Green Chemistry: An Interdisciplinary Approach to Sustainability

A Course Developed at the
Berkeley Center for Green Chemistry
University of California at Berkeley
Spring Semester 2011

Table of Contents

Course Details

"Green Chemistry: An Interdisciplinary Approach to Sustainability" was taught as a graduate course in Spring 2011 at UC Berkeley. The course comprised two 1.5-hour classes per week for 14 weeks (27 1.5-hour classes). It was cross-listed in four colleges and departments: College of Chemistry, Environmental Studies and Policy Management department in the College of Natural Resources, School of Public Health, and College of Engineering. 50 graduate students from diverse disciplines took the course. This syllabus and other supporting materials can be found on the website of the Berkeley Center for Green Chemistry (http://bcgc.berkeley.edu/) on the course homepage.

Class Webcasts, Audiocasts and Slides

For the Spring 2011 course, each 1.5-hour class was videotaped, which consisted of recording webcasts of the slide presentations along with audiocasts of the presentations and discussions. Links to the webcasts, audiocasts and slides are provided for all Class Presentations. The collection of all available webcasts is available as a set of UC Berkeley webcasts and as a YouTube playlist. The collection of all available audiocasts is available as an iTunes playlist.

Course Readings, Supplemental Readings and Resources

Readings, supplemental readings and resources for each class are identified in the syllabus for each class day. Course Readings are compiled alphabetically and available on the course homepage.

Class Assignments

Students were given short assignments to prepare for seven of the classes, available here.

Course Group Projects

The students formed interdisciplinary groups to conduct course projects, the majority of the course grade. Projects are introduced in Class 3, and proposals and posters are available here.

Case Study

Perfluorinated chemicals are used as a case study to provide continuity and depth for many of the issues presented by different disciplines throughout the course. This case study is introduced in Class 4 and lessons summarized in Class 19.

Student Surveys

Student surveys about the course were taken periodically during the Spring 2011 course. Results of these surveys are available here.

Support

The Berkeley Center For Green Chemistry gratefully acknowledges the California Environmental Protection Agency Department of Toxics Substances Control for supporting the development of this curriculum and the and teaching of this course.

Instructors and Disciplines

The following instructors from the indicated disciplines participated in teaching from the perspective of their own disciplines in the Spring 2011 course.

Professor John Arnold
Chemistry
Director, Berkeley Center for Green Chemistry

Dr. Martin Mulvihill
College of Chemistry
School of Public Health
Executive Director, Berkeley Center for Green Chemistry

Dr. Michael P. Wilson
Center for Occupational and Environmental Health
School of Public Health
Associate Director, Integrative Sciences
Berkeley Center for Green Chemistry

Professor Chris Rosen
Haas School of Business
Associate Director, Business and Economics
Berkeley Center for Green Chemistry

Professor Alastair Iles
College of Natural Resources
Associate Director, Law and Policy
Berkeley Center for Green Chemistry

Megan Schwarzman, MD, MPH
School of Public Health
Associate Director, Health and Environment
Berkeley Center for Green Chemistry

Joseph H. Guth, JD, Ph.D.
School of Public Health
Law and Policy, Berkeley Center for Green Chemistry

Akos Kokai, MS
School of Public Health
Health and Environment, Berkeley Center for Green Chemistry

Course Learning Objectives

1. Learn an interdisciplinary approach to the scientific and societal issues arising from industrial chemical production, including the facets of chemistry, public policy, law, business, and environmental health sciences that can be integrated to promote green chemistry and the redesign of chemicals, industrial processes, and products.

2. Understand the basic principles of toxicology, including hazard, exposure, vulnerability and risk, as they are applied to assessing the impact of chemicals on humans and the environment, setting priorities in public health decision-making and identifying opportunities for informing chemical design.

3. Understand and identify structure/function relationships with respect to chemical properties, biological activity, and product performance. Be able to rank competing synthetic methods using the twelve principles of Green Chemistry along with other technical metrics.

4. Understand the role of law and economics in shaping industrial activity, and be able to identify different legal approaches to chemical regulation, including the cost-benefit analysis paradigm and the precautionary approach.

5. Be familiar with chemicals regulation in the US under the Toxic Substances Control Act, as well as efforts to reform that law, the California Green Chemistry Initiative and the European Union's REACH regulation.

6. Understand and be able to critically assess methods for identifying and evaluating the environmental, social, and health impacts of a chemical product over the life cycle of the product, from "cradle to grave."

7. Be able to evaluate the key business models, drivers, markets, supply chains, and decision-making criteria that business managers employ in investing in green chemistry and bringing safer products to market at a profit. Be able to make a business case for and against green chemistry.

8. Understand the use of alternatives assessments that combine chemical, environmental health, regulatory, and business considerations to develop safer products.

Class 1: Introduction to Interdisciplinary Study of Green Chemistry (Part 1)

Class Goals/Learning Objectives

Student and instructor introductions; survey student areas of study; introduce course from broad perspective and from perspective of each discipline.

Presentations (All Instructors) (Slides, Video, Audio)

A. Course Introduction

Introduce the California Green Chemistry Initiative, the role UC Berkeley has played, and continues to play, in the Initiative, including the 2006 COEH report to the California Legislature and the 2008 report to California EPA. Introduce Berkeley Center for Green Chemistry, and California EPA support for this curriculum development.

Describe the role of interdisciplinary education in advancing green chemistry; that is, everyone needs to be at the table, including chemists, chemical engineers, environmental health scientists, public policy experts, economists, ethicists, business strategists. Green chemistry implies working at the roots of the problem of chemical exposures and global chemical contamination. There is no single root problem; there is no single solution.

To be successful, to be fully integrated into industry and into the economy, green chemistry will need an interdisciplinary approach: the incentives that drive industry innovation and investment, for example, are not oriented toward green chemistry. If you are working in an industry setting, with a whole portfolio of ideas about how to practice green chemistry, you might be marginally successful in the small world of your own lab, but if the company itself is primarily motivated by drivers other than safer chemical designs and processes, your efforts during your lifetime will be met with very small bore successes.

We, you, don't have time for that, given the pace and scale of global chemical production and its attendant health and environmental damage, particularly in the developing world. We are expecting that you will be positions of leadership. For this, you will need an understanding of more than chemistry: you'll need at least the tools and the degrees of awareness that we are hoping to touch on, to introduce to you, in this course.

B. Key Issues In Environmental Health

The material in this course related to environmental health will:

1. Provide background information on exposure (synthetic chemicals and pollutants are ubiquitous in the environment and people), and hazard (chemical exposure is known or suspected to contribute to a wide range of common diseases).
2. Teach key concepts in toxicology, and how they can be applied to help set public health/research priorities, guide selection of alternatives and inform design of safer substances.
3. Elicit students' thoughts on how best to use environmental health concepts and tools in green chemistry, including their application in many types of decision-making (policy, research, prevention, etc).

C. The 12 Principles of Green Chemistry

1. Have students brainstorm what they think a "green" reaction would look like: What types of regents would be used? What types of solvents? What properties would the products have?

2. Briefly go through the 12 principles of Green Chemistry highlighting that many of the students' common sense ideas, are incorporated into the 12 principles.

3. Look at two examples of chemical reactions and ask students to identify the greener reaction and relate the answer to the 12 principles.

4. Discuss the circuit board example, which considers the need for interdisciplinary collaboration to come up with the greenest solution.

D. <u>Overview of Law and Policy Issues in Green Chemistry</u>

This component of the course will delve into four principal topics:

1. The role of law in governing the economy; law as antecedent to economy; legal rules, including environmental laws, provide incentives and disincentives to economic actors.
2. Overview of environmental law, focusing on comparing two competing frameworks for environmental decision-making that are at issue in chemicals policy reform: welfare maximization using cost benefit analysis versus precautionary approaches.
3. Regulation of chemicals in the US under the Toxic Substances Control Act; how TSCA does not adequately promote Green Chemistry.
4. The various approaches that are emerging for chemicals policy reform, including the Safer Chemicals Act of 2010, the California Green Chemistry Initiative and REACH.

E. <u>The Role of Business in Green Chemistry</u>

1. Businesses play two important roles in green chemistry:
    a. As major players through investment in R&D, manufacturing, marketing, distribution, and take back of green chemistry materials and production.
    b. As lobbyists and public relations forces – usually to oppose stronger regulation.
2. Positive role of business is as important as the negative role; study examples of Dow and DuPont initiatives. We will examine what they are doing and why, primarily from the perspective of drivers and management strategies behind the positive role. We will also examine the main constraints that inhibit firms from taking a more active positive role.

Class 2: Introduction to Interdisciplinary Study of Green Chemistry (Part II)

Class Goals/Learning Objectives

Introduce interplay of different disciplines by discussing issues raised by the PFC-ski wax case as reported in an article in San Francisco Chronicle; characterize 1 to 3 key issues raised in the Chronicle article from the perspective of each academic discipline represented in the class; generate discussion among the students within, and then among, their own disciplines; presentation from instructors on 1 to 3 issues of greatest importance from the perspective of their discipline.

Readings

1. Cheryl Katz, "Waxing skis may be hazardous to your health" *San Francisco Chronicle* (Dec. 19, 2010).
2. Paul T. Anastas and John C. Warner, *Green Chemistry Theory and Practice*, Chapters 1 and 2 (Oxford University Press 2000). Explains the case for pollution prevention, and defines the science of Green Chemistry.
3. M.P. Wilson, M. Schwarzman, T. Malloy, et al., "Green Chemistry: Cornerstone to a Sustainable California," (University of CA, 2008). There are three barriers to an effective market for chemicals and products in California: 1) the Data Gap, (2) the Safety Gap and (3) the Technology Gap. It advances and reflects he findings of a 2006 report commissioned by the California Legislature, *Green Chemistry in California: A Framework for Leadership in Chemicals Policy and Innovation*, also by UCB COEH researchers. These two reports served as a framework for new legislation and the state's Green Chemistry Initiative.
4. McNulty and Davis, "Should the C-Suite Have a "Green" Seat? (HBR Case Study and Commentary) *Harvard Business Review* (Dec. 2010). Observe the competitiveness issues that have led the corporate executives in this article to consider whether to hire a Corporate Sustainability Officer to more effectively incorporate sustainability into their operations and business strategies. Note that the consultants HBR asked to comment on the article also disagree about this. Why is this issue open to such disagreement?
5. Organisation for Economic Co-operation and Development, "Summary of the Environmental Outlook for the Chemicals Industry" (Chapter I) in *Environmental Outlook for the Chemicals Industry*, OECD (2001), pp 9-17. An assessment of the Chemical Industry with an eye towards (1) future growth of the chemical industry and (2) the industrial response to growing sustainability concerns.

Assignment To Be Completed Before Class

Students will complete the readings and submit responses to three questions relating to the SF Chronicle reading. The three questions are presented in the **Class 2 Assignment**.

Class Discussions

1. Before instructor presentations, small group discussion of the three assignment questions by students in groups of similar disciplines**;** report back; class response.
2. After instructor presentations, small group discussion of the three assignment questions by students in groups of multiple diverse disciplines; report back; class response.

Presentations (Guests, all Instructors) (Slides, Video, Audio)

A. Introduction

This class will use the problem of ski wax as a way to understand the interdisciplinary nature of green chemistry problems. Students should come away from this class with a sense of how green chemistry can inform their own discipline, and visa versa. We will ask students to consider: What is one thing that environmental health scientists (or environmental lawyers, or chemists, or business leaders, or policy analysts, e.g.) could learn about your discipline, and what is one thing you could learn from them?

B. Cheryl Katz, Reporter, Environmental Health News

(See presentations videotape)

C. Perspectives on PFC-Ski Wax – Chemistry Implications

1. Discuss technical challenge of reducing wet and dry friction simultaneously.
2. Briefly discuss the options from traditional waxed through perfluorinated waxes.
3. Introduce the key chemical features of each option.

D. Perspectives on PFC-Ski Wax – What Motivates a Chemist?

1. Academic chemists are evaluated in terms of their publications and grants. They are interested in new chemistry, and making things that have never been made before.

2. Industrial chemists are evaluated based on new patents for the company. They are interested in cost, efficiency and new intellectual property.

3. In future, we expect all chemists will still be evaluated based on publication, intellectual property, etc., but that they will also consider impacts on human health and the environment.

E. Perspectives on PFC-Ski Wax -- Health/Environment

The article presents the problem of protecting people from exposure to potentially harmful substances, and the broader problem of the management (containment, proper disposal, etc.) of pollutants. The central problem: Once a chemical is produced and put on the market, it becomes extremely difficult to limit human exposure throughout the lifetime of that substance, and it becomes virtually impossible to control the ultimate environmental fate of the chemical. There is a fallacy in the very idea of the "containment" of pollutants. The root cause of this problem lies in the design of chemical substances, more so than in their careful handling.

a. Personal protective equipment and engineering controls cannot be taken for granted, and are not always provided or implemented.

b. Even if primary users (e.g. workers) are protected from exposure, how is the rest of the biosphere protected against eventual exposure? Does adequate ventilation protect the atmosphere?

c. The potential for uncontrollable human and environmental exposure to chemicals such as PFCs is amplified by persistence, bioaccumulation, and long-range transport.

F. Perspectives on PFC-Ski Wax -- Health/Environment

The standard environmental health-driven question in a case like this is "How much ski wax would a person be exposed to, and would that create intolerable risk?" Or simply, "Is it safe to use PFCs in ski wax?" This produces a series of detailed investigations into health effects and exposure scenarios in an attempt to quantify the associated risk.

Asking the question this way bounds the analysis and reduces its relevance. Instead, we should:

a. Account for the effects of *aggregate exposures*– resulting from multiple sources of exposure to the same chemical.

b. Account for the effects of *mixed exposures*– many chemicals affect the same physiological processes, and people are simultaneously exposed to hundreds of chemicals.

c. Ask "Is it necessary?" not "How much harm is acceptable?"

G. Perspectives on PFC-Ski Wax – Environmental Law

1. This case illustrates how the legal system provides incentives and disincentives that guide the economy.
2. The law presumes economic activity will benefit society, even if there is some collateral damage. Government can regulate PFC-ski wax, but only if it shows there is a risk of harm caused AND that the risks outweigh the benefits. Plaintiffs can sue for damages, but the burdens are even heavier than the government's; that is why the federal environmental laws were adopted! Thus, this system leads to vested economic interests that can resist regulation and litigation, which creates a seeming conflict between economy and environment.
3. Under REACH, the burden of proof for PFC-ski wax may be placed on industry to show benefits outweigh costs.
4. Paul Anastas, one of the fathers of green chemistry and now working at EPA, believes voluntary measures and R&D are the best way to promote GC.

H. Perspectives on PFC-Ski Wax -- Environmental Policy

1. The ski wax case shows the human ecological footprint arises as the cumulative impact of a multitude of factors, many of which relate in some way to chemicals. Only a few impacts by themselves would be deeply problematic for the biosphere as a whole, and yet together they are devastating.
2. The newspaper article on ski wax mentions that PFCs are found in wildlife, the environment and nearly all people tested. In our legal system, we evaluate the costs and benefits of PFCs individually in isolation. Does that make sense? Shouldn't we be evaluating them as a component of our excessive footprint?
3. And, finally, what about the ethics of some companies and skiers externalizing risks to people and other species just to obtain faster skis?

I. Perspectives on PFC-Ski Wax -- Business

Business managers will look at this as a business problem – is it a threat to their bottom lines? If so, they will have to decide how to manage the problem, depending on how they assess threat level. Should they ignore it? Monitor it? Invest in developing alternatives? Withdraw from market? Mount effort to fight off regulation? Debunk the science behind the concerns?

J. Perspectives on PFC-Ski Wax -- Government

1. Government in capitalist economies ideally has two responsibilities, in addition to providing for the common defense: (a) to ensure that the market has sufficient information to function; i.e. to correct market failures; and (b) to ensure that the production of goods and

services does not come at the expense of public health and safety and the preservation and protection of the environment.

2. The extent to which government can and should exercise these responsibilities is in a constant state of debate and flux. Documenting and acting on the presence of a market failure is a debatable matter, as is the extent to which the production of a good or service in fact is causing a negative impact on health or the environment.

3. This debate is clearer in cases where the impact is obvious. In the trading of securities, buyers need the same information as sellers. In pharmaceuticals, the production of medicines that in fact kill people quickly is a documentable public health impact. Where fires in factories and apartment buildings kill large numbers of people (e.g. Triangle Shirtwaist fire) government action is easier to muster.

4. In the U.S., however, between 5,500 and 6,000 people are killed on the job from fatal injuries; that is, trauma that in various ways inflicts horrific injuries on the victim. The presence of these cases is undeniable, and yet government action has been extraordinarily minimal. Most occupational safety experts point out that these injuries are mostly preventable. More difficult are the 55,000 to 60,000 premature deaths that occur each year as a consequence of occupational exposures to toxic substances, including chemicals, particulates, vehicle exhaust, and dusts. The federal government (NIOSH) recognizes that these disease fatality rates are grossly undercounted; however, government action to prevent occupational diseases has been virtually non-existent, even when the attribution to workplace exposures has been clearly established, and it is widely recognized that these disease cases exact a tremendous toll economically and are eminently preventable.

5. As such, government action around perfluorinated compounds on skis is unlikely to occur. A documented public health, safety or environmental harm will be difficult to establish. The presence of these compounds in the blood of ski establishment workers or in the adipose tissue of fish in nearby streams does not, by itself, and in the current political climate, constitute an actionable event worthy of regulation.

6. Government is also under pressure to protect employment, if for no reason than it is of paramount importance to the public, and the prospect of large unemployment lines presents a tangible picture of government failure. If that failure can be tied to a government action taken in response to a weakly documented or theoretical health or environmental harm, the government in power at the time will be widely and deeply criticized.

7. From the government's perspective in the U.S., this is a difficult issue that will hopefully blow over as the ski season starts up again in earnest.

Class 3: Introduction To Class Group Projects

Class Goals/Learning Objectives

The student team projects are intended to provide students with concrete examples that will illustrate current issues in green chemistry. Throughout the semester students will apply what they are learning in class to these projects. Each instructor will develop and present possible projects. Students will select projects or develop their own and form into interdisciplinary project teams of 3-5 students.

Readings

1. Potential Project Proposals prepared by instructors.
2. Katharine Sanderson, "It is not easy being green" *Nature*, **2011,** 469, 18-20.
3. John R. Ehrenfeld, "Chapter 2: Solving The Wrong Problem: How Good Habits Turn Bad," pp. 10-21 in *Sustainability by Design: A Subversive Strategy for Transforming Our Consumer Culture*, Yale University Press (2008). Discusses the challenge of creating solutions that address the root of problems rather than the symptoms of problems.

Presentations (All Instructors) (**Slides, Video, Audio**)

Instructors will each outline and lead discussion of suggested interdisciplinary projects, and be available to discuss them with interested students. Summaries of the projects are available **here**. Students should indicate: 1) Which project interests you? 2) Do you have other project ideas? 3) Are there specific people you would like to work with on an interdisciplinary team? Project teams will be created during class or and shortly thereafter.

Posters for Class Group Projects

At the end of the semester, each student project team will present a poster on their project. The posters are available on the **BCGC website**.

Class 4: Introduction To Fluorinated Surfactant Case Study

Class Goals/Learning Objectives

Present background on PFC case study that will be used to illustrate numerous issues in the class, including: the nature of current fluorinated surfactants; their use in products; outline of health and environmental impacts; their current regulatory and legal status.

Readings

1. David Brown and Caroline E. Mayer, "3M to Pare Scotchgard Products; One Long-Lasting Compound Is Cited" *The Washington Post*, May 17th, 2000.
2. Chemistry World, "Polarizing The Debate" *Chemistry World*, RSC Publishing, August 2007, pp. 54-59.
3. Kellyn S. Betts, "What the Evidence is Telling Us," *Environmental Health Perspectives*, 115 (5), 2007, pp. A250-257.
4. Tom Meersman, "3M talks had short guest list," *Minneapolis Star-Tribune* (Feb. 7, 2010) (see also the comments).
5. Takashi Okazoe, "Overview of the history of organofluorine chemistry from the viewpoint of material industry," *Proc. Jpn. Acad.*, Ser. B, Vol. 85, pp. 276-289 (2009).

Supplemental Readings

1. Environmental Working Group, "3M and Scotchgard: "Heroes of Chemistry" or a 20-year Coverup?" Chemical Industry Archives: A Project of the Chemical Industry Working Group (Mar. 29, 2009).
2. 3M Corporation, "3M's Phaseout and New Technologies."

Presentations (Iles, Mulvihill, Guth) (Slides, Video, Audio)

A. Introducing PFC's Class Case Study – Environmental Health Impacts

1. PFCs are found in numerous products that we use daily – spanning from cookware, clothes, shoes, food packaging, to carpets. The reasons why chemical and consumer product companies have found many applications for PFCs lie in the functionality of these chemicals.
2. We need to think about why companies have chosen to use particular chemicals, and how their decisions have collectively created the scale of use. We also need to consider how decisions made decades ago can become entrenched in product designs.
3. PFCs are troubling because: as a class, PFCs are persistent, toxic, and bioaccumulative. Many PFCs are chemicals with high levels of exposure to consumers. There's not just one source of PFC in our lives; there are multiple, cumulative, potentially interacting sources. There is significant scientific evidence that PFCs are found in humans and wildlife everywhere in the world, and that their levels are increasing. The Centers for Disease Control have found that Americans almost universally contain PFOS, as well as PFOA, in their blood. Looking in greater detail at the toxicology of PFOS reveals that this chemical is associated with a range of health effects.

B. Introducing PFC's Class Case Study – Chemistry of Perfluorinated Surfactants

1. Basic fluorine chemistry and naming various types of fluorine compounds.

2. Introduce fluorinated surfactants and discuss the synthesis of these compounds.
3. Discuss chemical properties of these compounds and relate them to environmental persistence.
4. Discuss the current research relating to fluorinated surfactant exposure and toxicity.

C. Introducing PFC's Class Case Study – History and Motivations In Scotchgard Phaseout

1. Discussion of how 3M came to develop Scotchgard and became aware of the toxicological effects of PFOS in the 1990s.

2. Discussion of why 3M voluntarily withdrew Scotchgard in 2000. Was it really voluntary, and was it a case of a company acting ethically? Query: Why did 3M make the decision to withdraw Scotchgard at this particular time, instead of earlier? What criteria should industry use, and how does your discipline's existing framework see these criteria? As it turns out, 3M did not eliminate Scotchgard but adopted a PFC-based alternative that may not be as non-toxic as it appears.

D. Introducing PFC's Class Case Study – Regulatory and Legal Status of PFC's

1. Voluntary actions are often taken to resolve legal disputes. Plea bargains are an example from criminal law. The history of the 3M "voluntary" withdrawal of PFOS/Scotchgard shows that 3M was threatened with more severe action on PFC's by EPA based on concerns over threats to workers, the public and the environment.

2. EPA has taken action on PFC's under various provisions of TSCA, including Sections 5 and 8. EPA has never taken any action on PFC's under TSCA Section 6.

3. Readings refer to numerous legal steps that have been taken on PFC's at many levels of government: state tort actions; some steps by EPA to achieve voluntary action; regulation by EU and Canada; international listing under POPs treaty. The different levels of the legal system often interact and respond to each other.

Class 5: Introduction to Chemistry: 12 Principles Of Green Chemistry -- A Framework For Technology Development

Class Goals/Learning Objectives

This lecture will introduce students to the 12 principles of green chemistry developed by Paul Anastas and John Warner. Students will be able to recognize that these principles encourage us to consider:

1. Design of processes to maximize the amount of raw material ending up in the product;
2. Use of safe, environment-benign substances, including solvents, whenever possible;
3. Design of energy efficient processes; and
4. The best form of waste disposal: not to create it in the first place.

As a result of this lecture, students will be able to:

1. Discuss specific examples of practical value.
2. See the principles from a chemist's perspective.
3. Analyze the case of ibuprofen as an example of a green approach.

Readings

1. Paul T. Anastas and John C. Warner, "Chapter 4: Principles of Green Chemistry," in *Green Chemistry: Theory and Practice* (Oxford University Publishers 2000).
2. Anastas and Eghbali, *Chem. Soc. Rev.*, 2010, 39, pp. 301–312.
3. Mike Lancaster, "Chapter 2: Principles of Sustainable and Green Chemistry" in *Handbook of Green Chemistry and Technology*, Clark, J. and Macquarrie, D. (eds.) (Blackwell Publishers) pp. 10-25.

Presentation (Arnold) (Slides, Video, Audio)

A. What is green chemistry? Some practical definitions
B. Drivers of green chemistry
C. Summary of the 12 principles of green chemistry
D. Principles to Focus On
    1. Atom economy
    2. Designing safer chemicals - example: marine antifoulants
    3. Safer solvents and auxiliaries - Pfizer's results
    4. Design for energy efficiency
    5. Renewable resources (Biopolymers; Levulinic acid)
    6. Catalysis
    7. Design for degradation
    8. Real-time analysis for pollution prevention
    9. Inherently safer chemistry for accident prevention
E. Case study: Ibuprofen synthesis

Class 6: Introduction to Health and Environment: Principles of Hazard, Exposure, Vulnerability, and Risk

Class Goals/Learning Objectives

The goal of this class is to introduce the core concepts of toxicology relevant to understanding drivers of chemical hazard, exposure and risk. At the end of this class, students should be able to discuss:

1. Basic concepts of how substances can have toxic effects, including health and environmental effects, basic mechanisms of action, and factors that confer increased vulnerability or exposure potential.
2. The application of these concepts in thinking about green chemistry in the context of (a) understanding toxicological and epidemiological data (e.g., what is "safe"?) and (b) the "how" of accomplishing select principles of Green Chemistry.

Readings

1. National Library of Medicine Toxicology Tutorials.
   a. Tox Tutor I -- skip Tox testing methods and Exposure standards
   b. Tox Tutor II -- do only Introduction and Biotransformation
   c. Tox Tutor III -- do only Introduction and Basic Physiology
2. David L. Eaton and Curtis D. Klaassen, "Chapter 2: Principles of Toxicology" in *Casarette and Doull's Essentials of Toxicology*, C. Klaasen and J. Watkins eds. (McGraw-Hill 2003), pp. 6-20.
3. Veerle Heyvaert, "Reconceptualizing Risk Assessment," *Review of European Community & International Environmental Law* 8(2): 135-143 (2002).
4. Myers P. and Hessler W., "Does 'the dose make the poison?' Extensive Results Challenge a Core Assumption in Toxicology," Environmental Health News (April 20, 2007).

Supplemental Readings

1. Bollati V. and Baccarelli A., "Review: Environmental Epigenetics," *Heredity* (2010) 105, pp. 105–11.
2. Dolinoy DC, Weidman JR, Jirtle R, "Epigenetic gene regulation: Linking early developmental environment to adult disease," *Reproductive Toxicology* 2007; 23:297–230. Discusses mechanisms of epigenetics.

Assignments To Be Completed Before This Class

Students should complete the Class 6 Assignment, a chemical risk classification exercise.

Class Activities

Discussion by students in small groups to brainstorm hazard traits according to categories identified in presentation.

Full class discussion of homework chemical risk classification exercise.

Presentation (Schwarzman) (Slides, Video, Audio)

A. The types of evidence generated through toxicological and epidemiological studies

1. Traditional practice of EHS has emphasized studying exposure routes (L side of hand-drawn diagram), and correlation with health effects
2. Toxicology traditionally focuses on animal studies with apical endpoints, plus investigation of molecular mechanisms
3. The challenge is to generate information that is most relevant to chemical design, predictive (rather than only descriptive), with potential to screen many compounds and combinations thereof

B. Introduce four elements of basic method of risk assessment

1. Hazard identification
2. Dose-response assessment
3. Exposure assessment
4. Risk characterization

C. Introduction to "hazard" assessment

1. General categories of toxic agents (e.g., chemical; radiation; tobacco; stress)
2. Categories of human health effects (e.g., cancer; birth defects; chronic disease)
3. Types of mechanisms (e.g., direct genotoxicity or organ effects; indirect endocrine alteration; epigenetic effects; oxidative stress)
4. Modulators of effect (e.g., gene environment interaction; vulnerability conferred by developmental stage)
5. Examples: Altered binding of natural ligands (e.g., thyroid hormones); altered enzyme activity (aromatase promotion)
6. Concept of "adverse effect" as defined by US EPA and conceptualized by the NAS in *Toxicity Testing in the 21st Century*
7. Types of hazard traits, as organized by Cal/EPA's Office of Environmental Health Hazard Assessment (OEHHA)

E. Introduction to Gene-Environment interactions

1. Direct DNA alteration through damage or mutation
2. Epigenetic alteration through methylation, histone modification (etc.) altering gene expression
3. What determines heritability of genetic or epigenetic changes?

F. Introduction to determinants of vulnerability and sources of inter-individual variability

1. Particular developmental windows (e.g., organogenesis; puberty) confer susceptibility to particular kinds of health effects from a given exposure
2. Other factors can decrease adaptive capacity (e.g., pre-existing disease; multiple exposures)
3. Small shifts in a physiological parameter (e.g., thyroid hormone level) can have large population-level impacts because of the range of inter-individual variability in response to toxicant exposure

G. Role of biotransformation in determining toxicity

1. Human physiological factors
2. Environmental transformation
3. Compounds can be toxic in original state (parent compound), as a metabolite, or both
4. Altering the processes that govern biotransformation (e.g., enzyme activity or metabolism/excretion) can alter the effect of a toxicant
5. Example: Covalent modification of enzyme activity (e.g., parathion metabolite inhibits AcH degradation)

H. Introduction to concepts of determining dose-response relationships

1. Threshold vs. non-threshold effects
2. Low dose effects and issues arising from extrapolation from high doses
3. Linear vs. non-monotonic dose-response relationships

Class 7: Introduction To Business: Green Chemistry From The Perspective Of The Corporate Bottom Line -- Is Industry Ready?

Class Goals/Learning Objectives

Students should learn the importance of business R&D/commercialization/ marketing of green chemistry materials and products; the impact of market barriers, such as negative externalities, imperfect information, public goods problems and weak regulation on incentives for business investment in G.C. innovation. Given weakness in regulatory environment, understand the important role that non-regulatory drivers are playing in emerging business participation in G.C. innovation, including internal organizational drivers (leadership and CSR); social drivers (NGO campaigns, legitimacy); market drivers (e.g. environmental supply chain management, green government procurement, greening of insurance industry, eco-labels).

Class Group Project

Complete and turn in abstract for class group project.

Readings

Plambeck, Erica and Denend, Lyn, "Walmart's Sustainability Strategy," (Rev Sept. 2008) Harvard Business Case Product # OIT71-PDF-ENG. This case provides an inside look at the decision making process that led Walmart to introduce a an ambitious sustainable business plan that has served as a market driver for sustainability innovation not only at Walmart itself, but for many of the firms whose products Walmart sells. It also examines the operational challenges Walmart faced (and still faces) trying to implement this plan.

Assignments To Be Completed Before This Class

Students should submit answers to questions about the reading in the Class 7 Assignment.

Class Discussion

The class will discuss the answers submitted to the questions about the readings.
After the presentation, there will be a class discussion of these questions about green chemistry drivers: What non-regulatory drivers are most important? How can a business (market) case be made for GC innovation? What is needed to strengthen market drivers?

Presentation (Rosen) (**Slides, Video, Audio**)

A. <u>Industry has critically important roles to play in GC innovation</u>
Problem for advocates of GC: motivating industry to engage

1. Market problem: firms are market institutions operating in imperfect markets characterized by negative externalities; imperfect information; public goods; suboptimal incentives and results
2. Regulatory problem: regulation is weak causing sub-optimal results

B. Regulatory and non-regulatory drivers of innovation in GC

1. Internal organizational drivers
    a. Top down leadership and bottom up initiatives
    b. Top down leadership especially important at this point (examples)
    c. Corporate Social Responsibility (CSR) values
    d. Environmental management systems
2. Social drivers
    a. Environmental NGO campaigns (adversarial vs. educational)
    b. Media exposure, litigation etc
    c. Trade association training
3. Market drivers
    a. Consumer demand and eco-labels (problems)
    b. Corporate procurement and environmental supply chain management; motivations (internal, market, legal, regulatory, social); How such programs are operationalized; Case study (computer industry in 1990's); Walmart's supply chain Sustainability Initiative
    c. Government Procurement
4. Developing drivers; New, green insurance underwriting principles and practices; banking (due diligence, lending incentives)
5. Regulatory drivers; EU (eco-labels, EMAS, other EU directives); Market based vs. command/control regulation

Class 8: Introduction To Law and Policy: The Role Of Economics And Law In Societal Decisions That Affect The Environment And Human Health

Class Goals/Learning Objectives

This Introduction comprises three topic areas: (1) Economics and the environment, including welfare economics and ecological economics. (2) Overview of environmental law, including the common law and the major federal environmental statutes. (3) Introduction to the legislative and regulatory process, and the role of each in environmental law.

Readings

1. Percival et al., *Environmental Regulation: Law, Science, and Policy*, Wolters Kluwer, Aspen Publishers, 6th Ed. (2009). Read pp. 26-31 (Section C, "Economics and the Environment," Part 1, "The Role of Prices and Markets").
2. Herman E. Daly and Joshua Farley, *Ecological Economics: Principles and Applications*, Island Press (2004). Read pp. 3-13 (Chapter 1: "Why Study Economics?").
3. Percival et al., *Environmental Regulation: Law, Science, and Policy*, Wolters Kluwer, Aspen Publishers, 6th Ed. (2009). Read: pp. 2-8 (Section A: Environmental Problems and Progress); pp. 88-99 (excerpts from Chapter 2, section 2.A: Environmental Statutes: A Historical Perspective); and pp. 239-40, 243-46 (Ch. 3 excerpts: Preventing Harm in the Face of Uncertainty).

Supplemental Readings/Materials

1. Gund Institute's Ecological Economics website, and video explanations of various principles of ecological economics.
2. Joseph H. Guth, *Law for the Ecological Age*, Vermont Journal of Environmental Law, vol. 9, Issue 3, pp. 431-512 (Spring 2008). Read pp. 432-37 (Role of environmental law in governing economy).
3. Presidential Executive Order 12866, "Regulatory Planning and Review" (58 FR 51735; October 4, 1993), Read Sections 1(a) and 1(b), particularly Section 1(b)(6) (requiring federal agencies to justify rules using cost-benefit analysis).
4. U.S. House of Representatives, "Tying it all together: Learning about the Legislative Process."
5. U.S. Senate, "Legislative Process: How a Senate Bill Becomes Law."
6. U.S. EPA "Rulemaking Gateway -- A Portal to Priority Rules Under Development."

Presentation (Guth) (Slides, Audio)

A. Economics and the environment

1. Law is antecedent to the economy; it provides a set of incentives to economic actors.
2. Many questions about the proper relationship between economy and environmental health cannot be answered by economic actors competing to create wealth (e.g., our responsibilities to future generations, to nature, to other nations, and to equity), but must be decided by society at large
3. Why many social goals must be incorporated into laws in order for society to accomplish them, particularly where they implicate public goods/services or moral issues

4. Neoclassical economics seeks to maximize social welfare by relying on free markets; views environmental damage as a cost that can be justified by greater gains to welfare; and presumes there are no limits to economic growth and that substitutes can be developed for all natural resources

5. Ecological Economics is concerned with containing scale of the throughput of the economy; the distribution of wealth; and sustainable development, distinguishing "development" from "growth"

6. The problem of public goods and externalities; solutions involving government action, reform of common law, common pool resource management, private ownership and free-market environmentalism

B. Overview of environmental law

1. The common law; prevailing structure of nuisance and negligence; burden of proof on plaintiff; invented to promote industrial revolution and encourages economic growth; structure is basis of modern federal statutes; important ongoing current cases

2. Historical factors leading to federal environmental laws of 1970's

3. Overview of federal environmental laws; their fragmentation into different media, economic contexts, agencies, decision-making structures; TSCA as one of many environmental laws

4. Different structures of safety standards in different laws dealing with chemicals, including health-based standards, technology-based standards, and cost-benefit balancing (e.g., TSCA)

5. Different allocations of burden of proof reflect different starting assumptions in the law (compare FDA act for pharmaceuticals, Delaney Clause, TSCA for industrial chemicals)

C. Introduction to the legislative and regulatory processes

1. How statutes arise, and the causes and purposes of administrative discretion

2. How regulations arise, and the exercise of administrative discretion by agencies

3. Executive Order 12,866, OMB, and the discretionary use of cost-benefit analysis in implementing environmental laws; burden of proof on government before it can regulate means that default of federal environmental laws is in favor of economic activity

Class 9: Should Chemicals Be Assumed To Be Safe Or To Be Dangerous?

Class Goals/Learning Objectives

Students should learn why is it necessary to define such a starting position in social-decision-making structures, and consider whether it is preferable to adopt an initial assumption that chemicals are safe or that they are dangerous, and why. Students will think about the purely scientific question, given the partial information that is available, of what proportion of industrial chemicals are likely to present a hazard to human health or the environment? Students will consider the impact of chemicals on human health and the environment chemicals and pollution as a component of the human global ecological footprint.

Readings

A. Readings on what proportion of industrial chemicals are likely to be hazardous

1. John Warner interviewed in "Green Chemistry — 'Green' As In Money." *Compliance Side Total Chemical Management Today* 2007, 3 (1).

2. European Commission. *Extended Impact Assessment* (SEC(2003)1171/3) (2003). Section 6: Potential Health and Environmental Benefits, pp. 24-28.

3. Richard A. Denison, *Not That Innocent: A Comparative Analysis Of Canadian, European Union And United States Policies On Industrial Chemicals*, Environmental Defense Fund (April 2007), pp. IV-17 to IV-25 (the "categorization" of 23,000 chemicals on Canada's Domestic Substances List).

B. Readings on chemicals and pollution as a component of the global human footprint

1. James Gustave Speth, *The Bridge at the Edge of the World*, Yale University Press (2009). Read pp. xx-xxi (The Great Collision charts), pp. 17-45 (Chapter I: Looking into the Abyss).

2. Johan Rockström et al. 2009. A safe operating space for humanity. *Nature* 461(7263):472-475; DOI:10.1038/461472a.

3. Johan Rockström et al. 2009. Planetary boundaries: Exploring the safe operating space for humanity. *Ecology and Society* 14(2):32. Read sections "Chemical Pollution," "Interactions Among the Boundaries," and "Discussion."

Class Discussion

Students will be organized into discussion groups for discussion and report-back on these questions at appropriate times during the course of the class.

1. What proportion of industrial chemicals do you believe are likely to present some degree of hazard to human health or the environment?

2. Are chemicals likely enough to present some threat to human health and the environment that chemical producers should be required by the government to go to the expense of testing them?

3. Should chemicals be considered as potential contributors to an excessive human ecological footprint, or should the costs and benefits of each chemical be considered independently?

4. Is there a "chemical pollution planetary boundary?" If so, how could it be defined? Is there a way to know we are approaching it before we get to it? What should we do about this in terms of chemicals policy?

Presentations (Guth, Kokai) (Slides, Video, Audio)

A. The law's default position on whether chemicals are hazardous

1. Since the law must reach decisions, legal decision-making structures allocate the burden of proof to a party. This allocation creates a default position of the law, the position the law takes if there is an absence or failure of proof. This allocation is outcome determinative under conditions of uncertainty and creates incentives or disincentives to produce information.
2. In nuisance, plaintiffs bear the burden of proof to show defendant was unreasonable. Default assumption is that defendants are not unreasonable, even if they harm plaintiffs
3. In TSCA, government must show chemicals present an unreasonable risk; default assumption is that chemicals do not present an unreasonable risk
4. For pharmaceuticals under FDA Act, drugs must be proved safe and effective to be approved. Default assumption is that drugs are not safe and may not be marketed.
5. Under the authorization provisions of REACH (for CMR's, PBT's etc.), chemicals must be shown to have a socioeconomic benefit. Default assumption is that such dangerous chemicals do not have net socioeconomic benefit

B. Factors that are considered by legislators and courts in allocating the burden of proof

1. Allocate to party who has best access to information or ability to produce it
2. Default defines a protected, preferred interest. Defines type of error most preferred
3. Estimate of probabilities -- default should reflect most likely outcome

C. What proportion of chemicals are likely to be hazardous?

1. John Warner's opinion is that about 90% of the materials/technologies we currently use need to be reinvented because they contain or depend upon a hazardous substance somewhere in the life cycle. (See interview with John Warner)
2. The European Commission: "of the new substances assessed under existing EU legislation around 70% have been shown to have one or more dangerous properties. An unknown but potentially significant proportion of all chemical substances will enter the environment and reach sufficiently high concentrations to induce adverse effects." (See EC Extended Impact Assessment)
3. Probably the largest-scale systematic chemical safety evaluation was done by Health Canada and Environment Canada between 1999-2006. 4,350 out of 22,400 chemicals on the Domestic Substances List (about 20%) were categorized for further attention, because they might be of some concern to human or environmental health. (See Denison reading)
4. Canada's "categorization" process (see the reading by Denison, pages IV-17 to IV-25)
    a. Goals of the Canadian agencies: to determine which chemicals require ("categorized") or do not require ("not categorized") further risk assessment by the government.
    b. Categorization was according to criteria defined by law (CEPA 1999). These criteria are based on a specific selection of chemical characteristics: human exposure potential, environmental persistence, bioaccumulativity, and "inherent toxicity."

c. Note how the categorization criteria were formulated using numeric metrics where possible (e.g. environmental endpoints), and decision algorithms (health endpoints).

d. Note the substantial gaps in available hazard information, and the ways Canada addressed these data gaps.

e. The ~20% of chemicals "categorized" represent those that could be affirmatively identified to meet the CEPA criteria for this stage of risk assessment.

f. Questions: What does the Canada DSL 20% figure mean? Are the other 80% of chemicals safe? Are all the categorized chemicals uniformly unsafe?

5. Other questions to consider: Is it possible to prove that a chemical is safe? How many biological "targets" are available in living beings? How many interactions are possible between these targets and chemicals? Can we conceivably model all these interactions (e.g. molecular toxicity pathways) with QSARS; can we conceivably test for these interactions? Has your estimate changed as we have discussed what proportion of chemicals are likely to present a hazard?

D. Minimum Data Sets

1. Are chemicals likely enough to present some threat to human health or the environment that chemical producers should be required to go to the expense of testing them?

2. Consider the economic impacts of requiring companies to produce data. Will the data be worth the costs?

3. Consider the impacts on the rate and quality of innovation in the development of new materials and technologies.

4. Is there a reasonable minimum amount of data that can be used to set a useful standard of safety?

E. Planetary Boundaries and Chemical Pollution

1. Chemical pollution is one component of the global human footprint. The impact of the human footprint on ecological systems has been discussed in terms of "Limits to Growth," "Carrying Capacity," "Declines in Ecosystem Functioning."

2. New work by Rockstrom et al. proposes that the Holocene, a desired stable state of the earth system, is defined by a series of attributes, or boundaries, that we must stay within or risk tipping the Holocene into another state that would be less hospitable to us. One of these Planetary Boundaries is chemical pollution that adversely affects ecosystem structure and function. It interacts with other boundaries, and is hard to define.

3. The impact on the biosphere of chemicals can be seen as one component of a larger human footprint, and as contributing to surpassing a Planetary Boundary. This perspective would require us to consider the cumulative impact of chemicals and their contribution to this larger problem, which is much different than trying to evaluate the impact of one chemical taken alone as though it was the only impact.

Class 10: Environmental Fate And Ecology In Chemical Design

Class Goals/Learning Objectives

1. Draw connections between chemical properties, environmental fate, and ecological effects. Emphasize the perspective of design and alternatives assessment (rather than restriction or risk assessment).
2. Look at methods for assessing some relevant environmental properties of chemicals. What data and metrics can be used? Specific examples with synthetic chemicals will illustrate the use of these tools.
3. Develop understanding of modeling and predictive methods, and how these can be used as tools, and how they can be developed further to be more useful. Learn how to use the EPA's PBT Profiler (http://www.pbtprofiler.net).

Readings

1. Des W. Connell, "Distribution of Chemicals in the Environment," Chapter 18 in *Basic Concepts of Environmental Chemistry*, pp. 413-430 CRC Press (1997).
2. Vasseur P, Cossu-Leguille C. 2006. Linking molecular interactions to consequent effects of persistent organic pollutants (POPs) upon populations. *Chemosphere* 62(7):1033-1042.

Supplemental Readings

1. For more on the basics of environmental modeling: Mackay D. 1979. Finding fugacity feasible. Environ SciTechnol 13(10):1218-1223.
2. Ballschmiter K. 1992. Transport and fate of organic compounds in the global environment. *AngewandteChemie International Edition* in English 31(5): 487-515. doi:10.1002/anie.199204873. Read sections 1 (Introduction), 3 (The Chemical Stability of Chemicals under Environmental Conditions), and 4 (The Concept of Multiphase Equilibrium Distribution).
3. Prevedouros K, Cousins IT, Buck RC, Korzeniowski SH. 2006. Sources, fate and transport of perfluorocarboxylates. *Environ SciTechnol* 40(1):32-44; doi:10.1021/es0512475.

Assignment To Be Completed Before This Class

The Class 10 Assignment involves use of a publicly available computational tool, the PBT Profiler, to evaluate and compare environmental effects of chemical substances and processes.

Presentation (Kokai) (Slides, Video, Audio)

A. Environmental fate and ecology in chemical design

1. Introduce the context for the science that will be described in this class. This is about making a link between chemical design and environmental effects. The tools that will be described here can help with assessing the behavior of chemicals in the environment during the chemical design process.
2. Look at basic concepts concerning the interactions of chemicals with the environment. Provide examples, where possible drawing upon known/understood relationships between

structure and environmental behavior. At each opportunity, link the concepts with metrics and tools for chemical assessment.

a. The structure of the environment; environmental compartments; chemical partitioning, using the concept of fugacity (and solubility, vapor pressure, etc.). Tools: Fugacity-based multimedia modeling; air-water-octanol model system (K_{AW}, K_{OW}, K_{OA}). Example: PBT Profiler exercise.

b. Sorption interactions; the structures of minerals, soil, organic matter, atmosphere.

c. Transport of chemicals in the environment; global long-range transport through air and water. Tools: Quantitative structure-property relationships (QSPRs); multimedia models. Example: Global transport of contaminants to polar regions.

d. Persistence; degradation, half-lives, overall persistence (P_{OV}). Tools: QSPRs; linear free energy relationships (chemical kinetics); multimedia models. Example**:** PBT Profiler exercise; Correlation of intake fraction to different measures of persistence.

3. Present some major types of ecological effects of pollutants, and their mechanisms.
    a. Reproductive toxicity
    b. Bioaccumulation (including bioconcentration and trophic magnification)
    c. Discuss testing methods, metrics, and molecular determinants of bioaccumulation potential. Tools: Quantitative structure-activity relationships (QSARs); multimedia modeling; biological and ecological models; biomonitoring. Example: food-chain bioaccumulation.
4. Look at some unique traits of perfluorinated surfactants, which demand different ways of measuring and assessing environmental fate and ecological effects.
5. Discuss the role of models and experimental testing in the development of safer substances, and in the development of better tools for designing safer substances. Besides the concepts/tools described above, mention other key environmental traits known to be relevant to green chemical design; highlight areas where metrics or tools exist.

Class 11: Exposure Sciences And Green Chemistry

Class Goals/Learning Objectives

Introduce the concept of a chemical exposure continuum that includes chemical design, emission sources, points of human contact, and health damage. Describe a hierarchy of approaches to reduce or eliminate exposures that includes end-of-pipe controls, process engineering controls, and upstream chemical redesign and substitution approaches. Explore the role of green chemistry in each of these approaches.

Class Group Project

Key Questions and annotated bibliography are due.

Readings

1. Paul Anastas, Kevin Teichman and Elaine Cohen Hubal, "Ensuring the Safety of Chemicals," *Journal of Exposure Science and Environmental Epidemiology* (2010) 20, 395–396. Concise description of the linkages among toxicology, exposure sciences, chemicals policy, and green chemistry.
2. Wilson M, Hammond SK, Hubbard A, Nicas M. 2007. Worker Exposure to Volatile Organic Compounds in the Vehicle Repair Industry. *J Occ and Env Hyg.* May(4) 301-310. The technical process of assessing exposures to volatile organic compounds in the workplace.
3. Lioy PJ 2010. Exposure Science: A View of the Past and Milestones for the Future. *Environ Health Perspectives* 118:1081-1090. doi:10.1289/ehp.0901634. The emerging field of exposure sciences. Read only Figures 1 and 2 for a sense of the scope of exposure sciences; page 1081 for some history and pages 1087-1088 for the potential role of exposure sciences – mainly as emission factors – in informing green chemistry.
4. Dana B. Barr, Amanda Bishop, Larry L. Needham. 2007. Concentrations of xenobiotic chemicals in the maternal-fetal unit. *Reproductive Toxicology* 23, 2007, 260–266. Illustrating the limitations of exposure sciences as seen through the lens of chemical exposures occurring during fetal development. Read the abstract and introductory paragraphs.

Supplemental Readings

1. Smith T. and Kriebel D. 2010. *Characteristics of Exposure and its Measurement*. In: A Biologic Approach to Environmental Assessment and Epidemiology. Oxford University Press. 27-64. Primer on exposure assessment.
2. Sheldon L.S., and Cohen Hubal E.A., "Exposure as Part of a Systems Approach for Assessing Risk," *Environ Health Perspectives* 2009: 117: 1181–1184. This review calls for a more holistic approach to exposure sciences in the context of risk assessment.
3. U.S. EPA. January 2009. A Conceptual Framework for U.S. EPA's National Exposure Research Laboratory. EPA's approach to developing an approach to exposure sciences that is on par with the Agency's computation and predictive toxicology efforts.

Presentation (Wilson) (Slides, Video, Audio)

A. Exposure is an important element in prioritizing risks from toxic substances

For example, if two chemicals theoretically exert a similar toxic effect at a similar point in human development at a similar physiological dose, it is relevant to understand the sources and paths of exposure. If one chemical is used in work places as a solid and one is used as an aerosol, the latter would present a much higher potential for inhalation exposure and would therefore be prioritized for substitution or exposure controls.

B. <u>However, real world is more complicated than this</u>
There are many degrees of complication in exposure sciences.

1. Present the three elements that make up risk (hazard, exposure, vulnerability) and describe the case of a worker using an aerosol product while conducting an oil change.
2. Present more complicated occupational and environmental examples that constitute potentially more complicated exposure scenarios.
3. Present the case of bioaccumulative substances for which the sources and paths of exposure are poorly understood.
4. Present the exposure sciences as located within a continuum from chemistry to public policy and located within the environmental health sciences; that is, as bridge between environment and human health.
5. Characterize the three spatial factors of exposure potential: Source, Path and Receiver, and describe examples. Describe how bioaccumulative and environmentally persistent substances increase exposure potential temporally, over months, years, and generations.
6. Describe how exposure potential is reduced at the source, path and receiver. Give examples of substitution strategies where toxic materials were replaced with non-toxic ones. Describe process changes to eliminate use of chemicals.
7. Describe weaknesses in the use of exposure potential in assessing risk: Pace and scale of global chemical production; proliferation of environmental contamination, including from waste sites designed to be impermeable (therefore without an exposure pathway); bioaccumulative and persistent materials

C. <u>Understanding exposure potential can improve chemical design and drive green chemistry</u>

1. Reducing volatility (= reduced inhalation exposures in workplaces and homes)
2. Avoiding fat solubility (= reduced bioaccumulative potential)
3. Design for degradation (= reduced persistence and environmental residence time)
4. Examples of chlorinated molecules using environmental persistence with the addition of each chlorine atom.

D. <u>Conclusions</u>

1. The concept of exposure has evolved since Paracelsus: Health effects are not simply a function of dose (and therefore exposure). Similar doses by body weight delivered at differing times over the human life span can have strikingly different health effects. Those delivered during fetal development can alter the developmental process at critical junctures. Therefore dose (and exposure) seem to be best described by Montague.
2. Chemists can improve chemical design by understanding the concepts of exposure and by recognizing that even seemingly harmless substances, if they are biologically and environmentally persistent, could pose as-yet-unknown health effects among future generations.
3. Physical-chemical properties matter; chemists can design substances will much lower exposure potential both spatially and temporally.

Class 12: Chemical Assessment

Class Goals/Learning Objectives

Introduce multiple Modes of Action and methods for assessing toxicity, including the future of high-throughput screening and using "upstream" indicators of harm. At the end of this class, students should be able to discuss: (1) What do we need to know about chemicals? (2) How is that information generated now? (3) How is that changing? (4) What are some of the tools?

Readings

1. National Library of Medicine Tox tutor section on toxicity testing. This short segment of the tutor provides just a brief overview of epidemiological studies and animal tests. Don't get hung up on the details, and you don't have to answer the "for academics" questions.
2. Schmidt C, Tox21: New Dimensions of Toxicity Testing. Environmental Health Perspectives. Aug 2009;117(8):348-353. This news piece provides an overview of the new directions EPA is taking toxicity testing, including high-throughput *in vitro* chemical screening.
3. National Academy of Sciences/National Research Council "Toxicity Testing in the 21st Century: A Vision and Strategy." National Academies Press, Washington D.C. 2007. Read chapter 4 only. This fills in the gaps left by the tox tutor by reviewing some of the new non-animal based methods of toxicity testing under development, including Structure Activity Relationships (SAR) and cell-based tests.

Supplemental Readings

1. Woodruff TJ, Zeise L, Axelrad DA, et al. Meeting Report: Moving Updtream--Evaluating Adverse Upstream Endpoints for Improved Risk Assessment and Decision-Making. Environ Health Persp. 2008;116(11):1568. Assessing "upstream" indicators of hazard.
2. Spurgeon DJ, et al. Systems toxicology approaches for understanding the joint effects of environmental chemical mixtures. Science of the Total Environment. 2010; 408:3725-3734. Understanding chemical mixtures.

Presentation (Schwarzman) (Slides, Video, Audio)

A. Basic steps in risk assessment (review)

1. First presented in Class 6 Introduction to Hazard and Risk; the risk posed by a chemical is a function of its inherent hazard, the exposure, and the recipient's vulnerability
2. Relevance of risk assessment for this class: understanding how chemicals are compared and informing the design of safer substances
3. Review concept of biological pathways whose alterations can lead to adverse effects (based on NAS report concept—see Class 6).

B. General determinants of effect and where they occur

1. Drivers of external exposure (e.g., dispersion or environmental partitioning)
2. Toxicokinetics (absorption, distribution, metabolism, and excretion)
3. Toxicodynamics (interactions with receptors, proteins, DNA)
4. Bioavailability

5. Bioactivity

6. Example of how the many types of information about a chemical can be assembled to understand its potential effects, using phthalates: molecular mechanisms, tissue-level changes, and their relationship to apical disease endpoints, and their correlation with effects seen in humans.

7. Example of how a biological pathway approach can be used to identify chemicals associated that may raise the risk of a certain disease: the Breast Cancer and Chemicals Policy Project.

C. Introduction to the "New Toxicology"

1. Development of non-mammal, tissue-based, or *in-vitro* chemical testing methods
2. Adaptation to rapid, high-throughput screening methods
3. Application in assessing chemical mixtures
4. Use of these methods for predicting health effects
5. Computational methods

Class 13: Designing for Degradation

Class Goals/Learning Objectives

Introduce molecular design motifs for small molecules and polymers which enhance biodegradability; molecular design for safety.

Readings

1. R. S. Boethling, Elizabeth Sommer, and David DiFiore, Chemical Reviews. 2007, 107, 2207-2227.
2. Des W. Connell, “Chapter 3: Environmental transformation and degradation processes” in *Basic Concepts of Environmental Chemistry*, 1997, CRC Press, Boca Raton, FL, pp 45-73.

Supplemental Readings

1. Ranjith Jayasekara, Ian Harding, Ian Bowater, and Greg Lonergan, “Biodegradability of a Selected Range of Polymers and Polymer Blends and Standard Methods for Assessment of Biodegradation” *Journal of Polymers and the Environment*, 13 (3), 2005, 231-251.
2. “Toward molecular design for hazard reduction—fundamental relationships between chemical properties and toxicity” Anastas et al. Trahedron, **2010**, 1031, and Chem. Rev. **2010**, 110, 5845.

Class Discussion

Class discussion of significant of this subject for Green Chemistry

Presentation (Mulvihill) (Slides, Video, Audio)

A. Define key terms for the discussion of chemical degradation.
B. Discuss natural chemical cycles and how human development has perturbed these cycles. Emphasize the idea that green chemical design can help bring these cycles back into balance and the scope of chemical use in our society.
C. Outline the most common pathways for chemical degradation, and the factors that influence the rates and effectiveness of these pathways.
D. Present the design rules for small molecule degradation. These design rules relate most directly to bio-degradation and were originally outlined by Boethling and others at the EPA (see reading).
E. Show how the “dirty dozen” persistent organic pollutants contain the design features which hinder degradation and lack design features that help degradation.
F. Discuss three example classes of compounds: Dielectric Coolants, Soaps, and Biocides. Depending on the amount of discussion and depth of information these can each take awhile to discuss, choosing one or two examples may be sufficient. Using the design principles students can identify the molecules that are most likely to readily degrade in the environment.
G. Discuss the available modeling software and other available resources relating to biodegradability of chemicals.
H. Extend the degradation rules to the design of polymers, these rules and concepts are outlined in the supplemental reading and are natural extensions of the small molecule rules.

I. Discuss how the design rules are embodied in the common available biodegradable polymers: Starches, Poly Alcohols, and Esters. Note the fact that not all biodegradable polymers are made from renewable resources, and that conversely not all polymers made from renewable resources are biodegradable.

J. Bring up the recent study comparing polymer "greenness" using both LCA and the 12 principles of green chemistry as metrics. Depending on the choice of metrics various polymers rank very differently.

K. Mention the recent trend toward polymer blends as an intermediate solution to balance bio-degradation and performance.

L. Introduce the concept of safer chemical design; non-linear nature of biological responses; common mechanisms of action in the body; tiered strategies for minimizing toxicity of chemicals.

M. Compare the strategies for enhancing bio-degradation and minimizing toxicity. Note how some of the strategies are contradictory and discuss the nature of trade-off considerations during the design of greener chemicals.

N. End by revisiting the fluorinated surfactants and discussing how these design rules related to current PFC design and properties. What features should be incorporated into a greener surfactant?

Class 14: Designing for Materials and Energy Efficiency

Class Goals/Learning Objectives

This lecture presents practical chemical examples of the implementation of the 12 principles of GC. At the end of this lecture, students will have an appreciation of practical considerations that must be taken into account when designing chemical compounds and processes.

Readings

1. Evan S. Beach, Zheng Cui and Paul T. Anastas, "Green Chemistry: A design framework for sustainability" Energy Environ. Sci., 2009, 2, 1038–1049.
2. Roger A. Sheldon, Isabel Arends, Ulf Hanefeld, *Green Chemistry and Catalysis*, Wiley-VCH, Weinheim, Ger., 2007, Ch. 1: "Introduction Green Chemistry and Catalysis."
3. Listen! Two programs on BBC Radio: 1) Green Chemistry; 2) catalysis.

Presentation (Arnold) (Slides, Audio)

1. Practical Tools in Green Chemistry
2. 12 Principles of Green Chemistry
3. Summary of GC Metrics
4. Traditional metrics in chemistry
5. Common GC metrics
6. E (Environmental) Factor (or E Value)
7. E Factor
8. Atom Economy
9. Example: The Wittig Reaction
10. Reaction Mass Efficiency (RME)
11. Catalysis
12. Introduction to catalysis
13. Selectivity
14. Turnover number
15. Turnover frequency
16. Catalyst phase: homogeneous or heterogeneous
17. General Scheme for Catalytic Activity
18. Selectivity
19. Turnover Number
20. Turnover Frequency (TOF)
21. Heterogeneous vs. Homogenous
22. Nobel Prize in Chemistry 2005
23. Alkene Metathesis
24. Mechanism
25. Ammonia Synthesis – The Haber Process
26. Global Polyolefins Industry
27. Applications of oligomers and polymers from olefins
27. Timetable and historical development of metallocene research
28. Ziegler-Natta (Nobel Prize 1963)
29. Important Types of PE
30. Ziegler-Natta Polymerization
31. Important Isomers of Polypropylene
32. Metallocene Catalysts

Class 15: Environmental Decision-Making Structures

Class Goals/Learning Objectives

This class will consider four topic areas: (1) How cost-benefit analysis is used in environmental decision-making; (2) The precautionary principle as a decision-making structure; (3) Arguments advocating cost-benefit analysis or the precautionary principle. Issues include practical and theoretical considerations of non-economic values, ethics, future generations, environmental justice disparities, interests outside the U.S., cumulative impacts.

Readings

1. Percival et al., *Environmental Regulation: Law, Science, and Policy*, Wolters Kluwer, Aspen Publishers, 6th Ed. (2009). Read: pp. 31-35 (Section 2: Cost-Benefit Analysis); pp. 35-38 (Section 3: Valuing Ecosystem Services).
2. Wingspread Statement of the Precautionary Principle.
3. Nancy Myers, "Frequently Asked Questions about the Precautionary Principle," Science & Environmental Health Network.
4. Joseph H. Guth, "Two Rules For Decisions: Trust In Economic Growth Vs. Precaution," Rachel's Democracy & Health News #919 (August 19, 2007).
5. Richard L. Revesz and Michael A. Livermore, *Retaking Rationality: How Cost- Benefit Analysis Can Better Protect The Environment And Our Health*, Oxford University Press (2008). Read pp. 9-19 ("The Case for Cost Benefit Analysis").
6. Cass R. Sunstein, "Throwing precaution to the wind: Why the 'safe' choice can be dangerous," Boston Globe, July 13, 2008.
7. Thomas O. McGarity, Sidney Shapiro, and David Bollier, *Sophisticated Sabotage: The Intellectual Games used to Subvert Responsible Regulation*, Environmental Law Institute (2005). Read pp. 1-16.

Supplemental Readings/Materials

1. Douglas A. Kysar, *Regulating From Nowhere: Environmental Law and the Search for Objectivity*, Yale University Press (2010). Read pp. 1-22 (Introduction).
2. Stephen Breyer, Breaking the Vicious Circle: Toward Effective Risk Regulation, Harvard University Press (1993). Read: pp. 3-29 (Introduction); pp. 33-51 (Chapter 2: Causes: The Vicious Circle).
3. Nancy J. Myers and Carolyn Raffensperger, eds., *Precautionary Tools for Reshaping Environmental Policy*, MIT Press (2006), excerpt from Introduction (pp. 1-16), available at bottom of page at: http://www.sehn.org/ppfaqs.html.
4. Frank Ackerman and Lisa Heinzerling, *Priceless: On Knowing the Price of Everything and the Value of Nothing* (The New Press, New York 2004). Read: pp. 1-12 (Chapter 1: Prices Without Values); pp. 13-40 (Chapter 2: Myths and Markets); pp. 205-34 (Chapter 9: Values Without Prices).

Presentation (Guth) (Slides, Audio)

A. Review of two different economic visions

Neoclassical economics and ecological economics; these two different economies require different guiding legal structures.

B. Environmental legal decision-making structures

They comprise three essential elements: a safety standard reflecting a balance of values the law seeks to achieve; allocation of the burden of proof defining the law's default position; and the level of certainty required for the decision-maker to act.

C. Cost – benefit analysis

The prevailing decision-making structure in US law comprises a cost-benefit balancing; the burden of proof on government; generally a preponderance of the evidence. It's implicit goal is welfare maximization and to ensure that government will only intervene in the economy when it can prove the intervention will improve net welfare. E.g. Presidential E.O. 12,866; TSCA.

1. Advocates of CBA argue it is a neutral basis for making decisions, makes government accountable, allows society to allocate resources to most beneficial purposes, ensures wealth maximization (though inequity must be handled separately), and can clarify where there are uncertainties.

2. Shortcomings of CBA include that we are very poor at doing the calculations, the allocation of the burden of proof permits substantial damage that is not in fact justified by welfare maximization, ignores unfair distribution of costs and benefits, views damage to nature solely in terms of instrumental value to humans, ignores damage projected outside US, handles future generations only by discounting of costs and benefits, ignores cumulative impacts in finite world and contribution of each incremental impact to ecological overshoot.

D. The Precautionary Principle

Wingspread Statement, key elements are preference of avoiding damage to human health and the environment, acting in the face of uncertainty, placing burden of proof on actor causing threat, considering alternatives, democratic decision-making. It is not self-implementing.

1. Advocates justify preference for protecting health and environment based on ethical arguments; they are systematically undervalued compared to economic interests; the uncertainties are greater; the need to cap cumulative impacts in a finite world.

2. Sunstein argues PP is "incoherent." Risks are on all sides of decisions. Attributes attraction of PP to cognitive dysfunction, irrational fears, communication problems, inaccurate risk perception.

3. Issues to consider are the role of expert agencies versus democratic decision-making, freedom being on all sides of government regulation, the meaning of "sound science," the impact of the burden of proof on outcome of cost-benefit analysis.

E. Case Study.

In *Entergy Corp. v. Riverkeeper, Inc.* (US 2009), US Supreme Court affirmed EPA interpretation of Clean Water Act to allow use of CBA in developing regulations to protect aquatic life rather than established more-precautionary interpretation of technology-based standards.

Class 16: The U.S. Toxic Substances Control Act of 1976

Class Goals/Learning Objectives
This class will introduce the U.S. Toxics Substances Control Act of 1976 (TSCA); major provisions of TSCA, including Section 4, Section 5 and Section 6; the data gap, safety gap and technology gap; market failure caused by these gaps; cost-benefit decision-making structure of TSCA § 6; how perfluorinated chemicals have been managed under TSCA.

Readings

1. Percival et al., *Environmental Regulation: Law, Science, and Policy*, Wolters Kluwer, Aspen Publishers, 6th Ed. (2009). Read: pp. 246-64 (Section 3: Risk-Benefit Balancing Approaches. Summary and introduction to TSCA (pp. 246-49); asbestos under TSCA, including excerpts from EPA asbestos rule (pp. 249-52), excerpts from Corrosion Proof Fittings Fifth Circuit decision (pp. 252-258), notes and questions (pp. 258-64)).
2. U.S. Toxic Substances Control Act § 6 (a) "Scope of Regulation" (especially the first paragraph). TSCA has been codified in the U.S. Code, and this section is codified as 15 U.S.C. § 2605(a).
3. Michael P. Wilson and Megan Schwarzman, "Toward a New U.S. Chemicals Policy: Rebuilding the Foundation to Advance New Science, Green Chemistry, and Environmental Health," 117 *Environmental Health Perspectives* 1202-1209 (2009).

Supplemental Readings/Materials

1. David Michaels, "Doubt is Their Product," *Scientific American*, June 2005, pp. 96-101 (industrial interests sometimes intentionally to create doubt and confusion).
2. A useful compilation TSCA materials including background reports is available on the website of the Chemicals Policy and Science Initiative at the Lowell Center for Sustainable Production.
3. U.S. Government Accountability Office has prepared numerous reports on TSCA and its implementation by EPA over the years. See http://www.gao.gov/ and search GAO reports for "chemical regulation" or "Toxic Substances Control Act." For a recent example, see U.S. Government Accountability Office, "Chemical Regulation: Observations on Improving the Toxic Substances Control Act," GAO-10-292T, Dec. 2, 2009. See also U.S. Government Accountability Office, "Chemical Regulation: Options Exist to Improve EPA's Ability to Assess Health Risks and Manage Its Chemical Review Program," GAO-05-458, June 2005.
4. Lynn R. Goldman, "Preventing Pollution? U.S. Toxic Chemicals and Pesticides Policies and Sustainable Development," 32 *Environmental Law Reporter* 11018-41 (2002). Read pp. 11018-11020 (Introduction), pp. 11023-11030 (U.S. management of industrial chemicals).

Presentation (Guth) (Slides, Video)

A. Chemicals are regulated by numerous federal and state laws

1. System is balkanized and fragmented.
2. Resulting problems include "chemical of the month" syndrome and "regrettable substitutions."

B. <u>Outline of Toxic Substances Control Act of 1976.</u>

1. First generic law to regulate industrial chemicals.

2. Designed according to welfare maximization theory of law and economics; burden of proof placed on government to show regulation provides net benefit.

3. TSCA Section 2: Preamble. Sounds powerful and progressive, but has no force.

4. TSCA Section 8: TSCA Inventory; Exemptions; Existing Chemicals; New Chemicals; Inventory Update Rule.

5. TSCA Section 5: New Chemicals Program. PMN program; SNUR's; Data requirements; CBI provisions.

6. Hazard data gathering under TSCA. Section 4 (EPA may require testing); Section 5 (health and safety data for new chemicals); Section 8 (CBI rules recently changed by EPA); Voluntary HPV program (SIDS data).

7. TSCA Section 6: Burden of Proof on government; four factors to show unreasonable risk; cost-benefit test for "unreasonable risk" under E.O. 12,866; "least burdensome" and "other statute" requirements.

C. <u>Corrosion Proof Fittings v. EPA (Fifth Cir. 1991).</u>

1. Calculations of value of human life.
2. EPA's conclusions in asbestos rulemaking.
3. Fifth Circuit's opinion of EPA's rule.
4. Regulation of asbestos by other nations.
5. What EPA has regulated under Section 6 to date; Enforceable Consent Agreements.

D. <u>Regulation of Perfluorinated Chemicals Under TSCA.</u>

1. History of "voluntary withdrawals," Enforceable Consent Agreements, SNUR's, voluntary PFOA Stewardship program; polymer exemption revision and recent EPA Action Plan.

2. These actions all reflect attempts to employ TSCA Sections 8(e), 6(a), 4, and 5.

E. <u>Structural Weaknesses of TSCA.</u>

1. Data Gap; Safety Gap, Technology Gap.
2. Objectives government is trying to achieve.
3. Incentives provided to chemicals industry.
4. Incentives and impacts on downstream users, including consumers.
5. Special case of nanomaterials: evading TSCA altogether.

F. <u>Progressive steps being taken and considered by Obama Administration.</u>

1. Test Rule under §4 to bring remaining HPV chemicals into voluntary HPV program.
2. Examining whether §6 can be used to regulate some bad actors, e.g., PFC's.
3. Promulgating rule eliminating CBI for health and safety studies submitted under §8.
4. Action Plans on 8 hazardous chemicals and chemical classes.
5. Supporting reform of TSCA.

Class 17: Chemicals Policy Reform

Class Goals/Learning Objectives

Students will learn the major approaches to chemicals policy reform including REACH, the California Green Chemistry Initiative (AB 1879 and SB 509) and the TSCA reform bill (proposed Safer Chemicals Act of 2010); their effectiveness at closing the data, safety and technology gaps; intended impact of these new laws on promotion of green chemistry; intended effects on chemicals market.

Readings

1. Various perspectives on TSCA reform, available on the website of the Chemicals Policy and Science Initiative at the Lowell Center for Sustainable Development:

(a) Industry perspective: American Chemistry Council, "Ten Principles for Modernising TSCA"; (b) NGO perspective: Richard A. Denison, "Ten Essential Elements in TSCA Reform," 39 Environmental Law Reporter 10020-28 (January 2009); (c) U.S. EPA, Essential Principles for Reform of Chemicals Management Legislation (2009).

2. Two-page summary of Safe Chemicals Act of 2010, available from the website of the Chemicals Policy and Science Initiative at the Lowell Center for Sustainable Development.

3. California Department of Toxics Substances Control, California Green Chemistry Initiative Final Report (2008). Read pp. 1-4 (Executive Summary of six goals of California Green Chemistry Initiative).

4. Government Accountability Office, *Comparison of U.S. and Recently Enacted European Union Approaches to Protect against the Risks of Toxic Chemicals*, (Aug 17, 2007). Read over pp. 1-30 (report comparing major provisions of TSCA with REACH).

Supplemental Readings/Materials

1. S.3209, Safe Chemicals Act of 2010, Sponsor: Senator Frank R. Lautenberg (D.N.J) (introduced 4/15/2010).

2. Assembly Bill No. 1879 (Feuer 2008) (One of two Green Chemistry Initiative laws signed by Governor Schwarzenegger in 2008).

3. Senate Bill No. 509 (Simitian 2008) (One of two Green Chemistry Initiative laws signed by Governor Schwarzenegger in 2008).

4. The REACH regulation: Regulation (Ec) No 1907/2006 Of The European Parliament And Of The Council (18 December 2006).

5. Excellent discussions of various issues relating to the substance, current status and politics of efforts to reform of TSCA can be found on the blog of Richard Denison, Senior Scientist, Environmental Defense Fund. The current status of TSCA reform is also followed on the website of the Safer Chemicals, Healthy Families coalition of NGO's.

6. The current status of the California Green Chemistry Initiative can be followed on the California EPA Department of Toxic Substances Green Chemistry Initiative website.

In recent years, many bills in numerous states have been enacted relating to the regulation of chemicals. For a compilation of these efforts, see the website of the Chemicals Policy and Science Initiative at the Lowell Center for Sustainable Production.

7. For excellent summary of REACH, detailed analyses and ongoing updates in the implementation of REACH, see the website of the Chemicals Policy and Science Initiative at the Lowell Center for Sustainable Production. Chemicals policy reform efforts and statements of goals are occurring elsewhere in the world, at the international, national, regional, and corporate levels. A compilation of these efforts can be also be found on the website of the Chemicals Policy and Science Initiative at the Lowell Center for Sustainable Production.

Presentation (Guth) (Slides, Video, Audio)

A. Review of Role of Law in Economy

1. Neoclassical economics. Seeks welfare maximization; assumes no limits to growth; views damage to environment and health costs that may be acceptable to optimize welfare.
2. Ecological economics. Concerned with scale of economy, development rather than growth and distribution of wealth.
3. Prevailing legal structure promotes neoclassical economics. Burden of proof on government (and plaintiffs) to show regulations will increase net welfare; E.O. 12,866.
4. TSCA designed accordingly. Summary of TSCA Sections 4, 5, 6, 8. Data Gap, Safety Gap, Technology Gap.

B. Precautionary Principle as Alternative

1. Five elements of Wingspread Statement of Precautionary Principle
2. Closing the TSCA Safety Gap. Developing precautionary decision-making structures; health/environment-based safety test; reversing the burden of proof.
3. Closing the Data Gap. Old vs. New chemicals; No data, no market; quantity of data required; confidential business information; testing data vs. QSARS.

C. REACH

1. Current Status.
2. Overview of process. Registration; evaluation; authorization; SVHC substances.
3. How REACH closes Data Gap. Data required by REACH at different tiers compared to US HPV program (SIDS data set).
4. How REACH closes Safety Gap. Authorization; SVHC's; switching burden of proof on socioeconomic benefit test; availability of alternatives.

D. California Green Chemistry Initiative

1. Six components of Green Chemistry Initiative.
2. Legislation signed in 2008 (SB 509 and AB 1879).
3. Process to be established under AB 1879. Identify chemicals of concern; identify consumer products; perform alternative analysis; life cycle analysis; regulatory response.
4. Current status of regulatory development.

E. Safe Chemicals Act of 2010 (Reform of TSCA)

1. Minimum Data Set.
2. Prioritization of chemicals of concern.
3. Safety test with BOP on industry: Reasonable certainty of no harm.
4. Confidential Business Information.
5. Responses of US EPA; industry; NGO's.

Class 18: When It Pays To Be Green And Competitive Business Strategy

Class Goals/Learning Objectives
Under what conditions can green chemistry confer competitive advantage? What economic and non-economic difficulties and questions do businesses face trying to internalize negative externalities? Examine GC from a business strategy perspective: Understand cost leadership, product differentiation leadership; beyond compliance and eco-branding strategies; gains from production innovation vs. gains from organizational innovation; win/win rhetoric vs. reality; stages in the development of GC strategies in competitive market environments; SWOT analysis.

Readings

1. R.J. Orsato, "When Does it Pay to Be Green?" *California Management Review* 48:2 (Winter 2006), pp. 127-141. This article provides an overview of some of the key aspects of and issues in corporate environmental strategy.
2. P. Gruber, "Natureworks: Green Chemistry's Contribution to Biotechnology Innovation, Commercialization, and Strategic Positioning," Harvard Business Case **UV2021-PDF-ENG** (Darden Case UV2021, 2006.) This business case concerns the make or break decisions that managers of NatureWorks, a company that has developed a new biobased plastics, had to make in the pivotal year of 2005.
3. A. Larson, "Illustrating the Financial Benefits of Green Chemistry," Harvard Business Cases product number, **UV 1358-PDF-ENG** (Darden, 2006). This case examines the 12 Principles of Green Chemistry from a business perspective, assessing them from the perspective of the economic benefits they may (or may not) provide the companies who develop products or processes that embody individual principles.

Assignments To Be Completed Before This Class
Students should submit answers to questions about the reading in the Class 18 Assignment.

Presentation (Rosen) (**Slides, Video, Audio**)

A. Why do Corporation choose to invest in GC?
   1. Regulatory drivers: because they have to
   2. Non-regulatory drivers:
      Because management thinks it's the right thing to do (corporate social responsibility)?
      Because management thinks it will give their firm a competitive advantage?
   3. Weak regulation makes non-regulatory drivers very important à huge focus on this GC as a competitive business strategy
   4. Michael Porter: competitive advantage is based on cost leadership and/or product differentiation. How achieve? Through product innovation, organizational innovation
   5. Barriers to corporate action: Upfront costs; uncertainty and risk, externality and informational problems; opportunities for profit limited
   6. Renate Orsato's strategy matrix: 4 approaches:
      a. Organizational innovation focus
         1. Eco-efficiency – profit comes from reducing costs of production

   2. Beyond compliance cost leadership - profit comes from firm's reputation for environmental leadership.
   3. Do these strategies always pay off? What are limits? Risks?

b. Products and Services differentiation focus
   1. Eco-branding - create premium product with desirable GC qualities
   2. Environmental cost leadership - create a product that is not only green but also costs less than conventional products

c. Discussion
   1. Do these strategies always pay off? What are problems? Risks?
   2. Where do 12 principles of GC fit in this matrix? Which principles are most likely to produce profits? Which are less likely to produce profit?
   3. Where does NatureWorks fit in this matrix? What is main source of profit?

B. <u>CG Strategy process: implementing a GC initiative (Nature Works case discussion)</u>

1. Opportunity recognition
2. Develop project mission/goals
3. Context, rationales, and needs of project (SWOT analysis, business case)
4. Set time your frame
5. Develop an action plan
6. Identify resource requirements for each step in your plan
7. Figure out how to execute your plan in operational and organizational sense
8. Further case discussion: What would you advise?
   a. Other strategic challenges pre and post 2005?
   b. Since case published?
   c. Natureworks and Sunchips – opportunity and problem
   d. Natureworks competitive market environment – other biobased plastic packaging competitors

Class 19: Fluorinated Surfactant Case Study (2) -- What We Have Learned So Far

Class Goals/Learning Objectives

Review of data from each discipline on the design and life cycle of fluorinated surfactants.

Readings

1. Rebecca Renner, "The long and the short of perfluorinated replacements" *Environmental Science and Technology*, 2006, 12-13.
2. Scott Mabury et al, "Production of perfluorinated carboxylic acids (PFCAs) from the biotransformation of polyfluoroalkyl phosphate surfactants (PAPS): Exploring routes of human contamination" Environmental Science and Technology, 2007, 41, 4799-4805.
3. EPA information regarding PFOA including details of the voluntary initiative.
   a. EPA Webpage, "Perfluorooctanoic Acid (PFOA) and Fluorinated Telomers."
   b. EPA Webpage, "2010/2015 PFOA Stewardship Program."
   c. EPA Webpage, Perfluorooctanoic Acid (PFOA) and Fluorinated Telomers; New Chemical Review of Alternatives."
4. Environmental Working Group, "Packaging and DuPont's Greenwashing: Voluntary Phaseout Not Working." An evaluation of the EPA voluntary initiative by EWG.

Supplemental Readings

1. Marla Cone, "US EPA Calls for End to Releases of Chemical in Teflon Process, *Los Angeles Times* (Jan. 26, 2006).
2. Danish Ministry of the Environment, *More Environmentally Friendly Alternatives to PFOS Compounds and PFOA* (2005) (a very detailed review of the PFC alternatives).
3. Tom Cortina, *The Phaseout That Didn't Happen*, Fire Fighting Foams Coalition. Industry article about why PFCs haven't been phased out from foams despite all predictions.

Presentation (Mulvihill) (Slides, Video, Audio)

A. Update class progress, at this point in the semester most of the technical information and tools have been provided. This class will help transition us to a discussion of decision-making.
B. Review the structure and uses of the molecules discussed during this lecture.
C. Environmental Emissions data for PFOA and PFOS, citations included on the slides.
D. Discuss how each of the fluorinated surfactants partitions and how this effects the environmental fate and persistence of this compounds.
E. Review the persistence data, first presented by Akos, discuss how this could have been predicted based on our design rules.
F. Discuss human exposure, bio-transformation, and health effect studies. Relate the understanding of mechanism to some of the health effects.
G. Review the regulatory and voluntary initiatives that have influenced use of PFOS, PFOA.
H. Discuss recent business trends, including the use of new fluorinated molecules as replacements for PFOS and PFOA.
I. Review current alternatives based on application sector. This data comes from the Danish government and is included in the 2nd supplemental reading.
J. End the class with a discussion of various proposed alternatives.

Class 20: Evaluating Evidence and Understanding Uncertainty

Class Goals/Learning Objectives

Introduce the sources of uncertainty inherent to how scientific evidence is generated and limitations of our knowledge about the health effects of chemicals; discuss some factors that affect how scientific outcomes are influenced; introduce tools for decision-making in the face of uncertainty. At the end of the class, students should be able to discuss: complexities involved in understanding the health effects of chemicals; the difference between ignorance and uncertainty and the implications of each; some methods for taking action in the face of uncertainty.

Readings

1. Gee D, and Stirling A, Late lessons from early warnings: improving science and governance under uncertainty and ignorance.Chapter 13 in *Precaution, Environmental Science and Preventive Public Policy*. Tickner JL ed. Island Press, Wahington DC. 2003. pp 195-213.
2. Steeland K, Fletcher T, Savitz D. Epidemiologic Evidence on the Health Effects of Perfluorooctanoic Acid (PFOA). Environ Health Persp. 2010 Aug;118(8):1100. Read the abstract, the first section (up to the heading "Lipids..."), and the discussion section.

Supplemental Readings

1. D.Gee, "Establishing Evidence for Early Action: the Prevention of Reproductive and Developmental Harm," *Basic and Clinical Pharmacology & Toxicology*, **2008**, 257.
2. Levins R. Whose Scientific Method? Scientific Methods for a Complex World. Chapter 23 in *Precaution, Environmental Science and Preventive Public Policy*. Tickner JL ed. Island Press, wahington DC. 2003. pp.355-375.

Assignment To Be Completed Before This Class

Students should submit answers to questions about the reading in the Class 20 Assignment.

Presentation (Schwarzman) (Slides, Video, Audio)

A. Review of the context of uncertainty

1. Number of chemicals in commerce, current and projected
2. Ubiquity of chemicals in consumer products, homes, workplaces
3. Biomonitoring finds hundreds of synthetic chemicals in people
4. The risks are poorly understood for the vast majority of chemicals in commerce

B. A simple framework for understanding the range of responses to uncertainty in the context of chemicals: Stop all action, vs. make decisions with the information available, vs. proceed until receive incontrovertible evidence (see video for diagram and discussion).

C. Example of how "dueling evidence" can play out in the literature based on the example of a short editorial on endocrine disruptors published in the *American Family Physician*, including unpublished email conversations with the editorial staff.

D. Steps necessary to understand the risk a chemical poses to human health or the environment, the differences between uncertainty and ignorance. Using this framework, discussed several inherent challenges/limitations in performing risk assessments:

1. Hazard can be affected by life stage and timing of exposure
2. Hazard can be difficult to identify due to many factors, including time-lag from exposure to effect, mixed exposures with additive effects, and multiple endpoints (which is the most sensitive?)
3. Dose response extrapolation can be misleading
4. Levels of evidence used to establish proof can exceed what is reasonably attainable in animal experiments or epidemiological studies
5. The process of obtaining evidence can be further complicated by some commercial interests who promote conflicting science
6. Scientific evidence evolves over time (example of 1000-fold drop in levels of mercury associated with observed health effects over 30 years. Regulatory thresholds followed the science, but early assumptions of safety based on 1970s science delayed more health-protective standards)

E. Tools for taking action in spite of uncertainty (historical example of John Snow removing the handle of the Broad St. pump, whose service area corresponded with the distribution of cholera deaths, despite absence of mechanistic understanding of cholera or how the pump could be the origin of the disease).

1. Minimize the impact of ignorance by limiting scope of possible surprises (examples given)
2. Generate more data and make good use of available information

Class 21: Life Cycle Thinking

Class Goals/Learning Objectives
Students will be familiar with the concept of Life Cycle Thinking

Readings
Adisa Azapagic, "Chapter 5: Life Cycle Assessment : a Tool for Identification of More Sustainable Products and Processes" in *Handbook of Green Chemistry and Technology* eds. James Clark and Duncan Macquarrie, Blackwell Science, Oxford, UK, 2002, pp 62-85.

Supplemental Readings
Michaelangelo D. Tabone, James J. Cregg, Eric J. Beckman, and Amy E. Landis, "Sustainability Metrics: Life Cycle Assessment and Green Design in Polymers," *Environmental Science and Technology, 2010, 44 (21), pp 8264–8269.*

Presentations (Mulvihill, Kokai) (Slides, Video, Audio)
A. Introduce the concept of Life Cycle thinking. Emphasize that life cycle thinking is a way to consider material and energy flow throughout a system or process. This way of thinking leads to better design and design that is more sustainable.
B. Briefly place Alternatives Assessment, Hazard Assessment, and Risk Assessment into this context and discuss how there are many tools to accomplish each of these.
C. Introduce the steps for performing a formal Life Cycle Analysis (which is just one of these tools).
D. First LCA example: bromination of toluene
    1. Goals and Scoping: i.e., what factor will we consider and which processes
    2. Innovatory: Endpoints and midpoints. Considering data sources
    3. Impact Assessment: running calculations for each of our factors using available data
    4. Summarize the data for the 4 potential bromination reactions
    5. Interpret the results for this example. Which of the 4 options seems best based on this LCA. Does this match with expectations?
D. Second example: Sugarcane to Polyethylene
E. Third example: Book vs. E-reader
F. Discuss tools and data sources for LCA
G. Compare LCA and the 12 principles of green chemistry

Class 22: Alternatives Assessment (Part I)

Class Goals/Learning Objectives
To understand the conceptual framework, scientific basis, and technical practice of alternatives assessment (AA); the role of AA in decision-making and in green chemistry.

Assignments To Be Completed Before This Class
Explore the IC2 Safer Alternatives Assessment Wiki.

Readings

1. Lavoie, M et al. Chemical Alternatives Assessment: Enabling Substitution to Safer Chemicals. *Environmental Science and Technology* 2010, 44, 9244–9249. doi: 10.1021/es1015789
2. O'Brien, M. Making Better Environmental Decisions: An Alternative to Risk Assessment. (The MIT Press, Cambridge MA. 2000). Chapter 2 (pp.17-37), Chapter 13 (pp.191-202), Chapter 15 (pp.215-222).
3. Mark Rossi, Joel Tickner, and Ken Geiser. 2006. *Alternatives Assessment Framework of the Lowell Center for Sustainable Production*.

Supplemental Readings

1. US EPA. 2011. *Design for the Environment Program Alternatives Assessment Criteria for Hazard Evaluation* (draft 3). Just skim this document.
2. US EPA. *Partnership to Evaluate Flame Retardants in Printed Circuit Boards*.
3. Clean Production Action. 2009. *The Green Screen for Safer Chemicals Version 1.0*.

Class Activity: Students groups will do alternatives assessment of a hypothetical herbicide.

Presentations (Schwarzman, Kokai) (Slides, Video, Audio)

A. Comparing alternatives assessment, life cycle thinking and risk assessment

1. All these are different ways to inform decision making and design. In that sense, they can all be used for the same common goal (e.g. sustainability).
2. However, the different approaches tend to ask different questions, sometimes leading to different ideas of what it means to solve a problem. This is especially true for RA, which contrasts most strongly with AA.
3. The tools that have been developed and are associated with each approach are different. There are also philosophical and political undercurrents to each. All of this creates a situation where these appears competing schools of thought. But there is nothing that *intrinsically* prevents them from usefully complementing one another.

B. The leading formal frameworks for alternatives assessment

1. The Lowell Center Framework. This is very general.
2. Chemical Alternatives Assessment as conceptually defined by US EPA (Design for Environment) and Clean Production Action (Green Screen). This focuses on direct chemical substitution as a way of improving products and processes.

3. Describe the US EPA's DFE AA criteria; how they are used to assess the level of hazard of a substance; how substances can be compared in a systematic way. **Example:** Flame retardants for printed circuit boards. Note the connection to LCA in chemical alternatives assessment, which considers chemicals in the context of their industrial life cycle. Discuss the EPA method; does it seem useful as a decision making tool? Does it appear scientifically defensible?

4. Green Screen framework for chemical alternatives assessment. Version 1.0 of GS. The GS benchmark system is intended to guide decision-making. Example: Two substances from the previous flame retardant AA, evaluated according to the GS 1.0 system.

C. Broader discussion of chemical AA among the class

1. What considerations besides human and environmental health hazards are relevant?
2. Is direct chemical substitution the best option? What other options are feasible?
3. Discussion of resources that are required to conduct AA, especially information about chemicals and their hazard properties. Overview of and links to some sources of data for chemical hazard assessment. Example searches in online databases. Introduce emerging online predictive toxicology tools.

D. Group activity: Alternatives assessment of a hypothetical herbicide

1. This is based on the City of San Francisco's alternatives assessment for RoundUp.
2. The problem: Groups of students were asked to put themselves in the position of a municipal government wishing to reduce the use of a toxic herbicide in the city. They were asked: How would you approach an alternatives assessment for this herbicide?
3. After a brief discussion period, we solicited questions or requests for additional information from the students. We then revealed a list of uses within the city for this herbicide: Private lawns; gardens; Public parks (turf areas); Built environment(e.g. cracks in pavement); Road median strips; Airport runways; Natural areas(invasive weed control)
4. Outcomes: we found that some students approached the task by asking questions like, why is the herbicide toxic? How toxic? How much of it can be safely used? And so on. It's good to point out that that is the approach of risk assessment! It does not actually address the need for an alternative solution.
5. We presented a graphic summarizing the Lowell Center Framework for AA while students were working on this. The first step according to LCSP is to identify chemicals of concern, and the second step is to identify and prioritize uses for further evaluation.
6. Students would ideally think about what are the goals of each specific use of the herbicide, and what are other ways to reach those goals.
7. Lessons from the original work by SF Environment (presented by Debbie Raphael):
    a. The key question to ask was whether RoundUp is truly necessary for each use.
    b. San Francisco achieved 90% reduction in use with the following alternatives:
        1. Goats, hand weeding, flamers, compost tea
        2. Prevention: mulch, sealing cracks in pavement
        3. Acceptance: grassy parklands as meadows rather than lawns
        4. Elimination was not feasible in a few uses:
           Median strips (too dangerous for workers to spend much time there)
           Invasive weeds in "natural areas"
           Airport runways (other activities dangerous on highly active runways)

Class 23: Alternatives Assessment (Part II)

Class Goals/Learning Objectives
To understand the role that green consulting firms are playing in developing alternative assessment principles, protocols, and tools and the relationship between these business initiated approaches and the forms of LCA and Alternatives Assessment discussed previously. To examine alternative approaches to conceptualizing green chemistry that move beyond innovation at the molecular level to innovation at the business systems level. How can innovative business relationships such as Chemicals Strategy Partnerships, by-product synergies and industrial waste exchanges contribute to Green Chemistry?

Readings

1. D. Lee and L. Bony, "Cradle-to-Cradle Design at Herman Miller: Moving Toward Environmental Sustainability," Harvard Business Case, 9-607-003, Rev: Dec. 2009. This case examines the green chemistry focused product design standard developed by a leading sustainability business consulting firm and the role it played in the development of a new office chair.
2. S. Mackenzie, "Applied Sustainability LLC: Making A Business Case for By-Product Synergy," Harvard Business Case Product #E118-PDF-ENG, Rev: Aug 2006. This case examines the challenges a consulting firm faced trying to implement an innovative approach to reducing chemical waste that requires new forms of interaction and cooperation between firms.

Assignments To Be Completed Before This Class
Students should submit answers to questions about the readings in the Class 23 Assignment.

Presentation (Rosen) (Slides, Video, Audio)

A. Focus broadly on alternatives assessment
   1. Focus on branded tools, concepts and strategies for integrating GC into product design and the design of industrial systems created by innovators within business.
   2. How do these relate to AA, LCA ideas and tools discussed previously?
   3. What do they tell us about the boundaries of green chemistry?

B. Branded tools and vision: McDonough Braungart Design Chemistry's Cradle to Cradle (C2C) Design Protocol
   1. Eco-effectiveness is better than eco-efficiency
   2. Waste equals food (virtuous closed loops)
   3. Use current solar income (renewable energy)
   4. Respect human and natural systems
   5. Implementation of MBDC C2C Protocol
      a. Disassembly requirement
      b. Recyclability and recycled content requirement
      c. Material chemistry over product life cycle; Human and non-human health effects assessed; Green – Yellow – Orange – Red Evaluation criteria tool
      d. Evaluation process and scoring system tools

e. MBCD's 12 Principles of Green Engineering

f. Bigger picture: tools and protocols for redesigning corporate organization as well as products – innovation on many levels

6. Case Discussion

a. Impact of C2C Protocol on development of Herman Miller's Mirra chair: design, manufacturing, supply chain management, sales and marketing, EOL management

b. How does C2C Protocol relate to AA and LCA principles and tools?

E. <u>Branded tools, vision - Chemical Strategies Partnership, Chemical Services Contract</u>

1. Strategy for aligning interests of sellers and purchasers of chemical to reduce volume of chemicals used in manufacturing

2. "Shared Savings contract" – gains sharing key – involves selling a chemicals service rather than simply a chemicals product

3. Is this green chemistry?

F. <u>Branded tools, vision – G. Pauli and ZERI (Zero Emissions Research Init.) UN project</u>

1. By-product synergies: turn industrial waste streams into feedstocks
2. Tools and methodologies
3. ZERI focus is developing world and agricultural products
    a. Gains from using bamboo as a substitute for wood pulp in paper mfr. etc.
    b. Gains from utilizing wastes from beer making

G. <u>Branded tools and vision (cont.) – Andrew Mangan and Applied Sustainability</u>

1. Mangan wanted to apply by-product synergy concept in U.S. (inspired by Kalundberg (Denmark) industrial waste exchanges)

2. Applied Sustainability to provide by-product synergy services

3. Case discussion

a. What services? What kinds of challenges did Mangan face? Impact?

b. Should we consider these kinds of systems change to be integral parts of Green Chemistry? Or not? Pros and cons of broadening definition

c. What is the role for business entrepreneurs in Green Chemistry? How compare role of public policy makers and regulation? Scientists?

Class 24: Role of Chemical Users

Class Goals/Learning Objectives

To develop an understanding of the power that consumers could play in the development of green chemistry, and whether and to what extent consumers can in fact fulfill this role.

Readings

1. O'Rourke 2005. Market Movements: Nongovernmental Organization Strategies to Influence Global Production and Consumption Journal of Industrial Ecology, Volume 9, Number 1–2, p. 115. Provides a good analysis of how non-governmental actors can influence manufacturers and retailers to change their products.
2. Bonini & Oppenheim 2008. Cultivating the Green Consumer. Stanford Social Innovation Review Fall 2008. Introduces features of "green consumers" and highlights the challenges of converting expressed green preferences into actual buying behavior.

Guest Lectures

1. Bill Pease, GoodGuide, Inc., “Role of consumers from perspective of GoodGuide”
2. Tony Kingsbury, Dow Chemical, “Role of consumers from perspective of Dow”

Presentations (Guests, Iles) (Slides, Video, Audio)

A. Introduction to Role of Consumers and Other Users of Chemicals

1. Consumers playing a key role in shaping the trajectory of green chemistry.
2. Companies may respond to consumer behavior for a mixture of reasons. These reasons include preserving the company’s reputation, maintaining market share, increasing access to consumers, assuring greater profitability, improving relationships with government agencies, deferring proposed regulation, and reducing exposure to lawsuits.
3. There are a number of pathways through which consumers may exert their influence over industry: boycotts, campaigns, information strategies, eco-labels.
4. In thinking about the role of consumers, it’s key to remember that consumers do not form a homogenous class. There is diversity among consumers in terms of their characteristics. Research suggests that consumers can be located on a spectrum of greenness, varying in their cognitive ability to process information, willingness to research, values, and social affiliations. People can move along the spectrum with time and experience. Consumption research also shows that a deep gap exists between the expressed willingness of consumers to buy green products and their actual behavior.

B. Questions posed to guest lecturers Bill Pease and Tony Kingsbury

1. What is the potential role that consumers can play in greening chemistry, and why?
2. Is there *really* market or consumer demand now for greener chemicals? What is your view on this, and what examples can you provide?
3. What strategies would you use to increase the ability of consumers to stimulate the production of safer products?

C. Presentation by Bill Pease, GoodGuide (consumer information viewpoint)

1. Goal is to generate consumer pressure on manufacturers, rather than give consumer information about chemicals, because that merely generates concern among customers.
To tap consumer concern, educate consumers about chemicals' impact and channel that energy into a useful direction, is a big challenge.

2. NGO's may not solve the whole chain of problem for consumers.
Scorecard.org: consumer information about chemicals contribution to environmental damage.
GoodGuide: Helps consumers buy products that are healthier, greener, socially responsible.

a. Simple rating (0-10 scale: rate on Health, Environment, Society.) The system deals with misinformation, incomplete information.

b. Provide information at point of purchase (10sec for one decision) → Cell-phone as a consumer decision supporting device. Direct consumers to incrementally better products.

c. Consider positive attributes as well: viewed by EPA and demonstrated to be of least effect on environment. (Focus on relative comparison.) Example: BPA demonized, while its substitutes are also endocrine disruptors as well.

Q: How to normalize the rating? A: By company revenue.

Q: Source of information used for scoring at the product level or company level? Product level information -> health. Company manufacturing process information -> rate environment.

3. Initiatives focused on Greening Product Formulations.

Consumer-facing: 1. GoodGuide (multiple product categories), 2. SkinDeep (narrower)

Supplier-facing (Direct retail decisions have huge impact): 1. Walmart GreenWercs 2.SC Johnson Greenlist 3.Clean Production Action GreenScreen; Whole Foods (brand): quality standards; Walmart: requring supplier information. Ingredients --> hazard screening --> not really informing consumer yet, not yet influencing purchasing behavior. But right direction.

4. Challenges and future directions for tapping consumer purchasing power to influence suppliers. Overall trend: Light green, dark green segment is increasing.

D. Presentation by Tony Kingsbury, Dow Chemical (industry viewpoint)

1. Case Study #1: PLA vs. other PET cups.
Which is greener? Why don't the greener products kick off?
Greener: compostable, renewable (not completely)
What's stopping further adoption: price, promoting landfills, significant performance problem (don't hold carbon dioxide in soda, also melts under high temp.).

2. Case Study #2: Electronics, flame retardants (an issue since late 1970s - 1980s)

Companies looking for alternatives (pressured by research, media, public concern, etc.) In market, viable alternatives must be compatible with different plastics, price, etc. Hurdles include regulatory requirements, performance, cost & buyers' willingness to pay (commodities tougher to change vs. specialty chemicals). When chemists conquer these barriers, green product kicks off: monitors get rid of flame retardants (phosphorus alternative in monitor plastics). Companies don't talk about these achievements because the public will ask for more: why don't you change everything?

3. Adoption of Greener Chemistry. Strong driver: government purchasing. Early adopters are companies that value their brand. New model: downstream producers partner with Dow.

Class 25: Who Decides, Who Benefits -- And What Role Will You Play?

Class Goals/Learning Objectives
Students should consider their personal, professional and political role in green chemistry.

Class Group Project
Class Group Project due.

R**eadings**

1. Ketelsen L. Scientists and the Real World. Afterword in *Precaution, Environmental Science and Preventive Public Policy*. Tickner JL ed. Island Press, Washington DC. 2003. pp. 377-380. Short discourse on the role of scientists in creating change.
2. Meadows D., “Leverage Points: Places to Intervene in a System,” The Sustainability Institute. Hartland, VT. 1999. pp 1-19 (Systems change. Read the introduction (to p. 5) and the last 2 pages).

Presentations (Schwarzman, Guth, Kokai) (Slides, Video, Audio)

A. Who decides and who benefits from environmental decisions?

1. Presentation of the relationship between society (distinguishing public actors from private actors), and the environmental commons (natural resources), including the interactions among economic production, consumption of environmental commons (natural resources), and social decision-making.
2. The environmental commons consist of shared natural resources on which we depend (e.g., clean air, clean water, food sources, a stable supply of energy), and these are finite, depletable resources.
3. Human activities are depleting the resources of the environmental commons.
4. Benefits of actions that affect the commons do not accrue equally to all sectors of society.
5. The environmental commons and the public good are not necessarily served by the current methods of decision-making.

B. Systems theory of production and society

1. Introduction to the language of systems theory (including term “leverage point”)
2. Leverage points according to Donella Meadows
3. Examples of academic work hitting various different leverage points
4. Exhortation to students to think about what leverage points they aim to pull in their subsequent careers/lives

C. Discussion on role students see for themselves in Green Chemistry

1. Social Institutions: Law and social norms. Social institutions governing behavior include laws but also social norms; which raises question of responsibility of individuals to society.
2. Two different visions of role of individual in society. One vision is that of accepting the law, and then pursuing your own gain within that law, and by pursuing your own gain,

thereby benefiting society. But there are other views of responsibility of individuals in a free society. See, e.g. Remarks of President Barack Obama – As Prepared for Delivery, “The Country We Believe In,” The George Washington University, Washington, D.C. (April 13, 2011). Though this speech was about the budget, it is not a big leap to think about what it means for chemists and green chemistry.

3. The role of social norms, individuals, in Green Chemistry. Chemists have a special role in establishing social norms in Green Chemistry.

   a. Different roles of chemists

   b. What kinds of workplaces are you considering for yourself?

   c. Have you experienced an instance where you thought that some kind of chemicals-related safety step should be taken but the organization you were working in was not taking it? Carefully choose your workplace. Can you ask prospective employers what they think about green chemistry? When would you best ask?

Class 26: Take Home Lessons And Class Discussion

Class Goals/Learning Objectives
Summarize the main point of the class from each instructor's perspective. Give students a chance to reflect and give feedback on the course.

Assignments To Be Completed Before This Class
Complete the final class survey.

Presentations (All Instructors) (Slides)

A. Final Thoughts, Chemistry

1. The principles of green chemistry are intuitive; lead to safer more elegant chemistry.
2. Making green chemistry common practice will take a broadening of our perspective and better communication and data throughout the chemical supply chain.

B. Final Thoughts, Chemistry

From perspective of a chemist, this course has confirmed that:

1. Chemistry has a huge societal impact
2. Chemists need to consider wider implications of their work
3. The general public does not always recognize the god things chemists do, but focuses on the problems
4. Metrics to gauge the impact and importance of problem chemicals are needed; different people (groups?) have different tolerances, thresholds
5. GC-thinking has the potential to change the way we all think about chemistry

C. Final Thoughts, Environmental Health

Many achievements in green chemistry have addressed resource consumption (energy, water), and waste reduction, while reducing the toxicity of chemical processes and products has been trickier to accomplish. This is likely the result of several factors, including:

1. Monetization: Energy, water, and waste are all expensive for research labs and manufacturers, whereas there is little current monetary incentive to reduce the use or production of hazardous substances
2. Metrics: Good measures exist for resource use and waste production, whereas metric for toxicity and ecotoxicity are much more complex and multi-faceted
3. Data Gaps: There are significant gaps in our understanding of how chemicals may be toxic to people and ecosystems, and what drives exposure. Combined with a decision-making structure that demands certainty, this has hindered the development of safer chemistries
4. There are many things we can do to advance green chemistry—from the perspective of the environmental health sciences, including:
    a. Generating information on hazard and exposure that chemists and engineers can apply as design criteria for producing safer chemicals, processes, and products
    b. Creating metrics and tools to perform alternatives assessments and inform chemical design
    c. Educating the next generation of chemists and engineers

d. Equipping decision-makers with legal tools and policy frameworks for taking action in the face of uncertainty.

D. Final Thoughts, Environmental Health

1. Tools and methods for the practice of green chemistry are still being developed. Many of what are now our best achievements will be seen as inadequate and will be surpassed in the future.

2. The shift toward new ways of doing chemistry is not just an incremental change in technology. It involves systems change, and at some levels requires changing ways of thinking.

3. Think solutions!

E. Final Thoughts, Law and Policy

One of the key lessons that we've learned in the course is that we need to connect production and consumption. Building on what Joe said about the importance of regulatory reforms and making a new social norm, we need to ask: what do we want our chemicals to do for us? Part of the answer is to find ways for societal actors to play a greater role in greening chemistry, and demanding different, alternative products from industry. We also need to find ways to educate citizens and consumers about the possibilities of green chemistry so that they can play a more informed role in asking questions about what they want chemicals to do, not just chemists and companies making all the decisions.

F. Final Thoughts, Law and Policy

A. Law and Economics

1. Law provides incentives and disincentives that shape economy. Current law and economy built around idea of welfare maximization.

2. Current environmental law presumes net benefit, even where damage is caused, and places BOP on government to prove otherwise.

3. Cumulative impacts; scale, distribution, future generations, other species, polities.

B. Chemicals Policy Reform

1. TSCA: Data Gap, Safety Gap, Technology Gap

2. REACH, TSCA Reform, California GCI aim to fill those gaps

3. Goal is to correct market flaw and allow market to drive safer product development and government to systematically protect human health and environment.

C. Role of social norms. Legal norms cannot accomplish this task unless society adopts these goals. YOU are critical to establishing these social norms.

Class 27: Course Poster Session And Presentations For Class Group Projects

Class Group Project
Poster Session for all group projects