THE ACS GREEN CHEMISTRY INSTITUTE® PRESENTS

Design Principles for Sustainable Green Chemistry & Engineering

Introduction to "Design Principles for Sustainable Green Chemistry and Engineering"

Since the word "Green" first started being placed in front of chemistry, many people have argued about what the "right" definition of green chemistry is or isn't. And, more importantly, what should one actually do to make chemistry "green" or "greener?"

What follows is a collection of design principles that various individuals and groups have proposed over time to answer that question. Most people stop at 12 principles, and most separate chemistry from engineering as if it were possible to do green chemistry in the absence of engineering. I've never found a way to do that and I firmly believe that there are no two disciplines, and no two communities more intimately tied to making the world more sustainable than chemistry and engineering. What you will find on the following pages is an attempt to organize various principles of green chemistry and engineering and present them in a way that helps people to make their chemistry and engineering "greener" and more sustainable. I hope you find this particular way of combining and presenting these principles to be helpful and useful.

Sincerely,

David J.C. Constable

David Constable, Director, Green Chemistry Institute ®

MAXIMIZE RESOURCE EFFICIENCY

DESIGN

OUTPUT-PULLED vs. INPUT-PULLED
Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials**

ATOM ECONOMY
Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product *

FIND ALTERNATIVES
The use of auxiliary substances (e.g., solvents, separation agents) should be made unnecessary whenever possible and innocuous when used*

REDUCE DERIVATIVES
Unnecessary derivatization (blocking group, protection-deprotection, and temporary modification of physical / chemical processes) should be avoided whenever possible *

USE CATALYSIS
Catalytic reagents (as selective as possible) are superior to stoichiometric reagents *

MEASURE

MASS BALANCES
Establish full mass balances for a process****

HEAT AND MASS TRANSFER
Anticipate heat and mass transfer limitations****

CONVERSION
Report conversions, selectivities, and productivities****

BY-PRODUCT FORMATION
Identify and quantify by-products****

UTILITIES
Quantify and minimize the use of utilities****

BE EFFICIENT

REDUCE
Separation and purification operations should be designed to minimize energy consumption and materials use**

MINIMIZE
Energy Requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure*

OPTIMIZE
Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency**

INTEGRATE
Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows**

PREVENT
Strive to prevent waste***

BE SUSTAINABLE

MINIMIZE
Minimize depletion of natural resources.***

CONSERVE AND IMPROVE
Conserve and improve natural ecosystems while protecting human health and well-being ***

CHEMISTRY

ENGINEERING

REFERENCE:
* Anastas, P. T.; Warner, J. C. Green Chemistry: Theory and Practice; Oxford University Press: New York, 1998; p 30.
** Anastas, P. T.; Zimmerman, J. B. Design through the Twelve Principles of Green Engineering. Environ. Sci. Technol. 2003, 37(5), 94A-101A.
*** Abraham, M. A.; Nguyen, N. "Green Engineering: Defining the Principles" - Results from the San Destin Conference, Environmental Progress, 2003, 22(4), 233-236.
****Winterton, N. Twelve more green chemistry principles? Green Chem. 2001, 3, G73-G75.

ELIMINATE & MINIMIZE HAZARDS & POLLUTION

■ CHEMISTRY

■ ENGINEERING

DESIGN

AVOID PERSISTENCE
Chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation products*

INHERENTLY NON-HAZARDOUS
Designers need to strive to ensure that all material and energy inputs and outputs are as inherently nonhazardous as possible**

SYNTHETIC METHODS
Wherever practical, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment *

SAFER PROCESSES
Substances and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires. *

PREVENTION
It is better to prevent waste than to treat or clean up waste after it is formed. *

MEASURE

REAL-TIME ANALYSIS
Analytical methodologies need to be developed further to allow for real-time in-process monitoring and control prior to the formation of hazardous substances*

LOSSES
Measure catalyst and solvent losses in aqueous effluent****

THERMOCHEMISTRY
Investigate basic thermochemistry****

INCOMPATIBILITIES
Recognize where safety and waste minimization are incompatible****

WASTE
Monitor, report, and minimize laboratory waste emitted****

BE SUSTAINABLE

CONSERVE AND IMPROVE
Conserve and improve natural ecosystems while protecting human health and well-being***

REFERENCE:

* Anastas, P. T.; Warner, J. C. Green Chemistry: Theory and Practice; Oxford University Press: New York, 1998; p 30.

** Anastas, P. T.; Zimmerman, J. B. Design through the Twelve Principles of Green Engineering. Environ. Sci. Technol. 2003, 37(5), 94A-101A.

*** Abraham, M. A.; Nguyen, N. "Green Engineering: Defining the Principles" - Results from the San Destin Conference, Environmental Progress, 2003, 22(4), 233-236.

****Winterton, N. Twelve more green chemistry principles? Green Chem. 2001, 3, G73-G75.

DESIGN SYSTEMS HOLISTICALLY & USING LIFE CYCLE THINKING

DESIGN

HOLISTICALLY
Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools***

USE LIFE CYCLE THINKING
Use life cycle thinking in all engineering activities***

END OF USE
Products, processes, and systems should be designed for performance in a commercial "afterlife"**

DURABILITY
Targeted durability, not immortality, should be a design goal**

CONSERVE COMPLEXITY
Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse or beneficial disposition**

MINIMIZE MATERIAL DIVERSITY
Material diversity in multicomponent products should be minimized to promote disassembly and value retention**

MINIMIZE CHEMISTRY IMPACTS
Consider the effect of the overall process on the choice of chemistry****

COLLABORATE WITH ENGINEERS
Consult a chemical or process engineer****

CONSIDER INCOMPATIBILITIES
Recognize where safety and waste minimization are incompatible****

BE SUSTAINABLE

THINK LOCALLY
Develop and apply engineering solutions while being cognizant of local geography, aspirations and cultures***

ENGAGE
Actively engage communities and stakeholders in development of engineering solutions ***

APPLY MEASURES
Help develop and apply sustainability measures****

INNOVATE TO ACHIEVE
Create engineering solutions beyond current or dominant technologies; improve, innovate and invent (technologies) to achieve sustainability***

USE RENEWABLES
A raw material feedstock should be renewable rather than depleting whenever technically and economically practical*

Material and energy inputs should be renewable rather than depleting**

CHEMISTRY

ENGINEERING

REFERENCE:

* Anastas, P. T.; Warner, J. C. Green Chemistry: Theory and Practice; Oxford University Press: New York, 1998; p 30.
** Anastas, P. T.; Zimmerman, J. B. Design through the Twelve Principles of Green Engineering. Environ. Sci. Technol. 2003, 37(5), 94A-101A.
*** Abraham, M. A.; Nguyen, N. "Green Engineering: Defining the Principles" - Results from the San Destin Conference, Environmental Progress, 2003, 22(4), 233-236.
****Winterton, N. Twelve more green chemistry principles? Green Chem. 2001, 3, G73-G75.

Green Chemistry & Engineering:
Innovation for a Sustainable Future

The mission of the ACS Green Chemistry Institute® (ACS GCI) is to catalyze and enable the implementation of green chemistry and engineering throughout the global chemical enterprise.

ACS GCI:
www.acs.org/greenchemistry
Annual Green Chemistry & Engineering Conference:
www.gcande.org

Follow GC&E Posts by joining ACS Green Chemistry Institute® On:

facebook.com/ACSGreenChemistryInstitute
linkedin.com/in/acsgci
twitter.com/acsgci [@ACSGCI]

Green Chemistry & Engineering conference hashtag: #gcande

ACS Chemistry for Life®
American Chemical Society

ACS Green Chemistry Institute®

THE ACS GREEN CHEMISTRY INSTITUTE®
1155 SIXTEENTH STREET, NW,
WASHINGTON, DC 20036, USA,
+1 202-872-6102 gci@acs.org