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# Pollution Prevention Educational Resource Compendium:

# Chemistry

NATIONAL POLLUTION PREVENTION CENTER FOR HIGHER EDUCATION

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## Pollution Prevention Educational Resource Compendia

### Goal Statement and Summary

*Education offers one of the greatest opportunities for achieving a more sustainable society. [illegible] tomorrow's leaders. With them in mind, the NPPC offers pollution prevention [illegible] disciplines. These compendia, developed by NPPC [illegible] [illegible] principles of pollution prevention [illegible] industry [illegible] [illegible] fill the compendia. The NPPC encourages contributions from business, industry, and academia.*

*This is the Chemistry compendium. Other compendia in progress cover disciplines such as Accounting, Agriculture, Architecture, Business Law, Chemical Engineering, Corporate Strategy, Environmental Engineering, Environmental Studies, Finance, Industrial Ecology, Industrial Engineering and Operations Research, and Operations Management. For more information, contact the NPPC directly.*


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The mission of the NPPC is to promote sustainable development by educating students, faculty, and professionals about pollution prevention; create educational materials; provide tools and strategies for addressing relevant environmental problems; and establish a national network of pollution prevention educators. In addition to developing educational materials and conducting research, the NPPC also offers an internship program, professional education and training, and conferences.

**_Your Input Is Welcome!_**
We are very interested in your feedback on these materials. Please take a moment to offer your comments and communicate them to us. Also contact us if you wish to receive a documents list, order any of our materials, collaborate on or review NPPC resources, or be listed in our *Directory of Pollution Prevention in Higher Education.*

**_We're Going Online!_**
The NPPC provides information on its programs and educational materials through the Internet's World Wide Web; our URL is: http://www.snre.umich.edu/nppc/

We may also update the NPPC information available through gopher (gopher.snre.umich.edu) and anonymous FTP (ftp.snre.umich.edu). Please contact us if you have comments about our online resources or suggestions for publicizing our educational materials through the Internet. Thank you!

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All documents can be ordered separately [illegible] NPPC Order Form. [illegible] documents are free of charge [illegible] photocopying there is a small fee for longer documents.

# Explanation of Compendium Contents

## Introductory Materials

- **Overview of Environmental Problems.** Each chapter highlights a major area of environmental concern: energy use, global change, resource depletion, land use and development, waste, air quality, water quality and quantity, ecological health, and human health. Includes definitions of concepts and terms, current data and research findings on the state of the environment, tables, figures, and guidance on obtaining more information.

  This document is designed to help faculty in all disciplines prepare course materials and lectures. For people who may not have extensive knowledge of environmental issues, it provides background information; for those already familiar with environmental problems, it is a convenient, concise source of current data. The formal allows individual topic areas to be easily reproduced for distribution to students; all figures and tables are provided in a full-page format suitable for overhead projection.

- **Pollution Prevention Concepts and Principles.** This shorter paper introduces the concepts, terminology, objectives, and scope of pollution prevention. It discusses how government and the private sector are currently perceiving and implementing pollution prevention and describes the barriers and benefits encountered in implementing pollution prevention activities.

- **Pollution Prevention Applications to Chemistry.** Chemistry plays a critical role in advancing key principles of pollution prevention and sustainable development. This introduction will provide a framework for improving the design and management of chemicals and chemical processes; present tools for designing environmentally preferred synthetic pathways and less toxic chemicals; and introduce methods for environmental assessment to assist faculty in incorporating pollution prevention concepts and practical tools into chemistry curricula.

## NPPC Resources

- **Pollution Prevention and Chemistry Resource List.** A list of all relevant resources known to the NPPC. The "Educational Tools" section lists three articles; the "Reference Materials" section lists 146 articles, three books, three reports, five publishers, five online services, four faculty involved in pollution prevention education, and five organizations. Includes summary matrix. Most of the materials listed are commonly found in college libraries or bookstores; for others, the list explains how to obtain them.

- **Annotated Bibliography of Chemistry-Related Pollution Prevention Sources.** Alphabetically lists and describes all materials cited in the Resource List.

Pollution Prevention in Chemistry

NATIONAL POLLUTION PREVENTION CENTER FOR HIGHER EDUCATION

# Pollution Prevention and Chemistry Resource List

*Prepared by Kellie DuBay and Jason Schweitzer, NPPC Research Assistants, under the direction of Thomas Dunn, Professor, Department of Chemistry; Gregory A. Keoleian, Assistant Research Scientist, School of Natural Resources and Environment; and Nancy A. Osborn, Publications Manager, NPPC.*

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## *Using This Compendium*

There are many ways to incorporate pollution prevention principles into the field of chemistry — industrial applications, academic research, educational curricula. These are illustrated in the journal articles, reports, books, conference proceedings, and educational tools cited in this Resource List. We recognize that this list does not identify every source relevant to the topic of pollution prevention in chemistry. But we believe that it will help people get a good start on incorporating pollution prevention into the chemistry curriculum.

In this Resource List, we have grouped all citations under several main themes. Then, to more specifically describe the contents of the citations, we have assigned codes to them. Finally, each citation has a number corresponding to its audience level. (For a description of these themes and codes, see "Classification of Resource Materials" on the page 3.)

At the end of the Resource List is a summary matrix. An alphabetical list of the citations runs down the left side of the matrix. Codes run along the top. The numbers in the cells represent the audience level.

Thus, you may approach this set of resources from any angle. If you want to examine everything within a theme, start with the text of the Resource List. If you would prefer to keep a narrower focus, start with the appropriate column in the matrix — you will be able to quickly identify all citations pertaining to a general topic (e.g., "alternative synthesis"), a specific subject (e.g., "a synthesis employing biological systems"), or a combination (e.g., "alternative biological catalysts" or "toxicity/risk assessments of solvent alternatives").

Complementing the Resource List is our Annotated Bibliography, which describes all Resource List materials in more detail; it is arranged alphabetically by author name. Once you have chosen citations from either the Resource List or its matrix, you may turn to the Annotated Bibliography for a more detailed description. The Resource List, its matrix, and the accompanying Annotated Bibliography are designed to make this compendium easily accessible by a wide range of users.

## *Terminology and Framework*

When evaluating the content of these documents, it is important to understand that pollution prevention within the chemistry discipline is relatively new, with little uniformity in the use of terminology. Phrases and words such as "benign," "non-toxic," "benign by design," "green chemistry," "environmental chemistry," safer chemical design, and clean processes are often used synonymously to describe very different concepts. Specific criteria for definitions are usually not given, and frameworks for definitions are rarely explicitly stated. This lack of uniform definitions becomes a problem when chemicals or chemical syntheses are evaluated. For example, a certain chemical may be ecologically safe and deemed a "benign" alternative, but the synthesis of that chemical may involve highly toxic intermediates or by-products.

To label a chemical substance or process with a word like "benign," one must consider all aspects of the chemical and its synthesis. A comprehensive examination encompasses all of these issues: material processing, manufacturing, use, material or energy recovery, and disposal. The following framework[1] defines several important criteria for the design and management of chemical substances and processes.

- Environmental Criteria. Resource depletion (renewable and nonrenewable), energy consumption, waste generation (air and water pollution, solid and hazardous waste), human health risks (workers, consumers, communities), ecological degradation (sensitive species, habitat resiliency).
- Performance. Chemicals are required to serve a variety of functions within the economy: as cleaning agents, lubricants, solvents, flavorings, pharmaceuticals, etc. They must perform effectively and efficiently to be accepted by consumers as a viable product. Performance requirements often influence and constrain environmental requirements; inadequate performance can result in more negative impacts.
- Cost. Regardless of how well a product performs and meets environmental criteria, economics strongly influences how one produces a chemical. Costs to consider over the product's life cycle include: commodity chemical prices, monitoring and permitting, the explicit energy costs of manufacturing, potential liability and remediation costs, and costs associated with treatment and disposal.
- Legal. Compliance with mandatory regulations is an important "must" requirement for a chemical product system. Legal requirements include local, state, and federal environmental, health, and safety regulations. As a preventative measure, pending legislation should also be taken into consideration. In order to avoid regulatory conflicts, new chemicals and processes that exceed current regulations should be developed.

Of course, few chemicals or processes will be in perfect accord with all of these criteria. Tradeoffs will occur, and the outcome of design and management decisions will depend on how one weights the individual issues. We encourage readers to make their own judgments about the "environmentally preferable" alternatives presented in this compendium based on the above "Life Cycle Design" criteria.

[1]Keoleian and Menerey. *Life Cycle Design Framework and Demonstration Projects: Profiles of AT&T and AlliedSignal.* Cincinnati: Risk Reduction Engineering Laboratory, U.S. Environmental Protection Agency; May 1995.

## Classification of Resource Materials

The citations in this Resource List are grouped into five main themes. The citations themselves have been assigned General and Subject codes to further describe the information they cover. Also, in order to give the reader an idea of a citation's complexity, numerical codes indicate each document's intended audience.

### MAIN THEMES:

I. Incorporating Pollution Prevention Into Curricula

II. Less-toxic Alternatives in Chemical Syntheses

III. Computer or Mathematical Modeling

IV. Pollution Prevention: Related Programs

V. Overviews or General Discussion

### GENERAL CODES

**A:** Describes a new, more environmentally responsible synthetic route to a product. One example is the substitution of supercritical $CO_2$ for organic solvents when synthesizing polymeric materials; another is the synthesis of polyurethane from the catalytic carbonylation (as opposed to the phosgenation) of nitroaromatic compounds.

**B:** Describes the replacement of a product with a new, less-toxic alternative. An example is the substitution of isocyanate sealants with acetoacetate-based sealants in the adhesive industry.

**C:** Presents broader overviews of topics relevant to pollution prevention in chemistry. These documents may provide information on the history, future, and/or recent developments of a chemical synthesis, industrial process, or research program. Often included are general discussions of cost, waste, and toxicity.

### SUBJECT CODES

**Bio.** A synthesis or catalysis employing *biological* systems (e.g., the synthesis of catechol from a biocatalytic/enzymatic pathway as opposed to benzene alkylation).

**Cat.** Chemical design incorporating alternative *catalysts*.

**CS** An industrial application of pollution prevention principles—a *case study* providing readers with a demonstration of how P2 principles can be incorporated into industry.

**Econ.** The *economic* aspects of chemical production.

**EU** Assessments of chemical substitutes for *end-use* applications based on performance, toxicity, and other issues.

**F/R** Chemical design incorporating alternative *feedstocks* or *reactants*.

**Opt.** Approaches for *optimizing* a synthetic procedure so that yield is enhanced and/or the generation of harmful by-products is reduced or eliminated.

**SAR** Mathematical relationships between a chemical's structure and its measurable behaviors. [These documents may address *structure-activity relationships* or quantitative structure-activity relationships (QSARs).]

**Sim.** The use of computer modeling or *simulation* in the development of new synthetic pathways or novel compounds

**Sol.** Chemical design incorporating alternative *solvents*.

**T/R** *Toxicity* or *risk assessment* of chemicals.

### AUDIENCE LEVEL CODES

1: Requires some elementary science background.

2: Requires undergraduate knowledge of chemistry.

3: Requires advanced knowledge of chemistry (intended audience is most likely to be faculty, industry professionals, degreed chemists).

## Educational Tools

Goller, Edwin J., and John H. Miller. "Microscale Qualitative Analysis." *Journal of Chemical Education* 70, no. 6 (June 1993): A159–A160.

Reel, Kevin. "Hydrogen Sulfide Is Not Such a Rotten Idea." *Journal of Chemical Education* 70, no. 10 (October 1993): 854.

Wilcox, Mary F., and Judith G. Koch. "A Freshman Laboratory Program Without Chromium." *Journal of Chemical Education* 70, no. 6 (June 1993): 488.

## Reference Materials

### I. Incorporating P2 Into Curricula

Carey, Francis A., and Andrew F. Carey. "Environmentally Benign Synthesis in the Introductory Organic Chemistry Lecture Course." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 180. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [C] [Econ, 2]

Huheey, James E. "Incorporating Environmental Issues Into the Inorganic Chemistry Curriculum." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 181. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [C] [2]

Keoleian, Gregory A., and Jonathan W. Bulkley. "Incorporating Pollution Prevention Into the Chemistry Curriculum: New Challenges and Opportunities." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 186. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [C] [1]

Singh, Mono M., Ronald M. Pike, and Zvi Szafran. "Pollution Prevention in the Organic and Inorganic Chemistry Laboratory: Microscale Approach." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 194–197. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [A] [2]

Smith, Leverett R. "Securing Environmental Concerns in the Chemistry Curriculum." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 198–200. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [C] [2]

Steinfeld, J. I., and D. S. Bem. "Graduate Research and Training in Chemistry of the Environment at M.I.T." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 187–190. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [C] [2]

Szafran, Zvi, Mono M. Singh, and Ronald M. Pike. "The Microscale Inorganic Laboratory: Safety, Economy, and Versatility." *Journal of Chemical Education* 66, no. 11 (November 1989): A263–A267. [C] [1]

Tully, J. C. "Environmental Education From an Industrial Perspective." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 203. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [C] [CS, 3]

Vellaccio, Frank. "Making a Place for Environmentally Benign Synthesis in the Introductory Chemistry Curriculum: Is it a Moral Imperative?" *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 179. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [C] [2]

Zwaard, A. W., H. P. W. Vermeeren, and R. de Gelder. "Safety Education for Chemistry Students: Hazard Control Starting at the Source." *Journal of Chemical Education* 66, no. 4 (April 1989): A112–A114. [C] [F/R, Cat, T/R, 1]

## II. Less-Toxic Alternatives in Chemical Syntheses

### II.A ALTERNATIVES TO PHOSGENE IN INDUSTRIAL SYNTHESES

DePompei, M. F. "Non-Isocyanate Sealants." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 393–394. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [B] [EU, CS, 3]

Gargulak, J., and W. Gladfelter. "Homogeneous Catalytic Carbonylation of Nitroaromatics." *Journal of the American Chemical Society* 116 (1994): 8933–8495. [A] [Cat, Opt, 3]

Komiya, Kyosuke, Muneaki Aminaka, Kazumi Hasegawa, Hiroshi Hachiya, Hiroshige Okamoto, Shinsuke Fukuoka, Haruyuki Yoneda, Isaburo Fukawa, and Tetsuro Dozono. "New Process for Producing Polycarbonate Without Phosgene and Methylene Chloride." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 343–346. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [A] [F/R, CS, 3]

McGhee, W., Pan Yi, and D. Riley. "Highly Selective Generation of Urethanes from Amines, Carbon Dioxide, and Alkyl Chlorides." *Journal of the Chemical Society–London, Chemical Communications* (1994) 699–700. [A] [F/R, 3]

McGhee, William D., Mark Pater, Dennis Riley, Ken Ruettimann, John Solodar, and Thomas Waldman. "Generation of Organic Isocyanates From Amines, Carbon Dioxide and Electrophilic Dehydrating Agents: Use of o-Sulfobenzoic Acid Anhydride." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 206–210. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [A] [F/R, 3]

Riley, Dennis, William D. McGhee, and Thomas Waldman. "Generation of Urethanes and Isocyanates from Amines and Carbon Dioxide." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul T. Anastas and Carol A. Farris, 122–132. Washington: American Chemical Society, 1994. [A] [F/R, CS, 3]

Waldman, T., and W. McGhee "Isocyanates From Primary Amines and Carbon Dioxide: 'Dehydration' of Carbamate Anions." *Journal of the Chemical Society–London, Chemical Communications* (1994): 957–958. [A] [F/R, CS, 3]

### II.B SUPERCRITICAL CARBON DIOXIDE AS AN ALTERNATIVE SOLVENT

Aresta, Michele. "Perspectives of Utilization of Carbon Dioxide as a Building Block." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 316–319. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [A] [F/R, Cat, 3]

Bradley, David. "Solvents Get the Big Squeeze." *New Scientist* 143 (6 August 1994): 32–35. [C] [Sol, Cat, 2]

Combes, J. R., Zhibin Guan, and John M. DeSimone. "Homogenous Free-Radical Polymerizations in Carbon Dioxide: Telomerizations of 1,1-Difluoroethylene in Supercritical Carbon Dioxide." *Macromolecules* 27 (1994): 865–867. [A] [Sol, CS, 2]

DeSimone, J. M., E. E. Maury, Z. Guan, J. R. Combes, Y. Z. Menceloglu, M. R. Clark, J. B. McClain, T. J. Romack, and C. D. Mistele. "Homogeneous and Heterogeneous Polymerization In Environmentally Responsible Carbon Dioxide." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 212–214. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [A] [Sol, CS, 3]

DeSimone, John M., Zhibin Guan, and C. S. Eisbernd. "Synthesis of Fluoropolymers in Supercritical Carbon Dioxide." *Science* 257 (August 14, 1992): 945–947. [A] [Sol, CS, 2]

Donohue, Marc D., and Jennifer L. Geiger. "Reduction of VOC Emission During Spray Painting Operations: A New Process Using Supercritical Carbon Dioxide." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 218–219. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [A] [Sol, CS, 3]

"Gassy Plastics." *Discover* 16, no. 6 (June 1995): 80. [A] [Sol, CS, 1]

Guan, Zhibin, and John M. DeSimone. "Fluorocarbon-Based Heterophase Polymeric Materials: Block Copolymer Surfactants for Carbon Dioxide Applications." *Macromolecules* 27 (1994): 5527–5532. [A] [Sol, 3]

Johnston, K. P. "Safer Solutions for Chemists." *Nature* 368 (17 March 1994): 187–188. [A] [Sol, 2]

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Sawan, Samuel P., Yeong-Tarng Shieh, and Jan-Hon Su. *Evaluation of the Interactions Between Supercritical Carbon Dioxide and Polymeric Materials.* Los Alamos National Lab Report #LA-UR-94-2341. Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA, 22161, (703) 487-4650 ,or the Office of Scientific and Technological Information, P.O. Box 62, Oakridge, TN, 37831, (615) 576-8401. [C] [Sol, CS, 3]

Tanko, James M., Joseph F. Blackert, and Mitra Sadeghipour. "Supercritical Carbon Dioxide as a Medium for Conducting Free-Radical Reactions." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul T. Anastas and Carol A. Farris, 98–113. Washington: American Chemical Society, 1994. [A] [Sol, 2]

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Tumas, William, Shaoguang Feng, Richard LeLacheur, David Morgenstern, Paul Williams, Steve Buelow, Carol Burns, Bernard Foy, Michael Mitchell, Mark Burk, and Robert Waymouth. "Chemical and Catalytic Transformations in Supercritical Fluids." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 211. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [A] [Sol, Cat, 3]

## II.C D-GLUCOSE AS AN ALTERNATIVE STARTING MATERIAL

Dell, K. A., and J. W. Frost. "Identification and Removal of Impediments to Biocatalytic Synthesis of Aromatics from D-Glucose: Rate-Limiting Enzymes in the Common Pathway of Amino Acid Biosynthesis." *Journal of the American Chemical Society* 115 (1993): 11581–11589. [A] [Cat, Opt, 3]

Draths, K. M., and J. W. Frost. "Conversion of D-Glucose into Catechol: The Not-So-Common Pathway of Aromatic Biosynthesis." *Journal of the American Chemical Society* 113 (1991): 9361–9363. [A] [Cat, Bio, 3]

Draths, Karen M., and John W. Frost. "Environmentally Compatible Synthesis of Adipic Acid from D-Glucose." *Journal of the American Chemical Society* 116 (1994): 399–400. [A] [F/R, Cat, Bio, 3]

Draths, Karen M., and John W. Frost. "Microbial Biocatalysis: Synthesis of Adipic Acid from D-Glucose." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul T. Anastas and Carol A. Farris, 32–45. Washington: American Chemical Society, 1994. [A] [F/R, Cat, Bio, Econ, 3]

Draths, Karen M., D. L. Pompliano, D. L. Conley, J. W. Frost, A. Berry, G. L. Disbrow, R. J. Staversky, and J. C. Lievense. "Biocatalytic Synthesis of Aromatics from D-Glucose: The Role of Transketolase." *Journal of the American Chemical Society* 114 (1992): 3956–3962. [A] [Opt, Bio, 3]

Draths, K. M., T. L. Ward, and J. W. Frost. "Biocatalysis and Nineteenth-Century Organic Chemistry: Conversion of D-Glucose Into Quinoid Organics." *Journal of the American Chemical Society* 114 (1992): 9275–9276. [B] [F/R, Bio, 2]

Emsley, John. "A Cleaner Way to Make Nylon." *New Scientist* 141 (12 March 1994): 15. [A] [F/R, Bio, CS, 3]

Frost, John W., and Jeff Lievense. "Prospects for Biocatalytic Synthesis of Aromatics in the 21st Century." *New Journal of Chemistry* 18 (1994): 341–348. [A] [F/R, Cat, Bio, CS, Econ, 2]

Frost, John. "Green Chemistry at Work: Products Can Be Made From Glucose Instead of Benzene." *EPA Journal* 20, no. 3 (Fall 1994): 22–23. [A] [F/R, Cat, Bio, 1]

## II.D BIOCATALYSIS OR BIOLOGICAL REAGENTS

Anders, M. W. "Designing Safer Chemicals: Role of Bioactivation in Chemical Toxicity." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 366–368. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [B] [T/R, CS, 3]

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Rotman, David. "The Quest for Reduced Emissions, Greener Processes." *Chemical Week* 153 (7/14 July 1993): 117–118. [A] [F/R, Bio, CS, 1]

## II.E DEVELOPMENT OF NEW, NON-BIOLOGICAL CATALYSTS

Arzoumanidis, Gregory G., and Nicholas M. Karayannis. "Fine-tuning Polypropylene." *Chemtech* 23 (July 1993): 43–48. [A] [Cat, CS, 3]

Bao, Rong, W. Scott Dodson, Thomas C. Bruton, and Yuzhuo Li. "New Applications of Photoinduced Redox Reactions on $TiO_2$ in Organic Synthesis." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 411–415. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [A] [Cat, CS, 3]

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Chynoweth, Emma. "Shaping Environmental Solutions With Clay-Based Catalysts." *Chemical Week* 148 (26 June 1991): 57–58. [B] [Cat, CS, 2]

Clerici, M. G., G. Bellussi, and U. Romano. "Synthesis of Propylene Oxide From Propylene and Hydrogen Peroxide Catalyzed by Titanium Silcalite." *Journal of Catalysis* 129 (1991): 159–167. [A] [Cat, Opt, CS, 3]

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## *Organizations*

American Chemical Society
1155 16th Street NW
Washington, DC 20036
phone: (202) 872-4600

The Division of Environmental Chemistry in the American Chemical Society (ACS) seeks to promote research, disseminate information and improve education and public awareness regarding chemistry of the environment. Symposium topics have included benign synthesis, design for the environment, and design of safer chemicals.

American Institute of Chemists
501 Wythe St.
Alexandria, VA 22314-1917
phone: (703) 836-2090
fax: (703) 836-2091
e-mail: 76744.2677@compuserve.com

The American Institute of Chemists (AIC) is a non-profit association that represents more than 5,000 chemists, chemical engineers and biochemists. Members keeps informed of developments in the chemical field through the AIC publication *The Chemist*. Although not directly involved with pollution prevention, AIC will refer inquiries regarding pollution prevention in the chemistry field to an appropriate member.

Chemical Manufacturers Association
2501 M Street NW
Washington, DC 20037
phone: (202) 887-1100

The Chemical Manufacturers Association (CMA) requires all member companies to join the CMA-sponsored Responsible Care Program, which includes the pollution prevention code of management. CMA's mutual assistance program gives new members the opportunity to link up with members who have been successful in achieving their pollution prevention goals.

National Microscale Chemistry Center
Merrimack College
N. Andover, MA 01845
phone: (508) 837-5137
fax: (508) 837-5017
e-mail: msingh@merrimack.edu

The mission of the National Microscale Chemistry Center ($NMC^2$) is to "implement the ideas of chemical-use reduction, air-quality improvement, exposure limitation, recycling, and waste reduction into every chemical worker's and every student's thinking." $NMC^2$ has published numerous laboratory textbooks and manuals for microscale organic and inorganic chemistry. Contact $NMC^2$ for a list of publications.

Synthetic Organic Chemical Manufacturers Association
1330 Connecticut Avenue NW, Suite 300
Washington, DC 20036
phone: (202) 659-0060

The Synthetic Organic Chemical Manufacturers Association (SOCMA) is currently developing a program modeled after CMA's Responsible Care Program. SOCMA's version of Responsible Care will be designed to confront the issues specific to SOCMA's members.

## *Matrix*

**Themes:**

I. Incorporating P2 into curricula
II. Less-toxic alternatives in synthesis
II.A. Alternatives to phosgene
II.B. Supercritical $CO_2$
II.C. D-Glucose
II.D. Biocatalysis/biological reagents
II.E. Non-biological catalysts
II.F. Miscellaneous routes/chemicals
III. Computer/mathematical modeling
IV. P2-related programs
V. Overviews/general discussion

**Subject Classifications:**

A = Alternative synthesis
B = Alternative chemical
C = Background info/gen. discussion

**Audience Codes:**

❶ Some elementary science
❷ Undergraduate knowledge of science
❸ Advanced knowledge (faculty, etc.)

**Content Classifications:**

F/R Feedstock/Reactant
Sol Solvent
Cat Catalyst
Opt Optimization
T/R Toxicity/Risk Assessment
SAR Structure-Activity Relationships
Bio Biological
Sim Computer Simulation
EU End-Use
* Economic
CS Case Study

| | Theme | A | B | C | F/R | Sol | Cat | Opt | T/R | SAR | Bio | Sim | EU | CS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ainsworth & Thayer** | IV | | | ❶ | | | | | | | | | ❶ | ❶ |
| **Amato** | IV | | | ❶ | | | | | | | | | | |
| **Anastas** | V | | | ❶ | | | | | | | | | | |
| **Anastas & Farris** | V | | | ❷ | | | | | | | | | | ❷ |
| **Anastas, Nies, & DeVito** | III | | | ❸ | | | | | | | | | ❸ | |
| **Anders (1994; "Designing ...")** | II.D | | ● | | | | | | ❸ | | | | | ❸ |
| **Anders (1994; "SARs ...")** | III | | | ❸ | | | | | ❸ | ❸ | | | | ❸ |
| **"Applications of Electro. ..."** | II.F | ❷ | | | ❷ | | | | | | | | | ❷ |
| **Aresta** | II.B | ❸ | | | ❸ | | ❸ | | | | | | | |
| **Ariens** | V | | | ❶ | | | | | ❷ | | | | ❷ | |
| **Arzoumanidis & Karayannis** | II.E | ● | | | | | ❸ | | | | | | | ❸ |
| **Bao et al.** | II.E | ● | | | | | ❸ | | | | | | | ❸ |
| **Baumel** | III | | | ❶ | | | | | | ● | | | | |
| **Bell et al.** | II.E | | ● | | | | ❸ | | ● | | | | | ❷ |
| **Bertini & Luchinat** | II.D | ● | | | | | ❸ | | | | ❸ | | | ❸ |
| **Bodor (1995)** | III | | ● | | | | | | ❸ | ● | | | ❸ | ❸ |
| **Bodor (1984)** | III | | | ● | | | | ❸ | | ● | | | ❷ | |
| **Boethling** | V | | ❸ | | | | | | ❸ | | ❸ | | ❸ | ❸ |
| **Bolzacchini et al.** | II.F | ● | | | ❸ | | | | | | | | | ❸ |
| **Borman** | II.F | ❸ | | | | | | | | | | | | ❸ |
| **Bradley** | II.B | | | ❸ | | ● | ● | | | | | | | |
| **Buch & Kashiwagi** | II.F | ❸ | | | | | | | | | | | ❸ | ❸ |
| **Carey & Carey** * | I | | | ❷ | | | | | | | | | | |
| **Casanova** | III | | ● | | | | | | | | | ❷ | | |
| **Cavanaugh** | IV | | | ❸ | | | | | | | | | | |
| **Chapman** * | II.F | ● | | | ❸ | | | | | | | | ❸ | |
| **Chynoweth** | II.E | | ❷ | | | | ❷ | | | | | | | ❷ |

| | Theme | A | B | C | F/R | Sol | Cat | Opt | T/R | SAR | Bio | Sim | EU | CS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Clarke | V | | ❸ | | | | | | | ❸ | | | | ❸ |
| Clerici, Bellussi, & Romano | II.E | ❸ | | | | | ❸ | ❸ | | | | | | ❸ |
| Clerici, Ingallina, & Rossi | II.E | ❸ | | | | | ❸ | | | | | | | ❸ |
| Combes, Guan, & DeSimone | II.B | ❷ | | | | ❷ | | | | | | | | ❷ |
| Czekaj et al. | II.F | ❷ | | | | ❷ | ❷ | | | | | | | ❷ |
| Dambach | V | | | ❶ | | | | | | | | | | ❶ |
| Dartt & Davis | II.E | ❸ | | | | | ❸ | | | | | | | ❸ |
| Dell & Frost | II.C | ❸ | | | | | ❸ | ❸ | | | | | | |
| DePompei | II.A | | ❸ | | | | | | | | | | ❸ | ❸ |
| DeSimone et al. | II.B | ❸ | | | | ❸ | | | | | | | | ❸ |
| DeSimone, Guan, & Eisbernd | II.B | ❷ | | | | ❷ | | | | | | | | ❷ |
| DeVito (1995; "Designing...") | II.F | | ❷ | | | | | | ❷ | ❷ | | | ❷ | ❷ |
| DeVito (1995; "General ...") | V | | ❷ | | | | | | ❷ | ❷ | | | ❷ | |
| DeVito (1995; "Using SARs...") | III | | ❷ | | | | | | | ❷ | | | | ❷ |
| DiCarlo | II.F | | ● | | | | | | | | | | ❷ | |
| Donohue & Geiger | II.B | ● | | | | ● | | | | | | | | ❸ |
| Draths & Frost (1991) | II.C | ● | | | | | ❸ | | | | ❸ | | | |
| Draths & Frost (1990) | II.D | ● | | | | | ❸ | ❸ | | | ❸ | | | |
| Draths & Frost (1994; "Environ...") | II.C | ● | | | ❸ | | ❸ | | | | ❸ | | | |
| Draths & Frost (1994; "Microb...")* | II.C | ● | | | ● | | ● | | | | ❸ | | | |
| Draths et al. | II.C | ● | | | | | | ● | | | ● | | | |
| Draths, Ward, & Frost | II.C | ● | | | ● | | | | | | ● | | | |
| Draxler | V | | | ❶ | | | | | | | | | | ❶ |
| Dwyer, Lewis, & Schneider | II.E | | ● | | | | ● | | | | | | | ● |
| Emsley | II.C | ● | | | ● | | | | | | ● | | | ● |
| Epling & Wang* | II.E | ● | | | ● | | ● | | | | | | | |
| Farris, Podall, & Anastas | IV | | | ● | | | | | | | | | | ● |
| Fiksel | V | | | ● | | | | | | | | | | |
| Flam (1994; "EPA Campaigns...") | IV | | ❶ | | | | | | ❶ | | | | ❶ | |
| Flam (1994; "Laser Chemistry...") | II.F | ● | | | | | | ● | | | | | | |
| Frost & Lievense* | II.C | ● | | | ● | | ● | | | | ● | | | ● |
| Frost & Draths | II.D | ● | | | ● | | ● | | | | ● | | | |
| Frost | II.C | ● | | | ● | | ● | | | | ● | | | |
| Gargulak & Gladfelter | II.A | ● | | | | | ● | ● | | | | | | |
| Garrett | V | | ● | | | | | | | | | | | |
| Garrett & DeVito | V | | ● | | | | | | ● | ● | | | ● | |

| | Theme | A | B | C | F/R | Sol | Cat | Opt | T/R | SAR | Bio | Sim | EU | CS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| "Gassy Plastics." | II.B | 1 | | | | 1 | | | | | | | | 1 |
| Glasser | II.D | | 3 | | | | | | | | 3 | | | 3 |
| Guan & DeSimone | II.B | 3 | | | | 3 | | | | | | | | |
| Haggin (1994; "Cat. Critical ...") | II.E | 2 | | | | 2 | 2 | | | | | | | 2 |
| Haggin (1994; "Cat. Gains ...") | II.E | 1 | | | | | 1 | | | | | | | 1 |
| Haggin (1993; "Cat. Process ...") | II.E | 3 | | | | | 3 | | | | | | | 3 |
| Haggin (1994; "Direct ...") | II.E | 3 | | | | | 3 | | | | | | | 3 |
| Haggin (1994; "New ...") | II.F | 3 | | | 3 | | | | | | | | | 3 |
| Hall | II.F | 3 | | | | 3 | 3 | 3 | | | 3 | | | |
| Hancock & Cavanaugh | IV | | | 1 | | | | | | | | | | |
| Hansch | III | | 2 | | | | | | 2 | 2 | | | | |
| Harris, Tuck, & McKee* | II.F | 3 | | | 3 | | | | | | | | | 3 |
| Hendershot | II.F | | | 3 | | 3 | 3 | | 3 | | | | | 3 |
| Hendrickson | III | | 2 | | | | | | | | | 2 | | 2 |
| Hirschhorn | V | | | 2 | | | | | | | | | | |
| Hudlicky | II.D | 3 | | | | | 3 | | | | 3 | | | |
| Huheey | I | | | 2 | | | | | | | | | | |
| Illman (1993) | V | | | 1 | | | | | | | | 1 | | 1 |
| Illman (1994) | V | | | 1 | | | | | | | 1 | | | |
| Jacobson & Willingham | II.E | | 2 | | | | | | | 2 | | | 2 | |
| Johnson & Sharpless | II.E | 2 | | | | | | | 2 | | | | | |
| Johnston | II.B | [illegible] | | | | 2 | | | | | | | | |
| Jones | II.E | | [illegible] | | | | | | 3 | 3 | | | | 3 |
| Keoleian & Bulkley | I | | | 1 | | | | | | | | | | |
| Komiya et al. | II.A | [illegible] | | | 3 | | | | | | | | | 3 |
| Kraus, Kirihara, & Wu | II.F | [illegible] | | | 3 | | | | | | | | | 3 |
| Lee, Garces, & Mai | II.E | | 3 | | | | 3 | | | | | | | |
| Lim | II.B | 3 | | | | 3 | 3 | | | | | | | 3 |
| Manzer | II.E | 2 | | | | | 2 | 2 | | | | | | |
| Marotta & Sheardy | II.D | | 3 | | | | 3 | | | | [illegible] | | | |
| Maxwell & Naber | II.E | [illegible] | | | 3 | | 3 | | | | | | | 3 |
| McGhee, Yi, & Riley | II.A | [illegible] | | | 3 | | | | | | | | | |
| McGhee et al. | II.A | 3 | | | 3 | | | | | | | | | |
| Milne & Wang | III | | 2 | | | | | | 2 | 2 | | 2 | | |
| Misono & Okuhara | II.F | 3 | | | | | 3 | | | | | | | |
| Mitchell | IV | | | 1 | 1 | | | | 1 | | | | | |

| | Theme | A | B | C | F/R | Sol | Cat | Opt | T/R | SAR | Bio | Sim | EU | CS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mitteiman et.al. | V | | | ❸ | | | | | | | | | | ❸ |
| Moss & Kent | IV | | | ❸ | | | | | | | | | | |
| Newman | V | | | ❷ | | | | | ❷ | | | | ❷ | |
| Newsome, Nabholz, & Kim | V | | ❸ | | | | | | ❸ | | | | ❸ | |
| Nikles et al. | II.F | ❸ | | | | ❸ | | | | | | | ❸ | ❸ |
| Richman | V | | ❸ | | | | ❸ | | | | | | | ❸ |
| Riley, McGhee, & Waldman | II.A | ❸ | | | ❸ | | | | | | | | | ❸ |
| Rotman (1993; "Chemists ...") | V | | | ❷ | | | | | | | | | | ❷ |
| Rotman (1991) | III | | ❸ | | | | ❸ | | | | | ❸ | | |
| Rotman (1990) | III | | ❶ | | | | | | | | | ❶ | | |
| Rotman (1992) * | II.E | ❷ | | | | | ❷ | | | | | | | ❷ |
| Rotman (1993; "The Quest ...") | II.D | ❶ | | | ❶ | | | | | | ❶ | | | ❶ |
| Sawan, Shieh, & Su | II.B | | | ❸ | | ❸ | | | | | | | | ❸ |
| Sheldon * | II.F | | | ❸ | | | | | | | | | | ❸ |
| Sherrington | II.F | ● | | | | | ● | | | | | | | |
| Sieburth | II.F | | ❸ | | | | | | | | | | ❸ | |
| Singh, Pike, & Szafran | I | ● | | | | | | | | | | | | |
| Slone, Anastas, & DeVito | III | ● | | | | | | | | | | ❸ | | |
| Smith | I | | | ● | | | | | | | | | | |
| Snider & McCarthy | II.F | ● | | | ❸ | | | | | | | | | |
| Spitzer * | V | | | ● | | | | | | | | | | |
| Steinfeld & Bem | I | | | ● | | | | | | | | | | |
| Stern | II.F | ● | | | ● | | | | | | | | | |
| Stern & Cheng | II.F | ● | | | | | | | | | | | | |
| Stern et al. | II.F | ● | | | ● | | | | | | | | | |
| Stern, Hileman, & Bashkin | II.F | ● | | | ❸ | | | | | | | | | ❸ |
| Stinson | II.F | ❸ | | | | | | | | | | | | ❸ |
| Sundaresan, Simpson, & Wei | II.F | ● | | | | | | ● | | | | | | ❸ |
| Sundell & Nasman | II.F | ● | | | ❶ | | | ● | ❸ | | | | | ❸ |
| Szafran, Singh, & Pike | I | | | ❶ | | | | | | | | | | |
| Tanko and Blackert | II.F | ● | | | | | ● | | | | | | | |
| Tanko, Blackert, & Sadeghipour | II.B | ● | | | | | ● | | | | | | | |
| Tanko et al. | II.B | ● | | | | | | ● | ● | | | | | |
| Thayer | IV | | | ❷ | | | | | | | | | | ❸ |
| Timberlake & Govind | III | | ● | | | | ❸ | | | | | ● | ❸ | ❸ |
| Tobin | IV | | | ❷ | | | | | | | | | | |

| | Theme | A | B | C | F/R | Sol | Cat | Opt | T/R | SAR | Bio | Sim | EU | CS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trogler, Simon, and Gray | V | | | 2 | | | | | | | | | | |
| Trost | V | 2 | | | | | | 2 | | | | | | |
| Tully | I | | | 3 | | | | | | | | | | 3 |
| Tumas et al. | II.B | 3 | | | | 3 | 3 | | | | | | | |
| Tundo, Marques, and Selva | II.E | 3 | | | | 3 | | | | | | | | 3 |
| U. S. EPA and NSF | IV | | 3 | | | | | | | | 3 | 3 | | 3 |
| U. S. EPA | V | | | 1 | | | | | | | | | | |
| Veith, De Foe, and Knuth | III | | 2 | | | | | | 2 | 2 | | | | |
| Vellaccio | I | | | 2 | | | | | | | | | | |
| Waldman and McGhee | II.A | 3 | | | 3 | | | | | | | | | 3 |
| Wallace | V | | | 2 | | | | | | | | | | 2 |
| Watts | IV | 2 | | | | 2 | | | | | | 2 | | 2 |
| Williamson and Anastas | IV | | | 2 | | | | | | | | | | |
| Wilson * | II.F | 2 | | | 2 | | | | | | | | | |
| Zhang, Yang, and Pawliszyn | II.F | 3 | | | | 3 | | | | | | | | |
| Zwaard, Vermeeren, and de Gelder | I | | | 1 | 1 | | 1 | | 1 | | | | | |

# Annotated Bibliography of Chemistry-Related Pollution Prevention Sources

*Prepared by Kellie DuBay and Jason Schweitzer, NPPC Research Assistants, under the direction of Thomas Dunn, Professor, Department of Chemistry; Gregory A. Keoleian, Assistant Research Scientist, School of Natural Resources and Environment; and Nancy A. Osborn, Publications Manager, NPPC.*
*[Bracketed information indicates the corresponding section in the Chemistry Compendium Resource List.]*

Ainsworth, Susan J., and Ann M. Thayer. "Chemical Manufacturers Welcome Challenges of Product Stewardship." *Chemical & Engineering News* 72, no. 42 (17 October 1994): 10–31. [IV]

Provides a detailed review of the chemical industry's implementation of the product stewardship code from the Chemical Manufacturers Association's Responsible Care Program. Discusses industry initiatives to analyze product life cycles with involvement from suppliers, employees, and customers. A section on greener products and processes specifically addresses alternatives to toxic substances in manufacturing.

Amato, Ivan. "The Slow Birth of Green Chemistry." *Science* 259 (12 March 1993): 1538–1541. [IV]

Discusses chemists' role in environmental protection through the discipline of environmental chemistry. Examines the historical reasons why the chemistry community has not embraced this field. Also touches on the relationship between the National Science Foundation and the U. S. Environmental Protection Agency in promoting green chemistry research.

Anastas, Paul T. "Benign by Design Chemistry." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul T. Anastas and Carol A. Farris, 2–22. Washington: American Chemical Society, 1994. [V]

Provides a thorough introduction to the concepts of pollution prevention, benign-by-design chemistry, and the important role the synthetic chemist plays in environmental protection.

Anastas, Paul T., and Carol A. Farris, eds. *Benign by Design: Alternative Synthetic Design for Pollution Prevention.* American Chemical Society Symposium Series, no. 577. Washington: American Chemical Society, 1994. [V]

Developed from symposium sponsored by the Division of Environmental Chemistry at the 206th national meeting of the American Chemical Society. Included in this book are original papers on benign chemistry that discuss tools for assessment.

Anastas, Paul T., J. Dirk Nies, and Stephen C. DeVito. "Computer-Assisted Alternative Synthetic Design for Pollution Prevention at the U.S. Environmental Protection Agency." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul T. Anastas and Carol A. Farris, 166–184. Washington: American Chemical Society, 1994. [III]

Provides a comparison between three programs (CAMEO, LHASA, and SYNGEN) designed to assist in identification of benign synthetic pathways to commercial chemicals.

Anders, M. W. "Designing Safer Chemicals: Role of Bioactivation in Chemical Toxicity." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 366–368. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.D]

Defines both receptor- and bioactivation-dependent toxicity and describes several mechanisms of the latter. Discusses the implications of safer chemical production based on the manipulation of bioactivation reactions.

Anders, M. W. "Structure-Activity Relationships of Haloalkanes." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 377–378. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [III]

Briefly discusses generalizations about the relationship between the structure and metabolism of haloalkanes, specifically monohalomethyl, dihalomethyl, and trihalomethyl groups.

"Applications of Electrochemical Synthesis of Organics Show Promise." *Chemical & Engineering News* 63, no. 2 (14 January 1985): 29–31. [II.F]

Explores the synthesis of ethylene glycol, explosives, fragrances, and food additives through electrochemical production. A major benefit of electrochemical synthesis is that new processes often require less energy and generate less waste while providing high selectivity.

Aresta, Michele. "Perspectives of Utilization of Carbon Dioxide as a Building Block." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 316–319. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.B]

Discusses the advantages of using carbon dioxide as a source of carbon in the synthesis of chemicals. Provides evaluation criteria, present and future uses of carbon dioxide, and new synthetic procedures.

Ariens, E. J. *Drug Design.* New York: Academic Press, 1980. [V]

The toxicity associated with every aspect of drug design is discussed using several examples of pesticides — a life cycle assessment of drug manufacturing.

Arzoumanidis, Gregory, and Nicholas M. Karayannis. "Fine-tuning Polypropylene." *Chemtech* 23 (July 1993): 43–48. [II.E]

Describes "innovations in polyolefin catalysis" for the production of commercial isotactic polypropylene. Examines the four generations of commercial polypropylene catalysts, the fourth of which generation possesses environmental benefits such as "full exploitation of the solventless polymerization process." Includes industrial examples of catalyst support preparation.

Bao, Rong, W. Scott Dodson, Thomas C. Bruton, and Yuzhuo Li. "New Applications of Photoinduced Redox Reactions on $TiO_2$ in Organic Synthesis." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 411–415. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.E]

Describes a simple new method for photoinduced transformations of organic compounds using particulate semiconductors as catalysts, specifically reductions of nitro compounds to hydroxylamines and azido compounds to amines.

Baumel, Irwin P. "Design of Safer Chemicals—An EPA Goal." *Drug Metabolism Reviews* 15, no. 3 (1984): 415–424. [III]

Explains in detail what structure-activity relationships are and how their evaluation is relevant to the reduction of environmental burdens in chemical manufacturing. Presents reviews of some EPA-funded projects that focus on structure-activity relationships.

Bell, A. T., L. E. Manzer, N. Y. Chen, V. W. Weekman, L. L. Hegedus, and C. J. Pereira. "Protecting the Environment Through Catalysis." *Chemical Engineering Progress* 91 (February 1995): 26–34. [II.E]

Provides examples of novel catalytic technologies designed to produce chemicals and fuels that are less harmful to the environment. This article addresses safer products, toxic materials management, waste minimization, fuel reformulation, and air pollutant control.

Bertini, Ivano, and Claudio Luchinat. "Biodegradation, Enzymes and Mechanisms." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 352–354. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.D]

Discusses the implications of enzymatic mechanisms for the development of environmentally benign chemical syntheses. Focuses on aerobic degradation, specifically enzymes with monooxygenase and dioxygenase activity.

Bodor, Nicholas. "Design of Biologically Safer Chemicals Based on Retrometabolic Concepts." In *Designing Safer Chemicals,* edited by Roger L. Garrett and Stephen C. DeVito. Washington: American Chemical Society, scheduled to be published in fall 1995. For information, call the ACS at (202) 872-4564. [III]

Bodor, Nicholas. "Soft Drugs: Principles and Methods for the Design of Safe Drugs." *Medicinal Research Reviews* 4, no. 4 (1984): 449–469. [III]

Discusses processes that optimize structure-activity and structure-metabolism relationships and presents case studies and background information on the evolution of "soft" drugs.

Boethling, Robert S. "Designing Biodegradable Chemicals." In *Designing Safer Chemicals*, edited by Roger L. Garrett and Stephen C. DeVito. Washington: American Chemical Society, scheduled to be published in fall 1995. For information on publication date, call the ACS at (202) 872-4564. [V]

Bolzacchini, Ezio, Anna Maria Brambilla, Marco Orlandi, and Bruno Rindone. "The Bis(Salycilideneimino)Ethylenecobalt(II)-Catalyzed Side Chain Oxidation of Lignin Model Compounds With Dioxygen." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 355–358. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.F]

Discusses the problems of current pulp and paper chlorine bleaching processes and describes an alternative bleaching process that uses a metal-centered system and dioxygen. The by-products of this alternative process are examined with a lignin model.

Borman, Stu. "Aromatic Amine Route Is Environmentally Safer." *Chemical & Engineering News* 70, no. 48 (30 November 1992): 26–27. [II.F]

Describes a new reaction for producing two intermediates in the production of rubber antioxidants: 4-nitrodiphenylamine and 4-nitrosodiphenylamine. This new reaction generates less halogenated waste.

Bradley, David. "Solvents Get the Big Squeeze." *New Scientist* 143 (6 August 1994): 32–35. [II.B]

A report on advances in green chemistry achieved through the use of supercritical fluids (SCFs). Discusses the properties, applications, and environmental benefits of SCFs, particularly water, carbon dioxide, and xenon; . Examines the work that J. DeSimone and M. Poliakoff have done with supercritical $CO_2$. Provides an easy-to-understand history and explanation of supercritical fluids.

Buch, Robert R., and Takashi Kashiwagi. "Silicones and Silicone Additives for Improved Fire Performance." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 277–279. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.F]

Examines the problems of halogen-based fire retardant agents currently used in the plastics industry. Provides a listing of alternative fire retardants and discusses the benefits of silicone additives.

Carey, Francis A., and Andrew F. Carey. "Environmentally Benign Synthesis in the Introductory Organic Chemistry Lecture Course." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 180. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [I]

Addresses the shortcomings of traditional introductory organic chemistry courses in relation to environmental concerns. Points out that real-world issues involving economics and ethics in synthetic design may have a place in these courses.

Casanova, Joseph. "Computer-Based Molecular Modeling in the Curriculum." *Journal of Chemical Education* 70, no. 11 (November 1993): 904–909. [III]

Provides a historical background of computer-based molecular modeling in structural chemistry and examples of computational exercises for an organic chemistry course. Describes the "early stages of routine use of theory to predict structure and chemical behavior for classroom use from computer-based methods."

Cavanaugh, Margaret A. "NSF's Environmental Research in the Chemical Sciences: Environmentally Benign Synthesis and Processing Program." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 224. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [IV]

Provides a quick review of various research programs funded by the National Science Foundation that target the reduction of toxic chemicals.

Chapman, Orville L. "The University of California-Los Angeles Styrene Process." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul Anastas and Carol Farris, 114–120. Washington: American Chemical Society, 1994. [II.F]

Describes the UCLA-styrene process: replacing benzene with mixed xylenes. The author states that this process is more efficient and economical than an existing styrene process threatened by a possible ban on benzene.

Chynoweth, Emma. "Shaping Environmental Solutions With Clay-Based Catalysts." *Chemical Week* 148 (26 June 1991): 57–58. [II.E]

Discusses replacement of Friedel-Crafts catalysts with less toxic clay-based catalysts. Pros and cons of clay catalysts as well as zeolites are examined along with industrial acceptance of the new catalysts.

Clarke, Eric A. "Evaluation of the Molecular Design Approach in the Development of New Dyes." *Drug Metabolism Reviews* 15, nos. 5 & 6 (1984): 997–1009. [V]

Discusses the use of molecular design principles in the design of safer synthetic dyes, specifically azo dyes due to their toxic synthesis. Calls for the less toxic compounds, risk reduction activities, and recognition of the limitations associated with the molecular design approach when developing alternative substances.

Clerici, M. G., G. Bellussi, and U. Romano. "Synthesis of Propylene Oxide From Propylene and Hydrogen Peroxide Catalyzed by Titanium Silcalite." *Journal of Catalysis* 129 (1991): 159–167. [II.E]

This paper examines the catalytic performance of titanium silcalite (TS-1) in several organic and inorganic solvents. The data should be useful in optimizing TS-1-based reactions. Includes a sketch of the experimental apparatus used in the epoxidation of propylene.

Clerici, Mario G., Patrizia Ingallina, and Luigi Rossi. "Clean Oxidation Technologies: New Prospects in the Epoxidation of Olefins." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 325–327. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.E]

Provides a brief review of current epoxidation processes, pointing out the environmental benefits of hydrogen peroxide. Also discusses new catalysts for epoxidations and describes the behavior of a titanium silcalite catalyst.

Combes, J. R., Zhibin Guan, and John M. DeSimone. "Homogenous Free-Radical Polymerizations in Carbon Dioxide: Telomerizations of 1,1-Difluoroethylene in Supercritical Carbon Dioxide." *Macromolecules* 27 (1994): 865–867. [II.B]

This paper explains the use of supercritical carbon dioxide as a replacement for CFC-based solvents in the homogenous free-radical polymerizations of fluorimated acrylic and styrenic monomers.

Czekaj, C. L., K. A. High, G. H. Laule, and L. L. Phegley. "Waste Minimization and Elimination in Industrial Process Chemistry: The Case of Sulfolane." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 232–233. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.F]

Introduces the benefits of sulfolane but also addresses the waste generation problems associated with its production. Discusses current research to understand reactions which occur during the hydrogenation step, creating liquid and solid by-products.

Dambach, Barry F. "Translating Industrial Ecology Into Design for Environment (DfE)." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 239–242. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [V]

Provides a good background on the concepts of design for the environment and industrial ecology. Presents applications of these concepts within AT&T.

Dartt, Christopher B., and Mark E. Davis. "Catalysis for Environmentally Benign Processing." *Industrial & Engineering Chemistry Research* 33, no. 12 (1994): 2887–2899. [II.E]

Presents a short overview of the "types of catalytic processes that have shown progress in creating clean technology." Discusses solid acid/base catalysis, clean oxidation catalysis, catalysis in water, and asymmetric catalysis. Makes suggestions for future clean processing.

Dell, K. A., and J. W. Frost. "Identification and Removal of Impediments to Biocatalytic Synthesis of Aromatics from D-Glucose: Rate-Limiting Enzymes in the Common Pathway of Amino Acid Biosynthesis." *Journal of the American Chemical Society* 115 (1993): 11581–11589. [II.C]

One challenge confronting microbial aromatic amino acid biosynthesis from D-glucose is the rate-limiting effects of common pathway enzymes. In this paper, the authors identify several rate-limiting enzymes and describe techniques that can be used for their removal.

DePompei, M. F. "Non-Isocyanate Sealants." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 393–394. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.A]

Provides a brief introduction to the chemistry of acetoacetate based sealant-adhesives developed by Tremco Inc. Includes a review of environmental problems associated with isocyanate sealants.

DeSimone, J. M., E. E. Maury, Z. Guan, J. R. Combes, Y. Z. Menceloglu, M. R. Clark, J. B. McClain, T. J. Romack, and C. D. Mistele. "Homogeneous and Heterogeneous Polymerization in Environmentally Responsible Carbon Dioxide." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 212–214. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.B]

Discusses the preparation of fluoropolymers in supercritical fluids as opposed to CFCs. Provides a brief overview of homogeneous and heterogeneous free radical polymerization studies with supercritical $CO_2$.

DeSimone, John M., Zhibin Guan, and C. S. Eisbernd. "Synthesis of Fluoropolymers in Supercritical Carbon Dioxide." *Science* 257 (Aug. 14, 1992): 945–947. [II.B]

This paper explains the use of supercritical carbon dioxide as a replacement for CFC-based solvents in the homogenous free-radical polymerizations of fluorimated acrylic and styrenic monomers.

DeVito, Stephen C. "Designing Safer Nitriles." In *Designing Safer Chemicals*, edited by Roger Garrett and Stephen DeVito. Washington: American Chemical Society, scheduled to be published in fall 1995. For information, call ACS at (202) 872-4564. [II.F]

DeVito, Stephen C. "General Principles for the Design of Safer Chemicals: Toxicological Considerations for Chemists." In *Designing Safer Chemicals*, edited by Roger Garrett and Stephen DeVito. Washington: American Chemical Society, scheduled to be published in fall 1995. For information, call the ACS at (202) 872-4564. [V]

DeVito, Stephen C. "Using Structure-Activity Relationships for the Design of Safer Chemicals." In *Designing Safer Chemicals*, edited by Roger Garrett and Stephen DeVito. Washington: American Chemical Society, scheduled to be published in fall 1995. For information, call the ACS at (202) 872-4564. [III]

DiCarlo, Frederic J. "Designing Safer Carboxylic Acid." In *Designing Safer Chemicals*, edited by Roger Garrett and Stephen DeVito. Washington: American Chemical Society, scheduled to be published in fall 1995. For information, call the ACS at (202) 872-4564. [II.F]

Donohue, Marc D., and Jennifer L. Geiger. "Reduction of VOC Emission During Spray Painting Operations: A New Process Using Supercritical Carbon Dioxide." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 218–219. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.B]

Describes the replacement of organic solvents in paint formulations with supercritical $CO_2$. Although spray atomization viscosity is reduced, the authors note that existing limitations merit further investigation.

Draths, K. M., and J. W. Frost. "Conversion of D-Glucose into Catechol: The Not-So-Common Pathway of Aromatic Biosynthesis." *Journal of the American Chemical Society* 113 (1991): 9361–9363. [II.C]

Describes a biocatalytic route to catechol that does not use the high temperatures, caustic solutions, metals, and peroxides typically employed in catechol synthesis.

Draths, K. M., and J. W. Frost. "Synthesis Using Plasmid-Based Biocatalysis: Plasmid Assembly and 3-Deoxy-D-*arabino*-heptulosonate Production." *Journal of the American Chemical Society* 112 (1990): 1657–1659. [II.D]

The authors report their success in localizing the genes encoding transketolase and DAHP synthase to a single plasmid; the result is an *E. coli.* strain that synthesizes substantially elevated levels of DAH and DAHP. Their new single-step plasmid-based biocatalysis has advantages over traditional multistep enzymatic synthesis and may have implications for biosynthetic routes that use D-glucose.

Draths, Karen M., and John W. Frost. "Environmentally Compatible Synthesis of Adipic Acid from D-Glucose." *Journal of the American Chemical Society* 116 (1994): 399–400. [II.C]

Describes a novel biosynthetic pathway that catalytically converts D-glucose into adipic acid. Ozone-depleting gases and greenhouse gases are not generated, and only mild temperatures and pressures are needed.

Draths, Karen M., and John W. Frost. "Microbial Biocatalysis: Synthesis of Adipic Acid from D-Glucose." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul T. Anastas and Carol A. Farris, 32–45. Washington: American Chemical Society, 1994. [II.C]

Describes in detail the authors' research in developing a two-step synthesis of adipic acid from the biocatalysis of D-glucose. From a pollution-prevention standpoint, the reaction is attractive, because benzene is not required. However, economics may be a barrier to the reaction's industrial acceptance.

Draths, K. M., D. L. Pompliano, D. L. Conley, J. W. Frost, A. Berry, G. L. Disbrow, R. J. Staversky, and J. C. Lievense. "Biocatalytic Synthesis of Aromatics from D-Glucose: The Role of Transketolase." *Journal of the American Chemical Society* 114 (1992): 3956–3962. [II.C]

The percentage of D-glucose that microbes such as *E. coli.* convert into aromatics is limited by catalytic activity of pathway enzymes such as DAHP and transketolase. The authors describe how to induce a two-fold increase in the conversion of D-glucose by amplifying catalytic levels of transketolase.

Draths, K. M., T. L. Ward, and J. W. Frost. "Biocatalysis and Nineteenth-Century Organic Chemistry: Conversion of D-Glucose Into Quinoid Organics." *Journal of the American Chemical Society* 114 (1992): 9275–9276. [II.C]

Quinoid organics such as quinic acid, benzoquinone, and hydroquinone can now be derived from D-glucose, a non-toxic feedstock derivable from renewable resources such as cornstarch and biomass.

Drexler, Eric K. "Molecular Manufacturing: A Sustainable Basis for Global Wealth." *Leaders* (October/November/December 1993): 98–99. [V]

Molecular manufacturing (also known as nanotechnology) may provide new avenues for reducing the environmental burdens of chemical syntheses and greatly improve the efficiency of existing alternative energy sources (such as solar energy). This paper is a brief overview of the history, potential, and current developments in the field of molecular manufacturing.

Dwyer, F., P. Lewis, and F. Schneider. "Efficient, Non-Polluting Ethylbenzene Process." *Chemical Engineering* 83 (5 January 1976): 90–91. [II.E]

Describes the alkylation of benzene with ethylene to make ethylbenzene using a newly developed, solid, non-Friedel-Crafts catalyst. The process has the advantages of more efficient energy usage, simpler design, lower cost, and reduced environmental burden.

Emsley, John. "A Cleaner Way to Make Nylon." *New Scientist* 141 (12 March 1994): 15. [II.C]

Describes the work of Frost and Draths on the synthesis of adipic acid from D-glucose and its implications for nylon production. Compared to synthesis from benzene, adipic acid production via biocatalytic pathways requires less fossil fuel and generates less nitrous oxide.

Epling, Gary A., and Qingxi Wang. "Preparative Reactions Using Visible Light: High Yields From Pseudoelectricochemical Transformation." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul T. Anastas and Carol A. Farris, 65–75. Washington: American Chemical Society, 1994. [II.E]

Discusses how dye catalysts and photocatalysts can be used in synthetic transformations to avoid heavy metal pollution from toxic metal oxidants. These types of catalyses often lead to reductions in cost, toxicity, and quanitity of reactants.

Farris, Carol A., Harold E. Podall, and Paul T. Anastas. "Alternative Syntheses and Other Source Reduction Opportunities for Premanufacture Notification Substances at the U.S. Environmental Protection Agency." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul T. Anastas and Carol A. Farris, 157–165. Washington: American Chemical Society, 1994. [IV]

This paper describes EPA's assessment methodology for new chemical substances using Premanufacture Notifications. Methodology includes evaluation of feedstocks, solvents, by-products, and impurities to identify opportunities to reduce or eliminate potential waste streams.

Fiksel, Joseph. "Principles of Industrial Ecology and Design for Environment." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 243–246. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [V]

Relates the concepts of IE and DfE more closely to chemistry and the activities of chemists. Describes DfE practices and environmental metrics, an important tool for establishing DfE infrastructure.

Flam, Faye. "EPA Campaigns for Safer Chemicals." *Science* 265 (9 September 1994): 1519. [IV]

Discusses the EPA's "Designing Safer Chemicals" program, which promotes research on chemical toxicity to aid the redesign of compounds to decrease environmental burden. Techniques used in drug design are described as feasible approaches to novel design of chemical substitutes. This article emphasizes the need for chemists to understand toxicology and synthesis.

Flam, Faye. "Laser Chemistry: The Light Choice." *Science* 266 (14 October 1994): 215–217. [II.F]

Despite past frustrations in laser-controlled chemistry, the lure of increased efficiency and decreased waste has led to continued research in this area. This article examines the principle of laser-controlled reactions and describes advances in this technique using simple molecules, such as HOD.

Frost, John W., and Jeff Lievense. "Prospects for Biocatalytic Synthesis of Aromatics in the 21st Century." *New Journal of Chemistry* 18 (1994): 341–348. [II.C]

Biocatalytic syntheses of indigo and quinoid organics from D-glucose are discussed in relation to currently employed industrial chemical routes. Background information on biocatalysis is presented as well as a concise discussion of the cost-effectiveness of biosynthesis.

Frost, John W., and Karen M. Draths. "DHS: A New Intermediate for Oxychemical Synthesis." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 225–226. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.D]

Provides an introduction to research into new routes to various aromatic oxychemicals that involves the conversion of glucose to 3-dehydroshikimate. Discusses the single-step biocatalytic conversion route to catechol.

Frost, John. "Green Chemistry at Work: Products Can Be Made From Glucose Instead of Benzene." *EPA Journal* 20, no. 3 (Fall 1994): 22–23. [II.C]

Provides a short but thorough introduction to the problems of using benzene in chemical production. Describes new technology that employs biocatalysis as a method for green chemical manufacturing. Focuses on using glucose as a starting material in the synthesis of products traditionally derived from benzene.

Gargulak, J., and W. Gladfelter. "Homogeneous Catalytic Carbonylation of Nitroaromatics." *Journal of the American Chemical Society* 116 (1994): 8933–8495. [II.A]

Another alternative route to isocyanates is the catalytic carbonylation of nitroaromatic compounds. This paper is a thorough investigation into the kinetics and reaction mechanism of one particular Rhuthenium-based catalyst. Using this information, isocyanate syntheses can be optimized. A detailed comparison of traditional polyurethane syntheses using phosgene and this procedure is forthcoming by the authors and shall be based in part on this information.

Garrett, Roger L. "Designing Safer Chemicals: A New Approach to Pollution Prevention." In *Designing Safer Chemicals*, edited by Roger L. Garrett and Stephen C. DeVito. Washington: American Chemical Society, scheduled to be published in fall 1995. For information, call the ACS at (202) 872-4564. [V]

Garrett, Roger L., and Stephen C. DeVito, eds. *Designing Safer Chemicals.* Washington: American Chemical Society, scheduled to be published in fall 1995. For information on publication date, call the ACS at (202) 872-4564. [V]

This book is based on research done in the field of novel chemical design, presented before the Division of Environmental Chemistry at the American Chemical Society's national meeting in August, 1994. Contains chapters on various aspects of designing benign chemicals based on toxicological principles.

"Gassy Plastics." *Discover* 16, no. 6 (June 1995): 80. [II.B]

Brief, general overview of the function, history, and potential future of supercritical fluids in large-scale chemical processes.

Glasser, Wolfgang G. "Structural Materials From Naturally Occurring Polymers." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 410. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.D]

Addresses the possibility of creating chemical substances with modified biopolymers.

Goller, Edwin J., and John H. Miller. "Microscale Qualitative Analysis." *Journal of Chemical Education* 70, no. 6 (June 1993): A159–A160. [Ed. Tools]

Provides microscale procedures for three classification tests: the nitrous acid test for amines, zinc/ammonium chloride reduction, and hydriodic acid test/Zeisel's alkoxyl method. These procedures come from a undergraduate qualitative organic analysis course taught by the authors at Virginia Military Institute. A description of the course is provided.

Guan, Zhibin, and John M. DeSimone. "Fluorocarbon-Based Heterophase Polymeric Materials: Block Copolymer Surfactants for Carbon Dioxide Applications." *Macromolecules* 27 (1994): 5527–5532. [II.B]

Describes the synthesis of block copolymer surfactants designed specifically for use in super-critical and liquid carbon dioxide. With these surfactants, fluorocarbon-based polymers can be synthesized with greater ease relative to traditional anionic polymerization techniques.

Haggin, Joseph. "Catalysis Critical to Benign Process Design." *Chemical & Engineering News* 72, no. 16 (18 April 1994): 22–25. [II.E]

Discusses the goals of benign design involving selective catalysis. Addresses problems of liquid acid catalysts and the use of superbases. Presents improvements in oxidation catalysis.

Haggin, Joseph. "Catalysis Gains Widening Role in Environmental Protection." *Chemical & Engineering News* 72, no. 7 (14 February 1994): 22–30. [II.E]

Highlights U.S.-Russian Workshop on Environmental Catalysis held January 1994 in Wilmington, Delaware and the application of catalysis in benign chemistry. Catalytic research discussed includes the development of combustion processes that eliminate nitrogen oxide emissions, the design of processes that reduce energy and transportation requirements, and the mechanism of selective catalytic reduction. The article notes the benefits of "just-in-time" production of hazardous materials using catalytic reactions. It also discusses the use of catalysts in pollution control activities, such as oil spill remediation and waste plastic recovery.

Haggin, Joseph. "Catalytic Process Cuts Isobutene From $C_4$ Streams." *Chemical & Engineering News* 71, no. 36 (6 September 1993): 31–32. [II.E]

Describes a new process for selective separation of isobutene from $C_4$ streams using a catalytic reaction. Lists advantages of this method over traditional practices and describes the results of the pilot test.

Haggin, Joseph. "Direct Process Converts Methane to Acetic Acid." *Chemical & Engineering News* 72, no. 16 (18 April 1994): 5. [II.E]

Describes a new scheme for creating acetic acid using a direct catalytic route. This article describes the reaction and catalyst, naming methanol and formic acid as the only significant by-products.

Haggin, Joseph. "New Processes Target Methanol Production, Off-gas Cleaning." *Chemical & Engineering News* 72, no. 13 (March 28, 1994): 29–31. [II.F]

Describes the economic, environmental, and engineering aspects of a process that converts carbon dioxide to methanol and a chemical processing innovation based on un-steady state operation.

Hall, Nina. "Chemists Clean Up Synthesis With One-Pot Reactions." *Science* 266 (7 October 1994): 32–34. [II.F]

Discusses the progress and benefits of cascade chemistry —designing waterfall reactions that reduce energy requirements and by-products. Examines the implications of cascade chemistry for development of biologically active compounds. Also provides a cascade recipe for creating a four-ringed compound.

Hancock, Kenneth G., and Margaret A. Cavanaugh. "Environmentally Benign Chemical Synthesis and Processing for the Environment." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul T. Anastas and Carol A. Farris, 23–30. Washington: American Chemical Society, 1994. [IV]

Discussion of National Science Foundation's partnerships with the Council for Chemical Research and the Environmental Protection Agency to fund research in environmental chemistry. Emphasizes the importance of research and education for chemists so that the scientific and technical challenges posed by environmental protection can be met.

Hansch, Corwin. "The QSAR Paradigm in the Design of Less Toxic Molecules." *Drug Metabolism Reviews* 15, no. 7 (1984–85): 1279–1294. [III]

Discusses the importance and history of quantitative structure-activity relationships (QSAR) in the design of less toxic and selectively toxic chemicals. Provides examples of QSAR applications in drug development and environmental science.

Harris, N., M. W. Tuck, and Davy McKee. "Butanediol via Maleic Anhydride." *Hydrocarbon Processing* 69, no. 5 (May 1990): 79–82. [II.F]

Describes a new butanediol process. The method is more efficient, economical, and environmentally friendly because its feedstocks are widely available and less hazardous. The three basic steps of the "Davy McKee butanediol process" that use maleic anhydride are explained in detail, and the economic advantages that will expand product usage are described.

Hendershot, Dennis C. "Chemistry—The Key to Inherently Safer Manufacturing Processes." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 273–275. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.F]

Defines chemical process and design safety strategies for manufacturing, emphasizing the importance of chemistry in the development of safer processes. Provides examples of inherently safer options.

Hendrickson, James B. "The SYNGEN Program for Teaching Alternative Syntheses." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 183–185. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [III]

Discusses the basic concepts and protocol of SYNGEN, a synthesis design program, that facilitates the generation of more environmentally benign syntheses.

Hirschhorn, Joel S. "Enabling Global Implementation of Industrial Pollution Prevention." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 266–267. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [V]

Provides a brief introduction to the author's paper on sustainable production through changes in industrial practices. Mentions a Critical Ratios Methodology developed by the author for benchmarking pollution prevention progress at the facility level and describes a database of clean technology sources.

Hudlicky, Tomas. "Biocatalytic Conversion of Halogenated Aromatic Compounds to Carbohydrates and Other Chiral Synthons." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 227. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.D]

Provides a reaction scheme for the conversion of aromatic and halogenated aromatic compounds into cyclohexadiene through soil bacterium. Discusses implications for medicinal chemicals.

Huheey, James E. "Incorporating Environmental Issues Into the Inorganic Chemistry Curriculum." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 181. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [I]

Provides an introduction to Huheey's presentation on current inorganic chemistry courses and the integration of environmental problems in textbooks and coursework.

Illman, Deborah L. "Green Technology Presents Challenge to Chemists." *Chemical & Engineering News* 71, no. 36 (6 September 1993): 26–30. [V]

Discusses topics addressed at the symposium on alternative synthetic design for pollution prevention held during the 1993 national meeting of the American Chemical Society in Chicago. The article emphasizes the role of the synthetic chemist in environmental protection. The author illustrates this role with success stories in current research, including the use of visible light to drive chemical transformations, advances in biotechnology, replacement of toxic solvents with supercritical fluids, and computer software tools to provide theoretical alternative synthetic pathways to target molecules.

Illman, Deborah L. "Environmentally Benign Chemistry Aims for Processes That Don't Pollute." *Chemical & Engineering News* 72, no. 36 (5 September 1994): 22–27. [V]

Reviews research presented at the American Chemical Society's national meeting in Washington D.C., which focused on Design for the Environment. Discussion ranges from biocatalysis to the development of an alternative synthetic route to aliphatic isocyanates that does not use phosgene.

Jacobson, Andrew, and Gary L. Willingham. "Designing an Environmentally Safe Marine Antifoulant." In *Designing Safer Chemicals*, edited by Roger L. Garrett and Stephen C. DeVito. Washington: American Chemical Society, scheduled to be published in fall 1995. For information, call the ACS at (202) 872-4564. [II.E]

Johnson, Roy, and Barry Sharpless. "Catalytic Asymmetric Epoxidation of Allylic Alcohols." In *Catalytic Asymmetric Syntheses*, edited by I. Ojima. New York: VCH Inc., 1993. [II.E]

The use of trace amounts (as opposed to stoichiometric amounts) of titanium-tartrate complex catalysts is possible when activated molecular sieves are added to asymmetric epoxidation processes. The advantages are relatively milder conditions, easier isolations, increased yields, and the potential for in-situ product derivations.

Johnston, K. P. "Safer Solutions for Chemists." *Nature* 368 (17 March 1994): 187–188. [II.B]

Discusses the properties of supercritical fluids as solvents, particularly carbon dioxide and water. Gives examples of organometallic reactions performed in these solvents.

Jones, Jeffrey P. "Predicting Rates of Cytochrome P450 Mediated Bioactivation, and its Application to the Design of Safe Chemicals." In *Designing Safer Chemicals*, edited by Roger L. Garrett and Stephen C. DeVito. Washington: American Chemical Society, scheduled to be published in fall 1995. For information, call the ACS at (202) 872-4564. [II.E]

Keoleian, Gregory A., and Jonathan W. Bulkley. "Incorporating Pollution Prevention Into the Chemistry Curriculum: New Challenges and Opportunities." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 186. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [I]

Describes the plans for the development and dissemination of a chemistry pollution prevention curriculum.

Komiya, Kyosuke, Muneaki Aminaka, Kazumi Hasegawa, Hiroshi Hachiya, Hiroshige Okamoto, Shinsuke Fukuoka, Haruyuki Yoneda, Isaburo Fukawa, and Tetsuro Dozono. "New Process for Producing Polycarbonate Without Phosgene and Methylene Chloride." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 343–346. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.A]

Describes Asahi Chemical Industry Co., Ltd.'s alternative non-phosgene processes to produce isocyanates and polycarbonates, based on "solid-state polymerization of amorphous polymers." Notes an innovative process for the production of diphenyl carbonate, important for polycarbonate production, which uses dimethyl carbonate without phosgene.

Kraus, George A., Masayuki Kirihara, and Yusheng Wu. "A Photochemical Alternative to the Friedel-Crafts Reaction." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul T. Anastas and Carol A. Farris, 76–83. Washington: American Chemical Society, 1994. [II.F]

This paper describes the development of an alternative to the Friedel-Crafts reaction that creates no unwanted by-products. The alternative reaction involves the photochemically mediated reaction of an aldehyde with a quinone. The authors claim that, with light as a reagent, several environmental benefits are attainable.

Lee, G. J., J. M. Garces, and J. J. Maj. "Applications of Shape Selective 3-DDM Zeolite Catalysts." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 234–235. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.E]

Briefly discusses the production, function, and application of 3-DDM zeolites as novel catalysts in cumene production. Notes that acidic waste disposal and corrosive material handling are eliminated as a result of 3-DDM zeolite catalyst use.

Lim, P. K. "Environmentally Benign Oil-Water Interfacial Synthesis." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 238. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.B]

A brief description of a new technique that eliminates the need for toxic solvents through the use of an innocuous oil-water mixture in conjunction with a surface-active catalyst complex.

Manzer, Leo E. "Chemistry and Catalysis: Key to Environmentally Safer Processes." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul T. Anastas and Carol A. Farris, 144–154. Washington: American Chemical Society, 1994. [II.E]

Provides examples of high-yield, low-waste processes, waste minimization, asymmetric catalysis, and environmentally safer products from DuPont R&D. Calls for more cooperative information transfer between industry and universities.

Marotta, Stephen P., and Richard D. Sheardy. "$Mg^{2+}/K^{+}$ Induced Self-Assembly of G-Rich DNA Oligomers Into High Molecular Weight Species." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 408–409. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.D]

The authors report their success in developing DNA-based catalytic systems.

Maxwell, I. E., and J. E. Naber. "New and Improved Catalytic Processes for Clean Fuels." *Catalysis Letters* 12 (1992): 105–116. [II.E]

Discusses the role of catalysis in modifying existing processes and developing new routes to less toxic fuels. Specifically, this article covers new routes to methyl tertiary butyl ether (MTBE), paraffin isomerization with zeolite-based catalysts in the synthesis of environmentally acceptable gas components, and natural gas conversion based on the catalytic oxidative coupling of methane.

McGhee, W., Pan Yi, and D. Riley. "Highly Selective Generation of Urethanes from Amines, Carbon Dioxide, and Alkyl Chlorides." *Journal of the Chemical Society–London, Chemical Communications* (1994) 699–700. [II.A]

The authors can produce polyurethanes in excellent yields and mild conditions with virtually 100% selectivity by reacting carbon dioxide and alkyl chlorides with amines in the presence of sterically hindered, powerful organic bases. The authors' novel synthesis is a viable alternative to traditional polyurethane syntheses that require the use of phosgene.

McGhee, William D., Mark Pater, Dennis Riley, Ken Ruettimann, John Solodar, and Thomas Waldman. "Generation of Organic Isocyanates From Amines, Carbon Dioxide and Electrophilic Dehydrating Agents: Use of o-Sulfobenzoic Acid Anhydride." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 206–210. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.A]

Describes the problems experienced with some dehydrating agents in the generation of isocyanates. Presents the results of an isocyanate synthesis using o-sulfobenzoic acid and examines a reasonable method for the recycle of the major by-product, an anhydride.

Milne, George W. A., and Shaomeng Wang. "Use of Computers in Toxicology." In *Designing Safer Chemicals*, edited by Roger L. Garrett and Stephen C. DeVito. Washington: American Chemical Society, scheduled to be published in fall 1995. For information, call the ACS at (202) 872-4564. [III]

Misono, Makoto, and Toshio Okuhara. "Solid Superacid Catalysts." *Chemtech* 23 (November 1993): 23–29. [II.F]

Describes current applications and potential uses of heteropolyacids. Suggests that superacids could make synthetic processes involving hazardous chemicals more benign. Provides detailed definitions of superacids and heteropolyacids and discusses their unique properties; includes data from recent research.

Mitchell, James W. "Alternative Starting Materials for Industrial Processes." *Proceedings of the National Academy of Sciences*, USA 89 (February 1992): 821–826. [IV]

This article addresses the effects of the chemical industry on society and the environmental and health risks posed by high priority toxic chemicals. Based on current environmental regulations, which restrict the activities of the chemical industry, the author presents a pollution prevention strategy based on chemical substitutes and on-demand chemical generation. The article also discusses the need for alternative precursor reagents in semiconductor manufacture.

Mittelman, Abe, Daniel Lin, Dorothy Gannon, and C-K Ho. "Inherently Safe Chemistry Guide." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 271–272. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [V]

According to the authors, an "inherently safe" chemistry practice is not one that merely minimizes the total volume of toxic waste products; rather, it is an environmentally advantageous process that is also safe to chemical factory workers and the public. The article gives an overview of several chemistry practices the authors deem as "inherently safe."

Moss, Ken, and Ray Kent. "Chemical Categories In EPA's New Chemicals Program." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 285–288. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [IV]

Provides background on EPA's premanufacture notice procedure for the testing of new chemical substances and describes the establishment of new categories for reviewing these substances. Notes the EPA's plans to development a list of "categories of concern" that will assist the development of safer chemicals.

Newman, Alan. "Designer Chemistry." *Environmental Science and Technology* 28, no. 11 (1994): 463A. [V]

Provides an overview of the benign-by-design concept presented at the August 1994 national meeting of the American Chemical Society in Washington, which focused on Design for the Environment. Discusses research in the areas of alternative synthesis and the design of safer chemicals using toxicological concepts.

Newsome, Larry D., Vincent Nabholz, and Ann Kim. "Reducing Aquatic Toxicity Through Safe Chemical Design." In *Designing Safer Chemicals*, edited by Roger L. Garrett and Stephen C. DeVito. Washington: American Chemical Society, scheduled to be published in fall 1995. For information, call the ACS at (202) 872-4564. [V]

Nikles, David E., Alan M. Lane, Song Cheng, and Hong Fan. "Pollution Prevention in the Magnetic Tape Industry: Waterborne Coating Formulations for Video Tape Manufacture." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 417–418. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.F]

Provides a brief description of a binder polymer system that can be used in a new waterborne coating formulation. Discusses experimental coating trials using new formulations and economic issues affecting large-scale implementation.

Reel, Kevin. "Hydrogen Sulfide Is Not Such a Rotten Idea." *Journal of Chemical Education* 70 (October 1993): 854. [Ed. Tools]

Describes a microscale procedure using "yellow" ammonium sulfide to produce hydrogen sulfide for quantitative analysis, replacing the use of the carcinogen thioacetamide. The author states this procedure serves as an acceptable alternative to the waste treatment of ammonium sulfide and provides a safer source sulfide ions for analysis.

Richman, Jack E. "The Rational Design of Active Site Catalysts." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 404–407. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [V]

According to author, the time has come for a committed investigation into the design of active site catalysts modeled after enzymes. The author's belief stems from advancements in areas such as modeling of active sites and site mutation theory. Discusses the roles of various sectors in the development of active site catalysts.

Riley, Dennis, William D. McGhee, and Thomas Waldman. "Generation of Urethanes and Isocyanates from Amines and Carbon Dioxide." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul T. Anastas and Carol A. Farris, 122–132. Washington: American Chemical Society, 1994. [II.A]

Presents an industrial application of benign chemistry, specifically the elimination of phosgene as a reagent in the production of urethanes and isocyanates. According to this study, a new $CO_2$-based route to isocyanates and urethanes occurs under mild conditions with greater ease than traditional syntheses.

Rotman, David. "Chemists Map Greener Synthesis Pathways." *Chemical Week* 153 (22 September 1993): 56–57. [V]

A review of the American Chemical Society's 1993 national meeting in Chicago, which addressed alternative synthetic design for pollution prevention. Describes advances made by industry and academia in finding less toxic substitutes for feedstocks, solvents, and catalysts. Addresses potential obstacles for commercialization.

Rotman, David. "Molecular Modeling Takes on Catalysts." *Chemical Week* 148 (26 June 1991): 52+. [III]

Discusses the use of molecular simulation in the development of novel catalysts. The benefits of computer modeling are described, along with current drawbacks.

Rotman, David. "Molecular Modeling Takes on Polymers." *Chemical Week* 147 (17 October 1990): 28, 30. [III]

Although this article does not explicitly discuss green chemistry, it describes how computer modeling can be used in the benign design of polymers. The author focuses on software that assists in making predictions about the bulk properties of polymers, stating that the goal of such efforts is to "design polymers with predictable and valuable bulk commercial properties."

Rotman, David. "Successes Emerge in Search for Cleaner Processes." *Chemical Week* 151 (9 December 1992): 66. [II.E]

Focuses on industrial activities in the area of pollution prevention, with a discussion of economic implications. The article addresses process changes that employ alternative catalysts. EPA-funded university research in novel chemical synthesis technologies is highlighted.

Rotman, David. "The Quest for Reduced Emissions, Greener Processes." *Chemical Week* 153 (7/14 July 1993): 117–118. [II.D]

Focuses on the chemical industry's progress in cleaning up processes through biological synthetic routes using biocatalysts. The author presents success stories but questions the feasibility of commercialization. The article discusses industry's short-term solutions to cut emissions from facilities, highlighting the synthesis of indigo dye by *E. coli*.

Sawan, Samuel P., Yeong-Tarng Shieh, and Jan-Hon Su. *Evaluation of the Interactions Between Supercritical Carbon Dioxide and Polymeric Materials*. Los Alamos National Lab Report #LA-UR-94-2341. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, (703) 487-4650 or the Office of Scientific and Technological Information, Box 62, Oakridge, TN 37831, (615) 576-8401. [II.B]

A report resulting from direct collaboration among Los Alamos National Laboratory, the Toxics Use Reduction Institute at the University of Massachusetts, Lowell, and International Business Machines Corporation. Focuses on the interactions between supercritical and subcritical carbon dioxide and polymeric materials to evaluate the use of $CO_2$ as a substitute for CFCs in precision cleaning of polymers. Examines the absorption, swelling, and dissolution of carbon dioxide in polymers at elevated pressures, as well as thermal and mechanical properties.

Sheldon, Roger A. "Consider the Environmental Quotient." *Chemtech* 24 (March 1994): 38–46. [II.F]

Evaluates alternative routes to several organic products based on their "environmental quotient": an empirical relationship invented by the author that incorporates issues of cost, yield, waste, and overall viability into chemical manufacturing procedures.

Sherrington, David C. "Polymer-Supported Systems: Towards Clean Chemistry?" *Chemistry and Industry* no. 1 (7 January 1991): 15–19. [II.F]

Argues that some polymeric reagents, polymer-supported catalysts, polymeric protecting groups, and mediators possess tech[illegible] advantages due to a macroscopic "handle" tha[illegible] increased procedural efficiency without any pollution problems.

Sieburth, Scott McN. "Isosteric Replacement of Carbon With Silicon in the Design of Safer Chemicals." In *Designing Safer Chemicals*, edited by Roger L. Garrett and Stephen C. DeVito. Washington: American Chemical Society, scheduled to be published in fall 1995. For information on publication date, call the ACS at (202) 872-4564. [II.F]

This chapter describes isosterism, silicon as an isostere of carbon, similarities and differences between silicon- and carbon-based chemicals, and the degradation and oxidative metabolism of organosilanes. Three case examples of silicon-for-carbon isosteric replacement in agrochemical research illustrate the effectiveness of the isosterism in the design of safer chemicals.

Singh, Mono M., Ronald M. Pike, and Zvi Szafran. "Pollution Prevention in the Organic and Inorganic Chemistry Laboratory: Microscale Approach." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 194–197. Presented at 208th ACS National Meeting, Washington, August 21–25, 1994. [I]

Describes the concepts of microscale chemistry and the environmental advantages of microscale reactions. Briefly reviews selected experiments from several types of chemistry laboratory texts to illustrate the microscale approach.

Slone, J. Eric, Paul T. Anastas, Stephen C. DeVito. "Using Computer Assisted Organic Synthesis in the U.S. Environmental Protection Agency's Premanufacture Notification Program: A Case Study in Pollution Prevention." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 221–223. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [III]

Examines the use of three computer programs that have the ability to model alternative syntheses of loratadine. Provides a brief critique of each and gives a general conclusion regarding the effectiveness of the programs as tools for benign synthesis.

Smith, Leverett R. "Securing Environmental Concerns in the Chemistry Curriculum." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 198–200. Presented at the 208th ACS National Meeting, Washington, D.C., August 21–25, 1994. [I]

States the two types of environmental concerns chemistry departments face: complying with regulations and redesigning curricula to address real-world issues. Addresses the need for awareness and provides suggestions to improve chemistry curricula.

Snider, Barry B., and Bridget A. McCarthy. "Mn(III)-Mediated Electrochemical Oxidative Free-Radical Cyclizations." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul T. Anastas and Carol A. Farris, 84–97. Washington: American Chemical Society, 1994. [II.F]

Discusses the results of several Mn(III)-based free-radical cyclizations. Such reactions may prove to be viable alternatives to free-radical cyclizations that employ toxic tin reagents.

Spitzer, Martin A. "Environmental Accounting." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 247. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [V]

Addresses the importance of full-cost accounting and life cycle cost assessment in the development of safer chemicals and cleaner technologies.

Steinfeld, J. I., and D. S. Bem. "Graduate Research and Training in Chemistry of the Environment at M.I.T." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 187–190. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [I]

Describes activities at Massachusetts Institute of Technology that incorporate environmental problems into education. Provides a detailed description of a weekly seminar examining a broad range of environmental issues through a series of case studies.

Stern, Michael K. "Nucleophilic Aromatic Substitution for Hydrogen: New Halide-Free Routes for Production of Aromatic Amines." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul Anastas and Carol Farris, 133–143. Washington: American Chemical Society, 1994. [II.F]

Describes two new routes to 4-aminodiphenylamine and 4-nitroaniline that are based on nucleophilic aromatic substitution for hydrogen (NASH). The authors claim that these syntheses are more environmentally favorable than previous NASH reactions. These mechanistic studies illustrate that the chlorination of benzene in the production of aromatic amines can be eliminated.

Stern, Michael K., and Brian K. Cheng. "Amination of Nitrobenzene via Aromatic Substitution for Hydrogen: Direct Formation of Aromatic Amide Bonds." *Journal of Organic Chemistry*. 58 (1993): 6883–6888. [II.F]

The authors report routes to *p*-nitroaniline and its derivatives that do not use halogenated oxidants or intermediates. The reactions are selective only to the *para*-substituted amine, proceed under mild conditions with high yield, and have only water as a major by-product.

Stern, Michael K., Brian K. Cheng, Frederick D. Hileman, and James M. Allman. "A New Route to 4-Aminodiphenylamine via Nucleophilic Aromatic Substitution for Hydrogen: Reaction of Aniline and Azobenzene." *Journal of Organic Chemistry* 59 (1994): 5627–5632. [II.F]

4-Aminodiphenylamine (4-ADPA) and its derivatives are widely used as antioxidants in rubber products; however, their manufacture is heavily dependent on toxic halogenated reagents. The authors report a new route to 4-ADPA that does not require halogenated reactants and generates only water as a major by-product.

Stern, Michael K., Fredrick D. Hileman, and James K. Bashkin. "Direct Coupling of Aniline and Nitrobenzene: A New Example of Nucleophilic Aromatic Substitution for Hydrogen." *Journal of the American Chemical Society* 114 (1992): 9237–9238. [II.F]

The authors report a novel example of nucleophilic aromatic substitution for hydrogen that proceeds in high yield under mild conditions. The reaction uses an amine as nucleophile and does not require an auxiliary leaving group or external oxidant. The reaction may have commercial implications since it eliminates the need for halogenated aromatics in the production of substituted aromatic amines.

Stinson, Stephen. "Cleaner Routes Found to Rubber Antiozonants." *Chemical & Engineering News* 71, no. 36 (6 September 1993): 30–31. [II.F]

Provides a report on new and better routes to certain important rubber-processing chemicals that are less costly, less energy-intensive, and do not require chlorinated organic compounds.

Sundaresan, Sankaran, Michael Simpson, and James Wei. "Alkylation of Isobutane With 2-Butene Over Zeolites." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 236–237. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.F]

Describes a "high-pressure flow reactor used to study the kinetics and selectivity of the solid-acid catalyzed alkylation of isobutane with 2-butene" in order to understand the deactivation of zeolite catalysts. Zeolites are a benign alternative to hydrofluoric acid and sulfuric acid—two substances that are currently used in the alkylation of isobutane with 2-butene.

Sundell, Mats J., and Jan H. Nasman. "Anchoring Catalytic Functionality on a Polymer." *Chemtech* 23 (December 1993): 16–23. [II.F]

Describes the preparation of novel polymer-supported catalysts and reagents. Polymer supports can be valuable because they improve the reactivity and selectivity of catalysts and reagents, are often non-toxic and nonvolatile, and in some cases facilitate the removal of reagents from industrial reaction pots.

Szafran, Zvi, Mono Singh, and Ronald M. Pike. "The Microscale Inorganic Laboratory: Safety, Economy, and Versatility." *Journal of Chemical Education* 66, no. 11 (November 1989): A263–A267. [I]

Discusses origins and need for microscale organic and inorganic chemistry. Describes four major difficulties with traditional inorganic labs that microscale labs reduce: waste generation, lab hazards, limited variety of available reagents, and time-consuming experiments.

Tanko, James M., and Joseph F. Blackert. "Alkylaromatics in Supercritical Carbon Dioxide." *Science* 263 (January 14, 1994): 203–205. [II.F]

Zeigler brominations are typically performed in carbon tetrachloride. An alternative to this environmentally problematic solvent is supercritical $CO_2$. The authors report higher yields and less by-product formation.

Tanko, James M., Joseph F. Blackert, and Mitra Sadeghipour. "Supercritical Carbon Dioxide as a Medium for Conducting Free-Radical Reactions." In *Benign by Design: Alternative Synthetic Design for Pollution Prevention*, edited by Paul T. Anastas and Carol A. Farris, 98–113. Washington: American Chemical Society, 1994. [II.B]

Discusses the use of supercritical carbon dioxide as a less toxic solvent in chemical synthesis and manufacture. Illustrates the effectiveness of this solvent by describing various brominations performed in it.

Tanko, James M., Kamrudin N. Suleman, Glenn A. Hulvey, Anna Park, and Jennifer E. Powers. "Solvent Pressure Effects in Free Radical Reactions: A Selectivity Inversion in Free Radical Brominations Induced by Solvent." *Journal of the American Chemical Society* 115 (1993): 4520–4526. [II.B]

The solvent pressure effects described in this paper are relevant to free radical brominations performed in organic solvents. In later research, the authors show that the relationships are valid for brominations performed in supercritical carbon dioxide as well. The data presented should be useful for those wishing to control or optimize reactions involving supercritical carbon dioxide.

Thayer, Ann M. "Growing Exchange of Information Spurs Pollution Prevention Efforts." *Chemical & Engineering News* 71, no. 30 (26 July 1993): 8–25. [IV]

Discusses the Responsible Care Program's pollution prevention code that requires implementation by members of the Chemical Manufacturers Association. Describes difficulties with environmental reporting that have contributed to increased pollution prevention efforts, such as lack of standards and uniform definitions. Provides examples of pollution prevention activities within industry.

Timberlake, Dennis L., and Rakesh Govind. "Expert System for Solvent Substitution." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 215–217. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [III]

Discusses the capabilities and procedures of PARIS (Program for Assisting the Replacement of Industrial Solvents)—a computer program that aids in identifying alternative solvent formulations for the printing industry.

Tobin, Paul S. "Risk Management Through Inherently Safe Chemistry." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 268–270. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [IV]

Examines the need for chemists to promote inherently safe chemistry within industry, research facilities, and curricula as a means of risk management. Covers relevant regulations and programs, resources for hazards analysis, and EPA's role in inherently safe chemistry.

Trogler, William C., John D. Simon, and Harry Gray. "Integrating Environmental Chemistry Into Introductory Chemistry for Majors and Nonmajors." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 182. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [V]

Overview of the goals, advantages, and shortcomings of a text that discusses real-world chemistry issues.

Trost, Barry M. "The Atom Efficiency—A Search for Synthetic Efficiency." *Science* 254 (Dec. 6, 1991): 1471–1477. [V]

Comparison of atom utilizations, on the basis of theoretical yields, is a rapid way to evaluate the environmental impact of alternative routes to a particular product. This article explains how such comparisons are made by way of several example syntheses that involve carbocyclic ring structures.

Tully, J. C. "Environmental Education From an Industrial Perspective." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 203. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [I]

A brief paragraph about changing trends in the chemical industry; focuses on the principles of industrial ecology. Explains the need to educate future decision-makers about environmentally minded curricula.

Tumas, William, Shaoguang Feng, Richard LeLacheur, David Morgenstern, Paul Williams, Steve Buelow, Carol Burns, Bernard Foy, Michael Mitchell, Mark Burk, and Robert Waymouth. "Chemical and Catalytic Transformations in Supercritical Fluids." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 211. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.B]

A short paragraph describing a research program that explores the use of supercritical fluids in the improvement of reactions, use of new pathways, and reduction of environmental burdens.

Tundo, Pietro, Carlos Alberto Marques, and Maurizio Selva. "Selective Mono-Methylation of Arylacetonitriles and Methyl Arylacetates by Dimethylcarbonate: A Process Without Production of Waste." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 336–339. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [II.E]

Describes the use of dimethylcarbonate in Gas-Liquid Phase Transfer Catalysis as a non-toxic, highly selective methylating agent that does not generate waste. Provides details about alternative methods for alkylating arylacetonitriles and arylacetic esters.

United States Environmental Protection Agency, Office of Research and Development and Office of Pollution Prevention and Toxic Substances; and the National Science Foundation. *Proceedings Document: Workshop on Green Syntheses and Processing in Chemical Manufacturing.* EPA/600/R-94/125. Washington: EPA, October 1994. (To obtain a free copy, call the National Center for Environmental Publications and Information at 513-891-6561.) [IV]

Details the proceedings from this workshop attended by more than 50 chemists, biochemists, and chemical engineering representatives from industry, government, and academia. Presentations from the opening session covered benign organic synthesis, benign biosynthesis, benign engineering approaches, and computer-based methods for green synthesis.

United States Environmental Protection Agency, Office of Research and Development. *Guides to Pollution Prevention: Research and Educational Institutions.* EPA/625/7-90/010. Washington: EPA, June 1990. (To obtain a free copy, call the National Center for Environmental Publications and Information at 513-891-6561.) [V]

Provides guidelines for conducting waste minimization audits and implementing waste minimization options at research and educational facilities. Outlines some material management and laboratory practices.

Veith, Gilman D., David De Foe, and Michael Knuth. "Structure-Activity Relationships for Screening Organic Chemicals for Potential Ecotoxicity Effects." *Drug Metabolism Reviews* 15, no. 7 (1984–85): 1295–1303. [III]

Summarizes progress in the development of structure-bioconcentration relationships and structure-toxicity relationships. The authors state that the SARs examined in this article "are directed at distinguishing structures which should be thoroughly tested from those that should not, and are not directed at prediction of ultimate environmental effects." The toxicity of industrial esters estimated using QSAR is also discussed.

Vellaccio, Frank. "Making a Place for Environmentally Benign Synthesis in the Introductory Chemistry Curriculum: Is it a Moral Imperative?" *American Che[...]al Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 179. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [I]

A short paragraph that poses thought-provoking questions regarding the content of chemistry courses. "An attempt to discuss the ethical issues involved in making a place for environmentally benign synthesis in the introductory chemistry curriculum."

Waldman, T., and W. McGhee "Isocyanates From Primary Amines and Carbon Dioxide: 'Dehydration' of Carbamate Anions." *Journal of the Chemical Society–London, Chemical Communications* (1994): 957–958. [II.A]

An alternative route to isocyanates, the primary feedstocks of the polyurethane industry, has been discovered by the authors. Carbamate anions derived from $CO_2$ and primary amines are converted in high yield syntheses to isocyanates via reaction with electrophilic 'dehydrating agents' such as $POCl_3$ or $P_4O_{10}$. The authors' new procedure is a promising alternative to traditional isocyanate production since it does not entail the use of phosgene.

Wallace, Michael J. "A Company Program to ntroduce Pollution Prevention (P2) Concepts Into Chemical Process Development." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 201–202. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [V]

This document is divided into three short sections covering (1) the benefits and incentives of pollution prevention, (2) the elements of an industrial pollution prevention program, and (3) the need to train industrial chemists in pollution prevention concepts. Describes various projects that should be incorporated into industrial pollution prevention educational programs.

Watts, Daniel J. "Emission Reduction Research Center Pollution Prevention in Batch Chemical Processing Through Selection of Synthesis Condition and Process Design." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 220. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [IV]

Briefly describes the membership criteria, goals, and activities of the Emission Reduction Research Center. The Center's research focuses mainly on non-VOC solvent systems and the development of a computer-based tool that assists decision-making.

Wilcox, Mary F., and Judith G. Koch. "A Freshman Laboratory Program Without Chromium." *Journal of Chemical Education* 70 (June 1993): 488.

Discusses the problems faced by the Ithaca College chemistry courses that used chromiumVI compounds, classified by Occupational Safety and Health Administration as carcinogenic, and the strategy used to preserve "the solid pedagogy" provided by chromium experiments. Provides two more environmentally benign complexes to replace chromium acac. Also gives experimental details for the following: preparation of tris(Acetylacetonato)manganese(III), colormetric analysis of $Mn(C_5H_7O_2)_3$, preparation of tris(Acetylacetone)iron(III), and titrimetric analysis of $Fe(C_5H_7O_2)_3$.

Williamson, Tracy C., and Paul T. Anastas. "Incorporating Alternative Synthetic Pathway Design Into the Synthetic Chemistry Curriculum: EPA Perspectives." *American Chemical Society Preprint of Papers, Division of Environmental Chemistry* 34, no. 2 (August 1994): 177–178. Presented at the 208th ACS National Meeting, Washington, August 21–25, 1994. [IV]

Explains the need to incorporate pollution prevention issues into classical synthetic and inorganic chemistry courses. Describes EPA's "Benign by Design" Chemistry Curriculum Program, listing its goals and methodology. A good source of background information.

Wilson, Sharon. "Peroxygen Technology in the Chemical Industry." *Chemistry and Industry* no. 7 (4 April 1994): 255–258. [II.F]

This article lists the environmental and economic benefits of using peroxygen as a reagent in chemical synthesis. Seven oxidation reactions that use peroxygen technology are described; hydrogen peroxide "in action" is illustrated through five examples.

Zhang, Zhouyao, Min J. Yang, and Janusz Pawliszyn. "Solid-Phase Microextraction: A Solvent-Free Alternative for Sample Preparation." *Analytical Chemistry* 66 (1 September 1994): 844A–853A. [II.F]

This report describes the problems associated with traditional sample preparation technologies, including the use of toxic organic solvents and barriers to change. Solvent-free techniques in three categories (gas-phase, membrane, and sorbent extraction) are reviewed and compared with solid-phase microextraction (SPME). Included are the theoretical aspects, extraction and desorption characteristics, applications, and future developments of SPME.

Zwaard, A. W., H. P. W. Vermeeren, and R. de Gelder. "Safety Education for Chemistry Students: Hazard Control Starting at the Source." *Journal of Chemical Education* 66, no. 4 (April 1989): A112–A114. [I]

Discusses safety practices and procedures in chemical laboratories with a description of a systematic, strategic approach aimed at eliminating hazards at their source. The substitution of toxic solvents and the reduction of labs to microscale level are used as examples of hazard control at the source.