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Sustainability through green chemistry and engineering

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Abstract

Nowadays, the terms "sustainability" and "sustainable development" are practically everywhere. So how exactly can we attain sustainability's objectives, and what steps can we take?

Green Chemistry (GC) or Sustainable Chemistry works to develop chemical products that don't use potentially harmful elements that could harm both people and the environment. In this regard, the 1990s-era Green Chemistry areas are quickly evolving technical advances that offer the most ecologically friendly solutions for the long-term advancement of science and technology. The environmental impact is decreased and chemical process economics are improved using green chemistry. While reducing environmental impact, Green Chemistry can be used to create environmentally friendly synthetic protocols, generate life-saving pharmaceuticals, environmentally friendly agrochemicals, new enzymes for biocatalytic chemical processes, innovative renewable energy sources, and are offering ground-breaking answers for both the present and the future. In the past ten years, various industrial processes have used "green" solvents and water-based industrial reactions The development of sustainable energy sources, the production of food and the accompanying agricultural practices, the depletion of nonrenewable resources, and the dispersion of poisonous and hazardous elements in the environment are some of the most important environmental concerns facing the globe today. In this review paper, we give particular examples and case studies and discuss the critical role that green chemistry and engineering play in addressing these issues.

Keywords: Sustainability, hazardous, non-renewable, depletion, biocatalysis

1. Introduction

The world and civilization cannot continue on their existing paths. The five fundamental obstacles to sustainability—population increase, energy use, food production, global climate change, and resource depletion—make it obvious that the way things are done in society today cannot continue indefinitely.

While it took all of human history up to 1927 for there to be two billion people on the planet, it only took 72 years to triple that amount and add another four billion. In the following ten years, there will be an additional billion people on the earth, with China adding as many as the United States is currently home to. Around 2050 (The World at Six Billion; (ESA/P/WP.154); United Nations: New York, October 12, 1999.) [1], the world's population is projected to exceed 9 billion people.

According to actual evidence on population increase, sustainable population growth and a higher level of living are strongly correlated. 95% of the 78 million individuals who are born each year into the world reside in less developed areas. This fact draws attention to one of the main obstacles to sustainable development:

Higher living standards have historically been associated with detrimental effects on both human health and the environment, so we must find ways to improve quality of life, particularly in developing countries, while also minimizing the impact on the environment. Higher living standards are linked to stable population growth.

So, scientists and engineers will be tasked with solving this problem to a major extent, with the help of green chemistry and engineering technologies.

The distribution of food supplies presents a greater challenge than supplying adequate food for a population of six billion people. But as the world's population rises this century, unsustainable agricultural practices will put strain on the planet's carrying capacity (OECD Environmental Outlook, 2001) [2]. The attempts to mitigate the environmental repercussions of their use will eventually become monetarily unsustainable, just as the depletion of fossil fuels is fundamentally unsustainable. There is now widespread agreement that the entire human population cannot live in the same way as the industrialized nations due to difficulties with global resource depletion and the spread of persistent and harmful substances. For instance, in 1996, the "ecological footprint" of OECD member nations—a measurement of human impact on the planet's ecosystems—was more than three times greater than that of non-OECD countries (Living Planet Report 2000. Loh, J *et al.*) [3]. According to estimates, a population of 5.8 billion people would need three earth equivalents of resources to survive, whereas a population of 10 to 11 billion people would need six earth equivalents (Rees, W.; Wackernagel, *et al*. 1994) [4]. Alternately, it has been calculated that the globe can only sustain two billion people at a middle-class standard of living in the long run (Mckibben *et al*. 1998) [5].

It is important to keep in mind that the world has previously engaged in unsustainable practices that it managed successfully, but this should not be overemphasized. When horses were the primary mode of transportation, it was prophesied that if current trends persisted, cities would be physically buried under accumulated dung. The projected demise of humanity was prevented by the development of new ways of transportation. The difficulties right now, though, are far more basic. Some people believe that productivity and efficiency are crucial components of a sustainable future. The productivity per person increased dramatically during the industrial revolution. Nonetheless, the total amount of resources used in absolute terms significantly rose (OECD Environmental Outlook, 2001) [2]. The current information technology revolution has resulted in enormous productivity increases and improvements in the efficient use of resources. These improvements, meanwhile, pale in comparison to the orders of magnitude needed for improvement.

What can molecular science and engineering provide in terms of tackling sustainability's problems? The science and technology discussed in this paper offer some case studies that can be used to support the claim that molecular advances will be required to achieve sustainability. The majority of the existing dangers to the health of the biosphere and the systems that support it are either derived from inherent qualities inside chemical structure or can be significantly reduced by these properties.

The effects of creating materials and molecular changes that are more ecologically friendly are felt across the entire lifecycle, from the intake of materials through the end of life and beyond. The concept of "beyond" includes the capacity to create molecular structures that permit reincarnation, reuse, or purposeful degradation into harmless compounds. According to actual statistics (see Table I), improving the standard of living for people in developing nations is an efficient strategy to bring population growth down to manageable levels. Yet it is crucial that this be accomplished in a way that significantly lowers the quantity of resources required for that improvement in quality of life. Chemists, chemical engineers, and those working in the field of molecular design are the ones who will be directly responsible for tackling this challenge. Innovations in materials and energy generation and storage, for instance, are necessary to provide the level of efficiency and safety needed on the scale of magnitude. A good challenge is one of the few things that chemists and chemical engineers enjoy more than anything else. In many ways, this era of history is ideal for chemical engineers and scientists. The problems facing the world are without a doubt the biggest problems that humanity has ever encountered. Simply put, humanity won't be there to face any more obstacles if we can't handle the challenges of preserving the biosphere's viability.

Table 1: Estimates of Population Growth from the United Nations

Major Area	1999 Population. (Millions)	Population growth rate. 1995-2000 (%)
World	5978	1.3
More developed region	1185	0.3
Less developed region	4793	1.6

Issues with Sustainability

The main problems for sustainability must be at the core of efforts in green chemistry and engineering. The production of energy, food, and resources, as well as the presence of environmental toxins, are some of these.

By creating next-generation goods and processes, the concepts of green chemistry (Anastas, P. T.; Warner, J. C. *et al*., 1998) [6] can be used to address these significant problems.

Climate Change Worldwide

Global climate change is increasingly acknowledged as a significant problem of growing concern. The following topics—energy generation, storage, and transport—will all continue to play a significant role in finding solutions. There will need to be the development of new, non combustion sources of heat and power. Chemical engineers and chemists have proven they can employ carbon dioxide to add value and improve performance to a variety of products, including cement and polymers. Whatever much carbon dioxide is captured by these applications on a product or process-by-process basis, it is still a small portion of the overall issue and should only be seen as a technological beginning deeply in the wells to generate carbonates. In other applications, carbon dioxide might be manipulated to react with road surfaces and other components of our infrastructure to generate carbonates in ways that improve performance and even "repair" fissures. The key idea here is that, as long as carbon dioxide is a necessary byproduct of combustion processes, it must be put to use in order to transform it from a waste into a usable feedstock. (P. T., Heine, L. G., Williamson, T. C.*et al*., 2000)

Energy Generation

It is crucial that existing technologies work to develop the most clean versions of the dominating fossil fuel sources in the short term. But, it is important to understand that in order for our long-term energy sources to be sustainable, they must by necessity be renewable. Agriculture's current methods are not sustainable. Pesticides that are very targetspecific and do not remain in the environment have been created thanks to breakthroughs in green chemistry and engineering. In addition, the amount of fertilizer required has been lowered as a result of the development of novel fertilizers and fertilizer adjuvants, lowering runoff that pollutes both surface and ground water. Green Chemistry and Engineering advancements in agricultural chemicals have the potential to make output in the most underdeveloped parts of the world more productive. (Anastas, P. T., Heine, L. G., Williamson, *et al*., 2001) [6].

Depleting Resources

The rate at which the Earth's resources are now being consumed by the human population is unsustainable. Despite the fact that some of the most cutting-edge materials and life-saving medications are made from feed stocks generated from petroleum, we still use petroleum as fuel. As a result of present methods, rare minerals are also being depleted and dispersed at an unsustainable rate. Green Chemistry concepts are leading to the creation of renewable and resource-efficient goods and procedures. Yet, in most circumstances, this will not result in the kinds of four-fold and tenfold gains required for sustainability. Instead, simply optimizing existing technologies may produce improvements of 10 to 25%, or in some cases even 50%.

This magnitude of improvements requires a molecular redesign as well as the use of renewable resources like carbon dioxide, agricultural and other bio waste, and substances like chitin. The tasks required by society will need to be provided by nano science applied to nanotechnology with a dramatic reduction in material use. (Bozell, J. J., Patel, M. K., Eds.*et al*., 2006) [10].

Environmental Toxics

The design of chemical products and procedures for lessening the inherent hazard of materials is outlined in the concepts of green chemistry. Characteristics of chemicals and other materials, such as toxicity, persistence in the environment, and bioaccumulation, can be controlled and decreased through appropriate molecular design, just like any other physical feature. It is possible to create anything so that it does not cause cancer, just as one may design a dye to be red. A material can be made to be flexible and not disturb hormones in the same way that it can be made to be flexible. The information, abilities, and methods needed for this kind of design are the same ones that chemists have used for generations. Another performance criterion that needs to be taken into account is the viewpoint that minimized intrinsic risk, whether it be physical, global, or toxicological. (Lichtenthaler, F. W. Ed.; VCH: Weinheim, *et al*., 1991) [9].

This review paper throws light on some innovative thinking in realising sustainability goals through the use of tasteful science and engineering. The fact that the discipline of green chemistry and engineering covers a wide range of materials, goods, and procedures is fascinating. Green Chemistry and Engineering technologies offer both incremental and completely novel answers to technical problems and demands. These technologies also clearly have positive effects on the environment and the economy.

Catalysis is one field of active research and catalysis offers to environmental sustainability may have been missed or overstated as a result of its well-known economic benefits. Potentially enormous material savings can be gained when a really catalytic process takes the place of a stoichiometric reaction. (Theopold, Gaynor *et al*.)

More selective reactions are made possible by catalysts, which increase resource efficiency by reducing waste byproducts. Equally crucially, reducing the amount of energy required for a chemical change can have significant advantages, particularly for large-scale processes.

One of the most crucial areas of research in green chemistry and engineering is likely biofeed stocks. Topics ranging from agriculture to global climate change are impacted by this field. This field has an impact on a variety of subjects, including agriculture, global climate change, and energy generation. Gao and coauthors address the synthesis of biocatalysts and the conversion of biomass to chemicals. Wool, Wyman and coauthors provide examples of the developments in science and technology related to biofeedstocks.

Case Studies and Applications

The Green Chemistry and Engineering technologies that are discussed in this paper provide concrete examples of how the principles and objectives of industrial ecology and sustainable development might be carried out. Fiksel looks at how the idea of industrial ecology may assist sustainable development while also ensuring shareholder value creation from a systems perspective. He explains how industrial ecology's comprehensive framework may direct the transformation of. He explains how transforming industrial systems from linear models to closed-loop models that more closely mirror the cyclical processes of ecosystems can be guided by the comprehensive framework of industrial ecology. Fiksel goes into more detail about how the field of green chemistry and engineering represents a significant set of design techniques for advancing the objectives of industrial ecology through basic discoveries.

Wyman *et al*. examines lignocellulosic biomass as a low-cost, sustainable resource that can be used for the large-scale manufacture of organic fuels and chemicals in order to satisfy the needs for future energy production and resource utilization. The reduction of carbon dioxide and other gases suspected to contribute to global warming can be achieved by converting biomass for these uses. In addition to reducing the usage of petroleum-based chemicals and goods, the conversion of biomass for these uses can help reduce the amount of carbon dioxide and other gases known to contribute to global warming. Advances in biomass conversion technology can potentially offer significant tactical and economic benefits. Collins and coauthors' main objective is to employ catalysis to lessen the dispersion of poisonous and dangerous substances in the environment. Their research focuses on the catalytic activation of hydrogen peroxide, a technique that holds great potential for the pulp and paper sector. Their catalysts offer a brand-new, completely chlorine-free method by triggering hydrogen peroxide to quickly bleach wood pulp with good selectivity at relatively low temperatures. Moreover, the effluents from chlorine dioxide bleaching plants that contain "colour" can be removed using catalyst-activated peroxide at low peroxide and tiny catalyst concentrations. The prospective uses for this technology that aim to decrease capital and operating costs, raise product quality, improve environmental performance, and increase energy efficiency are also focused upon.

The run-off of chemicals into groundwater is one of the environmental problems associated with agriculture, and Thompson and Sparks describe one green chemistry strategy to assist solve this issue. They explain how an integrated pest management (IPM) method that includes high levels of performance but with benign environmental consequences is supplying a greener option for agriculture through the fermentation of a naturally occurring soil bacterium. IPM technology is a useful technique for increasing food production and because the compound does not leach, bioaccumulate, volatilize, or persist in the environment, IPM technology is a useful tool for increasing food and fibre production on smaller acres while preserving the ecosystem. The technology mentioned illustrates how more ecologically friendly food production can be achieved.

Catalysis is used by Theopold and colleagues to address the need for industry to reduce the production of toxic byproducts and to utilise waste streams, particularly those that include gases suspected to contribute to global warming. Using oxygen and nitrous oxide as terminal oxidants is a desirable environmental alternative. The molecules' kinetic inertness is a drawback to this method, though. By attaching to transition metals and activating dioxygen and nitrous oxide, Theopold and colleagues hope to create homogenous catalysts that can carry out selective oxidations. Catalysis is used in Weinstock and coauthors' study with the aim of reducing the usage and release of hazardous and toxic substances into the environment. Its environmentally friendly method is based on an equilibrated polyoxometalate salt and oxygen solution, with one of its main uses being the bleaching of wood pulp used to make paper.

Their study outlines an innovative and all-encompassing method for creating soluble transition metal catalysts for aerobic oxidation in water. This chemistry, which differs from conventional technologies in that it only requires oxygen and water and generates no liquid waste, eliminates the numerous and efficacy of herbicides and insecticides. In greenhouse and field experiments, the usefulness of this technique has been successfully illustrated.

The technology of atom transfer radical polymerization, created by Gaynor and coauthors enables the creation of precise polymers with preset molecular weights, functions, and topologies. It is feasible to create polymers with unique applications thanks to the ability to modify material properties. This approach enables the production of materials that outperform equivalent polymers in terms of performance, material consumption, and catalytic waste production. These polymerizations can also be done in media that are benign to the environment, like water, supercritical or liquid carbon dioxide, and ionic liquids. The employment of chemical procedures that are less dangerous than traditional ones thanks to this technology helps save resources.

The process of creating a new technology is one of the initial phases in its implementation. As was already said, one of the main tenets of green chemistry is the design of a material or procedure with the intention of preventing pollution. Hendrickson offers a strict system of synthesis design that assists in finding all the optimal syntheses for any given target chemical to help with this design process. The design model, which is based on skeletal dissection and characterisation of substances and reactions, is put into motion using Hendrickson's SynGen programme. When using potentially dangerous substances must be used, the usage of such design programmes is extremely helpful in preventing wasteful resource consumption.

Gao and coauthors examine the application of catalysis in the synthesis of industrial biocatalysts and the conversion of biomass into chemicals. The production of a bacterial enzyme in starch media, including starch from maize and potato waste, is examined using a genetically modified Saccharomyces strain that breaks down starch. When it comes to recycling trash and reducing the use of dangerous and harmful chemicals in conventional production methods, the capacity to use biomass as a feedstock is beneficial. Berejka has investigated ways to reduce the usage of dangerous substances. Ionizing radiation produced by electron-beam accelerators and photoinitiated processes brought on by strong UV light have both been examined by Berejka. With the use of these technologies, the industry has been able to do away with the requirement for volatile organic compounds in coatings, inks, and adhesives. These procedures also use less energy and produce fewer wastes, which helps to conserve both energy and resources. By precipitating sulphur dioxide and nitrous oxides from stack gases and by dehydrohalogenating harmful halocarbons found in wastewater and soils, ionising radiation can also be utilised to reduce the quantity of garbage that is delivered to landfills. By implementing the utilisation of biobased materials, Wool and coauthors. The use of new and improved materials generated from renewable resources has been investigated, and they have researched the usage of enhanced, innovative materials that may either biodegrade or be recycled and are made from renewable resources. Plant oils, natural fibres, and lignin can all be used to create high-performance, inexpensive materials. These bio-based components are coupled with lignin, glass fibres, and natural fibres to create new low-cost composites that are practical for numerous high-volume applications. Agricultural machinery, automotive sheet moulding materials, civil and rail infrastructures, maritime applications, and the construction sector all use these composites. This study not only encourages conserving non-renewable resources and energy, but it also suggests ways to reduce carbon dioxide emissions when more biomass is cultivated for these uses. Fossil fuels are not a long-term option for a sustainable future, as was previously discussed. Green chemistry and engineering can assist make the technologies now in use more environmentally friendly, though, while we wait for fully developed sustainable energy technologies. The creation of a system to simultaneously cut emissions and turn byproduct waste streams into value-added goods is the main goal of Maroto-Valer and coauthors' research. For instance, the system described combines the installation of low-nitrogen-oxide burners, which effectively reduce nitrogen oxide emissions, with methods for managing the rise in byproduct streams that results, which are primarily fly ash and unburned carbon. By assisting in the reduction of emissions, these technologies are helping to meet the needs of the American electric power business today. By assisting in reducing nitrogen oxide emissions from coal combustion furnaces and the waste streams associated with their associated byproducts, these innovations are addressing current demands in the U.S. electric power industry.

Conclusions

Our chemists and engineers possess the skills necessary to create a sustainable future. There are still two things required: education and a sense of urgency. The current chemistry curriculum needs to be updated to reflect our growing understanding of the molecular causes of risk. It is now necessary to reorient the seemingly miraculous capacity of our chemists and chemical engineers to "engineer away environmental problems" once they have developed in order to include the development and application of procedures that, whenever possible, eliminate the need for the use of hazards. This education, this action, must not be performed at a walking pace. With the urgency that the sustainability of our world demands, it must be done right away.

Some contend that sustainability entails intricate social connections and value systems and goes much beyond a scientific and technological problem. They might be right. However, it is the duty of the small percentage of the population that is knowledgeable in science and engineering to make current (and probably future) behavior as sustainable as possible while they work to change the hearts, minds, and behaviors of six billion people to make society more sustainable. This can be accomplished by creating processes and products that are intrinsically benign. This can be accomplished by creating processes and products that are intrinsically benign. Just telling the poor world that improving their quality of life is an unattainable goal is not a workable solution. Our most difficult but feasible goal is to ensure that that improved quality of life has as little detrimental effect on the planet as possible.

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