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Sustainable Chemical Alternatives

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Abstract:

The ruthless human desire for growth and development is killing the humankind. Human activity is affecting all the four domains (lithosphere, hydrosphere, atmosphere and biosphere) of Earth. All the domains are polluted to such an extent that they are no longer self-healing. Humans too face the wrath of their acts in the form of pandemics, natural disasters, unpredictable weather, greenhouse etc. Carcinogens (mostly man-made) have invaded to such an extent that cancer is touching nearly every household. A radical change can save humankind from further harm. Sustainable chemical alternatives for established processes such as ethyl lactate instead of benzene as solvent (synthesis), enzyme-based catalysts instead of heavy metal catalysts (industries), disposable materials from corn/sugarcane starch (daily needs), and neem/ eucalyptus oil-based pesticides (agriculture) etc. are need of the hour. Such chemicals or products help reduce the pollution load on the four domains of the earth, providing a better living environment for the present and future of mankind.

Keywords:

Sustainable, pollution, chemicals, cancer, alternatives

Introduction:

Trinity of the sciences, mixing of elements (chemistry), perfect alignment of atoms/ molecules (physics), and correct amount of substance (mathematics) has created this universe. Millions of years later, when humans were able to interpret this fundamental principle of creation, they started creating things of their own desire, which provided more comfort and a competitive edge. The Industrial Revolution further fueled the rate of the production, products were made rapidly to cater to an ever-growing human population. All products produced were accompanied by by by-products, nature being a clever chemist always produces useful by-products, but the same does not apply to human-developed production processes. Barring a few examples, such as enzymatic reactions [1], nearly all the industry-produced by-products pollute all the four domains of the earth. This results in creating an environment that is full of malaises, affecting all body parts of humans with fertility, respiratory, cardiac and dermal taking a major hits. Carcinogens are ever accessible in the form of smoke, pesticides, food preservatives, cosmetics, hair-care products and more. These make a quick entry into the human body where when combined with unhealthy eating choices such as fried and sugary foods [2], they rapidly develop into a full-grown cancer. It is evident with rapidly rising cases of various types of cancer among humans globally including Indians. Moreover, the earth is getting depleted of its resources and getting filled with pollutants such as greenhouse gases, micro and nano-plastics, toxic chemicals, and biodegradable and non-biodegradable waste.

Green Chemistry and Sustainable Chemistry

Green chemistry was developed with the idea to reduce; if not stop the chemical processes that involve or produce hazardous materials. It is a practical paradigm shift with an aim to provide a "sustainable" environment both for Earth and its inhabitants. The primary goal of green chemistry is designing chemical processes and products in such a manner that they cause minimal effects to the biosphere yet are industrially accepted. In the 1990s, Paul Anastas and John Warner articulated green chemistry as a new approach requiring chemical synthesis generating less waste, with less energy, and more safety for workers and the environment [3]. They proposed 12 principles, based on some earlier suggestions by the US Environmental Protection Agency [4], and others [5]. The European Chemical Agency [6], and the Organisation for Economic Co-operation and Development (OECD) [7] too were aiming at cleaner processes, safer products and an increasing use of renewable rather than fossil-based resources [8].

Independently in Europe during the early 1990s, Sustainable Chemistry was used by the OECD as: "a scientific concept that seeks to improve the efficiency with which natural resources are used to meet human needs for chemical products and services [7].

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Sustainable chemistry encompasses the design, manufacture and use of efficient, effective, safe and more environmentally benign chemical products and processes [7, 9] The guidelines for sustainable chemistry and similar to those of green chemistry but sustainable chemistry aims at developing processes and products that will provide increased performance and value while meeting the goals of protecting and enhancing human health and the environment. The environmental and societal benefits of sustainable chemistry were suggested to include [10]:

- Avoiding the use of persistent, bio-accumulative, toxic, and otherwise hazardous materials.
- Using renewable resources and decreasing consumption of non-renewable resources.
- Minimising negative environmental impacts of chemical processing and manufacturing.
- Providing technologies that are economically competitive for and advantageous to industry.

In 1999, Otto Hutzinger, an Austrian-Canadian environmental chemist, published an editorial in response to a controversial debate around the terms of "green chemistry" versus "sustainable chemistry" within the Federation of European Chemical Societies, Division of Chemistry and the Environment [10, 11]. Hutzinger clearly pointed out a fundamental difference between the two concepts: whereas sustainable chemistry represents the "maintenance and continuation of an ecologically-sound development", green chemistry covers the "design, manufacture, and use of chemicals and chemical processes that have little or no pollution potential or environmental risk". This early conceptual delimitation attributes the development of society within the ecological boundaries to sustainable chemistry, whereas green chemistry is confined to chemicals, products or processes themselves and their technical feasibility [11].

Sustainable Chemical Alternatives:

Renewable Resources: The most widely used non-renewable resource by mankind are fossil fuels, which make all man-made things power and function but their reserves are depleting quickly to meet the energy demands, that it is has become one of the major global issues. The gathering of greenhouse gases in the atmosphere, causing global warming and the urgent requirement of renewable and eco-friendly energy resources has been a great concern. Solar, wind, hydroelectric and green hydrogen, with their promising clean features, could be the best options for the future energy system [12]. The processing of crude oil has provided many types of organic molecules which gave birth to many industries such as fine chemicals, pharmaceuticals, polymers etc. Polymers and especially micro/

nano-plastic have turned out to be a global killer, as it has a presence in our food and water everywhere [13]. Biomass-based products decompose under natural conditions producing non-toxic fragments and reducing plastic pollution [14].Alternatives derived from renewable resources, such as plant-based feedstocks (e.g., biomass, cellulose), and agricultural residues, are proving to be sustainable alternatives as disposables created using sugarcane/ corn pulp are easily available. Sustainable films, coatings, and packaging materials prepared using cellulose and its derivatives as raw material bring with them both biodegradability and renewability advantages. Biodegradable polymers, such as polylactic acid (PLA) and polyhydroxyalkanoates (PHA) [15], are sustainable alternatives to conventional plastics.

Green Solvents: Solvents are the key elements for most chemical transformations and manipulations. Solvents are designed to keep together reagents in chemical reactions, but subsequent chemistries such as purification techniques such as recrystallization, liquid-liquid extractions or chromatographic separations all are possible only with solvents [16]. Moreover, solvents are components of many consumer goods and household products such as degreasing cleaners, paints, varnishes, or building materials. Many sectors (including laboratories) and industrial branches consume a combined total of millions of liters of solvents every year [17]. A wide range of organic molecules are utilized as solvents such as aliphatic and aromatic hydrocarbons, halogenated compounds, ethers, esters, ketones, etc. Most of these organic solvents are volatile, potentially flammable and explosive, and many of them are toxic [17]. As an example of such hazards, the National Institute for Occupational Safety and Health (NIOSH) has recognized some common solvents like benzene, carbon tetrachloride, and trichloroethylene as carcinogens, 2-ethoxyethanol, 2-methoxyethanol, and methyl chloride as reproductive hazards, while others like n-hexane, tetrachloroethylene, and toluene have been tagged as neurotoxic [18]. Finding alternative solvents (green solvents) to traditional ones is necessary to achieve less dangerous reactions and processes for human health, and more environmentally friendly but equally effective. This would also lead to safer manufacture and less toxic industrial and household products. The first obvious choice was water, being universal solvent attention was natural for water but the organic nature of most chemistries made it not the perfect choice, even though some types of reactions exhibit an unusual reaction rate acceleration compared to the same reaction in an organic solvent [19]. Subsequently, many other options namely liquid polymers, ionic liquids, Deep Eutectic Solvents (DESs), Supercritical Fluids (SCFs), and Bio Based Solvents [20], have been reported. The self-developed solvents selection guides showing a greener alternative for solvents classified as undesirable were released by big pharmaceutical manufacturers, highlighting facts such as benzene should be avoided, toluene is usable, but ethyl acetate (synthesis) or ethyl lactate (solvent for paints, emulsions etc) is preferred [21].

Natural Extracts and Fibres: Agriculture, pharmaceuticals and cosmetics are three branches that are essential to humans, the last two branches can be considered additions as a result of modern lifestyle. The products from these branches are loaded with chemicals such as pesticides, growth stimulators or inhibitors, and biochemical-activity modifiers, which over time produce undesirable side effects and can be life-threatening. Food grains, fruits and vegetables are all grown with the help and support of various chemicals (fertilizers, pesticides, growth hormones, ripening agents/sweeteners), and these stay with the product till end-of-life. Packaged food is even worse, loaded with sugars, salts and preservatives that never provide what is claimed, better brain, longer height, smarter person. No pharmaceutical drug is free from side effects, it could be mild/high gastric flux or fatal cardiac fluctuations [22]. Desire for Asian shiny straight long hair, and glowing Korean skin has put many in death-like situations, but the consumer is both king/queen and a fool [23]. With the rise of phrases such as "organic farming", "natural", and "plant-based" many products are being reported as containing only chemical-free, with plant extracts or essential oils, proving to be sustainable alternatives to synthetic chemicals promoting good health and a safer environment to live. Easy availability of compost manure, eucalyptus or neem-based manures/bio-pesticides and household disinfectants etc have changed how plants are maintained even at the household level [24]. Sustainable fibers like hemp, flax, kenaf, jute and bamboo can replace conventional materials in textiles (nylon, polyester etc.) and packing materials (polyvinylchloride, polystyrene, etc.), reducing the environmental impact of these industries [25].

Enzymes: Enzymes found in nature possess excellent catalytic systems that manage the reactivity and selectivity. Their diverse functions and capabilities make them an attractive partner for sustainability [1]. Lipases are biocatalysts with the most applications in industries, both for (a) hydrolytic processes, in the food and laundry industries, and for (b) the synthesis of a large variety of esters via esterification, transesterification, interesterification, and (poly)condensation reactions in the fragrance and flavor, cosmetic, and pharmaceutical industries, as well as for the synthesis of biobased detergents, polymers, and biodiesel, among others [26, 27]. Polyester hydrolases have been detected in numerous fungi and bacteria, prevalently Actinomycetota from soil and compost habitats containing decaying plant materials where they play a crucial role in the recycling of plant biomass [28]. Among a wide range of plant polymer-degrading enzymes, many thermotolerant and thermophilic Actinomycetota produce ester-hydrolysing cutinases degrading the plant polyesters cutin and suberin. Actinomycetota has become an important source of thermostable synthetic polyester-hydrolysing enzymes and their cutinases have been served as scaffolds for the construction of engineered variants suitable for biocatalytic recycling processes [29].

Conclusion:

Humans have the capability to create beautiful things, but also can cause indescribable destruction and pain. Nature as a promotor of growth works in a manner so that the equilibrium of sustainability always stays in balance; but when things are out-of-balance her wrath becomes obvious in the form of a natural calamity, pandemic, or unexplained weather conditions. To respect her the 4Rs (reduce, reuse, recycle and refuse) are to be practiced diligently. Moving from fossil fuel and its uncountable off-shoot products will not be easy, the suppliers will always oppose such a move, but the true answer lies in simple questions like, will there be drinkable water left before all the oil disappears? Or when will fresh air be sold in bottles? Global warming is a clear indication that the human race has passed the danger mark, now all that remains is what we leave behind for our young ones. Ayurveda, the ancient Indian system of good health has always advised us to be close to nature, and accept the nature with its continuous changes. Will the rules of nature be a guiding principle for a sustainable future? Looking for solutions from basic gifts of nature seems like a good starting point for the creation of a sustainable future.

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