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GREEN CHEMISTRY FRONTIERS: MEETING THE GRAND CHALLENGES OF SUSTAINABILITY IN RESEARCH AND DEVELOPMENT AND MANUFACTURING

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ABSTRACT

Green chemistry is the design, development, and implementation of chemical products and processes with the goal of reducing or eliminating the use and production of harmful chemicals to human health and the environment. It is a non-regulatory, market-driven approach to long-term sustainability. Through practical examples, the undeniable benefit of Green Chemistry to business and the environment is shown. Green chemistry's potential to address sustainability at the molecular level must be acknowledged. Green Chemistry pushes innovators to design and use matter and energy in a manner that improves performance and value while preserving human health and the environment at the most basic level. Green Chemistry concepts must become the foundation for tomorrow's chemistry, including sustainability into science and its inventions.

KEYWORDS: *Green Chemistry, Sustainability, Metrics, Life Cycle.*

1. INTRODUCTION

Green chemistry is defined as the design, development, and implementation of chemical products and processes with the goal of reducing or eliminating the use and production of chemicals that are harmful to human health and the environment. Green Chemistry, unlike legal standards for pollution control, is a creative, non-regulatory, and commercially motivated solution to sustainability. The whole life cycle of chemical processes is seen as an opportunity for design innovation in green chemistry. Green Chemistry pushes innovators to design and use matter and energy in a manner that improves performance and value while preserving human health and the environment, rather than relying on regulatory limitations to manage risks [1]. The development of Green Chemistry will be demonstrated and difficulties will be addressed via a discussion of recent discoveries and partnerships. There is always room for improvement when an emphasis is placed on innovation. Green Chemistry's frontiers provide the difficulties and, at the same time, the impetus for designing for sustainability.

1.1. Green Chemistry Frontiers

It is essential to examine how Green Chemistry differs from other methods historically or now in use in order to properly understand the achievements that the discipline of Green

Chemistry has achieved so far and the future possibilities for advancing toward global sustainability. Green chemistry is defined as the development of chemical products and processes that minimize or eliminate the usage of hazardous chemicals. The Twelve Principles of Green Chemistry, which are utilized as a design framework, add to this concept. The Green Chemistry method is based on the understanding that all we have on Earth is matter and energy. Green chemistry aims to develop and build the next generation of matter (material) that underpins our society and economy with the least amount of negative impact on human health and the environment. The material utilized to create, store, and transmit the Corresponding author is included in this endeavor. 1 202 872 6206 (fax). Our civilization's source of energy The acknowledgment of Green Chemistry's breadth is essential because it clarifies that when the term "chemistry" is used, we are not talking about a particular industry or even a single academic department at a university. Green Chemistry is dedicated to the study of matter and all of its changes, as defined by Webster. The statement from the definition of the word that mentions ‘‘the use and production of hazardous chemicals" is also crucial to comprehending the scope of Green Chemistry. While there is no question that Green Chemistry can and has reduced waste and improved process efficiency, there is also no doubt that Green Chemistry has far-reaching implications beyond waste reduction and pollution avoidance. The whole life cycle of our material and energy processes is seen as an opportunity for design innovation by Green Chemistry. Green Chemistry has recorded major accomplishments in all phases of the life cycle, from the sources of feeds tocks and beginning materials through all production and product design to the repercussions after the end of commercial life.

The Presidential Green Chemistry Challenge Award program sponsored by the US Environmental Protection Agency is one tiny example of this accomplishment. This single initiative, which celebrated its tenth anniversary in 2006, projected that 3 billion pounds of hazardous chemicals were never utilized or produced for the approximately 50 prize recipients during the course of the program's ten years. Simply by glancing at the award winners, the Award program gets orders of magnitude more nominations than are ever tabulated. This award scheme has also been copied in a number of other countries, including the United Kingdom, Italy, Japan, Canada, and Australia [2]. The outcomes of these initiatives show that the benefits may be found not just at all phases of a product's life cycle, but also across a wide variety of industries. Medicine, food manufacturing, energy generation, packaging, home and commercial cleaning products, electronics, automotive, and a broad variety of consumer goods are among the items and processes that have adopted Green Chemistry Principles. To put it another way, the fact that Green Chemistry deals with matter and energy on a basic level explains why it can and does influence practically every area of our economy and everyday lives. Green Chemistry's efficacy as a tool for improving sustainability depends on its breadth of influence. The problems of global sustainability are the most complicated and serious of any that civilization has faced or will face. In the framework of Fig. 1, the three components of sustainability, environmental, social, and economic, must be acknowledged.

When thinking about the three components of environment, economy, and society, it's important to remember that the economy exists inside society and society exists within the environment [3]. While all three elements are necessary for progressing toward sustainability, simply attempting to ‘‘balance" the three areas will result in less-than-optimal trade-offs; the true long-term goal must be to ensure that the goals of the environment, society, and economy are all working together in a synergistic manner. The application of the Twelve Principles of Green Chemistry has shown that this synergism may be achieved by working at the molecular level, which is the most basic level.

1.2. Green Chemistry as an Engine for Innovation

Historically, the approaches we've used to manage our environmental issues, particularly those involving chemicals and materials, have been to decrease risk by lowering exposure. While this made sense at the time owing to a lack of knowledge of the foundation of danger and toxicity, it no longer does. If the only way to avoid a danger is to reduce exposure or contact with it, then avoidance in the context of the time means decreasing exposure or contact with it. Within this paradigm, methods were created that were sometimes technically difficult and sometimes creative ways of dealing with risks and limiting interaction with them. All of these methods had two characteristics:

1) They might (and, as a probability function, would) fail, and
2) They all had to be a financial drain. Many of these technical bandages were beautiful, but they didn't provide value to the product or process they were connected with.

As our understanding of the basic nature of risk has grown, we've been able to address it from the design stage. The chemist designer may potentially build molecules and molecular transformations to decrease or remove the chemical/physical characteristics of danger once the molecular foundation is known. Within the area of Green Chemistry, this idea is being put into reality on a large scale. This capacity is critical to Green Chemistry's effectiveness as a tool for sustainability. Unlike previous exposure controls, Green Chemistry may improve the performance, capacities, and efficiency of the goods and processes it is applied to while also addressing environmental and human health issues.

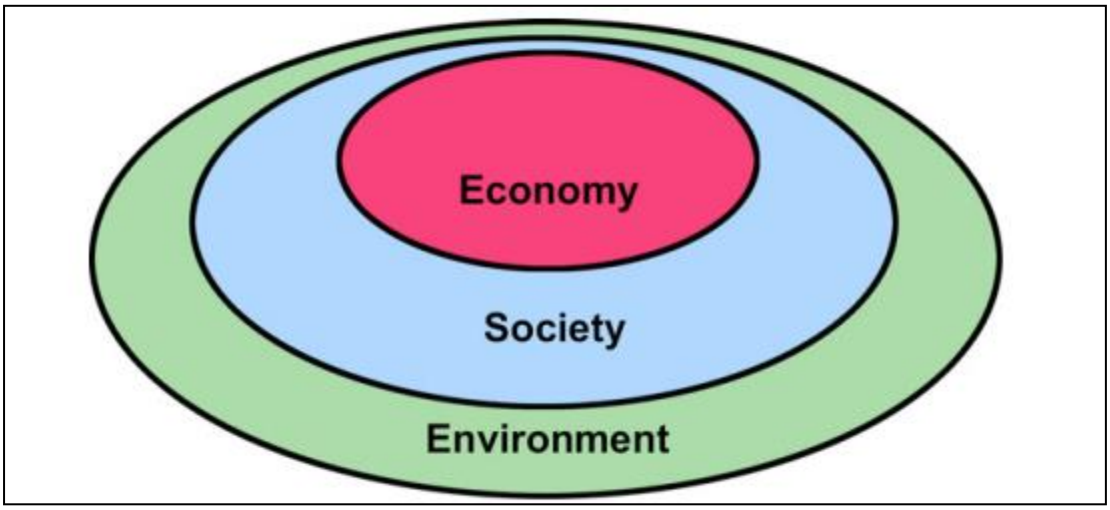

Figure 1: A Sustainable Community

2. DISCUSSION

3.1. Application:

One of the major themes that emerges when we examine contemporary society's goods is that of innovation. In 1853, William Perkin created the first synthetic dye, mauve, and became very rich. Others rapidly learned to manufacture mauve, and it became a commodity that customers didn't care if they bought it from Perkin or a rival, Perkin and the synthetic dye producers quickly recognized that innovation was required to remain competitive in a commoditized market. New hues, fade resistance, and fabric adhesion were all areas where synthetic dyes innovated. This narrative is not unique to the dye business; it can be found in almost every major industry, including plastics, cars, electronics, and medicines. To fully appreciate why Green Chemistry is a vital instrument in promoting sustainability, one must first realize that innovationist the only weapon that business has against the relentless weight of commoditization. Green chemistry is all about experimentation and development. Reduced hazard is seen as a performance criteria that may be changed and continually enhanced as another inherent physical/chemical characteristic. There is an understanding that genuine Green Chemistry is a pursuit of perfection that can never be attained but must be constantly pursued. Green chemistry innovation may be split into two categories that operate in tandem: (1) As an essential element of a product's performance, the market continues to demand goods that are favorable to human health and the environment. [Any misconceptions that the market is not requiring the goods are debunked by history, which shows that as soon as a bad impact of a product was discovered, there was market pressure to replace it, regardless of how effective it was, as with cyclamates, DDT, and PCBs.] More and more, the performance of a product or process is being evaluated on its ability to fulfill its purpose while also addressing significant environmental and human health problems [4]. There are many examples of this in practice, and the case studies will be mentioned as examples of the range of application of this strategy to meeting environmental and economic objectives via innovation that benefits society, rather than as a complete list. The following are some of the instances that will be discussed.

3.2. CO2-Based Electronic Manufacturing

The manufacturing and anticipated usage of a single 2.0 g memory chip uses about 1.7 kg of chemicals and fossil fuel, as well as 32 kg of water [4]. Chip manufacture now includes hundreds of wet chemical processes using hydroxyl amines, mineral acids, elemental gases, organic solvents, and huge quantities of high quality water at different stages. The need for faster computer chips with greater memory capacity necessitates continuous development of manufacturing methods for smaller chips with more transistors, capacitors, and other components. CO2 has emerged as a key enabler in modern semiconductor production processes. Some of the present difficulties in microelectronics processing, such as decreasing feature sizes and material compatibility, have been solved by using CO2's physical characteristics. The CO2 method, which is based on Green Chemistry, boosts both technical and environmental performance.

3Tin-free boat paint Tributylti (TBT) has long been used as an antifouling on boats and ships, as well as in a range of other goods including wood preservatives and textiles. It is very hazardous to aquatic life and an endocrine disrupting chemical that may prevent aquatic creatures from reproducing. It also does not breakdown readily in water. TBT's usage as an antifouling is now prohibited throughout Europe due to these concerns, which have resulted in regulatory restrictions severely limiting or banning its use. TBT chemicals that are utilized for other biotical applications (such as wood preservatives and textiles) must be phased off of the European market by September 2006. Rohm and Haas developed a wide range antifouling based on is othiazolone chemistry as a green alternative to TBT. When discharged into the environment, this product offers a long-lasting, stable formulation that is devoid of heavy metals and degrades quickly [8]. TBT exhibited a broad range of impacts on growth, development, and reproduction at levels as low as 2 parts per trillion (ppt) in a comparative study, while the Rohm and Haas antifouling showed no chronic or reproductive harm to marine species.

3.3. Non-Freon Fire Extinguishers

During usage, the aqueous film-forming foams developed by the United States Navy in the 1960s for use on volatile hydrocarbon fires emit hydrofluoric acid and fluorocarbons, and the Fluor surfactants often lead to groundwater pollution [10]. PYROCOOL Technologies, Inc. created fire extinguishing foam (FEF) in 1993 as a greener alternative to traditional fire extinguishing chemicals. The FEF is biodegradable and has been shown to be effective. It includes no glycol ethers or fluoro surfactants. The FEF put out an oil tanker fire that was expected to take ten days to extinguish in just 13 minutes, preventing the spilling of 78,000 tons of crude oil [2].

3.4. Perc-Free Dry Cleaning

In the commercial manufacturing and service sectors, solvents are extensively utilized. Despite all precautions, they eventually pollute the air, land, and water since their volatile nature makes them impossible to control. The dry cleaning business, in particular, is reliant on solvents, with percholorethylne (perc) being the main solvent used by roughly 100,000 dry cleaners globally. Perc is hazardous, according to many studies, and it affects plant employees and dry cleaning customers, as well as landlords and financial organizations that own polluted property and individuals who live near dry cleaning shops. Except for the dry-cleaned clothing, everything perc comes into touch with at a dry cleaning facility must be managed as ‘‘hazardous waste." Because it is ecologically benign, non-toxic, and biodegradable, and needs no hazardous waste disposal, supercritical carbon dioxide has been [5] developed and proven as a viable alternative to perc in dry cleaning applications, avoiding expensive regulatory compliance.

3.5. Lead-Free Car Paints

By separating the surface from ambient oxygen, anti-corrosion paints or coatings are often employed to prevent rust. Lead has long been used in anti-corrosion coatings, especially in applications related to automotive production and protection. The long-term harmful consequences of lead in people and ecological systems have received a lot of attention in recent decades. PPG Industries has developed a lead-free catholic epoxy electrocute (e-coat) for automotive manufacturers to address the environmental and human health issues connected with the usage of lead. This ground-breaking solution is a waterborne coating with VOC and HAP concentrations of less than 0.5 lb/gallon or 99 percent VOC and HAP free, reducing the costs of maintaining, monitoring, and approving these chemical classes. This innovative solution lowers the environmental effect of coating application (material transfer rates may reach 98%) and eliminates the long-term usage and exposure to lead-based goods [6]. Furthermore, according to Mercedes' comparative tests, the newest epoxy e-coat formulas perform similarly to previous e-coats containing lead.

3.6. Arsenic-Free Lumber

More than 95 percent of pressure-treated wood in the United States is now maintained with chromated copper arsenate (CCA), which consumes approximately 40 million pounds of arsenic and 64 million pounds of hexavalent chromium per year. The manufacture, usage, storage, and disposal of these compounds, as well as the possibility for substantial worker exposure to these chemicals, have major environmental concerns. The main human health concerns once these goods are on the market are that everyday exposure with arsenic leached from CCA-treated wood may raise the risk of cancer or other long-term health consequences. In 2002, the Environmental Protection Agency (EPA) made a voluntary choice to shift consumer treatment of treated timber away from arsenic-based chemicals and toward new alternatives. Chemical Specialties, Inc.'s alkaline copper quaternary (ACQ) wood preservative is one such option. ACQ, which contains a bivalent copper complex and a quaternary ammonium compound, outperforms conventional formulations including arsenic and hexavalent chromium against biological risks such decay and termite assault [7].

3.7. Metal Working Fluids That Don't Deplete the Environment

By cooling and lubricating during metal forming and cutting processes, metal working fluids (MWFs) improve industrial productivity and quality. MWFs are usually oil-in-water emulsions that include both petroleum-based oil and surfactant components. Despite their extensive usage (over 2 billion gallons per year in the United States alone), they pose serious health and environmental risks throughout their entire life cycle. A clear environmental enhancement to MWF technology would be beneficial [8].

3. CONCLUSION

Green Chemistry has shown to be a critical instrument for achieving sustainability in the workplace. The Twelve Principles have shown that it is feasible to create synergistic effects between environmental and social factors. Stewardship, economic success, and social responsibility are all words that come to mind when thinking about stewardship. By incorporating sustainability into the design process at the molecular [9] level Green Chemistry's incorporation into industrial applications has progressed. Significant accomplishments were recorded at all phases of lifecycle. However, the success that has been shown so far is just the beginning of the possibilities for incorporating Green Chemistry is being integrated into education, business, and research agendas. as well as public policy Green Chemistry will provide value throughout the product life cycle if it is included early in the development process. To lessen the impact of the double economic penalty connected with waste production (both the costs of purchasing chemicals that are not converted to products and the expenses of purchasing chemicals that are not converted to products). The Twelve Principles should be followed in order to dispose of this trash. Early in the creation of a product, it is used. Green Chemistry can help goods and processes operate better, have more capabilities, and be more efficient. It is used to address both environmental and human health problems at the same time. Metrics, in particular enhancing life cycle tools and establishing partnerships to make their use easier, must be improved. be a focal point for progress We must comprehend how to get information from one place to another from the supplier through the manufacturer to the end user, and to develop methods for managing the process's data intensity so that life cycle metrics may be created and applied. Despite the fact that there is an obvious need for improved application, It is the amount and direction of change in terms of measures That is critical. The success of the Presidential Green Chemistry Challenge Award program has been proven Green Chemistry and the Potential Impact of Innovation the environment, as well as the company's financial linen order to promote green chemistry, it needs to become more prominent in research agendas and funding sources. The creation of new green alternatives to current ones Syntheses of chemicals Research must be carried out in a systematic manner. To demonstrate its feasibility in industrial applications, it was tested in an academic environment. Green Chemistry Research and Development is a non-profit organization dedicated to the advancement of green endeavor [10].

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