GREEN CHEMISTRY AND SUSTAINABLE APPLICATIONS

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Green chemistry has emerged as a pivotal approach in addressing environmental concerns and promoting sustainability in chemical processes and industries. The goal of green chemistry is to do this by rationally designing chemical and processes based on a set of measurement and principles that have been developed over the previous many decades. Several political, social, economic, and technological aspects need to change in concert for green chemistry to realize its full potential. Tran materialization and dematerialization initiatives within the chemical industry are advanced by the conceptual and technological framework offered by green chemistry. In addition to other sustainability criteria the concepts of green chemistry aid in locating areas that merit innovation. Green chemistry guarantees that new technologies minimize unintentional risks and offers insight into the ramifications of new technologies and it differs from other technical development that concentrate nearly only on application by taking into account both the consequences for new technology and its application. This viewpoint encourages the multidisciplinary design and development of new technologies that are integrated with sustainable concepts. Overall, this book chapter underscores the pivotal role of green chemistry in fostering sustainable development and offers insights into its potential to address global environmental challenges while promoting economic growth and societal well-being.

2.1 Introduction

Green chemistry has been around for more than three decades, as a framework for contributing to the broad scope of global sustainability. American Chemical Society journals are a great place for these scientists to share their latest finding and serve as a resource for the chemistry community and beyond to understand current issues and envision solutions. We think this is a good time to highlight some of the top articles on the broad theme of green chemistry. that are being published today through a Virtual Issue of selected works from nine ACS chemistry and engineering journals (Sheldon et al., 2018; Zimmerman et al., 2020). The global economy has grown astronomically over the 20th century, and the industrialized world's quality of living has continued to rise. On the other hand, the amount of water consumed worldwide has quadrupled since the mid-1900s. The market for wood-based building materials has increased. The amount of wood needed to generate heat has quadrupled. The demand has raisedsix fold for raw materials for paper and wood pulp. Over the past 50 years, the amount of marine fish consumed has grown fivefold. There has been a consistent decline in farmland quality as a result of intensive livestock husbandry (Kar et al., 2021). More than a thousand creatures or plants are in danger of going extinct every year. Since the start of the industrial era, the atmospheric content of carbon dioxide has been progressively declining until it has reached zero. The atmospheric concentration of carbon dioxide has been continuously rising since the start of the industrial era (greenhouse effect). To put it another way, rising living standards and resource exploitation have come at a cost, with environmental pollution continuing to rise and natural resources being used to the furthest extent possible (Sheldon et al., 2022; Ganesh et al., 2021).

Green chemistry offers a conceptual and technology framework that advances the chemical enterprises dematerialization and transmaterialization efforts. Innovation opportunities are identified by the application of sustainability indicators and the concepts of Green chemistry and also take

care to minimize unintentional risk associated with new technology and provide insight into their ramifications. Green chemistry stand out from other technological trends that focus mainly on application by also considering the broader implications of new technologies. This perspective promotes the multidisciplinary design and development if innovations that adhere to sustainable principles. By evaluating both the applications and potential impacts green chemistry fosters the creation of technologies that support sustainability from multiple angles (Brandt, 2002).

Green chemistry tools and metrics help businesses evaluate their products through a "triple bottom line of environmental, economic and social factors. This approach promotes the creation of safer control costs. Regulatory advantages for green solutions could further incentivize their use. The adoption of green chemistry and sustainable practices is proving that green technologies can be economically competitive (Hofer & Bigorra, 2007). Green chemistry to be most effective it must be done at the design phase of a new chemical or process. When building a new chemical or product there are many opportunities for deeper forms of innovation, such as overhauling the production system which can start with small surface design changes and progress to full system redesign. Over the past fifteen years the biggest developments have occurred in chemical even though green chemistry fosters innovation throughout the chemical supply chain (Mulvihill et al., 2011; Sheldon, 2018).

The terms "green chemistry" and "minimum impact chemistry" were previously interchangeable, the EPA's initiatives led to the global adoption of the term "green chemistry" to refer to the design of chemical processes and products that minimize or completely eliminate waste generation and avoid the use of toxic or hazardous substances. It was dubbed "benign by design chemistry" at first. There are two approaches to approach the connection between analytical and green chemistry. Green chemistry is controlled and justified by the study of analytical chemistry. Here, analytical chemistry proves to be a useful instrument in verifying the environmentally friendly outcome of a chemical product or technology. However, chemical analysis techniques produce waste and need energy, solvents and reagents (Koel & Kaljurand, 2006; Horváth, 2018).

However, in many instances, the samples being analyzed are complex mixtures with interfering matrices that prevent the use of waste reducing methods. Identifying alternatives solvent is a crucial step towards adopting greener methodologies. In order to increase the sensitivity, selectivity, and reliability of the analysis while cutting down on analysis time the primary goal of this method should not only be the replacement of these solvents bur also the introduction of an extra benefit from their various features (Korany et al., 2017). Energy utilization is generally reduced by the use of instrumental methods, particularly when the process is highly automated and requires a little sample. An effective use of energy is made possible by the hyphenation of multiple techniques for sample treatment, component separation or combination of separation and complex detection methods. When a microwave treatment or even just microwave heating is used in the procedure more energy can be saved. Several sample procedures may also be significantly impacted by an ultrasonic irradiation. Another very green approach in analytical chemistry is the development of photochemical techniques (Chen et al., 2020).

The majority of the above mentioned method also provides safer chemicals and various chemical techniques for sample derivatization and chemical modification are still employed in many sample preparation and treatment scenarios. The creation of new techniques should include the search for less hazardous substances and waste-generation procedures. Electrically drive separation techniques are the most convenient for using the "green" concepts of analytical chemistry because they use less solvent and sample (Clarke et al., 2018).

2.2 History of Green Chemistry

The U.S. Environmental Protection Agency (EPA) introduced the term "green chemistry" to promote sustainable advancement in chemistry and chemical technology across government, academia and industry. Concurrently, the annual U.S. President Green Chemistry Challenge (PGCC) was launched in 1995. Following this, Europe established similar awards. Additionally, the International Union of pure and Applied Chemistry (IUPAC) formed a working party on green chemistry (Ali et al., 2020). The Green Chemistry Institute (GCI) which was established with branches across several nations to promote communication between academia, industry and government and research institute was established nearly a year this IUPAC initiative. In the meantime, academia conference on green chemistry, which was first held in Washington in 1997, has become an annual event. The first book and publications on green chemistry were published in the 1990s; two well-known journals in this field are green chemistry published by the Royal Society of Chemistry (RSC) and journal of Clean Processes and products published by Springer-Verlag. Nonetheless, a few other journals have also included section on green chemistry including Journal of Chemical Education and the Environmental Science and Technology (De Marco et al., 2019; Ali et al., 2020).

2.3 Principles of Green Chemistry

The pressing environmental challenges of the 21st century, including climate change, pollution, and resources depletion, demand innovative solutions that align economic growth with environmental sustainability. Green chemistry, also known as sustainable chemistry, represents a fundamental shift in how chemical process and products are designed, aiming to minimize or eliminate the use and generation of hazardous substances. Green chemistry is guided by twelve principles that provide a framework for designing safer chemicals processes (Table 2.1) (Khajuria et al., 2022; Ardila-Fierro & Hernández, 2021).

Table 2.1 The twelve (12) foundational principles of green chemistry

S.No	Principle	Description
1	Eliminate waste	It's more beneficial to prevent waste than to process it after it occurs.
2	Design safer chemicals and products	Chemical products should be manufactured to perform their desire role with minimal toxicity.
3	Element efficiency	Synthesis should be optimizing to incorporate all materials used into the final products.
4	Develop safer chemical synthesis	When feasible, synthetic procedures should be designed to use and create materials with minimal or no toxicity to human or the environment.
5	Non-hazardous solvent and auxiliaries	Reduce the need for auxiliary substances such as separation agent or solvents and ensure their safety when they must be used.
6	Enhance energy efficiency	Analyze the environmental and economic effects of energy consumption in chemical processes and minimize them. Whenever possible carry out synthetic procedures at standard temperature and pressure.
7	Apply renewable feedstock	Use renewable raw materials or feedstock's instead of non-renewable ones when technically and economically feasible.

S.No	Principle	Description
8	Minimize use of chemical derivatives	Reduce or eliminate derivatization (e.g., protection, non-permanent alteration and blocking group) when feasible to prevent the use of extra reagents and the generation of waste.
9	Reduced the risk of accidents	To reduce the risk of chemical accidents, examples, leaks, explosion and fire certain compound and their forms should be used in chemical operation.
10	Employ catalysts instead of Stoichiometry reagents	Whenever feasible, catalytic reagents are preformed over stoichiometric reagents.
11	Monitor in real time to avoid contamination	To prevent harmful substances from forming analytical methodologies must be developed further for real-time in process monitoring and control.
12	Synthesized chemical substances and products for degradation after use	Ensure that chemical products degrade into benign substances after their function and do not remain in the environment for extended periods.

2.4 Benefits of Green Chemistry

Green chemistry not only minimizes waste production but also offers effective solutions in the realms of economy and energy efficiency. It plays a crucial role in reducing the risk of accident by incorporating safety measures into the early stages of chemical reactions. Overall, this is a novel strategy to protect the environment and public health; it is actively utilized in many different contexts and will actively contribute to preventing environmental pollution in our nation (Sajid, & Płotka-Wasylka, 2022; Armenta et al., 2019). Green chemistry offers numerous advantages. The benefits to human health, the environment and the economy were listed in Table 2.2.

Table 2.2 The role of green chemistry in advancing health, environmental protection, and economic efficiency

Area	Benefits
Human Health	Enhanced environmental conditions, reduced discharge of toxic chemicals, leading to fewer respiratory health issues. Enhanced water quality, minimized discharge of toxic chemicals resulting in cleaner water for drinking and recreation. Safer food: elimination of persistent toxic chemicals that can contaminate the food chain, use of pesticides that target specific pests and degrade rapidly after application. Enhanced safety in products, new and safer products will become available for commerce, some items (pharmaceutical) will be produced with less waste and other products (cleaning solutions and pesticides) will serve as safer replacements for existing options. Increased safety for chemical industry employees, less use of dangerous materials, fewer protective outfits needed and reduced risk of incident such as explosion and fire.

Area	Benefits
Environment	The environment contains fewer poisonous chemicals, reducing exposure to plants and animals. Reduced reliance on landfills, particularly hazardous waste landfills. Reduced risk of climate change, smog development and ozone layer depletion. Chemical substances enter the environment through deliberate application (pesticides) unintended emissions or through disposal. Green chemicals aims to either convert to more environmentally friendly products or are recycled for further use
Economy and business	Enhanced efficiency of chemical reactions, consuming less feedstock to produce the same amount of product. Reduced waste generation, hazardous waste disposal, avoiding costly remediation, and end of pipe treatments More efficient processes, reducing energy and water usage, boosting plant capacity, and facilitating rapid manufacturing. Facilitate the replacement of commercial feedstock with waste Improved efficiency, requiring less product to perform the same task Improved marketability and sales with the display of a safer product label. Enhanced competition within the chemical industry and among their customers. Minimized reliance on petroleum products, decreasing consumptions and avoiding risk and cost variability

2.5 Sustainable Applications in Green Chemistry

Sustainable application in Green chemistry focuses on developing processes and products that minimize environmental impact. This involves using renewable resources, reducing energy consumption, and minimizing waste generation. Green chemistry aims to design efficient chemicals processes that prioritize safety and sustainability without compromising product quality or performance (Gawlik-Kobylińska et al., 2020; Cao & Su, 2021). By integrating principles such as atom economy and benign solvents, it seeks to promote eco-friendly alternatives across industries, fostering a more sustainable future (Figure 2.1).

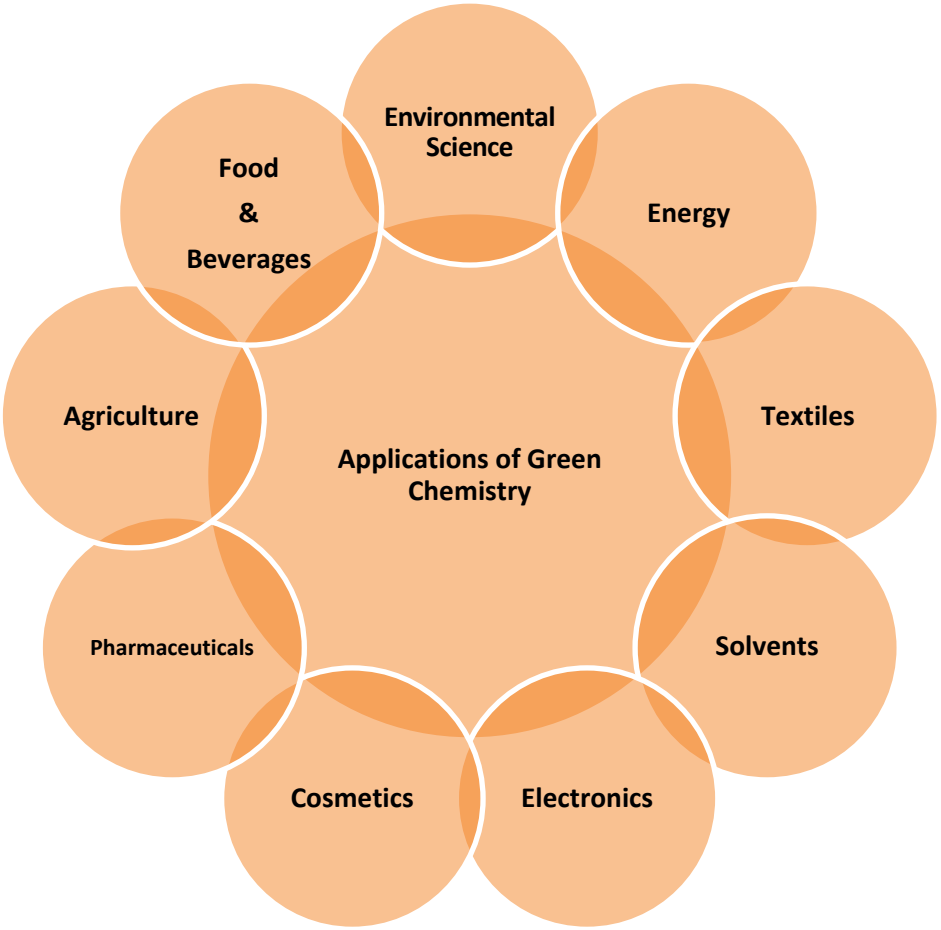


Figure 2.1 Innovative applications of green chemistry in various fields

2.5.1 Pharmaceuticals

Wasted or expired medication, as well as excess medication excreted by people and animals, end up in municipal sewage effluent treatment facilities. Several European nations' surface waters have been shown to contain pharmaceuticals since the 1980s, including clofibrate, antibiotics, cytostatic medications, and several analgesics and some products remain in the environment and end up finding their way back into drinking water. In addition to endangering human health, genotoxic chemicals can also impact environmental organism. It is reasonable to infer that bacterial populations are the area of aquatic ecosystem most impacted by the discharge of effluents containing antibiotic since drugs interfere principally with bacterial metabolism (Castiello et al., 2023). Also, infections that are challenging to treat arise from resistance to specific medications. Humans eat antibiotics and they are employed in fish farming, cattle production, and poultry production. Over the past 50 years, the usage of these medications has increased which has led to the genetic selection of more pathogenic bacteria. Animal excrement which contains unmetabolized pharmaceuticals, contaminate soil, and ground water when it is put to agriculture fields as manure or fertilizer. Depending on how mobile the excreta are it can also impact aquatic and terrestrial creatures by leaching from the fields (Pacheco-Fernández & Pino, 2019).

The disposal of solid waste in landfills by industrial effluent treatment facilities may result in the leaching of unmetabolized pharmaceuticals into groundwater (Polshettiwar & Varma, 2007). Seventy percent of the drugs supplied to fish in fish farms that are misused are discharged into the environment, primarily into the sediments surrounding the fish farms. The majority of drugs' modes of action in fish, animals, and humans are poorly understood. Additionally unknown are many potential adverse affects or side effects on nontarget receptor species as well as any potential

synergistic effects from medication combination. Humans ingest the meat from poultry and animals, which include growth booster, antibiotic and other veterinary medications (Campos et al., 2019).

In aquatic creatures, estrogens both natural and synthetic cause harmful consequences such feminization and hermaphroditism. A drug's photostability, binding and adsorption capacity, rate of disintegration and water solubility all effects how long it will last in sediment or soil. On the other hand, highly mobile medications are carried by surface runoff, drainage water, and groundwater, and they frequently seep into groundwater. Pharmaceuticals with high absorption rates typically accumulate in soil or sediment (Zimmerman et al., 2020). In Germany, the sewage treatment plant effluent contained 80% of 32 drugs, with concentration levels of the order of 6 μg/L, that belong to the classes of lipid regulators, beta blockers, antiphlogistics, psychiatric drug, sympathomimetics, and antiepileptic drugs. Additionally, 0.165 mg/L of clofibric, a lipid regulating agent was found in drinking, ground, and river water (Piontek et al., 2018).

In the UK, both drinkable water and groundwater included medications such as diazepam, methaqualone, and antibiotics called penicilloyl. Pharmaceuticals, hormones, and other organic wastewater pollutants were discovered in surface water in a 2002 U.S. Geological Society countrywide investigation. River silt, river water, and drinking water in Italy were discovered to include many medications, animal growth boosters, and antibiotics at the nanogramme level, in addition to ceftriaxone and tilmicosin. There was not enough of the discovered concentrations to have any pharmacological impact, many orders of magnitude lower. However, it's unknown what consequences people would have if exposed to these pharmaceuticals all their lives (Lasso et al., 2021).

2.5.2 Green solvents

The discharge of hazardous compounds into the environment is a key problem in the context of sustainability. This is one area where green chemistry can make a big difference. For example, solvents are used extensively in government, commercial and academia. Industrial solvents are employed in a variety of chemical process operation processes, including reactants, separation, carrier, degreasing, reaction, crystallization, and cleaning. Different kinds of solvents that are often utilized including hazardous air pollutants, toxic, flammable, and volatile organic compound. They also provide significant risks to process safety, environmental, management, waste, human and other health, and safety factors (Pacheco-Fernández & Pino, 2019; Häckl & Kunz 2018). Green solvents often referred to as biosolvents, are solvents derived from the processing of crops that are less harmful to the environment. The majority of chemical operations use petrochemical solvents, which have detrimental effects on the environment. Green solvents were developed as an environmentally acceptable replacement for petrochemical solvents.

A green solvent that is produced by digesting maize is ethyl lactate, for instance, lactic acid's ester is called ethyl lactate. As well as, being 100% biodegradable easily recyclable, non-ozone depleting, noncarcinogenic, noncorrosive, and lactate ester solvents are widely utilized in the coating and paint industry. High boiling point, high solvency power, low surface tension, and low vapor pressure make ethyl lactate a particularly appealing solvent for the coating industry (Perna et al., 2020). It works very well as a paint stripper and graffiti remover and it is a desired coating for metal, wood and polystyrene surfaces. A far safer work environment has resulted from replacing solvents like xylene, acetone, and toluene with ethylene lactate. Among ethyl lactates other uses is as a superior cleaner for the polyurethane resins can be dissolved by ethyl lactate due to its strong solvency power. Solid fuels adhesives, oil, and grease, may all be effectively removed from a range of metal surfaces because to ethyl lactate's exceptional cleaning capabilities. Since chlorinated solvents are no longer needed ethyl lactate is a very important tool (Vanda et al., 2018).

2.5.3Environmental Science

The scientific community has gradually shifted its approach to addressing environmental protection regulations during the 1990s. This transformation within the chemical industries and research and development labs has given rise to green chemistry. In recent years, green chemistry has become a widely acknowledged and accepted alternative for achieving sustainable development. As its name suggests, green chemistry is a scientific approach that complies with environmental protection regulations in a safer way than the conventional cleaning chemical that was in use before to the 1900s (Cue et al., 2009).

In order to comply with pollution regulatory boards' guidelines while employing conventional trash treatment or recycling technologies, industries are frequently required to pay high costs. Legislative committees are also now more closely examining the potential negative impacts of a greater variety of chemicals due to the aggravating environmental issues. For this reason, end-of-pipe cleanup has given way to green chemistry and environmentally safer production processes. This is due to the combined effect of current environmental safety regulations, growing scientific understanding of previously unknown toxic chemicals and their long-term effects on the biota, and industry financial interests. Because green chemistry may help bridge the gap between ecoefficiency and economic growth, it is becoming increasingly important (Campos et al., 2019). Process efficiency has undergone a paradigm change as a result of the increased environmental concern. These days, the emphasis is on the atom economy factor and the environment coefficient factors rather than the conventional chemical yields. When defining waste as everything that is created aside from the intended product the atom economy factor may be defined as the amount of waste generated per kilograms of product (Anastas & Eghbali, 2010).

One easy way to create two different roots for a given product is to use the atom economy calculation. To calculate it, divide the molecular weight of the desired product by the total molecular weight of all chemicals generated in the processes included in the stoichiometric equation. It can alternatively be defined by some writers as the total number of reactant atoms that are transformed into desired product atoms throughout a reaction. Stoichiometric reagent processes are less atom-efficient than catalytic processes. For example, conventional oxidations utilizing oxidants such permanganate or chromium reagent increase atom-economies when substituted with cleaner catalyzed oxidation (Wilson & Schwarzman, 2009).

In 2000, the United States alone emitted around 7.1 billion pounds of over 650 hazardous substances into the environment. The roughly 75,000 chemicals that are used commercially in the US are not even close to being represented by this inventory. Even though certain chemicals have been in use for several decades, their effects on human health and the environment are still mostly unknown (Campos et al., 2019). The U.S. industry spends about $10 billion per year on environmental R&D. A prefect process has a single step is easy to understand, atom efficiency, safe, creates no waste, employ renewable resources is acceptable to the environment has a total yield and only takes a few easy steps for separation. A perfect product would use the least amount of energy and safe, recyclable, packaging, and entirely biodegradable. In general, the public pays very little attention to the ideal user and instead concentrate on the procedure and final result. The perfect consumer is one who considers the environment, reuses; consumers little, recycle, and are aware of the environment impact of the products they purchase. The ideal user also supports “green” activities (Chanshetti, 2014).

2.5.4 Agriculture

Green chemistry in agriculture focuses on applying sustainable and environmentally friendly practices to agriculture processes and products. It aims to reduce the use of harmful chemicals, minimize waste, conserve resources, and enhance the overall sustainability of farming. By integrating green chemistry principles, agriculture can become more efficient and less harmful to the environment

and human health (Perlatti et al., 2014; Withers et al., 2015). Traditional agriculture relies heavily on synthetic pesticides and fertilizers, which can lead to soil degradation, water contamination, and harm to non target species including humans. Green chemistry promotes the development and use of bio-based and biodegradable pesticides and fertilizers. These alternatives are designed to be effective against pests and provide nutrient to crop while minimizing environmental impact. Bio-pesticides are derived from natural material such as bacteria, plants, and certain minerals. For example neem oil extracted from the neem tree is a natural pesticide that is effective against a wide range of pests.Bio-fertilizers include microorganism like nitrogen fixing bacteria and mycorrhizal fungi, which enhances soil fertility and plant growth by making nutrient more available to plant (Bryan et al., 2018).

Green chemistry plays a crucial role integrated pest management (IPM) by providing safer chemicals alternatives and promoting practices that reduce the need for chemicals interventions. For examples, pheromone traps use synthetic pheromones to lure and trap pests, reducing the need for broad-spectrum pesticides. Botanical insecticides made from plant extracts can target specific pests with minimal impact on beneficial insects and the environment. Green chemistry promotes practices that maintain and enhance soil fertility while minimizing erosion and degradation. This includes the use of organic amendments such as compost and biochar which improve soil structure ware retention and nutrient availability. Cover cropping is another practice supported by green chemistry. Cover crops such as legumes and grasses are grown off seasons to protect the soil from erosion, suppress weeds, and enhance soil organic matter. These crops can also fix nitrogen in the soil reducing the need for synthetic nitrogen fertilizers (Morin-Crini et al., 2019).

Agriculture activities can significantly impact water resources through runoff and leaching of chemicals. The green chemistry reduces these impacts by promoting efficient water use and minimizing the contamination of water bodies. Drip irrigation system deliver water directly to the plant roots, reducing water use and minimizing runoff. Slow release fertilizers and controlled release pesticides are designed to release their ingredients gradually reducing the risk of leaching into water sources. Green chemistry in agriculture also emphasizes the use of renewable energy sources and resources efficient practices. For examples, biofuels derived from agriculture residues and dedicated energy crops can provide a sustainable alternative to fossils fuels. Solar powered irrigation system and wind turbines can help farmers reduce their reliance on non-renewable energy sources (Shirmohammadli et al., 2018; Campos et al., 2019).

Genetically modified organisms (GMOs) have the potential to contribute to sustainable agriculture by enhancing crop yields, improving resistance to pests and disease and reducing the need for chemicals input. For instance, Bacillus thuringiensis (Bt) crops which are genetically modified to produce a bacterial protein toxic to certain insects, can reduce the need for chemical insecticides. However, the use of GMOs must be carefully managed to avoid issued such as the development of pest resistance and the impact on non-target species. Green chemistry promotes the use of plant growth regulators and natural plant hormones to enhance crop growth and resilience. These substances can improve crop yields and quality without the negative impacts associated with synthetic chemicals. For example, biostimulants which include seaweed extract, humic substances and beneficial microorganism can enhance plant growth and stress tolerance. They work by stimulating natural processes in plant improving nutrient uptake and enhancing resistance to abiotic stresses such as drought and salinity (Kummerer, 2007; Ahmed et al., 2017).

2.5.5 Food and Beverages

Food safety has become an increasingly pressing issue for society in recent year due to improvements in people's quality of life and increased consumer and organizational concern. In food supply chain, the unprocessed ingredients, storage procedures preparation, processing, and packing might contaminate food items (Pallone et al., 2018). Thus, it would appear that research on food contamination detection technologies is very crucial. Before detection pretreatments for

analyte extraction and preconcentration are crucial because of the complexity of food samples and the low concentration of food pollutant.

In this sense, the extraction of analytes at trace levels is demonstrate to be highly effective by microextraction method as liquid-liquid microextraction, and solid phase microextraction. However, employing hazardous organic solvents for extraction typically halogenated hydrocarbons does not align with the principle of green chemistry. Because HDESs have good hydrophobicity and dissolving capability they have been explored as great possible alternatives to the standard solvents in microextraction (Płotka□Wasylka et al., 2018). In fact, it is rather unexpected that the adaptability of HDESs makes up for some of the extraction process's drawbacks when substituting the organic solvents with HDESs, aside from boosting the advantages of quick operation, high selectivity, high sensitivity and low cost. One of the most often used microextraction methods in conjunction with HDESs is dispersive liquid-liquid microextraction (DLLME). This method increases the mass transfer and extraction efficiency by using the distributed droplets that the extraction solvents in the water samples create.

Nevertheless, several constraints persists including the requirement for an additional solvent for the dispersion the challenge of finding the trace extraction solvent and the energy expenditure associated with phase separation (Valduga et al., 2019). To guarantee that food meets quality standards for color, flavor, and shelf life, food additives are essential. The primary concern with food safety meanwhile is that certain illicit businesses misuse food additives for their financial gain. Overconsumption and improper application of food additives may be extremely dangerous for human health. Every single country establishes the recommended daily intake value of each addition fro safer purposes. Thus, there is an urgent demand for precise and trustworthy analytical methodologies (Cannavacciuolo et al., 2022).

Food packaging may increase shelf life and keep food from being contaminated. The main risk associated with food packaging is the leaking of toxic substances from the materials used for packaging, which also contributes to contamination of food products. When consumed with food, harmful pollutants can have a negative impact on health (Płotka□Wasylka et al., 2018). This raises the bar for the identification of these dangerous elements. Because of their light weight, low cost, and superior process ability, plastics are the most often used materials for packaging, which helps lower the expenses associated with food processing and shipping. Plastic materials are thought to make up around 50% of food packaging. Plastics have had many additives added to them to improve their functionality and toughness. Plasticizer, UV absorbent, antioxidant, and bisphenol compounds are only a few of the hazardous raw chemicals and additives found in plastic packaging that have been extracted and detected using HDESs.Some additives are completely prohibited as food additives due to their toxic nature. However, international use of these banned additives continues to pose a serious food safety concern (Efenberger-Szmechtyk et al., 2018; Farrán et al., 2015).

2.5.6 Cosmetics

A cosmetic item can be termed “green” whenever it contains plant-based active components, such minerals and plants, rather than chemically synthesized equivalents. It is preferable if it is manufactured using environmentally friendly, plant-friendly processing techniques in accordance with organic crops. To minimize the environmental effect, it is recommended to grow these cosmetics at zero km or on land close to the manufacturing laboratories, or to use sustainable modes of transportation. Different green goods have different qualities. It is essential to distinguish between organic, natural, and natural origin substances (Secchi et al., 2016; Mohamed, 2015). Chemical substances classified as natural components have not been refined or handled using mechanical, gravitational, or human techniques, nor have they been refined using naturally occurring solvents. They can also be removed from the air using any technique, dissolved in water, or heated to remove water. Naturally derived ingredients are those that come from plants, minerals, or animals and have undergone chemical processing or mixing with other ingredients; they do not include petroleum-

or fossil fuel-derived ingredients or ingredients that have been bio-manufactured through the use of processes like fermentation, condensation, esterification, or saponification to increase their performance or make them more sustainable (Dini & Laneri, 2021).

In 2020, the skincare and cosmetics sector needed to quickly change to satisfy the changing needs of a fickle and discriminating consumer base. Finding a balance between the natural and chemical components of cosmetics was the main problem. Notwithstanding the market's volatility, several patterns and associated industries exhibit encouraging signs of revival (Wan et al., 2022; Morin-Crini et al., 2019). In the realm of green cosmetics new trend have emerged recently such as nutricosmetics a nutritional supplement applied to the hair, nails, and skin to achieve beauty from inside. Three scientific fields of study pharmaceuticals, food, and personal care have produced nutricosmetics, sometimes known as beauty supplements. These can be firm or soft gel, pills, capsules, syrup, candies, or sachets that enhance personal care and include a concentrated form of vitamins, hyaluronic acid, minerals, or plant extracts. However, there is no dedicated regulatory framework for nutricosmetics at either the EU or USA levels (Saxena et al., 2017).

Beauty supplements are governed by the same regulations as dietary supplements; however, this work includes revisions to the nutrition matrix of cosmetics significance, bioactive molecules that may be used in cosmetics formulations, environmentally friendly technology for producing bioactive cosmetics ingredients and analytical techniques beneficial for dosing and purifying the active ingredients in vegetable and animal matrices. We aim to shed light on the nutricosmetic market waiting for a specific regulation for green cosmetics to help consumers make informed choices (Qidwai et al., 2018).

The manufacture and promotion of cosmetics and personal hygiene items is referred to as the "global beauty market." The average annual growth rate of this industry over the past 20 years has been 4.5%, indicating a tendency towards rising demand, particularly in the developing economies of Asia and Latin America. The scenario is also marked by the continuous appearance of new items, which is a result of the expansion of increasingly stringent criteria of beauty (Kuang et al., 2016). Nonetheless, public concern over the use of dangerous chemicals in cosmetics and the rise of ethical issues surrounding the cosmetics sector helped to propel the market for organic cosmetics. Naturally occurring cosmetics and organic products are typically linked to the "green" label, which is applied to goods that are environmentally friendly and manufactured according to certain guidelines. Common claims made in the context of green cosmetics are those that guarantee the goods are created in compliance with the Green Chemistry principles. It is described as the use of a set of guidelines that lessens or eliminates the use of hazardous compounds in the creation, production, and use of chemicals in order to limit the danger to the environment and public health (Barbulova et al., 2015; Dubey et al., 2022).

2.5.7 Energy

An energy source is considered renewable if it is replenished by natural processes at a rate equal to or faster than its consumption. A subcategory of sustainable energy is energy except for geothermal and tidal power, the majority of renewable energy sources eventually come from solar radiation. Utilizing the energy of the sun, photosynthesis processes plants to generate biomass, which is used as energy (Ratti, 2020). The Wind is the source of wind energy and also produced by the uneven heating caused by the sun of the atmosphere. Rain is a prerequisite for hydropower, yet rain is reliant on sunlight’s ability to evaporate water. Solar energy is the source of even fossils fuels, as they were originally formed from plant matter. Energy resources can be used straight away or converted into more practical kinds of energy. Windmills, water, and geothermal energy are a few examples of direct usage as are sun ovens. Biomass encompasses any type of plant or animal tissue including straw, dung, wood, and other natural resources that have the capacity to store energy. The energy contained in biomass can be extracted either by directly burning the material or by using microorganism to convert it into biogas (Weaver et al., 2017).

It has been projected that by 2040, the expected 10 billion people on Earth will require annual global energy consumption of 935 EJ, or 3000 W energy/per person. The technological potential of the world's winds is estimated to be five times that of the present energy consumption, or forty times that of the current electricity demand. At an elevation of 80 meters, this takes up 12.7% of the total land area. Natural gas supplies are expected to remain stable for the next fifty years, after which they are likely to be depleted. Nuclear energy which has only met 2% of our energy needs so far, is projected to be completely phased out by 2050 (Ostergaard et al., 2020; Gielen et al., 2019).

Developing and improving technologies for renewable energy sources, such as bioenergy, wind and solar, can reduce reliance on fossils fuels and decrease carbon emission. Green power is the term used to describe energy generated from renewable resources, which have a lower environmental impact than fossil fuels. Thus, green power includes electricity from small hydropower facilities, geothermal, solar, biomass, and wind farms. An endless supply of energy that refills swiftly is renewable energy (Güney, 2019). Energy doesn't pollute the environment or discharge harmful elements into the atmosphere, yet hydroelectric dams inflict harm to the surrounding vegetation and land area. Certain renewable energy methods have negative environmental effects. While hydroelectric dams may erect obstacles in the way of fish migration—a major issue in the Pacific Northwest where salmon numbers have been decimated wind turbines also pose a risk to soaring birds. Large tracts of land are needed for biomass and biofuel production. Distributing the collection across a wide region is necessary to transform the comparatively low-intensity energy that renewable energy sources supply into usable energy (Kuang et al., 2016). Figure 2.2 shows the different sources of energy used in different field such as, renewable energy (Biodiesel, hydropower, ocean waves, geothermal, solar/wind, and biomass while nonrenewable energy (crude oil, natural gas, coal, and nuclear).

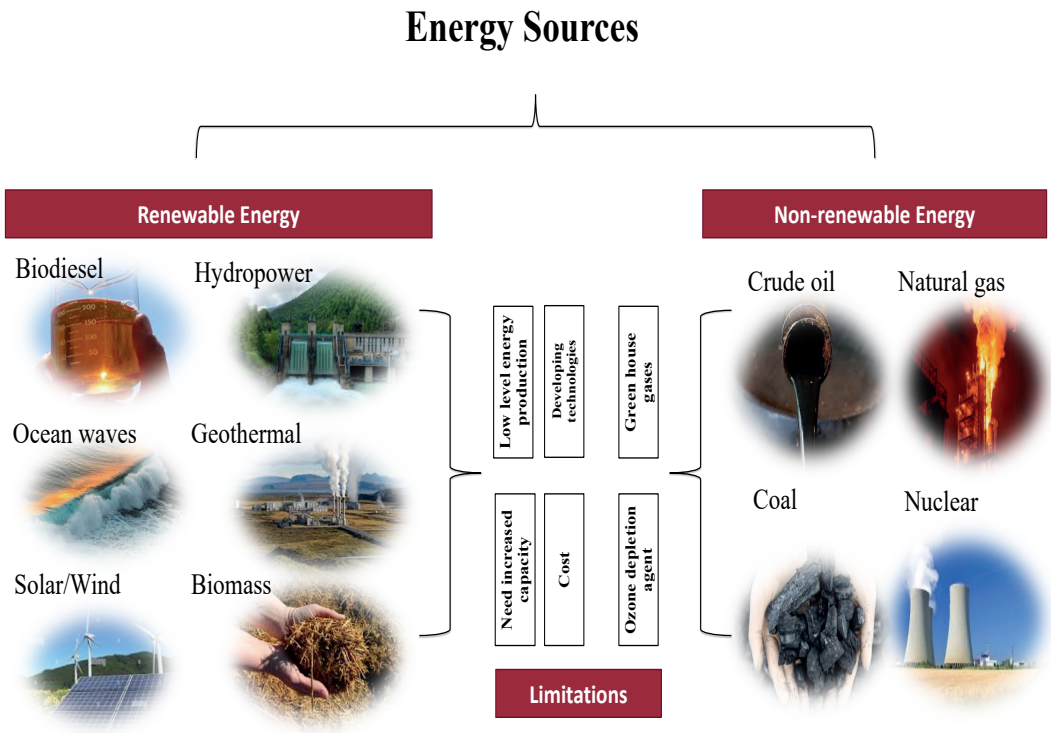


Figure 2.2 Types and categories of energy sources

2.5.8 Textiles Industry

The production of textiles uses a significant amount of water. The main contaminants found in textile effluent include recalcitrant organics, soaps, salts, color, toxicants, detergents, surfactant, inhibitory and chlorinated compounds. The hardest component of textile waste water to treat is dye, which can change on a daily or even hourly based on the campaign (Nimkar, 2018). Due to

the low COD/BOD ratio (less than 0.3) it is often challenging to treat textile industry wastewater using traditional biological methods. Two of the harshest processes that lead to the production of hazardous wastewater are desizing and scouring (Sun et al., 2021).

A combination of biochemical and chemical/physical processes appears to be promising in degrading such an effluent. The main issue is the presence of dyes in the wastewater since they are poisonous and recalcitrant. The dyes can be successfully degraded by both anaerobic and aerobic processes, but the best appears to be a combination of both. Treatment with living cells does not seem to be as effective as dye adsorption by dead cell (Barbulova et al., 2015).

In order to preserve energy, water, chemicals, and time while maintaining the performance features of the original alkaline scour systems, Novozymes developed an enzymatic technique (BioPreparation) for treating cotton textiles. According to field tests, substituting caustic scours or merging distinct scouring and dyeing processes into one might save water expenses for textile mills by 30–50% (Saxena et al., 2017). From scouring to finishing, 162 knitting mills typically utilise 89 million m3 of water annually. 27–45 million m3 of water would be saved annually with the new method. Comparing this technique to the traditional sodium hydroxide method also results in a 25% and 40% reduction in the biological and chemical oxygen requirements. Cost reductions of at least 30% would result from the switch. There are several benefits of using biomass instead of nonrenewable petroleum resources to make chemicals, such as reduced or zero net CO2 emissions (Sahu & Singh, 2019; Felgueiras et al., 2021).

Global production of dyes and pigments amounts to around 10,000 distinct types, with a yearly market volume exceeding 7 × 105 tonnes. A range of structural variations exist for dyes, including anthraquinone-based, azo, reactive, dispersion diazo, acidic, basic, and metal-complex dyes. In the visible spectrum, all absorb light. Just 2% of the colors generated are released into the wastewater directly (Lei et al., 2017). Furthermore, 10% is wasted while colouring textiles. Numerous dyes have been proven via studies to be extremely hazardous to the environment, mutagenic, and carcinogenic. Due of the intense color of untreated dye effluent, less sunlight can reach it, which inhibits photosynthesis. They negatively impact flora and wildlife, are harmful to fish and other mammals, and stop the growth of microorganisms. They can induce bowel cancer and problems in the brain development of fetuses since they are carcinogenic. The color of the textile dye effluent can be removed using a variety of chemical and physical techniques. One unresolved issue meanwhile, related to how to dispose of the precipitate or sludge. Adsorbent addition offers a number of benefits such as reduced toxic effects on microorganism due to the adsorption of harmful chemical and improved sludge-settling properties (Saxena et al., 2017; Uddin, 2021).

2.5.9 Electronics

The enormous global scientific and engineering work that has supported the growth of the modern solid-state electronic industry started with the development of the integrated circuit in 1959, which is largely attributed to the work of Jack Kilby (Texas Instruments Inc., Texas, USA) and Robert Noyce (Fairchild Semiconductor International, Inc., California, USA). Electronic technology has advanced at a rate that is exponential since Moore's Law was accepted as the basis for advancement (Zhu et al., 2016). In response, electronics technology has been used worldwide in an ever-growing variety of complicated consumer, medical, space, industrial, and military applications due to the frequent availability of computer chips that are either more powerful or less expensive. Modern electronics provide enormous social and economic benefits; nearly every endeavor undertaken by humans is impacted by solid state electronics to some extent.

The worldwide consumer electronics industry is predicted to reach over 1793 billion USD in 2024, having been valued at roughly 1180 billion USD in 2018 (Hsu et al., 2019). Electronics trash (e-waste) is produced in large quantities when the sheer number of electronics devices and related semiconductor devices, including silicon solar cells, is coupled with the quick turnover of

older technology that is replaced in a short amount of time. Consider the 20-50 million tones of consumer electronics that are reportedly thrown out annually around the world's current municipal solid garbage is represented by this (Kang et al., 2015). The increasing number of semiconductor based gadgets including rooftop photovoltaic cells, being distributed globally are contributing to the growing amount of e-waste from consumer electronics. It is predicted that by 2020 there will be 35000 tonnes of solar waste rising to 60 million tonnes by 2050, despite the fact that these devices have a far longer lifespan than consumer electronics (Marr & Marr, 2016). In the absence of measures to gather, recycle, and reduce our dependency on conventional solid-state electronic devices, the quantity of e-waste will have a significant and negative impact on the environment. Furthermore, burning plastic releases volatile substances that are classified as category 1 carcinogen, such as dioxin derivatives, polychlorinated biphenyls, and polychlorinated dibenzofuran. When e-waste is disposed of in landfills, large amounts of dangerous elements including arsenic, mercury, chromium, and lead can leach into soils and streams from semiconductor equipment (Hakola et al., 2020).

Green electronics which replaces some semiconductor electronics related functions and device structure with more ecologically friendly alternatives is becoming more popular as a means of reducing the amount of e-waste produced and its associated environmental impact. European Standards EN13432 states that under specific defined conditions of humidity, temperature, and oxygen concentration at least 90% of all materials used in green electronics must be transformed by fungi or microorganism into harmless components such as biomass, water, and carbon dioxide within 6 months of abandonment (Kang et al., 2015; Lei et al., 2017). The use of degradable materials offers additional, although specialized, benefits for a variety of applications beyond the elimination (or at least reduction) of harmful elements in the processing procedures and end products of green electronic technologies. In the context of green electronics the use of biodegradable or biocompatible materials may also be helpful in the creation of medical implants by reducing the need for surgical device removal after diagnosis, therapy, or monitoring thereby improving patient outcomes. Additionally, there is growing interest in biocompatible and biodegradable electronics materials due to the development of wearable electronics especially on flexible substrate (Liang et al., 2019; El-Seedi et al., 2019).

2.6 Future Perspectives

• A global awareness of environmental issues grows the importance of green chemistry continuous to increase. Green chemistry aims to design chemical products and processes that reduce or eliminate the use and generation of hazardous substances. Despite significant advancement the field faces ongoing challenges and opportunities for growth.

• Interdisciplinary collaboration and cooperation are needed to realize the full potential of green chemistry and engineering. Implementing real time monitoring and control systems can enhance the efficiency and safety of chemical processes. Future perspectives include integrating advanced analytical techniques and digital technologies (process analytical technology and AI) into green chemistry.

• Catalysts play a crucial role in making chemical process more efficient and sustainable. Innovation in biocatalysis, nanocatalysis and photocatalysis could lead to significant reduction in energy consumption and waste generation.

• Transition from fossils-based feedstock to renewable ones is essential for sustainable chemistry. The developing efficient method to convert biomass, CO2 and other renewable resources into valuable chemical and materials.

• The creation of safer compounds will go more quickly if high-throughput screening and predictive toxicity models are developed further. Solvents are often a significant source of waste and environmental impact in chemical processes.

• Public education campaigns will encourage informed consumer behaviour and assist reduce green washing. Data on chemical safety should be accessible to the public through reform of chemical policies. Improving chemical production and product development requires supply chain transparency.

2.7 Challenges in Green Chemistry

• One of the significant barriers to the adsorption of green chemistry is economic viability. Developing and scaling up green processes and materials can be costly, and industries may be reluctant to invest without clear financial benefits.

• Developing green processes that are scalable and economically viable for industrial applications is a significant challenge. Ensuring that green products and materials meet or exceed the performance of traditional counterparts is essential for adoption.

• Renewable feedstock can be more expensive and less consistent in quality compared to fossils based resources. Significant investment in research and development is required to develop new green technologies and processes which may not yield immediate returns.

• Effective regulatory and policy frameworks are essential to promote green chemistry. However, inconsistent regulations and lack of incentives can hinder progress. Complex and varying regulations across regions can pose challenges for the development and commercialization of green chemicals and processes. Insufficient incentives for adopting green chemistry practices such as tax breaks or subsidies can deter industries from making the transition.

• Raising awareness and educating stakeholders about the benefits and practices of green chemistry is crucial for its adoption. There is a need for comprehensive education and training programs in green chemistry for students, researchers and industry professionals. Moreover, increasing public awareness about the environmental and health benefits if green chemistry can drive demand for sustainable products and processes.

Conclusion

The global public perception views the chemical industry as highly polluting with concern about the safety, health, and environmental impacts of chemical products and manufacturing. Despite a significant reduction in emissions since the mid-1980s, this perception persists influenced by increased data accessibility through NGOs and awareness of the incomplete understanding of the long-term effects of many industrial chemicals. Innovation such as finding new use for CO2, biomass and advancements in biotechnology are seen as solutions to these problems, safer processes, offering waste reduction, lower energy and raw material usage.The adoption of life cycle analysis by all industries is essential, alongside the promotion of responsible consumers who reduce recycle and reuse products.This approach contrasts with the prevalent use and throw culture in the US and Europe, which needs reconsideration for sustainable development. Products should be evaluated for sustainability based on their net energy release.Furthermore, Green chemistry characterized by continual improvement, innovation, and interdisciplinary research require significant financial and collaborative support from government, industries and NGOs.Achieving environmentally benign chemical processes and product is crucial for preserving the world for future generation. Without government intervention green chemistry and greenhouse gas emission reduction will remain theoretical rather than practical.

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