

## Educational Resources for Green Chemistry: An Overview

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## Green Chemistry

- The design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances.

## Approaches

- Develop a new course
- Incorporate green chemistry concepts into existing courses
  - Classroom
  - Laboratory experiments
- Research
- Extracurricular activities
  - Student Affiliates
  - Conferences/symposia
  - Summer schools

## Barriers

- Lack of educational materials
- Overcrowded curriculum
- Perceived lack of rigor
- Inertia

## Resources: Texts

- **Green Chemistry: Theory and Practice.** Anastas, P. T.; Warner, J. C.; Oxford University Press: Oxford, UK, 1998
- **Introduction to Green Chemistry.** Matlack, A. S.; Marcel Dekker: New York, 2001
- **Green Organic Chemistry: Strategies, Tools, and Laboratory Experiments** Doxsee, K. M.; Hutchison, J. E.; Thompson Learning: Mason, OH, 2002
- **Green Chemistry: An Introductory Text.** Lancaster, M.; Royal Society of Chemistry: Cambridge, UK, 2003
- **Green Chemistry: Fundamentals of Sustainable Chemical Science and Technology.** Manahan, S.E.; ChemChar Research: 2004.

## ACS Resources

- Educational materials
  - *Going Green*
  - Annotated bibliography
  - *Introduction to Green Chemistry*
  - *Real-World Cases in Green Chemistry*
  - *Greener Approaches to Undergraduate Laboratory Experiments*
  - *Green Chemistry: Innovations for a Cleaner World*
  - *Green Chemistry: Meeting Global Challenges*
  - *Chemistry in Context*
  - *Chemistry in the Community*

## Annotated bibliography

- Available online at the ACS website  
<http://center.acs.org/applications/greenchem/>
  - Searchable by keyword
  - Provides author, title, reference, and abstract

**Author:** Martyn Poliakoff, Michael W. George, Steven M. Howdle, Viktor Bagratashvili, Bu-Xing Han and Hai-ke Yan

**Paper Title:** Supercritical Fluids: Clean Solvents for Green Chemistry

**Journal Title:** Chinese Journal of Chemistry 17 (3), 212-222, 1999

**Abstract:** Supercritical fluids are becoming increasingly attractive as environmentally acceptable replacement for organic solvents in chemical reactions and material processing. This paper highlights some of the properties of supercritical fluids, especially supercritical carbon dioxide, which offer particular advantages for the handling of polymers, metal complexes and the environmentally more friendly synthesis and manufacture of chemicals. The paper includes some of the researches in University of Nottingham and a number of recent reviews that together provide a comprehensive introduction.

**Keywords:** Supercritical Fluid, Carbon Dioxide, Solvent

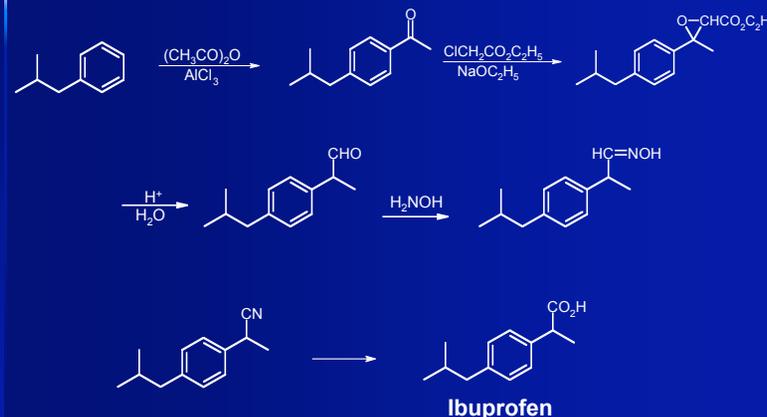
## Introduction to Green Chemistry

- Developed in conjunction with the Royal Society and the Gesellschaft Deutscher Chemiker
- Six key concepts
  - Get off to a safe start
  - Use renewable resources
  - Find safer solvents
  - Economize on atoms
  - Lower energy input
  - Return safe substances into the environment

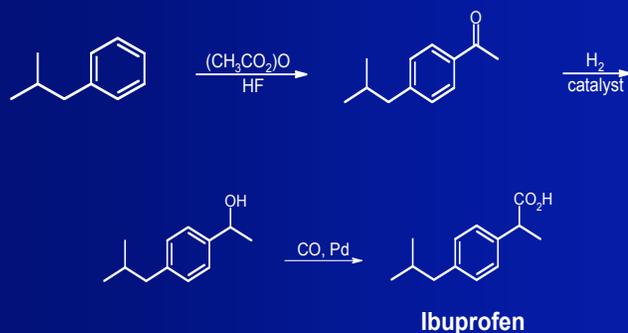
## Real-World Cases in Green Chemistry

- Taken from nominations to the Presidential Green Chemistry Challenge Awards Program
  - Presents the concerns with current products and processes
  - Offers a green chemistry solution
- Atom Economy
  - Highlights synthesis of ibuprofen
  - Applications
    - Incorporate into general chemistry (mass balance)
    - Emphasize in organic chemistry (addition, elimination, substitution, rearrangement)
    - Calculate atom economy *and* percent yield in lab
    - Illustrate more efficient synthesis in medicinal/pharmaceutical chemistry courses

## Pharmaceutical Applications



## Pharmaceutical Applications



## Greener Approaches to Undergraduate Laboratory Experiments

- Developed by
  - Jim Hutchison and Ken Doxsee, University of Oregon
  - John Warner, University of Massachusetts, Lowell
  - Gene Cioffi, University of South Alabama
- Emphasize environmental/safety/human health improvements over traditional experiments
- Available in Spanish

## Experiments

- Benzoin condensation
  - Uses thiamine as a catalyst in place of cyanide
- Pechmann reaction
  - Solid acid catalyst
- Synthesis of tetraphenylporphyrin
  - Microwave reaction
  - Metallation in more benign solvents

## *Journal of Chemical Education*

- One-pot synthesis of 3-carboxycoumarin in water
- Solvent-free Wittig reaction: A green organic chemistry laboratory experiment
- Infusing the chemistry curriculum with green chemistry using real-world examples, web modules, and atom economy in organic chemistry courses
- An asymptotic approach to the development of a green organic chemistry laboratory

## Visual Media

- Video: *Green Chemistry: Innovations for a Cleaner World*
  - Highlights three Presidential Green Chemistry Challenge award-winning technologies
- DVD: *Green Chemistry: Meeting Global Challenges*
  - Features four presentations from the 2002 Green Chemistry and Engineering Conference linking green chemistry to sustainability issues

## ACS Textbooks

- *Chemistry in Context*
  - ◆ Undergraduate non-majors text
  - ◆ Green chemistry concepts integrated into text
- *Chemistry in the Community*
  - ◆ High school text
  - ◆ Introduces principles in chapter on industry
  - ◆ Highlights greener technologies

## Going Green

- Provides strategies for integrating green chemistry into the curriculum
  - Background information
  - Essays by faculty members
    - Different approaches to green chemistry education
  - Available resources

## Benefits

- Interdisciplinary
  - Biology
  - Economics
  - Engineering
  - Environmental science
  - Ethics
- Supports student interest in environmental issues
  - retention
- Decreases lab waste
- Improves lab safety

## Greening the College Campus

- Green the curriculum while greening the campus



## St. Olaf College

- \$500K from Keck Foundation to incorporate green chemistry into the science curriculum
- \$98K from Kresge Foundation to design a sustainable and environmentally friendly science complex
- “In the end, what you ideally want is a building that’s green with a program that’s green.”

Dave Van Wylen, Associate Dean

## Student Affiliates

- Host a green chemistry speaker
- Develop a green chemistry activity with a local school
- Organize a green chemistry poster session on campus
- Work with a local company on a green chemistry project
- Make a current lab experiment greener
- Design a green chemistry web page

## Conclusions

- Varied approaches to integrating green chemistry into the curriculum
  - One size *does not* fit all
- Easy access to curricular materials lowers the activation energy to implementation of these greener approaches