GREEN CHEMISTRY

What Is Green Chemistry?

Green Chemistry is the synthesis of chemical products and processes with a view to reducing and eliminating the use and/or production of hazardous substances. Rather than being a specific area of chemistry, Green Chemistry is more of a philosophical approach which is integrated into many different branches of chemistry.

Sometimes described as “environmentally benign”, Green Chemistry aims to minimize the use and production of unsafe products and maximize the efficiency of chemical processes. Green Chemistry research has grown over the past decade and a half, with new technologies focused on reducing waste and energy use, using renewable resources and generating safe products. The benefits are not only health- and environment-related, but also economical, as the costs of storage, regulation and protecting workers and the public from exposure to hazardous chemicals are reduced.

The Principles of Green Chemistry

The 12 principles of Green Chemistry, which were formulated by Paul Anastas and John Warner,[1] are generally accepted as fundamental guidelines of the philosophy. A key aspect of these principles is that they should be implemented at the level of method design, rather than managing the consequences after the event.

The 12 principles:

1. Prevent waste. It is better to prevent waste rather than to treat it.
2. Atom economy. Aim to maximize the incorporation of all materials used in the chemical process into the final product. For example, minimize the production of byproducts and wastes.
3. Less hazardous chemical synthesis. Design methods such that any chemical substances produced have the least toxic effect on human health and the environment as possible.
4. Safer chemical design. Aim to produce chemicals which fulfill the desired function but have minimal toxicity.
5. Safer solvents and auxiliaries. Minimize the use of chemical solvents and related substances (which may be flammable, toxic and/or environmentally unsafe). If unavoidable, use non-hazardous solvents wherever possible.
6. Design for energy efficiency. Reduce the amount of energy resources required to perform a chemical process.
7. Renewable feedstock. Use renewable raw materials and agents whenever possible.
8. Reduce derivatives. Chemical derivatives are often produced as temporary intermediate molecules between the start and end products. Such multistage processes require the input of more resources and chemical reagents. Therefore, the minimization of such steps is desirable.
9. Catalytic agents. Use catalytic agents (small amounts required, reusable) rather than stochiometric reagents (larger amounts required, non-reusable).
10. Degradable design. Design products to be degradable after completing their function.
11. Pollution reduction by real-time analysis. It is necessary to ensure that new methods are truly safe and nonpolluting. This requires proper monitoring of reactions to identify potential short-term and long-term byproducts and their consequences. In order to achieve this, new analytical technologies may need to be developed.
12. Safer Chemistry. Reduce the use of dangerous chemicals and substances to minimize the risk of accidents.

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Green Chemistry in Practice

Given that almost all functional objects are processed, packaged or transported in a method that involves chemicals, Green Chemistry can be applied to almost every aspect of our lives. Products which have benefited from Green Chemistry research include but are not limited to medications, diapers, food processing and packaging, plastics, printing, textiles, photography, electronics, pesticides, paints, paper recycling, furniture and automobiles. The principles of Green Chemistry can be applied at different stages of a production process:

<u>Starting material:</u> *Avoid using hazardous or toxic raw materials.*

- Example: Benzene, a known carcinogen, has traditionally been used to produce chemicals used in nylon production and photographic developers. New methods have recently been developed to produce these chemicals from glucose, a simple nontoxic sugar compound.[2]

<u>Processes:</u> *Adjust reactions and choose reagents to be safer and/or more energy-efficient.*

- Example: Professor Galen Suppes, recipient of a 2006 Presidential Green Chemistry Challenge award, has developed a new method for converting **glycerin**, a co-product of biodiesel production, to **propylene glycol**, a nontoxic chemical which can be used in antifreeze. The new system uses a catalyst which reduces the temperature and pressure required for the reaction and produces fewer byproducts than alternative methods.[3]

<u>End product/target molecule</u>: *Look for ways to alter a chemical so that it still fulfills its function but is no longer harmful. Alternatively, research and improve understanding of the required function, which may enable the development of safer alternatives.*

- Example: New technologies are emerging in which biodegradable plastics can be manufactured from plant material such as maize or corn.[4] Such plastics are now used in packaging by several multinational food companies. After reaching the end of their useful life, these plastics decompose completely without leaving chemical residues.

Useful Resources and Further Information

- Environmental Protection Agency, www.epa.gov/greenchemistry/
- Wikipedia, http://en.wikipedia.org/wiki/Green_chemistry
- American Chemical Society Green Chemistry Institute, www.greenchemistryinstitute.com
- Institute for Green Oxidation Chemistry at Carnegie Mellon University, www.chem.cmu.edu/groups/collins/index.html
- Center for Green Chemistry at University of Massachusetts Lowell, www.greenchemistry.uml.edu/
- John Warner talk, http://gse.uml.edu/warner/greenchemistry.htm

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Sources:

[1] Anastas PT, Warner JC. *Green Chemistry: Theory and Practice*, Oxford University Press: New York, 1998.

[2] Ran *et al.*,Benzene-free synthesis of hydroquinone, 2001, *Journal of the American Chemical Society*, 123:10927-34; Niu *et al.*, Benzene-free synthesis of adipic acid, 2002, Biotechnol Prog, 18:201-11; Li *et al.*, Benzene-free synthesis of catechol: interfacing microbial and chemical catalysis, 2005, *Journal of the American Chemical Society*, 127:2874-82.

[3] Environmental Protection Agency. 2006 Academic Award. www.epa.gov/greenchemistry/pubs/pgcc/winners/aa06.html, viewed January 4, 2007.

[4] Plantic Technologies Limited, www.plantic.com.au/; Metabolix, Inc., www.metabolix.com/, Crystal Faraday. Nestlé launch compostable packaging. www.crystalfaraday.org/index.asp?PageID=172, viewed January 4, 2007.