of biocatalysts P450s (substrate vary, compound preference, and stability) with stress on industrial uses [83]. This technique has been helped by several advances in DNA technologies, metagenomics, and bioinformatics that have enabled the employment of biological systems (i.e., enzymes, metabolic pathways, and cells) to synthesize and produce chemicals from renewable resources (like sugars). There are many enzymes and metabolic engineering samples for synthesizing organic molecules with high potency and properties [84].*

11. The 'Bionic Leaf': Sunlight Splits Water and Bacteria Produce from Hydrogen Liquid Fuels

Solar-driven water-splitting hydrogen has the potency to supply clean, property, and plentiful energy. Impressed by natural photosynthesis, artificial solar water-splitting machines are now being developed for potency. Although sunlight-driven water rending could be a hopeful method for Hydrogen gas (H2) production as fuel, widespread execution is disturbed by the expense of the electrical phenomenon and photoelectron-chemical equipment. Hydrogen is formed from water by using various catalysts and integrated systems. [85, 86]. Scientists have made it possible to extend the potency for direct solar water splitting with a tandem solar cell whose surfaces have been changed with a replacement record of 14% potency [87]. H2 cell vehicles with zero emissions are being used in the new generation. Great attention has been paid to gas as a possible energy vector and the employment of water-splitting technology as a clean and renewable means to come up with gas mistreatment of alternative energy. Efforts are being made to introduce photocatalysts that will be active below ultraviolet light and below visible light to utilize solar energy efficiently. Electrical, photonic, electro-thermal, thermal, organic chemistry, photo-biochemical, photo-thermal, photo-electric, and thermal-biochemical are some potential sources of H2. Such energy is derived from renewable sources for H2-creating reasons [88,89].

12. Bionic Leaf for Photochemical Use of Sunlight

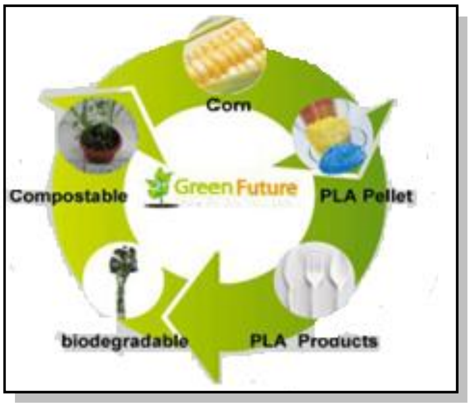
New analysis actions initiated the thought of bionic leaves for the capable rending of water by using photo chemicals in daylight. This research aims to capture sunlight and use it to produce liquid fuel rather than electricity stored in a battery. The set was designed to use solar energy for the separation of oxygen atoms in water from hydrogen, which was then changed into isopropyl alcohol by bacteria. Nickel-molybdenum-zinc (NiMoZn) catalyst and generating Reactive Oxygen Species (ROS) was used earlier to destroy bacteria's DNA. Prof Daniel Nocera, a known chemist, was the first to work on bionic leaves. Recently, Researchers have worked on an artificial Photosynthetic system (bionic leaf 2.0), which is responsible for storing solar energy and chemically decreasing Carbon dioxide. Scientists developed a hybrid water-splitting system with biocompatible inorganic catalysts by removing old nickel-molybdenum zinc with a Cobalt-phosphorus alloy catalyst. This catalyst does not lead to the formation of ROS that can damage the bacteria-H_2 and O_2 at low voltages on water splitting. The microorganism Ralstoniaeutropha along with H2, was used to synthesize biomass and fuel products (isopropanol) [90]. Many usable fuels can be generated through this system. It can also convert solar energy to biomass with 10% effectiveness, half seen within the fastest-growing plants.

13. Green Biocatalysts for the Industries

The pharmaceutical trade has held GC from the start for economic and reputation reasons, with importance placed on greener synthesis, low solvents, and the protection of the environment. Many medicines and substances are being formed with the help of biocatalysis under Green Technology. Biocatalysts used on a massive scale in synthesis, cost- and quality- benefit the trade. Apart from this, there are various inventions and discoveries in biocatalytic procedures using hydrolases, oxidases, transaminases, and reductases that are used to develop medications. The newly discovered enzymes add economic advantages to the chemical industry [91,92]. The synthesis of the prescribed drugs, flavors, fragrances, vitamins, and fine chemicals industries has expanded. Nevertheless, more must be done with a new catalyst for synthesizing medication and other ingredients. [93,94]. New scientific and technical progress has advanced factor synthesis and DNA sequencing for trade biocatalysts by protein engineering and design, as well as the ability to rearrange enzymes into new synthesis strategies [95-98].

14. New Developments in Degradable and Recycled Polymers

The Green economy is trying to encourage property and elective strategies for reducing the demand for staple resources and energy, low wastes, avoiding environmental pollution and dangerous substances, cutting greenhouse gas emissions, optimizing production techniques, and effectively using retired products and wastes. Non-degradable plastics and high amounts of waste are formed using petroleum raw materials and high energy inputs to form polymers in the Chemical Industry. The primary process for forming polyethylene (PE) needed 150°C temperatures and high pressures surpassing 1000 bar [99]. There was an increase in polymer and plastic material production globally. China is the largest producer, with around 25% of the output globally. Every year, an average person in developed countries consumes 100 kilograms of plastic (packaging materials and social unit items) [100]. The quality of many plastic materials improved, and the first biodegradable plastic products entered the market. The increase in plastic product manufacturing led to waste problems, causing water pollution, which proved to be a serious and rising issue. This was due to the lack of recycling and illegal discarding of waste [101]. Changing polylactic acid (PLA) into plastic material was biodegradable. Dextrose fermentation leads to the formation of L-lactic acid polymer from forage maize or different plant sources for sugar while not requiring genetically modified plants. [102,103].



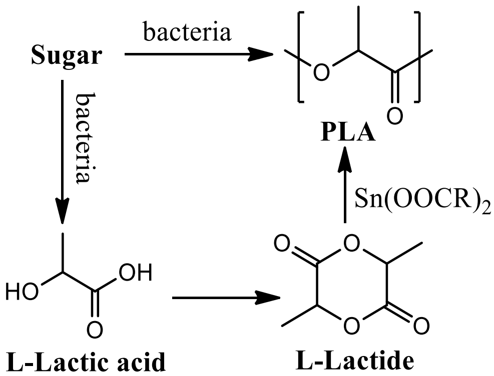


Figure 3. Poly (L-lactic acid) from microorganisms (bacteria) and by melt polymerization of lactide, produced from bio-based L-lactic acid. The PLA polymer is an excellent biodegradable polymer with numerous plastic products. There are many hopeful markets for these polymers, like polylactides. Plastic baggage for household bio-waste, planting cups, barriers for hygienic products and diapers, disposable cups, and plates are other applications. Biodegradable polymers are expected to be in demand in the next few years. PLA is a perfect material for food packaging and alternative products because of its low toxicity and environment-friendly nature. Also, because of its good biocompatibility and mechanical properties, PLA and their copolymers have become extensively employed in tissue engineering for the function restoration of impaired tissues [104-106].

The Plant Bottle has introduced a new biobased bottle for drinks. The bottle uses plant-based materials, primarily sugar cane, to form a necessary ingredient in plastic called monoethylene glycol (PET). After being used, these plastics degrade in the presence of oxygen, light, heat, and moisture as they contain 1-3% additive (metal salts), making the degradation process easy. In 2009, the world's largest beverage company, Coca-Cola Company, introduced the recyclable PET bottles of the first generation using up to 30% bio-based monomers. In the coming generation of 100% bio-based Plant BottleTM, the terephthalic acid will also be bio-based, utilizing bio-based p-xylene as an intermediate. In 2011, Coca-Cola Co. declared that it would manufacture plastic bottles made of 100 percent bio-based materials. In 2015, the bio-based Plant BottleTM was the primary plastic manufactured 100% from sugar *cane[107,108]. Big Chemical Industries and new firms are now dealing with biobased Polymers. Invista and Genomatica declared that they will pursue creating nylon intermediates from sugar. Biobased acrylic acid was used for superabsorbent polymers. In 2014, a new version of the Lycra brand textile was introduced, comprised of 70% dextrose derived from corn [109-111]. BASF, known as Ecoflex®, developed a compostable polyester film. BASF created biodegradable baggage, Ecovio®, fabricated from this film along with Cassava starch and calcium carbonate. These bags utterly decompose into the water, CO_2, and biomass in industrial composting systems. These bags are tear-resistant, waterproof, and elastic. They can be used as standard plastic baggage within the house and quickly degrade in composting systems.*

15. Polymers from Carbon Dioxide

Reducing anthropogenic carbon dioxide (CO_2) emissions has become a critical environmental issue. Carbon dioxide is an attractive feedstock for the chemical industries because of its abundance, low cost, non-inflammable nature, and renewable chemical compound. On a large scale, carbon dioxide is formed by capturing carbon from power plants, burning fossil fuels, and reforming steam to produce H2 from water and coal. Carbon capture materials release CO_2 for further transport, storage, and use. CO_2 is recovered by various methods [112]. In industrial processes, CO_2 is combined with energy-rich strained rings, like oxiranes, forming cyclic carbonates. Oxidants like ethylene oxide and propylene oxide produce biodegradable cyclic carbonate having high boiling and flash points in the presence of tetrabutylammonium bromide. They are used in green solvents to remove grease from oily steel, paint removal, and various alternative cleansing applications [113]. The first-ever changed hybrid polymer (PU) was green polyurethane, produced without the use of toxic isocyanates during the manufacturing process. The most effective mechanical properties of the polymer and the chemical resistance properties of epoxy binders are mixed in the formulation of Green Polyurethane [114]. Recently, cyclic carbonates have been synthesized by many new catalytic procedures. A high turnover of cyclic carbonates is achieved by combining carbon dioxide and epoxides with a Porphyrin catalyst [115]. Under mild conditions like atmospheric temperature and ordinary pressure, the cyclic amidinehydroiodide efficiently catalyzes the reaction of carbon dioxides and epoxides to produce cyclic carbonates in moderate to high yields [116]. The severity of the longer-term global warming has triggered researchers worldwide to work hard to decrease the amount of carbon dioxide in the atmosphere. There are several research projects and techniques for CO2 capture, separation, storage, transport, leakage, monitoring, and life cycle analysis [117]. Changing captured CO2 into products like chemicals, building materials, plastics, fuels, and alternative commodities has become a vital part of the workplace of Fossil Energy's carbon capture and storage program. This method can help decrease carbon emissions where geological storage of CO2 takes work. The analysis focused on the Polypropylene carbonate (PPC) polymer-producing scale-up of Novomer's novel catalyst ability [118].

16. Green Chemistry and Organic Photovoltaic Solar Cells

The OPV can produce electricity at a lower cost than first- and second-generation solar techniques. The limited effectiveness and the long-term consistency are still a significant barrier, though the photovoltaics have achieved nearly 11% efficiency. Most OPV cells utilize molecular or polymeric absorbers, resulting in localized exciton. The absorbent is combined with an electron acceptor like fullerene, which consists of molecular orbital energy states responsible for electron transfer [119]. This early-stage applied analysis investment focuses on displaying new photovoltaic concepts and trains the youth accountable for future PV technologies' success and commercialization. Current analysis focuses on increasing the effectiveness and life span of the device. Extensive benefits have been achieved by improving the absorber material, and research has been done to introduce an organic multi-junction architecture and optimize the absorbers. The contact material and the encapsulation process are being examined to prevent cell degradation [120]. Organic Photovoltaic solar cells are considered cheap and environment-friendly sources of power. The principles of GC applied to the production of conjugated polymers are referred to as necessary tips for manufacturing these materials in more significant amounts. In GC and technique analysis, it is justified that low cost can be a concern with environmental benignity when waste disposal is expensive. [120]. The effectiveness of organic photovoltaic solar cells has increased using perovskite solar cells. Researchers are looking into another crucial area of solar cells, like device natural hysteresis and film growth, as a result of the replacement of lead and thus the progress of tandem cell stacks. Another central and vital analysis issue is cell stability [121]. Researchers are working on several projects to improve the effectiveness of polymer solar cells by using a cycle structure. A large part of the spectrum of solar radiation is utilized, and thus, the thermalization loss of boson energy is diminished. Earlier, the unavailability of high-performance *bandgap polymers was the foremost limiting issue for getting high-performance tandem solar cells [122].*

17. Green Solvents, Catalyst-Free and In Water Reactions

When choosing the solvent for a synthetic process in the chemical industry, it is mandatory to focus on environmental protection and workers' safety. Most corporations are currently opting for greener solvents. Also, customers are turning towards replacements, from traditional solvents to greener solvents. The choice of the correct liquid has perpetually the ability to boost competitiveness. However, environmental advantages and worker safety are the keys to product differentiation and higher margins as the trade enters an improved environmental awareness era. The top principles of selecting a green solvent are procedure compatibility and solvent role. However, financial acts and environmental acts need not be reciprocally exclusive. Around 10% of the total solvent in the market is represented by green solvent [123,124]. Typical examples include multi-component reactions and many more. Other choice energy input systems were used in these reactions, like microwave and ultrasound irradiation. [125]. Ionic liquids (ILs) have gained massive attention from the scientific community. However, their greenness is usually challenged because their biodegradation could be better; they are used instead of organic solvents with extreme toxicity and high volatility. Deep eutectic solvents (DES) are alternate types of solvents representing the GC principle. The DES is outlined as a combination of 2 or more compounds, solids, or liquids which, at a selected composition, present a high melting point depression, turning into liquids at room temperature. DES may be used for biocatalysis, electrochemistry, and extraction [126]. Solvents are classified into four categories, from –being recommended to coming into the list of banned [127].

18. Green Chemistry and Oil-Based Paints

Due to their wide availability and applications, vegetable oils are considered an essential category of renewable resources. Recently, forms of vegetable oil-based polymers have been made by free radical, cationic, condensation polymerization, and olefin metathesis. [128]. Due to their worldwide availability, natural biodegradability, lower price, and excellent environmental credentials (low toxicity and ecotoxicity), vegetable oils are treated as the most important renewable source in the Chemical Industry. These natural properties are helpful in analysis and development, with oil-derived polymers and composites used in multiple applications such as paints, coatings, adhesives, and biomedicine [129]. Vegetable oil plays a vital role in producing materials like alkyds, epoxies, and polyether amides and their uses as protecting coatings [130]. A volatile organic compound oil is obtained from Oil-based "alkyds" paints. These Paint resins and solvents derived from fossil fuels were replaced by a combination of soya oil and sugar prepared by Procter & Gamble and Cook Composites and Polymers, cutting poisonous volatiles by 50%. [131].

19. Green and Renewable Energy Sources

A group of Researchers and Scientific communities throughout the planet believe that the availability of petroleum, coal, and natural gases is ultimately decreasing, becoming too expensive or environmentally polluting. In distinction, many renewable energy resources like wind, solar, biomass, geothermal, electricity, and ocean energy are often reloaded and can never decline. Global warming emissions may be reduced by the supply of renewable energy at the world scale level and by replacing carbon-intensive energy sources. The practice of GC results in a neat and more sustainable earth and is inexpensively applicable with numerous positive social impacts, primarily in recognizing and using renewable energy resources. These advantages motivate industrialists and governments to encourage the growth of sustainable energy processes accomplishments within the fields of renewable energy (biomass, biorefineries) [132-135]. Bio-refineries are progressing by using the alternative to oil with biomass as raw material for fuel and chemical making. Nearly all biomass feedstocks can be remodeled into totally different categories of biofuels and bio-chemicals in bio-refineries by jointly applied alteration techniques. This technological modification requires the addition of GC into bio-refineries and using low- and low-environmental impact technologies, future sustainable chains of biofuels, and high-value chemicals from biomass [136,137]. Due to the lower ash content and higher bio-oil produced, woody biomass is the selected material in the thermo-chemical process.75% of the starting material is converted into renewable bio-fuel with the help of thermal exchange by fast pyrolysis which is suitable for transportation [138]. Science has significantly advanced for third-generation biofuels (low input-high yielding feedstock), especially biofuels extracted from microalgae and considered viable renewable energy resources. The third generation needs the main demerits concerned with first-generation bio-fuels (mainly terrestrial crops, like sugar beet, sugarcane, maize, and rapeseed) and second-generation biofuels (derived from lingo-cellulosic crops Industrial experiences in the manufacturing of biofuels *showed the significance of mixing biofuel production with the yield of high-value biomass fractions in a bio-refinery model. [139].*

20. Innovative Agricultural Technologies

Green Chemistry predicts technical involvement and uses for usual farming practices, which can decrease environmental pollution and increase the sustainability of agricultural methods. Most researchers believe that the products of GC are essential to sustainably creating agricultural products without being dependent on poisonous materials and techniques that may cause work-related danger to farmers and destroy the natural resources of the environment. New, less harmful pesticides and biopesticides (obtained from plants or microbes) are used in agriculture's scientific and technical practices. At the same time, numerous innovative green techniques, like preventing soil erosion, conservation of diversity, weather change modifications, water management of irrigation, and intensive analysis of green techniques for biomass conversion into fuels and chemicals, are promoted [140–142]. Agricultural sustainability and innovative green techniques make it difficult to deal with environmental issues that must support 7 billion humans globally [143, 144]. The initial revolution (GR) was attributable to saving over a billion people from starvation through the Green Revolution. The expansion of GR in agriculture hurts both agriculture and wildlife diversity, increases environmental pollution, causes water management issues, and other adverse effects (agricultural soil scarcity) [145, 146]. Using nitrogen fertilizer to produce high yields leads to heavy dependence on modern crop production. However, its misuse negatively affects water quality (nitrogen pollution) and the climate due to nitrous oxide (N2O) emissions. The potential advances can be achieved equally from improved fertilizer production quality [147, 148]. In contrast to chemical fertilizers, bio-fertilizer technology relies on renewable energy resources and is not responsible for environmental pollution. As a low-priced green technology, it most applies to developing nations where labor is inexpensive. Several microbes and relatives of plants concerned with biofertilizer formation and their usage on the farm are considered valid. In addition to nitrogen, phosphorus also plays a vital role in the growth and metabolism of plants. Bio-fertilizers might contain a mixture of nitrogen-fixing and phosphate-mobilizing microbes in the coming years. The need for nitrogen management practices has arisen due to over-fertilization in green leafy vegetables. Recently, a unique slow-release fertilizer was developed and coated with inorganic minerals. [149].

21. Greener Electrochemical Storage Systems

Scientists and researchers assessing renewable raw materials felt that greener and more sustainable storage techniques were required. Thus, scientists had to include more material, eco-friendly artificial procedures, and life-cycle analysis in the design of new electrochemical storage systems. A couple of innovative techniques are being developed to address these problems. However, fundamental technical obstacles still exist. An outline of this state of energy storage from a sustainability perspective highlighted the present and future electrochemical storage systems beyond lithium-ion batteries, their quality, and the price of recycling battery materials from a sustainability perspective [150]. Sodium-ion batteries based on intercalation materials that use non-aqueous electrolytes- over lithium-ion batteries- were first explored in the mid-1980s. They had undergone regeneration within the previous couple of years because of better energy density than liquid batteries and lower price than Li-ion batteries. The sodium-ion batteries supply sustainability and cost-effectiveness and are considered a green alternative for the storage of energy various for the storage of energy [151]. Another material, graphene, has become one of the most popular topics in materials science due to its appealing properties. Among the various affected areas of materials science, this 'graphene fever' has significantly influenced the planet of electrochemical energy-storage devices. However, despite intensive initial interest from multiple scientists for the role of graphene as a compound for energy storage, there are yet to be advances in the field. Currently, analysis was carried out on the applications of graphene in lithium-ion batteries and electrochemical capacitors. Also, graphene materials were employed in promising technologies like metal-air and magnesium-ion batteries [152].

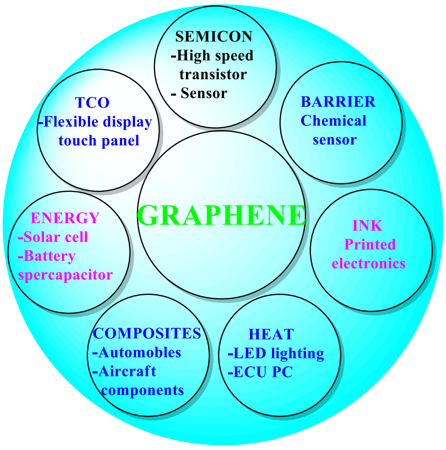


Figure 4. Graphene is an atomic-scale honeycomb lattice fabricated of carbon atoms with enticing physicochemical properties. It is the foremost promising nanomaterial that is widely used in everything from electrons to optics, sensors, and many other devices.
Following GC principles, efforts were made to boost the potential for competent changes in storage, transportation, and use of renewable energy. Earth-abundant and nontoxic compounds were made to avoid environmental issues [153].

22. Green Chemistry for Sustainability

Green Chemistry (GC) is gaining substantial importance within the chemical industries and new technological developments. This is due to their sustainable nature, energy potency, trust in renewable raw materials, safer chemicals, and cheap prices. Newly available products and customer products have created numerous practical applications in the standard of living concerning the earlier conditions of environmental pollution by solid waste materials. All these green technologies play a significant role in reducing environmental problems all over the world. Researchers believe that the rapid construction of industries has led to widespread global warming, decreased natural resources, air pollution, greenhouse effect, water pollution, soil pollution, and dangerous effects on the ecosystems. Various political and environmental initiatives have motivated the upcoming acceptance of environmentally friendly green techniques in every industry. Participation and investment in green technology have increased in the chemical industry, pharmaceutical industries, foods, and consumer products [154]. In the 21st century, along with the issues of environmental pollution and temperature changes, researchers felt that energy utilization should be sustainable and derived from renewable sources. GC solutions could lead to a good, sustainable, and secure energy future worldwide [155]. The importance of the management of GC advances and uses has been growing. Although significant production units have already dedicated critical analysis to green and sustainable solutions, a lot is still to be achieved. The challenge for upcoming generations of researchers, industrialists, chemical engineers, and environmental specialists is to develop and manufacture new techniques and approaches that may involve environmental objectives in design selections in the Industries. This review focuses on a range of the foremost vital and creative developments in GC fields after searching the scientific literature and research papers.

2. CONCLUSION

Green chemistry has advanced in various technology fields in the last decade, providing cutting-edge applications for a broad spectrum of chemical products and technology innovations. The most essential research and technical fields of GC include solutions. Among other things, reduction of global warming and use of CO2as a raw material for synthesis, microwave (MW), electrochemical and ultrasound synthetic methods, solvent-free reactions (or water as a solvent), waste management and wastewater, phytoremediation, eco-friendly dyes and pigments, innovative food products, catalysis and Biocatalysis, biopolymer technology, renewable energy sources, renewable materials, etc. Although there are many areas for improvement for GC products, we list some of the basics below.

a. Biocatalysis and biotransformation methods for synthetic reactions.
b. Directed progress, and use of new enzymes for synthesis.
c. Green chemistry is used in the pharmaceutical industry.
d. Hydrogen formation via catalytic splitting of water.
e. Green and renewable energy sources.
f. Green chemistry and agricultural technologies are compassionate to the environment.
g. Green chemistry, multicomponent reactions.

h. Green flow chemistry and constant processes in the chemical industry.
i. Green chemistry and biodegradable polymers.
j. Green chemistry and organic solar cells.
k. Solvent and solvent selection in industrial synthesis.
Apart from the above, there are also numerous other technological and advanced fields of GC. Some of these innovative inventions have been applied to improve sustainability, reduce pollution, and release less hazardous chemical products. Green solvents and industrial reactions in water have been used in numerous industrial processes. Vegetable oils have been used in various applications, including oil-based paints. The alternative of oil with biomass as raw material for fuel and chemical production is an attractive option for biorefinery growth. GC's involvement in traditional farming practices will decrease environmental pollution and improve the yields of various crops.

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Conflicts of Interests
The authors declare no conflict of interest.

Consent for Publication
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