Sustainable Green Chemical Technology for Developments in Process Industries

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***Abstract*:** The environmental and climate issues facing across the world are widely recognized as serious problems. Therefore, green technologies and ecological sustainable development is need of the hour as the quality of life is worsening. We have had major progress in technology causing depletion of natural life sustaining resources, especially clean air and water. These problems are causing considerable environmental, economic and social impairment on a worldwide scale. Sustainable development implies that renewable resources should be used wherever possible and that non-renewable resources should be husbanded (e.g., reduced and recycled) to extend their viability for generations to come. The paper will present the trend towards sustainability and green technologies in the chemical process industry (CPI). A broad review of state-of-the-art green technologies in the understanding and application of sustainability with few case studies highlighting the economic benefits of adopting green processes from a chemical engineering viewpoint is addressed. Green technologies increasingly uses renewable resources; reduce wastes, pollutants, emissions; recover, reuse and recycle; reduce the pressure on natural resources and restore the balance of the eco-system and biosphere and ultimately help in providing "ecologically sustainable development". These technologies are, therefore, viable, cost-effective, environmentally advanced and most appropriate to the climatic, economical, geographical, ecological and social conditions of the country. This aim can only be achieved by developing new environmentally friendly, safe and non-toxic materials and their based innovative technologies. Therefore CPI must promote sustainable development by investing in green technologies and ensure increased adherence to safety, health and environmental standards.

Keywords: Green technologies, sustainable development, environmental, CPI, renewable resource

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1. Introduction:

Environmental issues in the past were considered as part of the economic system and the rapid exploitation of natural resources.[1] It took many years to consider the established ways that materials were used (feedstocks), the initial design of chemical processes, the hazardous properties of products, the energy consumption and other parameters involved in the manufacture of products (life cycle, recycling, etc.).

The rapid development of new chemical technologies and the vast number of new chemical products in the last decades turned the attention of environmentalists to remedial actions for the negative impacts (monitoring environmental pollution, reduction of pollutants, recycling, etc). But the fact is that the most effective way to reduce the negative impacts is to design and innovation in the manufacturing processes, taking into account energy, materials, atom economy, use and generation of secondary materials which are dangerous and finally the life cycle of the products and their practical recycling into new materials.

Green Chemistry involves alternative more environmental - friendly synthetic routes, and was another area for production of chemicals on industrial scale with the mantra – 'Think Green'. Traditionally chemical engineers have been more concerned about selectivity than conversion. Green technologies explore alternate reaction conditions, alternate (solvent free) media and even alternate energy sources. [2] Green chemistry, the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances, is the most fundamental approach to pollution prevention. Green chemistry addresses the need to produce the goods and services that society depends on in a more environmentally benign manner. Life-saving pharmaceuticals can be produced while minimizing the amount of waste generated, plastics that biodegrade can be synthesized from plants, and reactions can be run in water rather than in traditional organic solvents by applying green chemistry principles to chemical products and processes.

2. Role of Green Chemical Technology:

Green chemical technologies have eliminated waste, improved safety, enhanced security, and saved industry money. This workshop will introduce the principles of green chemistry, provide industrial and academic examples of greener technologies, and highlight the economic benefits of adopting environmentally friendly processes. The chemical process industry aims particularly at energy, capital expenditure and variable feedstock cost savings due to fierce global competition and requirements for sustainable development. Increasingly novel processes are used in the industry to achieve these aims.[3] They are used in:

a) existing processes to renew parts;
b) process re-designs based on existing feedstock's and catalysts;
c) innovative processes (new feed stocks, new catalysts, new process routes, new multifunctional equipment).

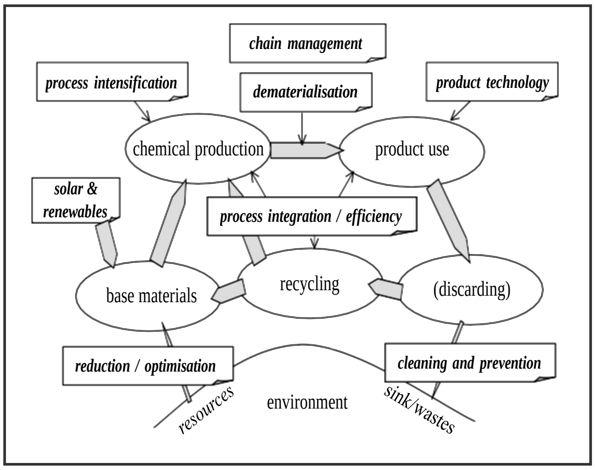

Figure 1: Focal areas of chemistry and chemical engineering for sustainable development

The ever-increasing globalization of the chemical process industries (CPI) is bringing an environmental awareness to various corners of the world at a pace never anticipated in the past. Green Chemical Engineering (GCE) is much more than a method for addressing environmental problems. It offers a framework for achieving innovation. Time and again, companies looking to the future through the lens of green chemical engineering have enjoyed tremendous environmental and economic returns. GCE is a way to not only improve the environment but also positively impact the client's bottom line. Avoiding the generation of waste (including energy) or pollutants can often be more cost-effective than controlling or disposing of pollutants once formed. Sustainable development is often used synonymously, but is more of an economic term describing how our economy should improve, and implying that an increase in quantity is not necessarily the goal, but rather an increase in quality [4].

3. Sustainability Concepts:

Sustainable development has become the accepted orthodoxy for global economic development and environmental protection since the end of the twentieth century. The three major aspects of sustainable development: environment, economy, and community.

a) The Natural Step
b) Pollution Prevention:
c) Design for Environment
d) Eco-Efficiency
e) Eco-Effectiveness
f) Cradle-to-Cradle Design
g) Industrial Ecology
h) Environmental Management Systems/Sustainable Management Systems

Pollution Prevention:

Pollution prevention incorporates the concepts of source reduction and recycling. Source reduction is defined as those multimedia activities that prevent waste generation and contaminant release. Recycling, for the purposes of pollution prevention, is defined as a process in which a waste material is reused in the original manufacturing process or another process.

Design for Environment:

Design for Environment (DfE) is defined as the systematic consideration during design of issues associated with environmental safety and health over the entire product life cycle.

Eco-Efficiency:

Eco-efficiency has been described as doing more with less. It involves minimizing waste, pollution and natural resource depletion (thus incorporating the concept of pollution prevention). Eco-efficiency is probably the easiest way to go, as well as the logical follow-up to the progress that has been made in the area of environmental management. Began with an era of no regulation followed by an era of regulation and strict compliance. [5] After which is coming a time of “beyond compliance”, where businesses are finding that it can be to their benefit to not just adhere to the letter of the law, but to go beyond it.

Eco-Effectiveness

Proponents of eco-effectiveness point out those natural systems are not very efficient, but they sure are effective, and they represent the ideal systems, which our systems must emulate in order to achieve sustainability.

Environmental Management Systems/Sustainable Management Systems:

Environmental management systems include:
Establishment of an environmental policy that contains commitments to continual improvement, compliance, and pollution prevention, environmental planning to identify significant environmental impacts, controlling these activities to minimize their impact on the environment; and setting environmental performance objectives and targets and tracking progress toward meeting them. [6]

Sustainability management systems are similar, but go one step further in that they provide a sustainability-based framework on which to base the targets developed by the EMS. One example is the combination of TNS with EMS.

4. Twelve Principles of Green Engineering:

Green engineering principles are based on the green chemistry principles, developed to help guide chemical engineers. [1,2] As for the Green Chemistry principles, the 12 Green Engineering principles provide a checklist for scientists and chemical engineers to use when designing new materials, products, processes and systems. Making products, processes and systems more inherently benign can come about by either changing the inherent nature of the system, or changing the circumstances/conditions of the system to reduce the release of toxins and associated exposure to harmful effects, or both. As for green chemistry, it is therefore important to apply these Green Engineering principles systematically, and together rather than in isolation, to achieve significant improvements. The 12 principles are summarized as follows:

1) *Inherent rather than circumstantial:* The inherent nature of the selected material should be

taken into consideration to ensure that it is as benign as possible (i.e. non-toxic, and/or minimal energy and materials inputs required to complete the process).

2) *Prevention instead of treatment:* Materials and processes that generate minimal waste should be used, which can avoid costs and risks associated with substances that would otherwise have to be handled, treated and disposed of.
3) *Design for separation:* Products should be designed with physical and chemical properties that permit self-separation processes, to reduce waste and save in disassembly and reassembly time and costs.
4) *Maximize mass, energy, space and time efficiency:* Products should be designed for maximum efficiency, using real-time monitoring to ensure the actual process is performing in accordance with the required design conditions.
5) *Output-pulled versus input-pushed:* The amount of materials or energy used should be minimized, by applying Le Châtelier's Principle to continually remove products or 'outputs' so that the output is then 'pulled' through the system.
6) *Conserve Complexity:* Complexity in products should be minimized to create more favorable properties for reuse and recycling.
7) *Durability rather than immortality:* Products should be designed to have a targeted lifetime, to avoid environmental problems such as waste to landfill, persistence and bioaccumulation.
8) *Meet need, minimize excess:* Technologies should be innovated that target specific demands of the user to minimize waste and cost.
9) *Minimize material diversity:* Products should be designed with less material diversity to create more options for recyclability and reuse.
10) *Integrate local material and energy flows:* Products, processes and systems should be designed to use local materials and energy resources to minimize inefficiencies and consumption associated with transportation.
11) *Design for commercial 'afterlife':* Products, processes and systems should be designed so their components can be reused or reconfigured to maintain their value and usability for new products (sometimes referred to as 'design for modularity').
12) *Renewable rather than depleting:* Renewable materials should be used so that the source can be replenished and provide virtually infinite service with minimal, if any, waste.

Some Recent Developments and Examples of Green Technology:

Scientists from all over the world are using their creative and innovative skills to develop new processes, synthetic methods, analytical tools, reaction conditions, catalysts, etc. under the new green technology cover. [7,8] Some of these are:

1) A continuous process and apparatus converts waste biomass into industrial chemicals, fuels, and animal feed. Another process converts waste biomass, such as municipal solid waste, sewage sludge, plastic, tires, and agricultural residues, to useful products, including hydrogen, ethanol, and acetic acid.
2) A method for mass producing taxol by semi continuous culture of the Taxus genus plant.
3) A fermentation method for the production of carboxylic acids.
4) A method of partially oxidizing alcohol, such as methanol to ethers, aldehydes, esters or acids, by using a
   Supercritical fluid mobile.
5) A process for producing a fluoropolymer by using supercritical carbon dioxide.
6) A cost-effective method of producing ethyl lactate, a non-toxic solvent derived from corn.
7) A range of ‘organic solvents’, for example, bioethanol, that are worker friendly and environmentally sound.
8) A new environmentally friendly technology in mixed metals recovery from spent acid wastes has been used to recover zinc and ferrous chloride from pickle liquor.
9) The demand for non-ionic surfactants is growing. A new example of this is alkyl glycoside, which is made from saccharide. This product can be used as a replacement for alkyl aryl sulphonate anionic surfactants in shampoos.

5. Use of Alternative Basic Chemicals as Feedstocks inChemical Industry and Research:

Until now we know from experience of the last 50 years that the majority of raw chemicals and starting materials not only for the chemical industry but also for other industries and workshops were products of the petrochemical industry.

a) Renewable feedstocks and raw materials:

Green chemical technology wants to change into renewable feedstocks. The second most desired property of basic starting materials is their lower toxicity and their environmental impact.[8] Health and safety protection of workers and the environment is a top priority. Green Chemistry proposes change of direction into biological raw materials (plant and animal waste, products from fermentation of plant waste, biogas, etc.).

b) Oleochemistry. New biological starting materials:

Fats and oils (from plants and animals) as oleochemical raw materials can become a new source of chemical feedstocks. Already a series of raw materials exist in the market with many applications in cosmetics, polymers, lubricating oils and other products.

d) Photochemistry. New Chemical Processes with the Aid of Light:

Green technology puts a lot of emphasis on photochemical reactions in chemical processes. Light (ultraviolet and visible) can become an important catalyst for many reactions, replacing toxic metals in many reactions. Scientists think that photochemistry has great potential and many research innovations and applications were introduced in the last years.

d) Photocatalytic synthetic routes with Titanium dioxide (TiO2):

In the last decades numerous research studies have been shown great promise for using TiO2 dioxide for photocatalyitic industrial reactions under visible light. The energy use is minimized, waste products are very low and the yields are much higher than conventional reactions.

e) Photocatalytic oxidations. Waste and toxic chemicals decomposition

TiO2 and other metallic oxides (Fe2+) can be used in photocatalytic oxidations for the decompositions of toxic and waste chemical materials. These decompositions, especially for polychlorinated compounds, phenols, etc, can produce neutral chemicals with minimum toxicity. A useful mixture is Fe_2+/H_2O_2 (Fenton reagent) with the aid of light can decompose toxic industrial waste.

f) Waste Biomass as chemical feedstock, biomaterials and biofuels:

The advance of the last decade into the use of biomass for the production of various materials was very impressive. It was known for decades that biomass from agricultural processes was wasted. [6,7] Scientists for year researched many aspect of biomass and it’s effective. Biomass is considered a very important problem of sustainability with increasing fossil fuel prices.

g) Biodegradation of biomass for biogas and biodiesel: Biomass is well known for its use for biofuels, especially from organic waste in landfills. Biomass, through chemical and physical processes can be used for the production of biodiesel.

h) Biocatalysis and biotransformations in the chemical industry:

Biocatalysis is considered particularly green technology with many applications which are considered benign for the environment and energy efficient. Enzymes have been used for many synthetic chemical routes with great advantages in the food and pharmaceutical industries.

i) Capture or sequestration of carbon dioxide:

Green Chemistry is involved in carbon dioxide reduction in chemical industries. [8,9]Climate change and the phenomenon of greenhouse effect due to CO_2 emissions are considered by Green chemists a very important environmental problem.

6. Applications of New Methodologies in the Synthesis ofChemical Compounds:

Some of the important changes in the synthesis of chemicals under green chemical engineering principles and alternative methods are discussed in this section.

a) Ionic liquids in organic synthetic routes:

Ionic liquids are used extensively in recent years as alternative solvents in organic synthesis. These substances are variously called liquid electrolytes, ionic melts, ionic fluids, fused salts, liquid salts, or ionic glasses. Ionic liquids have many applications, as powerful solvents and electrically conducting fluids (electrolytes). They are considered as good candidates for future improvements that can give “green” credentials to their use and applications.

b) Organic synthesis in water

Water was considered for many decades as a medium that was too avoided as solvent for synthetic organic chemistry. Water proved to be an excellent solvent for many synthetic methods. The most interesting example of water as a solvent is the Diels-Alder organic synthesis. [2, 10]

c) Organic synthesis in polyfluorinated phases

In these techniques chemists are using polyfluorinated two phase systems of solvents which dissolve catalysts with a long hyperfluorinated alcylo- or aliphatic chain. Reagents are dissolved in an organic solvent which is insoluble in the hyperfluorinated phase. Warming up the mixture accelerates the reaction with excellent yield of products.

d) Supercritical carbon dioxide and supercritical water:

Supercritical fluid is called any liquid substance at a temperature and pressure above its critical point, where distinct liquid and gas phases do not exist. It can effuse through solids like a gas, and dissolve materials like a liquid. In addition, close to the critical point, small changes in pressure or temperature result in large changes in density, allowing many properties of a supercritical fluid to be "fine-tuned".

e) Use of microwave techniques for organic synthesis:

Microwave furnaces are widespread now for food warming and cooking. Their use in organic synthesis started many years ago and their success in organic synthesis with “green’ criteria are very well established. Already, there are numerous research papers and applications for microwave organic synthesis with high yields, without solvents, low waste and very low energy requirements.

f) Sonochemistry. The use of ultrasound for synthesis:

Chemical reactions can start and enhanced by sonic waves. Sonochemical reactions by ultrasound are very advanced “green” techniques with exceptional high yields. There are three classes of sonochemical reactions: homogeneous Sonochemistry of liquids, heterogeneous Sonochemistry of liquid-liquid or solid–liquid systems, and, overlapping with the previous techniques, sonocatalysis. The chemical enhancement of reactions by ultrasound has been explored and has beneficial applications in mixed phase synthesis, materials chemistry, and biomedical uses.[11]

Conclusions:

Like any nation in the world, the challenges facing the sustainability of technological advancement of chemical industry today are re-inventing the use of materials. To address these challenge, green chemical technologies is actually central to many of the environmental and resource use issues at the heart of sustainable development. These technologies are, therefore, viable, cost-effective, environmentally advanced and most appropriate to the climatic, economical, geographical, ecological and social conditions of the country. This aim can only be achieved by developing new environmentally friendly, safe and non-toxic materials and their based innovative technologies. Therefore CPI must promote sustainable development by investing in green technologies and ensure increased adherence to safety, health and environmental standards.

References:

1) Anastas PT, Williamson TC. Green Chemistry: Designing Chemistry for the Environment. ACS publications, Washington DC, 1996.
2) Anastas PT, Warner JC. *Green Chemistry: Theory and Practice.* Oxford Science Publications, Oxford, 1998.
3) Anastas PT, Williamson TC (Eds). *Green Chemistry: Frontiers in Chemical Synthesis and Processes*. Oxford University Press, Oxford, 1998.
4) Sharma SK. *Green Chemistry for Environmental Sustainability*. Series: *Advancing Sustainability through Green Chemistry and Engineering*. CRC Press, Boca Raton, FL, 2010.
5) Ballini R (Ed). *Eco-Friendly Synthesis of Fine Chemicals*. RSC Green Chemistry Series, Royal Society of Chemistry publications Cambridge, 2009.
6) Soetaert W, Vendamme E. *Biofuels*. Wiley-VCH, Weinheim, 2009.
7) Cheng H, Gross R (Eds). *Green Polymer Chemistry: Biocatalysis and Biomaterials*. Oxford University Press, Oxford, 2011.
8) World Commission on the Environment and Development (WCED), *Our Common Future* Oxford, Oxford University Press, 1987, p. 43.
9) Roesky HW. *Experiments in Green and Sustainable Chemistry*. Wiley-VCH, West Sussex, 2009.

10) H.G.E., & Wrightson, I. (2000). Environmental, Health and Safety Committee (EHSC) note on Sustainable Development and the Professional Chemist. Retrieved from: http://www.rsc.org./lap/rsccom/ehscnotes.htm
on October 10, 2013.
11) The Royal Australian Green Chemistry Institute Inc.
website - *Australia's Green Chemistry Challenge*
http://www.raci.org.au, *Accessed* on October 5, 2013