# Green Engineering, Principles and Applications

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Research Paper

# Green Engineering

## Principles & Applications

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# Green Engineering

*Principles and Applications*

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Abstract

Stressing the environment in modern day world in the form of air pollution, emissions of toxic and hazardous substances in the air, and wastewater discharge is mainly the topic of concern for the researchers round the world. The population of the world is increasing at very rapid rate, and to cope with the requirements and demands the industrial sector is actively involved in creating pressure on the environment. This paper is aimed to incorporate the green engineering into the present-day manufacturing and processing units. A lot of studies from the researchers show the efficient use of the green engineering principles and its products to produce say, energy, food, and other certain requirements to feed the humanity. Certain findings from the literature study includes the integral use of green chemistry and green engineering, i.e., green chemistry tends to introduce the efficient feedstocks, solvents, and reagents. Also, the use of green compounds such as carbon nanotubes (CNT's) in wastewater treatment, treating the air pollution, recycling of the wastes, to renew the energy resources, and its use in biotechnology for the comfort of humanity is discussed. Following in the paper, certain innovative ideas have discussed which might just change the world into green land. But the immaturity of the recent technologies cannot try to achieve the desired goal of green engineering and sustainability. It is strongly suggested for the future technological area to keep a keen concern for the efficient and legal implications of the green technology principles and products.

Keywords:

Environment, pollution, toxic, hazardous, green engineering, manufacturing, principles, products, chemistry, CNT's, wastes, recycling.

## Introduction:

Green engineering deals with the design ideas, commercialization of the products, use of the available processes and available resources in a way that reduce environmental threats, enhance the product sustainability, and to keep an eye on the pollution caused and treats to human health without compromising on the economics feasibility and overall efficiency of the product. The term Green engineering also known as ‘’Green Technology’’, or ‘’Clean Technology’’.

Green engineering tries to adapt the innovative designing process for the products to achieve the following fundamental goals.

- To decrease in the amount of pollution caused by the processing plants in the form of industries, as the demand for the products increase, e.g., to no of vehicles are increasing at very rapid rate every next year. (see appendix, figure 01)
- To minimize the operator’s exposure to certain hazards i.e., to keep an eye on the workplace safety.
- To effectively use the available resources in the form of raw materials and energy throughout the lifecycle and design process of the desired product. Most of the energy available is utilized by the industrial sector among transportation, commercial, and residential sectors. (see appendix, figure 02)
- The product should be feasible in terms of the finance i.e., to keep an eye on the economic feasibility of the product. Generally, the cost of the product increases with quantity as well as quality. (see appendix figure 03)
- The designed or manufactured product should be practicable in the respective function or objective for which it is designed or manufactured.
- To minimize the wastes, enhance the recycling, and approaching the sustainability (see appendix, figure **).

The field of Green engineering has turned out the attention of design and manufacturing engineers towards itself due to its much serious positives obtained because of implementing the fundamental principles and standards of Green technology and engineering. The new inventions and advancements in almost every sector have also put some pressure on the planet, Earth. The field of automobile industry has put pressure on the planet in terms of the harmful and poisonous gases emitted by the automobiles as well as the manufacturing plants of these automobiles. In most of the cases this pressure on our planet comes out to be in the form of global warming and greenhouse gases. Serious attention needs to be given to this problem and to introduce some innovative techniques to affectively use the natural resources and the energy without causing threats to our planet and to the kind humanity living on the face of this planet. This proceeding study can be much helpful as it highlights the legal ideas and techniques of how to effectively use the available resources and energy to produce cost effective and sustainable products. Following in the paper various innovative and incentive design and manufacturing ideas have been discussed to produce the qualitative products with the help of processes using throughout their life cycle which are effective in terms of performance as well as environmentally friendly.

*Research Objectives:*

- To study and apply the fundamental principles of Green Engineering/Green Technology.
- Study of different ideas to imply the fundamental principles of Green Engineering/Green Technology in product manufacturing and processing.
- Study of the sustainability of the product in terms of the principles of Green Engineering.
- To study different Laws/Acts related to public health and environmental protection.

**Literature Review:**

The concept of Green engineering, Green technology, and clean technology are seemed to appear in the literature study from the last few decades. But still this technology is a challenge to modern day engineers, scientists, and manufacturer managers. Literature related to green engineering is still found to contain the phrases like, "Much remains to be done in the areas of sustainability, how to effectively use the available resources and energy" (García Serna, Pérez-Barrigón et al. 2013), "The current science is still far away from the exact and we still need to make some big efforts", etc. (García Serna, Pérez-Barrigón et al. 2013)

In 1987, the idea of sustainable and qualitative development came into existence with the publication of a report named, "Our Common Future" by the Brundtland commission in 1987. Previously in 1713, the concept of sustainable and qualitative development was studied in the field of forestry as evident from the work of German Miner Hans Carl where he defined sustainability as how much timber was regrowing to ensure the soil fertility.

From the last few decades many engineering institutes have started to include a brief sustainability study in their official curricula and to their assessment policies due to the positive impacts obtained because of this analysis and study. Most engineering institutes have incorporated the study of sustainability into their studies through different approaches i.e., horizontal approach and vertical approach. The Board of Accreditation for Engineering and Technology (ABET), which is the responsible authority for higher education in engineering disciplines in the United States and 35 other countries highlights the ultimate need of sustainability in engineering through the criteria that the students need to possess i.e., "An ability to design a system, component, or process to meet the desired needs within certain constraints, such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability". (Hallinan, Kissock et al. 2008)

The field of Green Engineering/Technology has also put an eye on the construction site from the last few years to improve the sustainability and efficient use of the resources. Factors like high energy prices, higher costs of building materials, etc. also compels the green technology to come up with the innovative techniques and to enhance their scope in construction side as well.

Much in the field of Green engineering/Green technology has been done to come up with the welfare of human beings and our planet environment as evident from the standards of NAAQS and SIPS (Cited, Saved Link), set by the Clean Air Act (CAA) in 1975 and 1977 respectively by the authorization of Environmental Protection Agency (EPA). National Ambient Air Quality Standards (NAAQS) was introduced to cope with the emission of dangerous, and toxic pollutants into atmosphere with the State Implementing Plans (SIPS) to set the preceding standards. A famous Mayor of New York city in 2006 stated when he introduced his plan of reducing the greenhouse gases emissions by 30% in 2030 that, "You can no longer deny the science and bury your head in the sand – climate change is real" (Ali, Boks et al. 2016).

The Pollution Prevention Act (PPA) introduced in 1990 (Cited, Link Saved) turned the attention of industrial sector, government policies, and public people towards reducing of global warming and greenhouse gases by making cost affective modifications in product designing, manufacturing processes and the way of how to use the available raw materials for sustainable and pollution free results.

The United States of America's President in 2007 signed the ''Energy Independence and Security Act (EISA)'' aims to move the state towards the energy independence and energy security, to enhance the clean and green production of clean renewable fuels, to protect the consumers from workplace hazards, to enhance the efficiency of products, buildings, and automobiles, to promote the research on green engineering, and to promote the economy (2020).

**Methodology:**

This paper is aimed to describe the innovative design ideas, the efficient use of the available natural resources, the treatment and recycling ideas, and the altering of the existing conventional manufacturing process and techniques to bring out sustainable products and full filing the criteria of green engineering. Our environment is at major risk today (see appendix, figure 04) as many of the respondents in a survey claimed, which was conducted to carry out some background information about the current status of our environment and the principles and applications of green engineering. It is therefore the ultimate need of the time to take major concern for our environment. There have been certain contribution factors towards the creation of certain imbalances in our environment, e.g., automobiles industry, power generating plants, and chemical industry and all of these has contributed well to destabilize our environment. This is also evident from the response of a survey which was done among the environmental analysts, (see appendix, figure 05). Many of the available research studies on environment protection, climate change, sustainability analysis, and clean and green technology shows that the demands for industry increases every next day and these industries create pressure on the existing environment. Many of the researchers has suggested the idea of green engineering for sustainable productions, so this paper proceeds with the fundamental principles of green technology, how to legally implement these principles in the modern-day manufacturing processes, the use of green resources, recycling, retreatment of the used resources, and some innovative applications which could change the world and thus a challenge to modern day technological advancements.

**Principles of Green Engineering:**

The above-mentioned objectives of this research paper provide a clear vision of what we need to achieve. These objectives are effective only when they come into real practice. Various alternatives are under the consideration of how to achieve these goals and objectives in various disciplines including industrial sector, construction sector, and other commercial sectors. The principles of green engineering provide a strong background for the engineers to involve in the design and manufacturing of new materials, products, operating processes, and complex systems that are beneficial to human health and the environment. The measurement of these principles in products vary from product to product depending on the desired need. The fundamental principles of green engineering are given below.

- The designers should try to ensure that the materials and energy input and output are essentially nonhazardous to public and the environment.
- It is better to try for not to produce wastes rather than to put efforts for the cleaning or removal, and recycling of the wastes.
- The process of purification, preparation, and separation (to make ready the input materials) should be carried out in a way that use less energy and materials use.
- Final products, operating processes, and total systems need to be designed to maximize the mass (output mass), space, energy (output energy), and time efficiency.
- Products, processes, and systems should be “output pulled” rather than “input pushed” using energy and materials.
- The complexity of the process should be considered as an investment when making design choices on recycle of the wastes, and reuse of the wastes.
- The durability of the product should be concerned, not the immortality of the product.
- The design for unnecessary capability or capacity should be considered as design flaw.
- The use of the materials in large assemblies/multi component parts should be minimized to provide an ease for the disassembling of the product for maintenance purpose.
- The designer should make the design ideas for the products, processes, and systems in accordance with the available energy and raw material.
- The designer should make the design ideas for the products, processes, and systems for the commercial use rather than local use.
- The designers and manufacturers should use the materials and energy in the input which can be recycled rather than destruction.

The design and manufacturing engineers should try to put an eye on the use of these principles as a guideway for sustainable production. Besides the above-described principles, the designer should also try to incorporate in the design process the two fundamental concepts of (a) life cycle considerations and, (b) Inherency.

The designer of the product need to consider the overall life cycle of the product in terms of the material and energy use, i.e., the material and energy life cycle should also be given prime importance because if a final product obtained after design and manufacturing process is kind to environment and in its performance in terms of generating power and efficiency but the manufacturing process of this power generating source is such that can't reuse or recycle the input energy, the product is then not sustainable. To make the product, process, and system sustainable and kind to environment the approach of changing the essential nature of the process needs to be changed or the circumstances and conditions of the system need to be changed. The principle of inherency diminishes the possibility of failure in the design product. Using the technological control techniques e.g., air scrubbers or effluent treatment of wastewater, can put a risk to public health and the environment. While using the inherent design the probability of the component/product failure vanishes. Various studies show that implementing the principle of inherency in the design process can have good results in terms of the sustainability of the system. The research example could be the design of an automobile for transportation in a way which is kind to the environment verses the design of an automobile using the traditional gasoline system (Kirchhoff 2003).

1. *Inherent rather than circumstantial:*

The effects of the hazardous substances which tend to cause harm either by toxicity, physical damage, or global can be minimized through investing time, capital, material, and extra energy resources but this in again not economical as well as not environment friendly. Rather the design and manufacturing engineers should analyze the fundamental nature of the selected raw materials and energy resource as an input as the prior step and to ensure that they are kind and neutral to the environment. The designers also need to analyze the process on molecular level to make the product sustainability easy. There are cases in which the inputs selection has certain associated hazards, these hazards can be removed from the process path during the process at the stage of purification or separation, but this process also requires constant assessment and monitoring. Also, the disposal of the hazards to some permanent off-site place is also required. The other alternative to cope with this problem is to incorporate the associated hazard into the final product and to recycle the hazard again and again, but this incorporated hazard in the final product has the risks of release through some accidents, spills, and leaks (Kirchhoff 2003).

2. *Prevention instead of treatment:*

The concept of "zero waste" is almost contrary to the fundamental principles of thermodynamics and entropy generation. The laws of thermodynamics states that no single process is 100% efficient and that there is necessary destruction of some part of the available energy in different forms. Also, there is no waste associated with the input material or operating process but is associated with the misuse of these ingredients. A process is said to have associated waste when it does not deliver the benefits for which it has been installed. Regardless of the nature of the waste produced, the handling and disposal of the waste takes some human effort, consumes time, and energy. Also, it needs additional costs for the monitoring and control. The waste factor is thoughtlessly incorporated into the input design and this is according to the basic concept that, ‘’inputs are designed to be part of the output’’. This is in accordance with the ‘’atomic economy”, which can be extended to “material economy” on large scale. The solution to this problem is to choose the idealized processes for the design and manufacturing, e.g., the use of fusion and fission reactions for the power generation as compared to the use of fuels which ultimately give rise to global warming and green house effects. The scope of nuclear energy needs to be revolutionized because of the harms caused by the fossil fuels (see appendix, figure 06) and much of the portion of today’s world is dependent on the energy consumption based on fossil fuels. The use of solar energy is also another alternative to this problem (Kirchhoff 2003).

3. *<u>Design for separation and purification:</u>*

The input material preparation process is usually associated with certain impacts which are not kind to the environment. The separation and purification process of the starting materials usually require hazardous chemical substances which are hazardous in nature, or some other alternative techniques are required which consumes lot of the energy in the forms of heat and pressure. This can be avoided by the designs of products containing the essential chemical properties of volatility and solubility to carry out the separation and purification of the input material in a very natural way, so that no negative impacts on the environment in the form of wastes disposal, dangerous gases emissions, etc. will be created. The cluster of unwanted parameters for the disposal of, say wastes which are time consumption, money requirements, resources for the disposal, transportation, and monitoring can be avoided by incorporating the desired properties in the components from which products, processes, and systems made. The use of reversible fasteners, or non-permanent joints in the design considerations provide a way for the recycling and reuse of the materials. The design should give keen concern to the up-front design to minimize the material and energy usage, e.g., the purification and separation process of column chromatography and purification require large amount of the hazardous substances and energy, respectively (Kirchhoff 2003).

4. *<u>Optimization of mass, space, energy, and time:</u>*

Many of the products, operating processes, and integrated systems require more power, materials, time, and space that the ultimate requirements resulting in inefficiency of the overall design. The wastage of the resources can also be observed when the product is not operated at its full efficiency capability. The design tools of optimizing the time and space should also be used in integration with the optimizing techniques for the materials and energy to enhance the product sustainability. The use of microreactors techniques in processing industries is innovated design idea for materials, energy, space, and time optimization. The traditional techniques of reactions in processing industries in the form of vessel reactors or batch reactors require very large amount of the input that that used the reactions. These innovative techniques of micro reactors in the processing industries tend to enhance the production quantity, and efficiency of the process using very low volume of the material at the input of the process. The design and manufacturing engineers should try to adopt these optimization techniques, e.g., replacing batch or vessels reactors by spinning disk reactors (see appendix, figure 07), replacing paints by powder coatings, printed media by digital information's, and eco-industrial plants to diminish poorly planned and auto dependent development (Tang, Bourne et al. 2008).

5. *Output pulled processes over the input pushed processes:*

This principle of sustainable design and manufacturing is analogous to Lechatelier's principle in chemical composition or chemical synthesis, i.e., applying stress to the process (in the form of providing energy or material) will try to create balance between the inputs and outputs. The continuous production in output will tend to maximize the materials and energy intake at the input of the manufacturing process, also leading to the maximization of space and time constrains. This maximization of the resources at the input of process leads to costly, inefficient, and unsustainable products production. The designers should try the minimize the quantity at output side, and this will pull the limited resources available at the input towards the production machinery. To put an end to this problem of maximizing the resources at the input, the design and manufacturing engineers and analysts should try to adopt the Just in Time (JIT) manufacturing process rather than continuous production process, also known as ''Push vs Pull'' manufacturing process (see appendix, figure 08). It means that the end user of the product is also the final purchaser of the product, and limited amount of the manufacturing is to be performed for the specific need. This will ultimately save the resources, operating time, energy, and the production quality will also be enhanced. The use of this principle is evident from the metal treatment processes of direct metal deposition vs the metal casting (Tang, Bourne et al. 2008).

6. *Conservation of complexity of the design:*

This principle of sustainable production deals with the conservation of the complex designs adopted for products manufacturing in terms of the benefits obtained from the investments which are done for the complex designs. Processes with the complexities are usually function of the material expenditure, energy expenditure, and time consumption. The designers should take the benefits from these complexities in the form of counter production or reuse, e.g., silicon chips in modern computer systems installed with more complexities tend to maximize the output performance in terms of time saving, and other certain factors as compared to the previous versions of Intel with relatively low complexities, but the output performance was rather poor than the former (2003).

7. *Focus on the durability rather than the immortality:*

The designers should take the concern for the goal of product durability rather than immortality of the product to reduce the threat and risks to humans and to the environment. Products which are designed based on the immortality can put serious threats to the environment in the form of solid wastes, nonbiodegradable substances, etc. So, the designs based on the limited and targeted lifetime needs to be designed. It is necessary to keep an eye on the stagewise maintenance operations in the process, and assembly to avoid any pre lifetime failure of the assembly and to avoid the following disposal problems as well. Keeping in view this limited and targeted lifetime will ultimately minimize the extra need of resources in the form of materials input, energy, and time. Thus, the process will lead towards the sustainable production. As an example, the use of disposable diapers has put a commendable amount of contribution to the environmental stress as they are composed of the materials which are poor in terms of the biodegradability and recycling of the municipal solid wastes. The solution to put an end to this environmental problem could be the use of starch and water-based materials which are easily self-soluble and biodegradable. The production of plastic and fibers-based components from petrochemical based polyacrylic acid need to replace by biological based polylactic acid which are kind to the environment as well as leads towards the sustainable production (2003).

8. *Meet the needs and minimize the excess:*

To check the ability of a process to move fast, easily, and flexibly at the design stage is very important. The designer should take the necessary steps for the disposal, and monitoring of the process at each stage of the process to overcome the extra production, which leads to unsustainability in terms of the materials and energy usage. In short, the design and manufacturing engineers should incorporate the design ideas to minimize the expenditures required for the resources. Production of the same amount of quantity for various levels of need will ultimately lead to environmental stresses in the form of harmful byproducts in enhanced amount. The purification or disinfection process of water by the method of chlorination could be the example of this case. The buildings available at the closest to the purification plant will be provided with the excess amount of chlorine product than those available at far from the purification plant and thus moderate amount or the amount according to the exact need will be provided. This is because this disinfecting product of chlorine degrades with respect to time. The problem can be overcome by the installation of the proper control systems throughout the distribution system. The results could be the reduction of environmental stresses and risks to human health in the form of trihalomethanes, the byproduct of disinfecting agents of chlorine (Ali, Boks et al. 2016).

9. *Minimize the materials diversity in multi component assemblies:*

Products having extensive use in daily life such as automobiles, computer systems, and packaging of food items are made up of diverse assemblies including woods, metals, composites, glasses, and plastics.

Each individual class of materials has their own negatives in the form of unkindness to the environment and human's life. The typical plastic material contains various dyes, fire retardants, plasticizers, stabilizers, and various hazardous chemical additives. These extensive amounts of components used in the products could create stress to both the environment and living beings present on the planet. The design and manufacturing engineers should consider the end-of-life criteria for the disposition, recycle, or reuse of the product. This is possible by adopting the design ideas for the assemblies which are easy to disassemble. The use of polymers as an alternative for the hazardous chemical additives can give some green effects, i.e., modifying the polymers properties for the required purpose can have beneficial effects in terms of environmental benign processes. The design and manufacturing engineers should try to build up the product prototypes based the single material use, e.g., the use of metallocene polyolefins for the product building. The analogues design ideas on molecular level could be explained by cascading reactions vs multistage reactions which would require some extra chemicals for providing energy in the form of ignition (Ali, Boks et al. 2016).

10. *How to reuse the consumed materials and energy:*

The traditional design and manufacturing techniques tend to use the materials and energy at input of the process, some of the resources used for operating the process and usually large fraction of these materials or energy wastes in the form of heat energy or, say industrial wastes. So, design ideas of how to recycle these resources should be incorporated into modern design ideas. Recycling these resources in an efficient way could reduce the additive expenditures required for the resources in the form of materials, and energy which would run the subcomponents of the operating unit. On industrial scale, the energy produced because of the large amounts of exothermic reactions usually wastes in significant amount in the form of heat generated in the process, or some other forms of energy. This much amount of energy needs to be recycled to reuse as the input for the process or to run some additional components used in the operating unit. This fundamental principle of green engineering could also be applied to chemicals industry by storing the byproducts obtained because of the many types of reactions, e.g., the byproducts obtained during the purification process of the chemically synthesized products. The innovative designs of cogeneration to produce electricity from industrial wastage energy could be the typical example (2003).

11. *Designing commercial "afterlife" ideas:*

Sometimes the market value of the valuable product become obsolete due to the new advances and the introduction of the new same purpose products which are more sustainable, efficient, and stylistic in looking, but the working capability of the product is still alive. To cope with the competitive status of the market, the designers should develop the ideas to use the existing components in the upcoming next generation of the product rather than to invest new costly resources in the form of materials, and energy. By incorporating the fundamental "afterlife" design idea in the very initial stage of the process could give some fruitful results in terms of the reinvesting the available resources. This principle of green engineering can give some good results for the introduction of new generations of the mobile phones, computers, and laptops as every new year the new generation of the former mentioned products come into market, creating the competitive environment for the designers and manufacturers. Xerox instrument used approximately 90% of the components which could be remanufactured. The use of old building materials in a new house could also be a typical example (2003).

12. *Use renewable resources rather than depleting resources:*

The designers should try to study the ultimate origin of the input material and energy required in a product operating process, because this can have far and wide effects on the product sustainability. The use of pure substances at each input stage require certain extraction, separation, and purification processes, so the use of new depleting materials at every input stage can produce certain environmental rifts. The use of biological renewable resources in this aspect is preferred. The application area of this principle of green engineering can be seen in wastewater treatment through natural ecosystem, biomass feedstocks recovery, and biological based plastics rather than additives-based plastics (2003).

The principles discussed above are not merely a set of goals, but a fundamental set of design and manufacturing methodologies to ultimately achieve the desired goal of green engineering, green technology, clean technology, and sustainability.

**Promoting green engineering through green chemistry:**

The decision of chemical engineers may bring fruitful results for the manufacturing engineering by making decisions for the products and processes they made. The properties, physical or chemical, of the substances or chemicals identified by the chemical engineers may highlights the use of a suitable machine, or say component in the form of reactor, boiler, condenser, etc. that to be used in the process. The life of the design and manufacturing engineers is simplified by the chemists in terms of the minimization or elimination of the use and generation of the hazardous substances. The integral use of green engineering and green chemistry is requiring for the sustainable production. Green chemistry ensures the safety of the operating process by the selection of safe substances, and in terms of the selection of the reagents, solvents and feedstock used.

The sciences of toxicology and mechanistic chemistry reveals that how the molecular functional groups interact with the living organisms present on this planet. Through the discoveries and inventions of analytical chemists for the detection of pollutants, the very minute amount of the pollutants can be detected with the help of certain equipment’s and methods. Having this information in hand, the chemists can design synthesis processes that that minimize or even eliminate the risks and hazardous by putting an end to such functional groups with cannot interact with the living organisms. These designs could be in the form of elimination of volatile organic solvents, transforming the active/functional groups with the help of less toxic chemicals, and introducing the products which do not cause stress on the environment (Mulvihill, Beach et al. 2011).

*Green chemistry applications:*

a) *Feedstocks*

Choosing the feedstock for certain manufacturing process, the factors of toxicity, source of the feedstock, and effects on the environments should be of the prime interest to be taken under the consideration. The researchers are trying to develop the biological renewable feedstocks rather than the petroleum-based feedstocks. Biological based feed stocks include the use of agricultural biomass, carbon dioxide, chitin, and waste byproducts. The efficiency of the two sources observed until now gives favor toward the use of petroleum-based feedstock resources.

Biological based feedstocks are more beneficial over petroleum-based feedstocks. Biomass derived compounds in the form of carbohydrates are more favored that that of hydrocarbon-based compounds which often require the use of heavy metals for further processing. Furfural being the most beneficial biobased chemical obtained from the carbohydrates and this chemical has vast amount of uses on the industrial scale. Furfural, a bio-based chemical is used as a solvent in the refining of lubricating oils, fungicide, and a weed killer.

A bio-based compound named lignocellulose, its transformations onto ethanol has created trends in the commercially competitive processes. The optimization of pretreatment conditions and the introduction of cellulase enzymes, and the design of genetically modified organisms, these two factors has contributed efficiently to lower the cost of bioethanol products. Ethanol, an essential ingredient required in the modern day for the advancements of fuel cells. Fuel cells are having potential applications in light duty automobiles and buildings. The active nature, high efficiency, and negligible fraction of the emissions into the atmosphere.

Carbon dioxide ($CO_2$) derived the petroleum-based feedstocks in large amounts can be used as a raw material in the manufacturing operations of the buildings. Carbon dioxide ($CO_2$) obtained mostly obtained from the flue gases is made supercritical by increasing its temperature and pressure which is then used in combination with the hydrated products, usually obtained from the cement pastes, to form carbonates. The carbonates formed are then used in the roof tiles, wallboards etc. which shows more durability and toughness than the conventional products obtained in the mold cavities. This process of converting industrial wastes in the form of carbon dioxide and fly ash into useful products is termed as Supramics (Kirchhoff 2003).

b) *Reagents:*

Most of the chemical reagents used in industry are corrosive, toxic, hazardous, and unkind to the environment and public as well. The oxidation chemistry is a useful substitution to the above problem to carry out the chemical processes in a safe manner. The emerging product of the oxidation chemistry is alcohol. Sheldon and cooperators have designed systems based on clean technology to convert alcohols into aldehydes and ketones. Other system

Sheldon and the coworkers combine ruthenium catalyst with TEMPO (a chemical substance) under aerobic media to oxidize a vast amount of alcohol and the only side product in the process is water.

Hydrogen peroxide ($H_2O_2$) being another chemical reagent is used for the oxidation process satisfying the goals of clean and green engineering. The Collins group Inc. has introduced a series of reagents in the form of catalysts that activate Hydrogen peroxide to bleach the wooden pulp for paper manufacturing industries. TAML being another chemical reagent and activator is effective over a wide range of pH values in chemical processes and diminishes the problem of chlorinated byproducts. In paper industry Chlorine dioxide has substituted chlorine as bleaching because of the unwanted organic chlorinated byproducts which cause cancer and endocrine infections to humans. The use of TAML in combination with hydrogen dioxide ($H_2O$) presents an idealized system for pulp bleaching without causing any disrupts to the environment and thus leading toward the sustainable production. Hydrogen peroxide being a clean technology product has also found its good name as a reagent in the epoxidation reactions. The conventional reagents i.e., oxygen, peroxides, and peracids used to carry out the epoxidation reactions are usually associated with the byproducts and wastes production. The effectiveness of Hydrogen peroxide as an epoxidizing reagent is enhanced by the catalyst named polyoxometalate which actively epoxidizes 1 hexene in aqueous Hydrogen peroxide and toluene (Kirchhoff 2003).

Phosgene, an intense toxic substance is widely used as a chemical reagent in the industry. The possible substitution for the Phosgene is Dimethyl carbonate (DMC), which is widely used for the methylation purposes in place of methyl halides and phosgene chemicals. Dimethyl carbonate (DMC) turns out to be prepared in a non-phosgene media from methanol and carbon dioxide. The processes associated with the Dimethyl carbonate (DMC) are usually carried out at high temperatures and pressures, but the processes are safe and kind to the environment leading to sustainable production.

*c) <u>Solvents:</u>*

Solvents are widely used in industry to carry out certain reactions. Many of these solvents are organic volatile substances, dangerous air pollutants, flammable, explosive, and toxic in nature. These associated factors with the solvents used on the industrial scale has turned out the attention of chemists to avoid the stress on environment and the risks to human life. The use of supercritical fluids, water, and ionic liquids could be the possible and useful substitution the traditional solvents used in industry.

Much of research has been done in the field of chemistry for the use of super critical carbon dioxide ($scCO_2$) as a reaction medium and as a solvent for many of the important industrial level reactions. The green properties associated with super critical carbon dioxide include nontoxicity, nonflammability, negligible and being inexpensive renewable resource with critical properties which can be easily achieved. The use of super critical carbon dioxide as a solvent has brought out certain revolutions in the commercial marketplace. Collaboration between the Nottingham university and Thomas Swan and Company led to operation of a full-scale industrial plant which carry tremendous amount of hydrogenation reactions in super critical carbon dioxide media (Mulvihill, Beach et al. 2011). Isophorone conversion to trimethylcyclohexanone (TMCH) was the first industrial scale reaction to run in this plant (see appendix, figure 09). The conventional method of hydrogenation of isophorone is associated with the over hydrogenated byproducts which needs secondary processing in the form of purification and separation thus leading to the extensive use of the resources. The innovated idea to carry out the hydrogenation reactions in super critical carbon dioxide has put an end to this problem. The super critical carbon dioxide ($scCO_2$) can also be used to carry out the Enantioselective hydrogenation of imines (see appendix, fig 10).

The field of green chemistry is also involved in the research area to get the alternative of organic solvents, i.e., they are focusing on the introduction of ionic liquids (IL's), organic solvents being a risk to the environment. The property of interest in ionic liquids as reaction media is that they possess very low vapor pressure and are nonhazardous thus fulfills the need of sustainability as well. The spread of ionic liquids to achieve its claimed goal requires the efficient synthesis of the ionic liquids. The challenge in the path of large-scale production of these ionic liquids is the usage of large-scale organic solvents need to remove the impurities, the unreacted starting materials, and byproducts as well. The use of microwaves in this trend could put an end to this problem, and to produce the ionic liquids (IL's) on large scale and to achieve the purity in the products. This method is introduced with the help of multimode microwaves system to control the process pressure, temperature, and reaction time. Ionic liquids. i.e., pyridinium, imidazolium, pyrazolium, and thiazolium are prepared using this green technology (Mulvihill, Beach et al. 2011).

Usually, the ionic liquids (IL's) are produced with the help of alkyl halide. The use of alkyl halides could change the physical properties of ionic liquids and can also dead the performance of the catalysts used in the reaction. 1-Alkylimidazoles can be combined with dimethyl sulfate or diethyl sulfate to produce the ionic liquids free of the halides (see appendix, figure 11). The reaction proceeds more faster in this way as compared to the use of alkyl halides.

The use of water as a reaction medium has also turned the attention of the chemists towards itself as this way could lead to sustainable productions. The application area can be seen from the fact that an acidic solid resin has recently been used in the production of tetrahydropyranols using water as a reaction media. The Heck reaction, which is widely used in chemical and pharmaceutical industry, can also be carried out using water as a reaction media and palladium catalyst (see appendix, figure 12).

Most of the useful reactions can also be carried out without the use of solvents required and this trend also has turned the attention of the modern-day chemists to revolutionize this trend. An application example can be provided that Clark uses sulfated Zirconia to catalyze the Fries rearrangement of benzoate esters in the absence of any reaction media. This Fries rearrangement is frequently used in the manufacturing of pharmacy products and pesticides. Also, Dihydropyrimidinones, having certain applications in the antihypertensive agents, calcium channel blockers, and anticancer drugs, are synthesized in the absence of solvents.

**Carbon Nanotubes in environmental protection and green engineering perspective:**

The discovery of carbon nanotubes by Bethune (1993) and Iijima (1991) has revolutionized the future area of nanotechnology. Carbon nanotubes (CNT's) are seamless macromolecules having cylindrical shaped structure with extremely small radii having size of few nanometers and having length up to several micrometers. The walls of these tubes are structured of hexagonal lattice of carbon atoms and are capped by fullerene like structures. They are classified as multi walled carbon nanotubes (MWCNT's)and single walled carbon nanotubes (SWCNT's). MWCNT's are comprised of two or more concentric cylindrical structures of graphene sheets and are coaxially arranged around a hollow cylindrical area with certain spacing between the layers of graphene (see appendix, figure 13). While SWCNT's are comprised of single cylinder graphite sheet held together by inter molecular forces (see appendix, figure 13). These CNT's can be commercially synthesized on large scale using the techniques of electric arc discharge, lase ablation, and chemical vapor deposition (Hills, Lau et al. 2020).

CNT's hybridization states and the high sensitivity of these structures to complex motions in synthesis conditions explore the physical, chemical, and electronic properties of these tubes as shown in table 01 which inspire the field of recent field of science and technology. These unique properties of the CNT's offer potential advancements in environmental systems from proactive to retroactive, i.e., prevention of environmental degradation, optimization of the energy efficiency, wastewater reuse, and pollution transformation.

**Theoretical and experimental properties of CNTs (Xie et al., 2005)**

| Properties | SWCNTs | MWCNTs |
|---|---|---|
| Specific Gravity | 0.8 g/cm$^3$ | 1.8 g/cm$^3$ |
| Elastic Modulus | ~1 TPa | ~0.3 – 1 TPa |
| Strength | 50 – 500GPa | 10 – 60 GPa |
| Resistivity | 5 – 50 μΩ cm | 5 – 50 μΩ cm |
| Thermal Conductivity | 3000 W m$^{-1}$ K$^{-1}$ | 3000 W m$^{-1}$ K$^{-1}$ |
| Thermal Stability | >700 °C (in air); 2800°C (in vacuum) | >700 °C (in air); 2800°C (in vacuum) |
| Specific Surface Area | ~400-900m$^2$/g | ~200 – 400m$^2$/g |

Table 01

Following in the study, various applications of CNT's in treatment of wastewater, monitoring of air pollution, biotechnology, renewable energy, and supercapacitors are discussed.

a) *Carbon Nanotubes in wastewater treatment:*

The wastewater discharging from certain domestic, industrial, and agricultural resources is associated with large amounts of contaminants and they have turned the attention of the designers and engineers all over the world because of the adverse effects they produce to environment as well as to living organisms. The wastes and contaminants particles found in water are heavy metal ions, 1,2-dichlorobenzene and dioxin which are non-degradable, highly toxic and possess the carcinogenic properties which can result in poisoning, cancer, and can affects the nervous system severely. To remove these contaminant particles and wastes, this depends on the absorption and adsorption capacity of the agent used. CNT's as these agents to remove the contaminant particles and wastes, have high surface active to volume ratio and the controlled porous dimensions, thus they possess the higher absorption and adsorption capability as compared to the traditional granular and powdered activated carbon which have certain limitations (see appendix, figure 14). Research studies have found that the absorption and adsorption capability of these CNT's depends on the surface functional, they possess, i.e., the surface acidity of these CNT's in the form of carboxylic acid, lactonic acids, and phenolic groups are interested in the adsorption of the polar compounds while on the other hand, the CNT's surfaces which are free from functional groups are interested in the adsorption of non-polar contaminants and wastes, e.g., polycyclic aromatic hydrocarbons. The working media for the CNT's to carry out the absorption and adsorption of the contaminants effectively, i.e., they present good capacity over a wide range of pH values, and optimized performance in the range of 7 to 10 pH. Other pH values than this range ionization and competition of the ionic species could occur and thus suppressing the desired performance of CNT's.

In addition to the use of CNT's as wastewater treating agents, certain technologies in the modern-day world also has used CNT's as nano filters to reduce the particles concentrations in the wastewater. Like absorption and adsorption capabilities of the CNT's in wastewater treatment, the attachment of certain functional groups at the nano scale pores of the CNT's could also be a deciding factor. Despite of being the hydrophobic substance, CNT's show extra ordinary results in the transportation of water through the nano scale channels. The molecular scale simulations of CNT's show that the hydrophobic nature of CNT's pores has very week interactions with the molecules of water, thus allowing the very past and frictionless flow of water in these nanoscale channels. This property of CNT's to allow the very fast and frictionless flow of water through the nano scale channels of CNT's has also brought about a revolution the field of microfluidics as well, microfluidics being an emerging technology which could revolutionize the world.

Research studies on CNT's has also revealed the capability of these nano scale filters to remove the pathogenic microorganisms such as protozoa, virus, bacteria in wastewater treatment, i.e., they play an important role in the recycling of wastewater as well. Brady-Estevez in 2008 has reported an effective method to remove the E. coli bacteria from the water at very low pressure single walled carbon nano tubes in the application (Ong, Ahmad et al. 2010).

The use of CNT's in wastewater treatment is not restricted through to filtration though nano scale pores and absorption/adsorption processes, but several antimicrobial properties of the CNT's have also been reported. This special property allows the CNT's to replace the chemical disinfectants to remove the microbial pathogens from the water. Using CNT's as an alternative to the chemical disinfectants avoids the formation of byproducts in the form of trihalomethanes, halo acetic acids, and aldehydes as these CNT's are chemically inert in water (Ong, Ahmad et al. 2010).

b) *<u>Carbon nanotubes in air pollution treatment:</u>*

CNT's outstanding electrical, electrochemical, and optical properties has turned the attention of the researchers and design engineers to explore its potential applications as sensing and detecting elements to detect and monitor the concentrations of the hazardous and toxic gases release in the atmosphere. CNT's also possess desirable electronic properties where the metallic or semi conductivity of these CNT's is greatly influenced by the specific structure, i.e., one dimensional cylindrical structure. The use of CNT's base gas sensors provides a numerous advantage over the traditional gas sensors which are based on metal oxide semiconductors, in terms of low power consumption, low processing temperature required, and high sensitivity. A typical CNT's based gas sensor is shown in figure (see appendix, figure 15). A thin film, of CNT's acts as a cathode and aluminum as anode, separated by 180-micron thick insulated gas. The CNT's create intense electric field near the ultra-fine tips (of CNT's) and enhance the overall electric field to speed up the ionization process. The detection of this sensor is based on the change of resistance, or conductance in CNT's because of the direct contact with the gas/gases. These CNT's based gas sensors have been used in various fields for the detection of nitrogen oxides ($NO_x$), ammonia ($NH_3$), and sulfur dioxide ($SO_2$) at room temperature. Although the sensing performance of these sensors is very good, but the time-consuming recovery of these gases is challenge in the modern-day technology. For this purpose, several ideas have been proposed, e.g., the heating of CNT's based sensor with the help of ultraviolet (UV) illumination and increasing the flux rate of the removing gases to improve the gases capability of desorption from the sensors. Certain efforts have been made to enhance the affinity and sensitivity of the CNT's based gas sensors by incorporating the polymers functional groups. This method of incorporating the CNT's in polymers such as polyaniline, and polypyrrole leads to an increase in the sensitivity of these sensors towards the selected gases and vapors. A study of polymer coating has reported that a CNT based gas sensor coated with polyethyleneimine (PEI) has showed high desire and affinity for $NO_2$ detection without interference from the $NH_3$ due to its low binding affinity and low coefficient of sticking on the electrons rich CNT's. On the other hand, a CNT bases gas detecting sensor coated with Nafion instead of PEI coated sensor, allowed higher selectivity and sensitivity for sensing $NH_3$ owing to the blocking of $NO_2$ on CNT's (Jafari 2018).

c) *Carbon nanotubes in Biotechnology:*

Due to the increasing demand for the innovative and environmentally friendly technologies, there has been a considerable growth the field of biotechnology where the living organisms are utilized to make efficient processes and products for specific uses. The emergence of biotechnology has provided certain opportunities to the use of carbon nanotubes (CNT's) to produce some useful products especially the biological fuel cells also known as biofuel cells. Biofuel cells are specific fuel cells that rely on biocatalytic activity to generate electricity in output. They are classified into microbial fuel cells (MFC's), and enzymatic biofuel cells (EFC's) (Ong, Ahmad et al. 2010).

MFC's utilizes microbial catabolic activities to produce electric power. They are considered as the future options in treatment of wastewater since a large variety of materials, i.e., complex organic waste and renewable biomass in wastewater can be used as resources. However, this technology is currently not practical due to low performance and lack of technical resources. Much of the research has worked on employing and altering the CNT's as electrodes to increase the power production in microbial fuel cells because of their high conductivity and large surface area. Tsai in 2009 introduced a new type of electrode architecture by coating carbon nanotubes (CNT's) over the carbon cloth to form a highly conductive electrode having high specific surface area in microbial fuel cells. Incorporating the CNT's into the working of microbial fuel cells has significant impact on the power production, i.e., the presence of CNT's results in an improvement of 250% in power density as compared with a non-CNT's coated electrode. Studies have confirmed that the use of electrodes with CNT's shows an increment of approximately 6-fold in power densities compared to non-CNT's electrodes. The optimization of the power density by achieving the biocompatibility of CNT's with microorganisms. It has been discussed previously that CNT's possess the antimicrobial capability, these effects can be reduced by modification techniques and refunctionalizing the CNT's by incorporating certain functional groups onto their surfaces.

Enzymatic fuel cells (EFC's) on the other hand utilize the enzymes or protein catalysis to carry out the microbial catalytic activities, i.e., the conversion of chemical energy, obtained from the metabolic reactions within the living organisms, to electrical energy. Until now from the past, the application area of EFC's as a power source for the communication devices, low power sensors, and medical implants have been suppressed due to their short lifetime, poor enzymes stability, and low power density. But the introduction of CNT's as bioelectrodes contribute up to major extent in EFC's. CNT's allows enzyme molecules to attach with their surfaces by covalent bonding. Enzymes covalently bonded with the CNT's are found to have high stability due to strong covalent linkage, which can afford the significant resistance against the denaturation of enzymes. Also, the spread of the CNT's increases the distance between the enzyme molecules, and so reduces the harmful interaction between the enzyme molecules and thus leading to an increased enzymatic stability. The enzymatic stability being an important parameter, offers good operational stability, which ultimately increases the power density and thus prolongs the lifetime of EFC's, e.g., the stabilized activity of glucose oxidase coated with the CNT's enables the continuous productive operation of EFC's for more than 16 working hours. Figure (see appendix, figure 16) shows a Mud Watt microbial fuel cell kit (Ong, Ahmad et al. 2010).

d) *Carbon nanotubes in renewable energy*:

Worldwide consumption of energy is estimated to increase by approximately 57% from the present up to 2030. This pressure on the energy resources expects the requirement for the advance renewable energy source technologies to meet the long-term energy demand challenge and to protect our environment from certain rifts which creates due to the imbalance of energy resources (Jafari 2018).

The CNT's can contribute efficiently to these energy resources, i.e., the major part contributed by the CNT's in solar energy sector is visible from their applications in photovoltaic devices (see appendix, figure 17). These photovoltaic devices produce the electricity by the conversion of photons (Energy packets) absorbed from the sun. From the past to this day, several major drawbacks have been reported for the conventional photovoltaic devices in terms of the high cost, and low stability under the illumination. These drawbacks have been found in commercially available silicon and semiconductor based photovoltaic devices. It is therefore, CNT's are found as an alternative material in these solar cell architectures, especially in silicon based solar cells, organic solar cells, and dye synthesized solar cells, due to their remarkable energy conversion and affordability. The active surface area of CNT's allows huge amount of photons absorption for the harvesting solar energy, while the presence of delocalized pi-electrons increases the mobility of the charges transfer (Venkataraman, Amadi et al. 2019).

Silicon based solar cells uses the simplest PN junction to separate the holes and electrons of the two blocks and to produce the current by exposing the PN junction to illumination. CNT's being conductive, and transparent, when incorporated into the junction as hetrojunction component, serves as a component for the charges transportation and charges collection. Thus, moderate efficiency with certain improvements in stability has been observed for the CNT's and Silicon heterojunctions.

Being flexible and having low production costs as compared with silicon bases solar cells, the development of organic solar cells has turned the attention of many of the researchers toward itself. These organic solar cells depend on the conductive organic polymers for light absorption and transfer of charges. Recent research shoes improvement in efficiency by incorporating the CNT's in top electrode, the photoactive layer, and the back electrode of organic cells. In photoactive layer, the CNT's serve as photoactive material and tends to optimize the performance of the cells by providing efficient holes and electrons transport at the interface of the CNT's and polymers. The photoactive component constructed from CNT's and polymers are examined to have higher open circuit voltage by considering the advantage of the high amounts of electron transport capability of the CNT's (Hallinan, Kissock et al. 2008).

Recent developments in hydrogen storage media have focused on CNT's as one of the current strategic research areas. Hydrogen, which is comparatively a clean fuel compared to conventional fuels, has been considered to use it as a source of clean and green energy. The United State Department of Energy (DOE) has kept an eye on minimum hydrogen storage of 6.5wt% to meet the demand of commercial storage requirements. CNT's have received an exceptional consideration as a potential storage material due to their affordability, recycling characteristics, low density, nano scale pore size distribution, and reasonable chemical stability as evident form the research investigations on strategies of how to achieve the hydrogen storage. Theories of Wang and Johnson (1999) shows that the amount of hydrogen adsorbed by the CNT's depends on the nature of the array and orientation of CNT's, with the adsorption of hydrogen being preferred on the outer surface of CNT's rather than the inner one.

Unfortunately, there is controversy until now both experimentally and theoretically, that CNT's possess the abnormal performance as a hydrogen storage since the high storage capability of CNT's is not available from other researchers of the same field. Thus, more efforts from the present-day technology are needed to achieve this goal.

e) *Carbon nanotubes in supercapacitors:*

Super capacitors or electrochemical capacitors have been considered as the alternative to replace the conventional batteries because of their small size, high power density, long life cycle and having high energy density, with good potential for reducing wastes disposal to the environment. Supercapacitors (Pan, Li et al. 2010), may also be considered as the ideal capacitors, are composed of high surface area activated capacitors that use a molecular thin layer of electrolyte as a dielectric as shown in figure (see appendix, figure 18).

Recent technological advancements have proposed the application of CNT's as the electrode material for the capacitor. The use of large active surface area of CNT's in electrode couple with a thin layer between the electrode and the electrolyte intensifies the ability of the capacitor to store high amount of the electric energy. Moreover, the use of vertically aligned CNT's with several atomic diameters in width can increase the super capacitance of these capacitors significantly, and hence the power density as well due to the increased surface area of the electrode. CNT's, having high surface area, stability, and strong mechanical properties, they are not preferred to be used alone as an electrode due to their low capacitance. It is therefore, CNT's are proposed as substrate high specific capacitance transition metal oxides like manganese oxides ($MnO_2$) and ruthenium oxide. Capacitances up to 5000 Farads have been reported with the supercapacitors and having energy densities up to 5Wh/kg, which is much higher than the conventional capacitors, i.e., having energy densities of only 0.5Wh/kg.

**Sustainability and green engineering innovations that might just change the world:**

The world must change if it is to survive. There has never been a greater interest and push for the sustainable products and technologies that there is today. The world has reached to a critical point regarding the climate change, and many innovators, businesses, and designers are stepping up to the level to build a green future. Following in the discussion are some incredible examples of sustainable innovation that could positively change the world as we know it, and they pave the way for a more sustainable way of living on the face of this earth.

1) *The smog free project:*

The smog free project (see appendix, figure 19) is a very long-term campaign for clean and green air in which Dann Roosegaarde and his teammates have created the world's first smog vacuum cleaner. This 7-

meter-tall smog free tower utilizes the patented positive ionization technology for production of smog free air in public areas like parks, hospitals, and resorts, allowing the people to use the fresh and clean air free of cost. This tower is equipped with the environmentally friendly technology and cleans 30,000 $m^3$ of air per hour. The resource require for the operation is small amount of electricity which is also produced by green technology for this specific tower. The function and working of smog free tower have been legalized by the results compiled by the Eindhoven University of Technology (2020).

With this innovation, one can even wear rings made from the compressed smog particles collected from the tower. This project has gained lots of attention since its very inception, winning multiple awards. Utilizing the same patented concepts, recent smog free tower campaigns and projects have been launched in South Korea, China, Netherlands, Mexico, and Poland.

2) *Zephyr solar balloon:*

Zephyr (2020) is a photovoltaic balloon (see appendix, figure 20) and environment friendly generator created by Karen Assaraf, Julie Dautel, and Cedric Tomissi. This aerial platform takes the shape of helium balloon. These solar balloons are operated individually or in the form of aerial network. These solar balloons can be installed within an hour, can fly up to 30 days at a time, they are able to withstand winds having speed of 43mph, and can fly at great altitudes. These balloons can be used for a vast range of sustainable activities. They are incorporated in various scientific missions observing the wildlife, to measure the air quality, and can be used to enhance the coordination during any natural disaster. This solar balloon for the first time reported in France. The modern-day technological team needs to take serious concern for introducing these solar balloons on large worldwide.

3) *The Green Building Initiative:*

The green building initiative (GBI) is a nonprofit organization (2020) introduced to accelerating the adopting of building practices that usually results is resource efficient, healthier and buildings which are environmentally sustainable. The strategy to achieve the desired goals involves education and promotion on the use of GBI’s Green Globes certification program for the commercial buildings and GBI’s Guiding Principles Compliance and third-party assessment program for federal building sustainability requirements.

4) *B-Droid:*

B-Droid (2020) is one of the several modern-day efforts to crate robotic bees that can pollinate crops as effectively as their organic alternatives. B-Droid’s aim is to help boost the population of natural bees by growing the low nutritional and high labor tasks of pollination to these robotic bees (see appendix, figure 21).

5) *Groasis Waterbox:*

The Groasis water box (2020), created by the Dutch flower exporter, Pieter Hoff, is a device that makes growing crops possible and resources efficient even in the deserts. It consists of an intelligent bucket made from the paper, which is recyclable, and helps in seed germination, and incubate the tree plants. It usually requires 90% less than traditional growing methods and can be used in some of the extreme climate regions (see appendix, figure 22).

*6) AirCarbon:*

AirCarbon (2020) was developed by Newlight technologies and has already won many awards for its sustainability. This AirCarbon is made from the carbon emissions that is usually just released into the atmosphere. It is a verified and legal carbon-negative material, i.e., every step of its production and use is fully sustainable and green. It is the best alternative to other synthetic materials as it is not made from the non-degradable usual plastics (see appendix, figure 23).

*7) Solar Glass:*

The discovery of the solar glasses (see appendix, figure 24) could change the world the way we create the modern-day homes and commercial buildings. Researchers at the University of Michigan are trying to develop the solar glass, being a sustainable and green product that has generated a lot of talk in the modern-day world. The glass would be able to capture and store the solar energy, if used as an alternative for the conventional brick's buildings (2020).

*8) The Seabin:*

The Seabin (2020), created by Andrew Turton and Pete Cenglinski with the aim to clean up the world's oceans. This Seabin can filter out the plastic, detergents, wastes, and oil, allowing the cleaned and green water to flow. The Seabin comprises of a catch bag, which traps the floating pollutants. An underground water pump sucks water through the bin and passing it out again once it has been cleaned. It needs to be emptied once a month and could make big, and long-lasting impacts on the water pollution in ports and harbors over the world (see appendix, figure 25).

*9) The Vegan Bottle:*

The vegan bottle (2020), created by lYSPACKAGING is made from natural bio plastic which id degradable and could replace the conventional non degradable plastic bottles forever. This bottle from its cap to the wrapper is made from 100 biodegradable materials. Usually, the bottle is made from the sugar cane extractions. Sugar can which requires far less water than any other crops, and the manufacturing of these bottles consumes low amount of energy as compared to conventional manufacturing processes (see appendix, figure 26).

*10) CloudFisher:*

CloudFisher (2020), created by Aqualonis is used to convert the fog into drinking water (see appendix, figure 27). This could easily be used by the people living in coastal areas or mountainous regions to convert fog into safe and fresh drinking water. The water produced could also be used to irrigate the crops or could be used for other purpose as well. It is made from a 3D mesh that can withstand high wind speeds, but still retaining water. The green engineering innovative example is already being used to help people round the world.

**Results and discussions:**

The modern-day existing world has been put to huge amount of pressure by certain factors which are induced due to rapid rate of increase in the world's population. The rapid rate of increase in the world's population lead to more requirements in the form of the resources, food, water and energy. To cope with this, the industrial sectors are trying to manufacture the required products at rapid rates, which on the other hand create a huge amount of pressure on the environment. There has been a significance need to introduce new and innovative design and manufacturing ideas to create the sustainable products, with less use of the resources in the form of materials and energy, cost effective products, and which are not harmful to our kind environment. This aspect of the production industry is a real challenge to the modern-day technology round the world. The principles of green manufacturing or green engineering has been discussed with respect to certain sectors for the qualitative productions and production processes. As suggested by the analysts and designers, that the integrated use of the green engineering and green chemistry, both being the vast fields could compete with the present-day challenges faces by our environment. Similarly, there are certain chemical substances/compounds have been discovered which can pave the path for the stress-free advancements in the future world, e.g., the use of carbon nanotubes (CNT's) as explained earlier in this paper could the most idealized alternative to the current conventional materials, in terms of the environmentally favorable working. In short, this paper highlights the importance and use of green engineering principles and products for the clean and green environment, thus leading to successful life on the face of this earth.

The efficient use of green engineering principles and green engineering materials is still lacking due to immaturity of the technical fields and processing media. It is therefore, strongly suggested to the present-day researchers to take the serious concern of this issue.

It is recommended for the environmental protection authorities and other regulatory authorities to keep an eye on the legal use of the natural resources for the production. Also, it is recommended for the authorities to create awareness among the masses through certain initiatives, where the masses are informed about the principles, uses, and methods of green engineering to cooperate in creating an idealized clean and green world.

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# APPENDIX

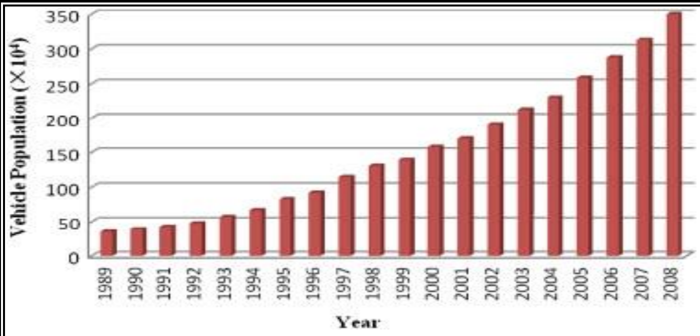



**Figure 01**

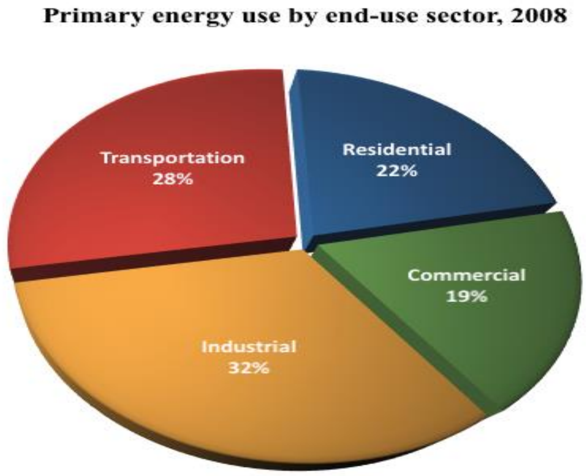



**Figure 02**

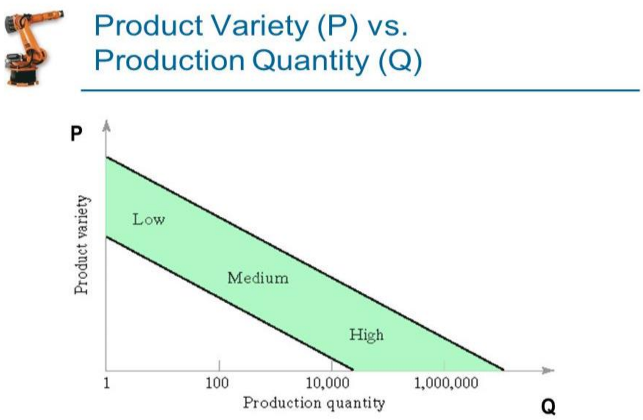
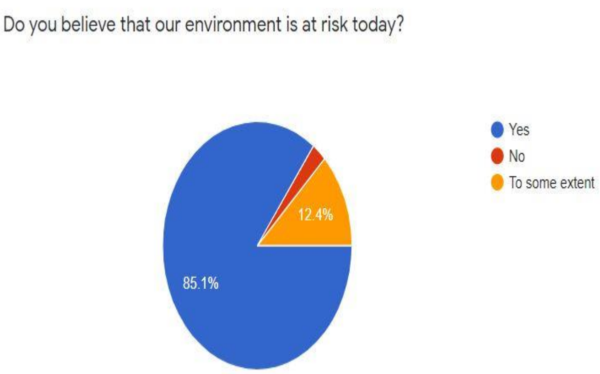



**Figure 03**

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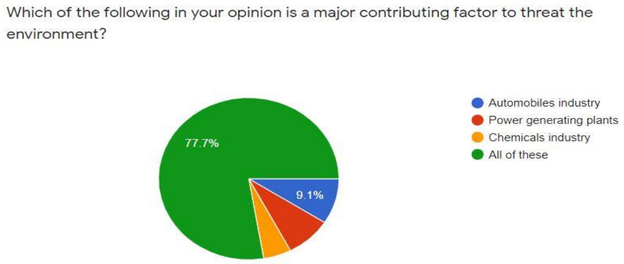
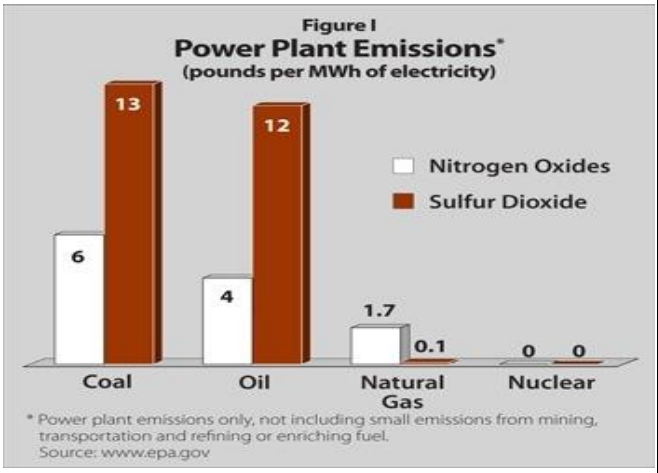



**Figure 05**

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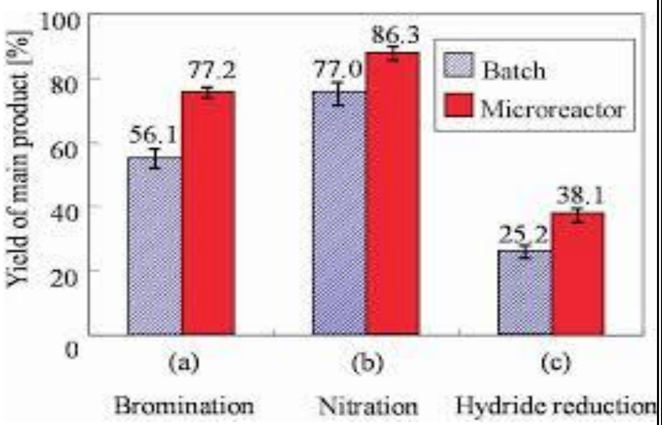



**Figure 07**

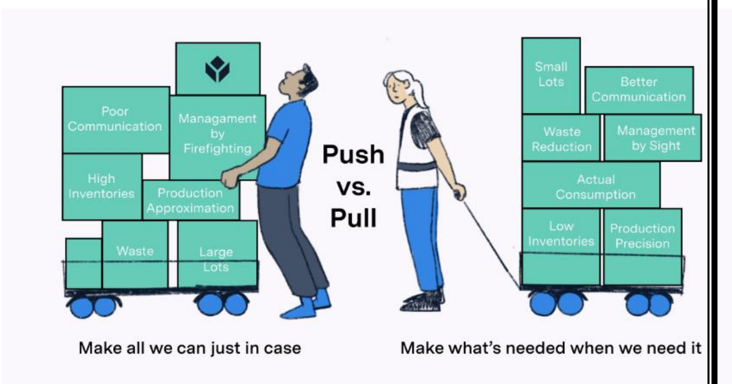



**Figure 8**

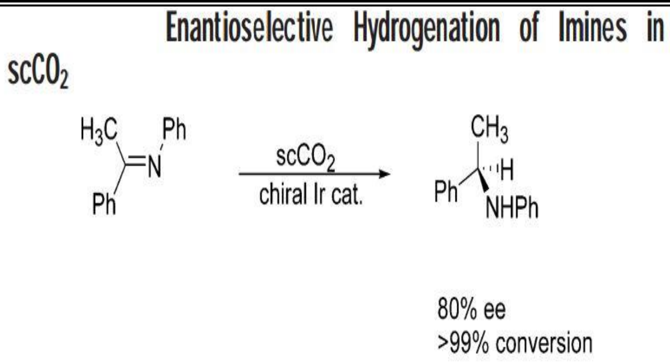



**Figure 09**

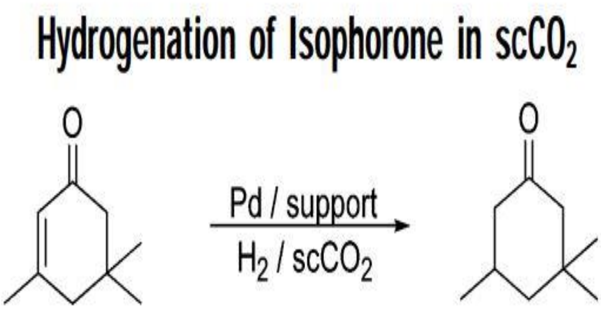



**Figure 10**

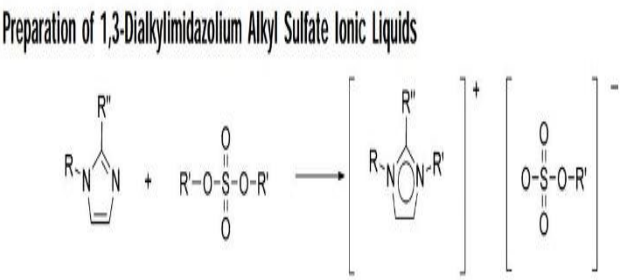
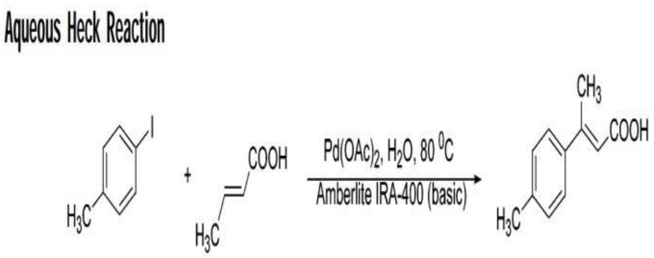



**Figure 11**

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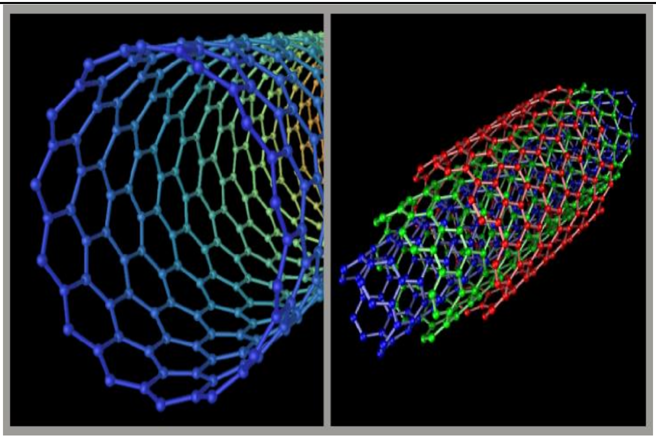

**Figure 13**

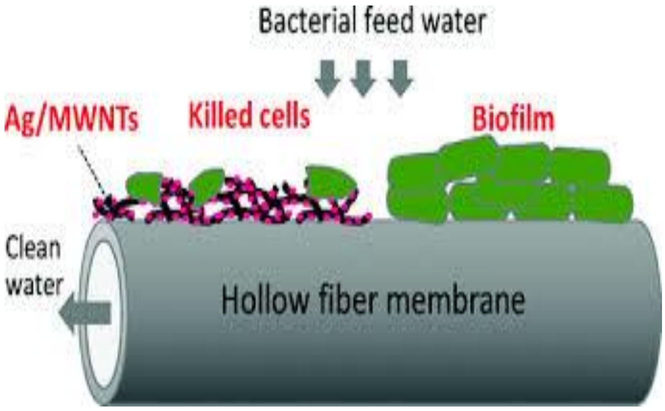


**Figure 14**

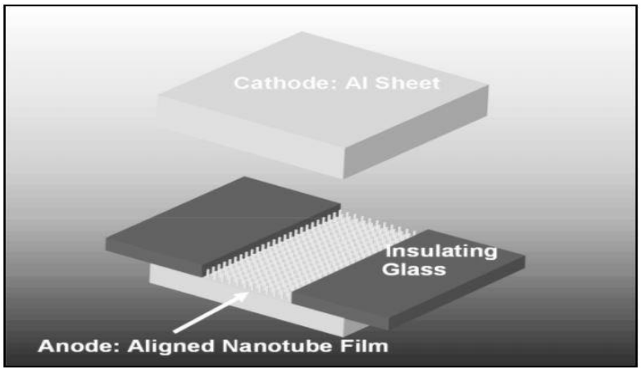


**Figure 15**

**Figure 16**

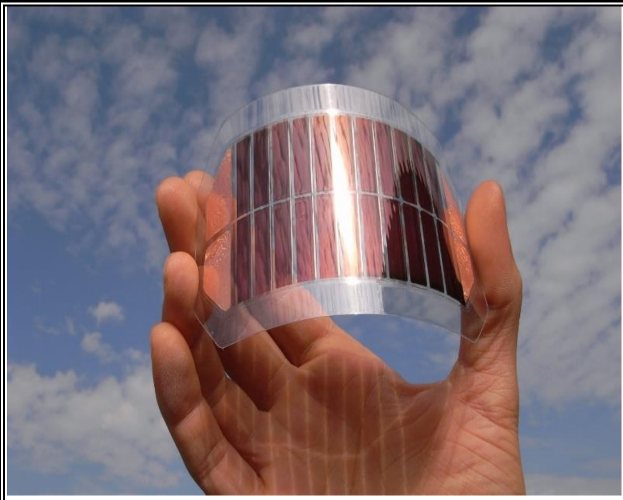

**Figure 17**

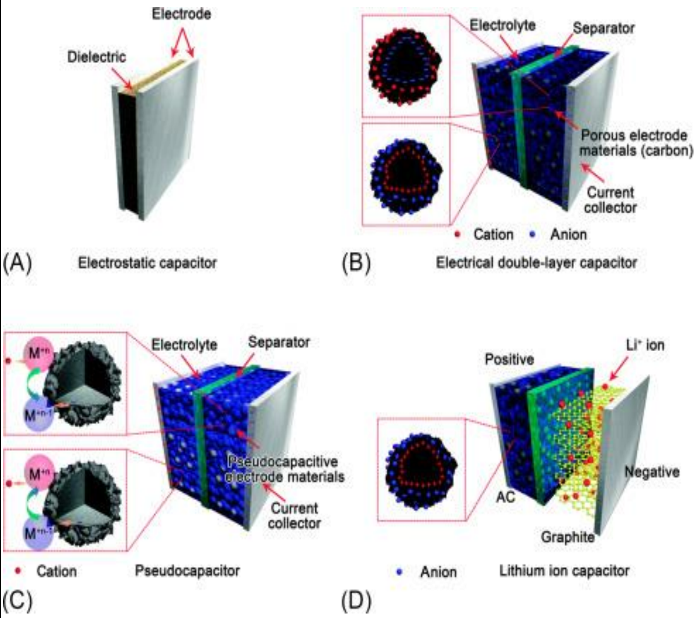


**Figure 18**

**Figure 19**

**Figure 20**

**Figure 21**

**Figure 22**

**Figure 23**

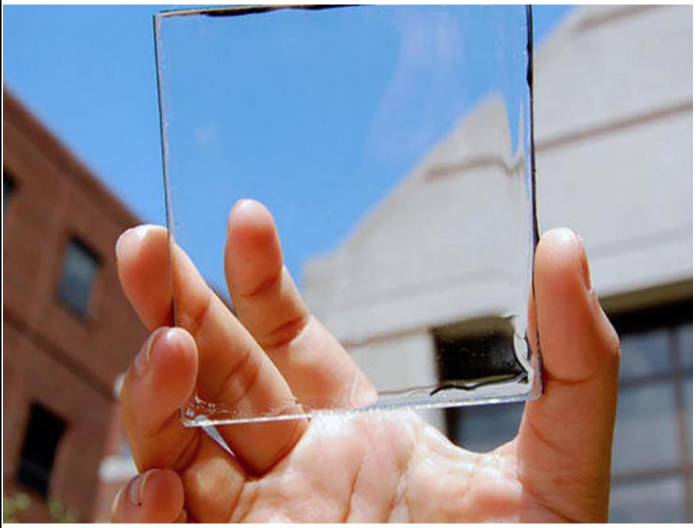

**Figure 24**


**Figure 25**


**Figure 26**

**Figure 27**

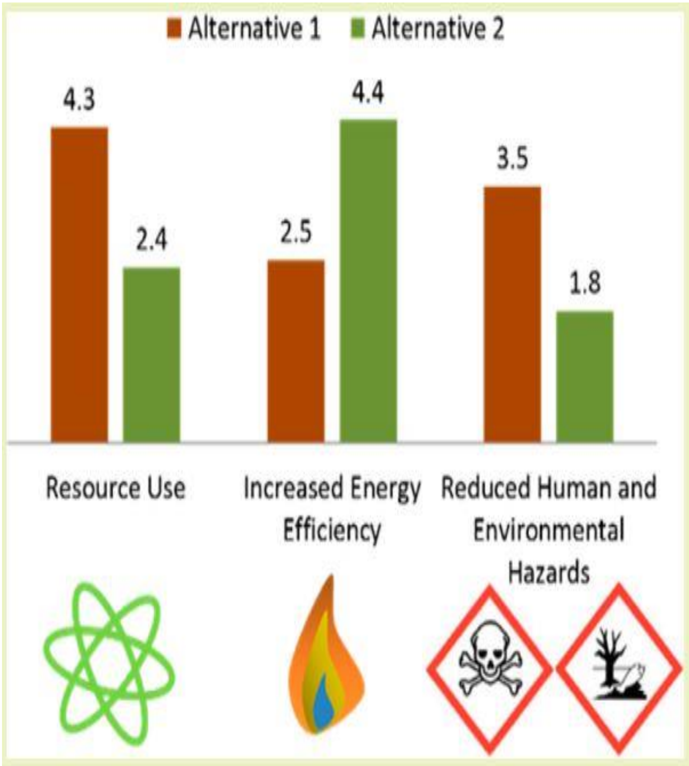


**Figure ****