Engineering and Health Impact Methods in Green Design

A course developed at the Berkeley Center for Green Chemistry, University of California, Berkeley, spring semester 2012

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Learning objectives
Learn how principles of environmental health can be used to make materials, products and manufacturing processes safer for workers, consumers and the environment, including:
  • Basics of assessing hazard and exposure;
  • Techniques for sustainable design;
  • Tools for evaluating alternatives.

Course details
“Engineering and Health Impact Methods in Green Design” was taught as a graduate course in Spring 2012, offered by the UC Berkeley School of Public Health. 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.

This syllabus, all class presentations, and the class project description can be found on BCGC’s website for this course. The majority of course work consisted of completion of the group project.

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Syllabus and readings

Class 1: Toxicological endpoints in health impact assessment
Presenter: Megan Schwarzman

Lecture outline:
• Health impacts in context
  o Sustainability: scale and ubiquity of synthetic chemical production; chemical pollution as a component of impacts on planetary ecological welfare.
  o Science: from molecules to populations, a range of related systems fall under different fields of scientific inquiry. Emerging relations among these fields enable seeing a more complete picture of the health impacts of chemicals.
  o Approaches to the assessment of health impacts: life cycle assessment (health impacts are one of many bulk impact categories), risk assessment (reductive analysis of health impacts to estimate risk as a function of hazard, exposure and vulnerability).
• Understanding hazard
  o Definition of adverse effects, types of hazards (categories, mechanisms, and modulators); hazard traits of chemicals under Cal/EPA taxonomy.
  o Mechanisms of action: exposure, toxicokinetics, and toxicodynamics. Examples of specific mechanisms that lead to adverse effects.
  o Gene-Environment interactions: genetic and epigenetic mechanisms of toxicity.
  o Variability and vulnerability: The importance of timing of exposure; windows of vulnerability (e.g. endocrine disruption and critical developmental periods). The role of co-exposures and biological susceptibility among populations.
• Linking hazard data with the design of substances and products
  o Examples of specific green design problems and goals of reducing health impacts.
  o Guidelines for research and technology development: The Twelve Principles of Green Chemistry; The Twelve Principles of Green Engineering.
  o Green chemistry and design can contribute solutions within the paradigms of industrial hygiene and exposure assessment: The Hierarchy of Controls and the source-path-receiver system.

Readings
Class 2: Design principles for sustainable materials & manufacturing processes, I

Presenter: Dave Dornfeld

Lecture outline:

• The issues/motivation
  o The IPAT equation: impact = population * affluence * technology
• Defining green and sustainability
  o Definitions of sustainability; sustainability and business; technical criteria and metrics for sustainability; sustainable limits of earth system processes.
• Sustainability in an engineering context
  o Technological solutions allow incremental reductions in environmental impact; engineering provides stabilization “wedges” to help approach sustainability goals.
  o Energy and material efficiency
  o Closed loop manufacturing
  o The 12 Principles of Green Engineering
• Sustainability in a manufacturing context
  o Manufacturing processes and systems
    ▪ Supply chains and phases of production
    ▪ Importance of local resource systems in determining total manufacturing impact
    ▪ Materials selection, material flows, recycling, yield
    ▪ Transitions in manufacturing paradigms
    ▪ “Internalizing all costs”
    ▪ Characteristics of manufacturing systems: choices available in designing systems; parameters; planning
  o Life cycle assessment
    ▪ Product life cycles, phases, and impacts
    ▪ Methods of LCA: Economic Input-Output; Process; Hybrid Top-Down; Hybrid Bottom-Up
    ▪ LCA as a product assessment tool: provides indicators of product contributions to environmental stressors
    ▪ Strategies for guiding design; embodied energy of materials and lifecycle phases
  o Developing metrics for sustainable manufacturing
    ▪ Goals and relevance of metrics to product/process; Types of metrics
    ▪ Total manufacturing sustainability footprint

Readings
• Julian M. Allwood and Jonathan M. Cullen, Sustainable Materials with Both Eyes Open, UIT Cambridge Ltd., 2012 (download at http://withbotheyesopen.com/)
Class 3: Assessing exposure to toxic chemicals
Presenter: Mark Nicas
Lecture outline:
• Definition of exposure; groups exposed and routes of exposure; relationship to dose
• Recognizing exposure potential and steps to exposure assessment
• Measure of population exposure: intake fraction
• Measurement of exposure intensity
  o Making measurements in environmental media: sampling, analysis
  o Exposure variability: Sources of variability in environmental conditions
• Mathematical modeling of exposure
  o Estimating inhalation exposure using models of indoor environments
  o Estimating exposure using a multimedia environmental model, CalTOX
  o Environmental modeling using an equilibrium steady-state flow system model
• Control of exposure via engineering versus personal protective equipment

Readings
• McKone TE and EG Butler, CalTOX: A Multimedia, Multipathway Source-to-Dose Model (see also: http://www.dtsc.ca.gov/AssessingRisk/ctox_model.cfm)
• Bennett DH, et al., Defining Intake Fraction, Environmental Science and Technology, May 1, 2002, 3A–7A.

Class 4: Design principles for sustainable materials & manufacturing processes, II
Presenter: Dave Dornfeld
Lecture outline:
• Dimensions of impact and influence on manufacturing sustainability footprint
  o Various approaches to reducing the footprint from different physical, technical, economic, and social dimensions.
• Operation and control of manufacturing processes
  o Detailed decisions required in designing manufacturing systems
    ▪ e.g. Materials selection for recycling
  o Sustainable design guides; opportunities and drivers for improvement
  o Strategies for greening manufacturing
• Optimizing energy use
  o Components of manufacturing energy use, and strategies for reducing energy use
  o Energy/impact matrix for manufacturing
  o Tradeoffs, e.g. optimizing material
• Supply chain management
  o Goals, planning, analysis, impacts, factors in decision making
• OECD sustainable manufacturing toolkit
Readings
download at http://www.oecd-ilibrary.org/content/book/9789264077225-en

Class 5: Methods for evaluating sustainability I: Life Cycle Assessment
Presenter: Tom McKone
Lecture outline:
• Sustainability and health; science and metrics of sustainability
• Life cycle assessment
  o Requirements and impacts of a product/process life cycle
• Incorporating health impact assessment into sustainability metrics for green design
  o USEtox source-to-damage framework for environmental impacts of industrial emissions
  o Overview of Health Characterization Factors (CFs) for LCA
    ▪ Environmental fate factor (FF)
    ▪ Exposure factor (XF)
    ▪ Effect factor (EF)
• Chemical fate assessment
  o Multimedia modeling: fugacity-based mass balance models, equilibrium and steady state systems
  o Example: trichloroethylene environmental fate
  o USEtox fate model structure
  o Mathematical definition of Fate Factor (FF)
• Exposure Factor (XF) and Intake Fraction (iF)
  o Direct and indirect exposures; definition and calculation of intake fraction
  o USEtox exposure model and human exposure pathways
  o Mathematical definition of human exposure factor (XF)
• Effect Factor (EF)
  o Dose-response assessment; measures of toxicity: NO(A)EL, LO(A)EL, ED_x, TD_x; dose-response curves
  o USEtox approach to calculating effect factors (EF); definitions of EF
  o Animal to human extrapolation; conversion among toxicity measures
  o Severity of damage: disability-adjusted life years (DALY)
• Characterization factors from emission to damage in USEtox
• Uncertainty: analysis and interpretation of model uncertainty un USEtox
• Model application and context in science
  o USEtox as a general tool for screening of chemicals for health impacts in life-cycle assessment
  o USEtox is a consensus model, not a research model
Readings


Class 6: Methods for evaluating sustainability II: Alternatives Assessment

Presenter: Akos Kokai

Lecture outline:

• Evaluating sustainability
  o Overarching question: How can we use scientific tools to guide us in evaluating and designing for sustainability when we work on specific, discrete problems?
  o This will requires both reductionist analysis and holistic thinking.

• Metrics and principles
  o Principles (e.g. of Green Chemistry) serve as guides for decision making, and metrics are how we measure impacts. Example: An study examines the relationship between adherence to Green Design principles using life-cycle impact metrics, and reveals a trade-off between renewable feedstock use and cradle-to-gate environmental impacts.

• Life cycle thinking and alternatives assessment
  o What fundamental questions are being asked by LCA methods? What other fundamental questions can be asked that may lead to advances in sustainable production?
  o Alternatives Assessment framework of the Lowell Center for Sustainable Production. Goal-oriented, use/function-specific; modular with respect to assessment criteria and methods; stressing stakeholder engagement.

• Life cycle thinking and health impacts
  o A spectrum of ways to evaluate health impacts: On one end are aggregated measures of overall health impact, and on the other end are more granular, multifaceted assessments of specific health hazards. An additional (often ignored) dimension is to consider the cumulative impacts of multiple exposures/stressors.

• Chemical alternatives assessment frameworks, methods, and tools
  o Major chemical hazard assessment frameworks: UN GHS; US EPA Design for Environment (DfE) criteria; the Green Screen. The latter two are specifically intended for use in alternatives assessment.
  o What these frameworks provide:
They specify categorizations of endpoints that are to be evaluated. (See slide comparing hazard categorization systems)

They specify collections of authoritative lists where known chemical hazards are classified by government and scientific agencies, and they specify how these lists can be used to evaluate chemicals for specific endpoints.

They specify what kind of test data can be used as evidence to evaluate specific hazard endpoints.

These three frameworks are striving for consistency around definitions and evaluation criteria, though they differ in intended application.

- Globally Harmonised System
  - Intended use: systematic hazard communication, with standardization of what scientific evidence means what kind of warnings to give to users.

- Design for the Environment
  - Intended use: “transparent tool for evaluating and differentiating among chemicals based on their human health and environmental hazards.”
  - DfE alternatives assessment implementation: Multi-stakeholder partnerships to conduct AA for specific materials in specific applications.
  - Example: flame retardants for printed circuit boards (PCB)
    - Diagram of exposure pathways considered throughout product lifecycle.
    - Tables of disaggregated hazard endpoint metrics as they are presented in this AA framework. Contrast with the way USEtox integrates several different kinds of data to produce a single metric, DALY, as a way to assess total impacts of human disease.

- The Green Screen for Safer Chemicals
  - Builds on GHS and EPA frameworks with an evaluative system of benchmarks.
  - Chemical lifecycle orientation: decomposition products must be evaluated. Synthetic precursors may also be evaluated.
  - Example for discussion: GS hazard assessment matrices for vinyl acetate and red phosphorus
    - Rhetorical question: which chemical is more hazardous? (Both were evaluated as benchmark 2; for more information, see example GS assessments at http://cleanproduction.org/Greenscreen.v1-2.php)
    - Underlying questions: How to make a holistic decision from many data points and data gaps? How to address trade-offs among impacts?

- The future of alternatives assessment practice
On political and social levels, alternatives assessment represents a shift in environmental thinking; emphasizes continuous improvement.

Compare fundamental questions asked by AA (how can harm be minimized?) with questions asked under the risk assessment paradigm (what level of harm is acceptable?).

Some active areas of development for AA. Situation of emerging design and decision making tools in a landscape of complementary but ultimately compatible ways of thinking.

Readings

- Lavoie, M et al., Chemical Alternatives Assessment: Enabling Substitution to Safer Chemicals. *Environmental Science and Technology* 2010, 44, 9244–9249. doi: [10.1021/es1015789](https://doi.org/10.1021/es1015789)