Integrating Green Engineering Throughout the Curriculum to Teach Sustainable Development

Robert P. Hesketh,
SEF Meeting
September 22, 2005

"Sustainability Education modules in schools and short courses for professionals
What is Green Engineering?


- Transforms existing practices to promote sustainability.
- Economically viable products, processes, and systems that
  - promote human welfare
  - while protecting human health
  - and elevating the protection of the biosphere
- New criterion for engineering solutions.
To fully implement green engineering solutions, engineers use the following principles:

1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.
2. Conserve and improve natural ecosystems while protecting human health and well-being.
3. Use life cycle thinking in all engineering activities.
4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.
5. Minimize depletion of natural resources.
To fully implement green engineering solutions, engineers use the following principles:

6. Strive to prevent waste.
7. Develop and apply engineering solutions, while being cognizant of local geography, aspirations and cultures.
8. Create engineering solutions beyond current or dominant technologies; improve, innovate and invent (technologies) to achieve sustainability.

There is a duty to inform society of the practice of green engineering.
Motivation based on Accreditation

• ABET Engineering Program Outcomes Criteria (Accreditation Board for Engineering & Technology) Approved 1 November 2004
  – (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
  – (f) an understanding of professional and ethical responsibility
  – (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
  – (j) a knowledge of contemporary issues

• AIChE Program Criteria (American Institute of Chemical Engineers)
  – working knowledge, including safety and environmental aspects, of material and energy balances applied to chemical processes;
MOTIVATION for Teaching Engineers

- Industry leaders moving to Sustainable Chemical Processing
- Dow Jones Sustainability Index (DJSI) World & DJSI STOXX (771 companies analyzed globally) launched in 1999
Forums to Incorporate Green/Sustainable Engineering

• Teach as an elective upper level course
• Integrate into regular engineering courses
• Graduate Education
• Graduate Research
• University setting an example through campus architecture
South Carolina Sustainable Universities Initiative

- Members of the university community will understand their environmental, social and economic impact on the world
- Our campuses will be models for sustainable use of resources
University of South Carolina “Green Dorm”

- $29 million, 500 bed residence hall project
- Expecting LEED Gold rating

Nearly Same Cost as a Previous Dorm!
A Ph.D. Program in Chemical Engineering at Lamar University

Emphasizing Methodology and Technology Development for Sustainability of Environment, and Economics, Industry
Sustainable Futures Institute at Michigan Technological University

- Mission: Create/disseminate new processes, methods, and tools that support / promote sustainability

- Institute brings together faculty / students to address research and education issues related to sustainability

- Provides the infrastructure for the Sustainable Futures IGERT Program
Michigan Tech &
Southern University and A&M College, Baton Rouge, LA
Integrative Graduate Education Research and Training Program (IGERT)

- Coursework in sustainability
  - Certificate in sustainability (MTU)
- Novel training elements
  - Industry internships
  - International experience
- Distance learning
- Inter-university advising
- Annual summit meeting
- A community of scholars
IGERT Trainees and Associates

Fund Doctoral students at

• Michigan Tech
  – Chemical Eng. (4)
  – Geological Eng. (1)
  – Environmental Eng. (5)
  – Mechanical Eng. (8)

• Southern University
  – Public Policy (8)
Multidisciplinary Coursework in Sustainability

• **ENG/SS 5510 Sustainable Futures I (3 cr)**
  – Offered at MTU and by distance to SUBR
  – Sustainability concepts, principles, and history
  – Green engineering and life cycle assessment
  – Technology policy and sustainable businesses
  – A focus on the developed world & technologies

• **ENG/SS 5520 Sustainable Futures II (3 cr)**
  – Offered at Southern University & by distance to MTU
  – Developing world sustainable development issues
  – Societal and policy aspects

• **ENG/SS 5530 Sustainable Futures III (1 cr)**
  – Offered at MTU and by distance to SUBR
  – Current readings in sustainability, class discussions
ENG/SS 5510 Sustainable Futures I (SF1) (Shonnard and Durfee)

- Sustainability Concepts and History
  - Readings from: “Our Common Future” (Brundtland Rpt)
  - Sustainability trends over time and projections (UN Rpt)
  - Sustainability indicators (SOLEC indicators)

- Methods/Tools for Analysis of Sustainability
  - LCA – Ch 13 from GE textbook and ISO 1404x, SimaPro6.0
  - Environmental Cost Accounting – Ch 12 from GE textbook
  - Industrial Ecology – Ch 14 from GE textbook
  - Student Projects – LCA of process/product/service

- Policy Issues / Private Authority for Sustainability
  - Introduction to public policy and governance
  - Sustainability business models / market forces
  - International legal dimensions / treaties
ENG/SS 5510 Sustainable Futures I (SF1)

- Student Profile
  - Environmental engineering 11
  - Chemical engineering 4
  - Mechanical engineering 3
  - Civil engineering 2
  - Forestry and environmental science 2
  - Social science and environmental policy 2
  - Business 2
  - Geological sciences and engineering 1
  - 24 graduate students and 3 undergraduates
Energy and Sustainability Institute Focus at Illinois Institute of Technology

- Energy storage, distribution and utilization
- Energy sources and conversion
- Material and energy conservation (recycling)
- Energy policy
- Energy and sustainability education
Educational Programs

• Energy Environment and Economics (E³) specialization and minor at both graduate and undergraduate levels for engineering and science majors
• Master’s and PhD degrees in environmental engineering
• Master’s degree in environmental management
• Elective courses in sustainability area for students in fields other than science and engineering
Sustainability Beyond the Classroom: The Georgia Tech Experience

• 1993 - GT establishes the Center for Sustainable Technology (CST)
• GE Fund donates almost $1 million to establish a curriculum on sustainable technology and development
• College of Engineering develops and deploys three course sequence on sustainability
• GT establishes an Institute-wide Sustainability Task Force
GE Project Conceptual Framework

NEW CURRICULUM

INTRODUCTION TO SUSTAINABLE DEVELOPMENT
COURSE 1

CASE STUDIES IN SUSTAINABLE DEVELOPMENT
COURSE 2

SUSTAINABLE DEVELOPMENT PROJECTS
COURSE 3

OTHER COURSES IN THE CURRICULUM

PHASE I

PHASE II

INTEGRATION

Analysis
Synthesis
Contextual Understanding
Engineering
Physical Sciences
Social Sciences
Life Sciences

PROBLEM–ORIENTATION

Academic Requirements
Industry/Society Requirements
Knowledge Domain

COMPUTER USE

Advanced Computer Tools for Instruction
Computer Tools in Knowledge Domain

EFFECTIVE LEARNING AND INSTRUCTION

Problem–Based Learning
Collaborative Learning
Case–Based Reasoning
Today at Georgia Tech

- Sustainability is central to both the Institute’s vision and the Campus Master Plan
- CST has grown to become the Institute for Sustainable Technology and Development (ISTD)
- Sustainability integrated throughout multiple new and emerging academic programs
- Sustainability integrated throughout multiple new and emerging research programs
- Nearly 20 affiliate centers and laboratories doing sustainability-related research
Georgia Tech Commitments to Sustainable Practices
From a Pedagogic Perspective

• At least 103 courses, taught through every college, have an emphasis on sustainability.

• Several majors offer a focus on sustainability.

• The College of Architecture stresses sustainability in each of their programs.

• Leadership is from deans and chairs, the provost, individual faculty, and student demand...
UASLP - San Luis Potosí

• Sustainability:
  – One of the institucional principles included in the new Rector’s action plan:
    Lic. Mario García Valdez
    Rector UASLP (2004-2008)

• Environmental and sustainability perspective:
  – Included in the vision and strategies of Integral Program for Institutional Strengthening (PIFI-UASLP).
  – Established in the Institucional Development Plan.
  – Financial support by UASLP, SEP-SESIC, Conacyt, Semarnat and other agencies.
  – Results and concrete actions
    See web page: “Our university works all year long in concrete actions …”
    (June 5, 2004 summary for the World Environmental Day)
Teaching and Training
Norms, organization, transversal programs, resources, procedures

Research and Graduate Studies
Programs, lines of research, projects, products

Promotion and Administration
Norms, organization, transversal programs, resources, procedures

Outreach
Alumni, undergrad studies training

UASLP Academic Entities
Services, laboratories, consulting, specific studies on demand

SPECIALIZED PROGRAMS

SOCIETY AND SUSTAINABLE DEVELOPMENT
Coordination of Agenda Ambiental and multidisciplinary programs

GENERAL SUPPORT PROJECTS
Networks
Courses and events
Internet

SPECIAL PROGRAMS
Outreach: Institutions and organizations

STRATEGIC PROGRAMS

SMA (EMS)
Coordination of Agenda Ambiental and multidisciplinary programs

PMPCA
Other University Initiatives

• UPC – Barcelona, Spain – Integration in all departments
• Delft University, Netherlands – University initiative
• Chalmers University of Technology, Sweden
• University of Surrey, Oxford, Cambridge, UK
• University of Windsor
• Autonomous University of San Luis Potosí, Mexico
• One to 3 courses are given at Universities in the USA – Georgia Tech, Univ. Tennessee, University of Texas-El Paso, Carnegie Mellon, Berkeley, Univ. Texas – Austin, MIT, Rowan University.
Is it Possible to Teach Sustainable Development/Green Engineering?

• Overcrowded Curriculum
• Outside of Professors Research Areas
• Lack of Time to Prepare New Materials
• How do you integrate these materials into current courses?
IMPLEMENTATION

• Sustainable/Green Engineering Champion
• Sustainable/Green Engineering Text for 4 years
• *Modules* prepared for each course
• Strong Support of Chair & Dean
• Excited & Cooperative Faculty
Green Engineering: Environmentally Conscious Design of Chemical Processes
Allen, David T and D. R Shonnard

- Easy to Utilize for a Green Engineering course
- Modules Created for Engineering Courses:
  www.rowan.edu/greenengineering
Rowan Green Engineering WEBSITE

Modules Prepared

- Freshman Engineering
- Material and Energy Balances
- Design
- Material Science and Engineering
- Heat Transfer
- Process Dynamics and Controls
- Separation Processes

http://www.rowan.edu/greenengineering
Need New Linked Modules

Mapping of Green Engineering Subjects with Course Text & Green Engineering Principles

- Selected Readings from Text
- Example Problems
- Homework Problems
- Case Studies

www.rowan.edu/greenengineering
Welcome

Welcome to the Green Engineering website for Educators and Students! To view as a guest login with username: guest and password guest. Portions of this website are viewable only by professors and professors may request an account by clicking here.

What's New?

THIS SITE IS CURRENTLY UNDER CONSTRUCTION. THE SITE IS STILL ONLINE, BUT MAY NOT WORK PROPERLY. IF A SECTION DOES NOT WORK PROPERLY PLEASE CHECK BACK IN A FEW HOURS. THANKS FOR YOUR HELP

Other Links
Contact | About

Material on this website is developed through the American Society for Engineering Education Green Engineering Program, funded by the U.S. EPA under grants # CX827688-01 and CX83052501-1. This web interface is based on work supported by the National Science Foundation under Grant # 9980887

www.rowan.edu/greenengineering
Welcome Jim Henry! You have prof privileges.

Welcome

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www.rowan.edu/greenengineering
Freshman/General Engineering Course Material

- Air Pollution from Burning Coal (Professor)
- Gasoline Emissions (Professor)
- Lethal Concentration (Professor)
- MSDS (Professor)
- Pollutants in Rivers (Professor)
- Bioaccumulation (Professor)
- Lethal Concentration and Its Effects (Professor)
- Dermal Exposure (Professor)
- Global Warming (Professor)
- Global Warming Graph (Professor)
- Half-Life Conversions (Professor)
- Dermal Exposure from Swimming (Professor)
- Life Cycle Assessment Project (Guest)

A Life Cycle Assessment Project to determine environmental friendliness.

- Personal Environmental Impact Log Project (Guest)

Water, Paper, and Electricity Use Inventory Project from Carnegie Mellon.

- Role Playing Debate Project (Guest)

Salmon Management in the Pacific Northwest Conflict Resolution Project from Carnegie Mellon.

www.rowan.edu/greenengineering
Freshman/General Engineering Course Material

Green engineering topics covered in the module

- Unit conversions - Green Engineering calculations
- Concentration Units - of pollutants in air and water
- Data analysis of Green Engineering problems
- Uncertainty in Green Engineering calculations (significant figures)

www.rowan.edu/greenengineering
Introduction to Sustainable Development: Freshman Engineering

Example Discussion/Lecture

• What role do engineers serve to society?
• What challenges will engineers face in the near future?
  – Energy
  – Other Natural Resources
  – Environment
  – Population growth and increase of material wealth of developing nations (China)
• What challenges will our children and grandchildren face as engineers? (e.g. How do we continue to meet the needs of the present without compromising the ability of future generations to meet their own needs?)

www.rowan.edu/greenengineering
Problems, modules and projects including several that address GE topics and design for recycling/reuse

www.rowan.edu/greenengineering
Life Cycle Thinking in Freshman Engineering

• Introduce students to the concept of examining the entire life cycle of a product or process
• Not a detailed life cycle assessment
• Simple Examples
  – Paper vs. Plastic
  – Beer Brewing
  – Coffee Machine

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Paper vs Plastic: Textbook Problem

Functional Unit: Based on volume of groceries to be transported. 2 plastic sacks ≡ one paper sack.

Air emissions and energy requirements for paper and polyethylene grocery sacks (Allen, et al., 1992)

<table>
<thead>
<tr>
<th>Life cycle Stages</th>
<th>Paper sack air emissions (oz/sack)</th>
<th>Plastic sack air emissions (oz/sack)</th>
<th>Paper sack air energy Required (Btu/sack)</th>
<th>Paper sack air energy Required (Btu/sack)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials manufacture plus product manufacture plus product use</td>
<td>0.0516</td>
<td>0.0146</td>
<td>905</td>
<td>464</td>
</tr>
<tr>
<td>Raw materials acquisition plus product disposal</td>
<td>0.0510</td>
<td>0.0045</td>
<td>724</td>
<td>185</td>
</tr>
</tbody>
</table>

Calculate energy required and emissions produced
Examine the effect of reusing the sacks
Make Conclusions

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LCA in Courses

• Freshman Engineering
• Elementary Principles of Chemical Processes
• Semester Projects associated with courses
• Research Projects

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Freshman/General Engineering Course Material

Principles of Chemical Processes

Material

Separation

Design

Life Cycle Assessment

System Dynamics and Control

Heat Transfer

Chemical Engineering Thermodynamics

Transport Phenomena

Chemical Reaction Engineering
Courses and Modules
(Links may exit this website)

Instructions on How to Add a Group & Page

We are continually adding new material to this website and would be very interested in your contributions to the website.

**Freshman General Engineering Course Material**

These problems, modules, and projects are for general or introductory engineering courses.

**Principles of Chemical Processes**

This group links Green Engineering material to the Principles of Chemical Processes/Materials & Energy Balance/ Stoichiometry Course. It is meant to accompany an instructor in a Chemical Engineering Material & Energy Balance Course who intends to integrate concepts of Green Engineering.


**Materials Science**

This group links Green Engineering material to the Materials Science Course. It is meant to accompany an instructor in a Chemical Engineering Materials Science Course who intends to integrate concepts of Green Engineering.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Reaction Engineering Element</th>
<th>Green Engineering Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive Catalytic Converter</td>
<td>Sec. 1.4.3 describes the mole balance for the packed bed reactor, and provides an example for a first order reaction.</td>
<td>Sec. 1.5 describes criteria air pollutants and begins to put the issue of pollution reduction into an appropriate context.</td>
</tr>
<tr>
<td>Aerated Bioreactor Lagoon</td>
<td>Sec. 1.3 and 1.4.1 describe batch and continuous stirred tank reactors, and describe the methodology for deriving the reactor design equation.</td>
<td>Sec. 5.3.2 and 5.3.3 describes techniques for estimating the persistence of chemicals in aquatic environments and the biodegradability of chemicals. Once the rate of decay is estimated, the reactor design equations can be used to build a system to accommodate a specific waste stream.</td>
</tr>
<tr>
<td>Membrane Reactor System</td>
<td>Sec. 1.2, the general mole balance, is required to complete a mass balance on this reactive system.</td>
<td>Sec. 9.4.3 describes the opportunities that can be achieved through process intensification, and in particular, the gains that can be achieved by coupling a reactor and a separator to increase the efficiency of the process.</td>
</tr>
</tbody>
</table>

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Example Structure of Problems

Chapter 3  Rate Laws and Stoichiometry

• Atom Economy - Ibuprofen
  – Green Chemistry Concept  – Green Engineering
  – Reaction Mechanisms  - Reaction Engineering

• Hydrogen Production for a Fuel Cell
  – Reactor Sizing (Find catalyst weight) - Reaction Engineering
  – Fuel Cell, Sources of Hydrogen  – Green Engineering

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Example Structure of Problems

Chapter 5: Collection and Analysis of Rate Data

• Biodiesel Production (Transesterification)
  – Renewable Fuels – Green Engineering
  – Integral and Differential Analysis - Reaction Engineering

• Ethanol Production from Waste Biomass
  – Initial Rate Method - Reaction Engineering
  – Renewable Fuels/ – Green Engineering

www.rowan.edu/greenengineering
Freshman/General Engineering Course Material

Principles of Chemical Processes
Materials Science
Separations Processes
Design
Life Cycle Assessment
System Dynamics and Control
Heat Transfer
Chemical Engineering Thermodynamics
Transport Phenomena
Chemical Reaction Engineering

24 problems
For 13 chapters
of Incorpera & DeWitt
Heat Transfer Concepts

Calculate the distance between steam injections to keep the crude above its pour point (35°C)

GE Concepts

Evaluate impact of building pipeline through rainforest and areas that sustain many earthquakes, landslides and soil shifting

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Replacement Windows

Heat Transfer Concepts

Compare rate of heat transfer through standard (air-filled) double pane windows to argon-filled windows

Green Engineering Concepts

Complete a life-cycle study on the windows using a 25 year mortgage as basis

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Heat Transfer Concepts

Calculate and compare the heat loss between an incandescent bulb and a fluorescent bulb.

Green Engineering Concepts

Evaluate the environmental impact by comparing the energy savings between the two bulbs.

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TAKING HOME PROJECT
Heated Swimming Pool

Heat Transfer Concepts
Calculate heat loss from heated swimming pool

GE Concepts
Determine the optimum time of day to turn on heater so as to:
1. maximize swimmer’s comfort and
2. minimize heat loss and energy usage

www.rowan.edu/greenengineering
I’ve had 3 students independently approach me to find out how they can pursue Green Engineering further (2 men, 1 woman).

They also happen to be 3 of the best students in the class.

--Ann Marie Flynn

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Critical Elements to Teaching Green Engineering

Provide students with a short, introductory text.

Periodically test students on their green engineering knowledge.

Include significant classroom discussion before and after homework assignments have been completed.

Assign group research projects.

Include homework assignments that address world issues and are industry-based.

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Need New Materials & Modules

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- Transport Phenomena
- Reaction Engineering
- Thermodynamics

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CONCLUSIONS

• The Solution is a University Issue
• Use Textbook and Modules for Curriculum
• Start Teaching Green from the First year -
  – Utilize Active Learning
  – Projects & Case Studies
  – Use the text starting in first year
• Integrate to Upper Levels - Reinforce & Build
• Senior Design Course(s)
• Research and Clinic Projects with Industry

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ACKNOWLEDGMENTS

• US EPA - Office of Pollution Prevention and Toxics and Office of Prevention, Pesticides, and Toxic Substances Grant: CX 827688-01-0 & X 83052501
• Kuyen Li, John Gossage, and Helen Lou Chemical Engineering Department Lamar University, Beaumont, Texas
• David R. Shonnard, Chemical Engineering and Mary H. Durfee, Social Sciences (Mich Tech)
• Khashruzam Choudhury, Nelson Mandela School of Public Policy and Urban Affairs Ghanashyam A. Joshi, Mechanical Engineering - Southern Univ
• Francis A. Gadala-Maria, Department of Chemical Engineering University of South Carolina
• Hamid Arastoopour and Henry R. Linden, Department of Chemical and Environmental Engineering, Armour College of Engineering, Illinois Institute of Technology
• Dr. Jorge Vanegas, School of Civil and Environmental Engineering, College of Engineering, Georgia Institute of Technology (Georgia Tech)
• Pedro Medellín-Milán and Luz María Nieto-Caraveo UASLP - Mexico