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?

The SanDestin Declaration of Green Engineering Principles (2003)

- 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.
9. Actively engage communities and stakeholders in development of engineering solutions.

There is a duty to inform society of the practice of green engineering.

Motivation based on Accreditation

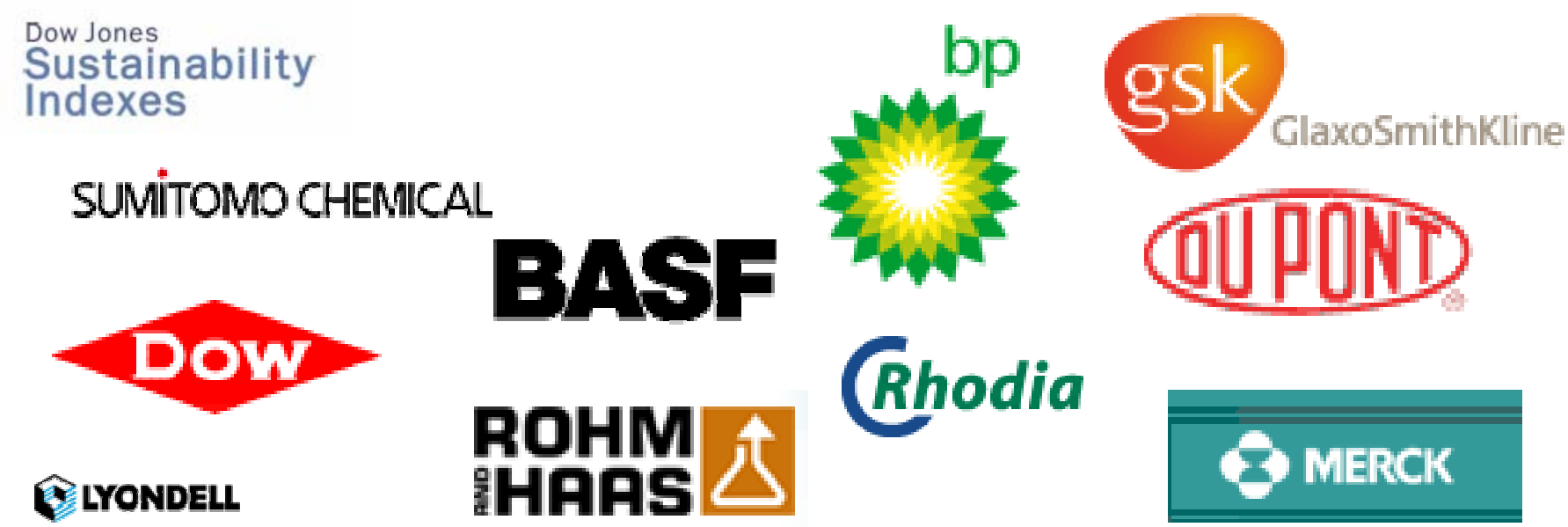
- ABET Engineering Program Outcomes Criteria (Accreditation Board for Engineering & Technology) Approved 1 November 2004
  - (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health 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;

ABET ACCREDITATION

AIChE

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**

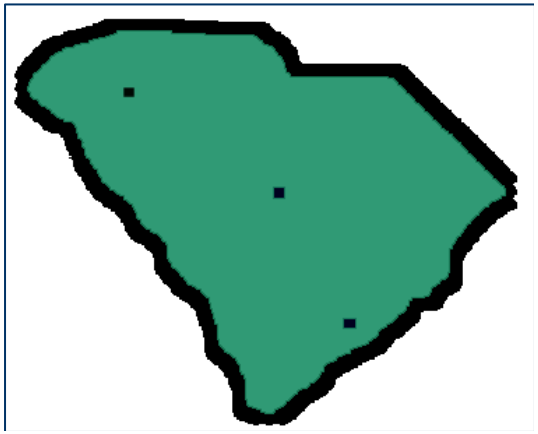


Forums to Incorporate Green/Sustainable Engineering

- 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



Francis A. Gadala-Maria
Department of Chemical Engineering
University of South Carolina

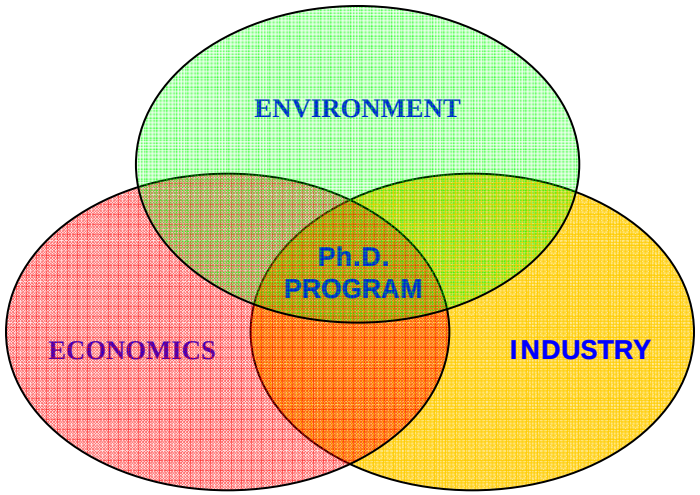
University of South Carolina "Green Dorm"

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

Nearly Same Cost as a Previous Dorm!

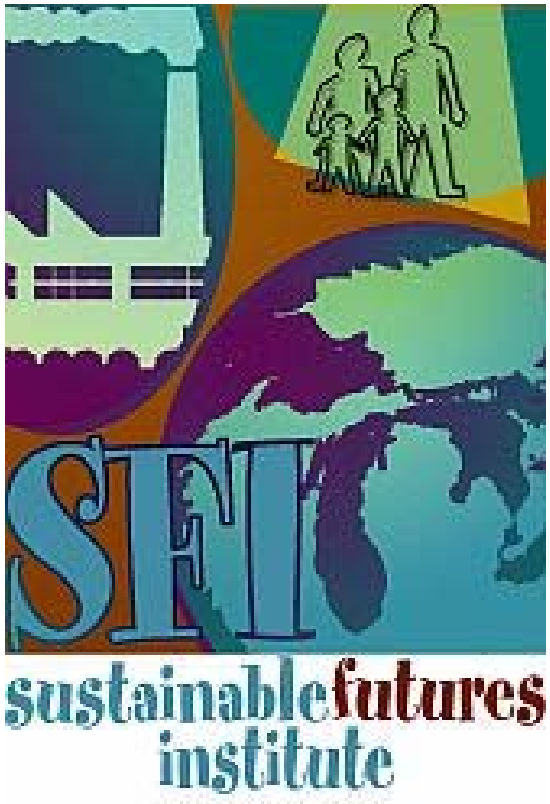
A Ph.D. Program in Chemical Engineering at Lamar University

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

MichiganTech

Southern University and A&M College

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)

MichiganTech

Southern University
and A&M College

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

MichiganTech

Southern University and A&M College

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

MichiganTech

Southern University and A&M College

ENG/SS 5510 Sustainable Futures I (SF1)

- Student Profile — Students
  - 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

MichiganTech

Southern University and A&M College

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

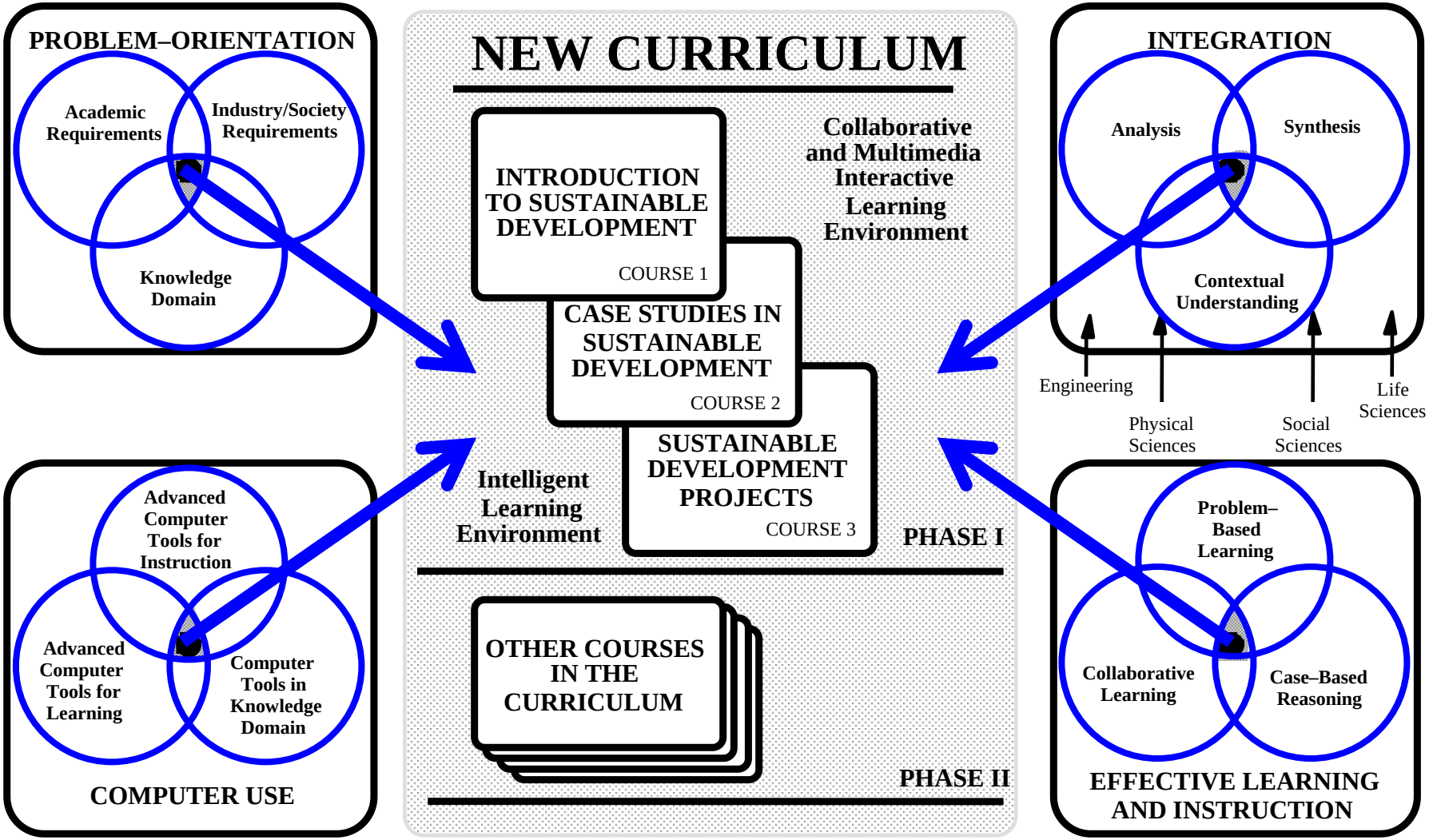
Educational Programs

- **Energy Environment and Economics (E^3) 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



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

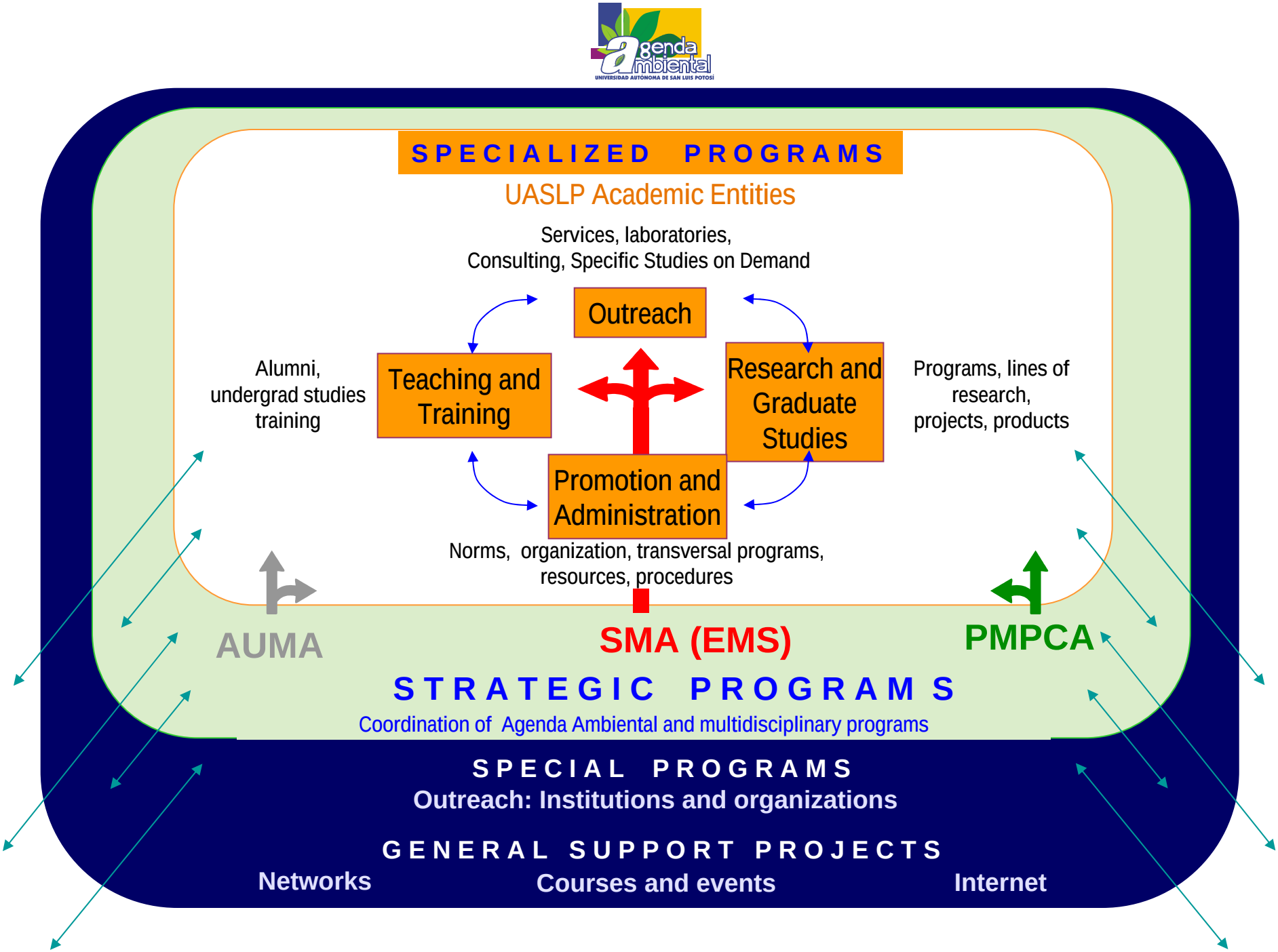
- At least 103 courses, taught through every college, have an emphasis on sustainability.
- Several majors offer a focus on sustainability.
- The College of Architecture stresses sustainability in each of their programs.
- ***Leadership is from deans and chairs, the provost, individual faculty, and student 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)

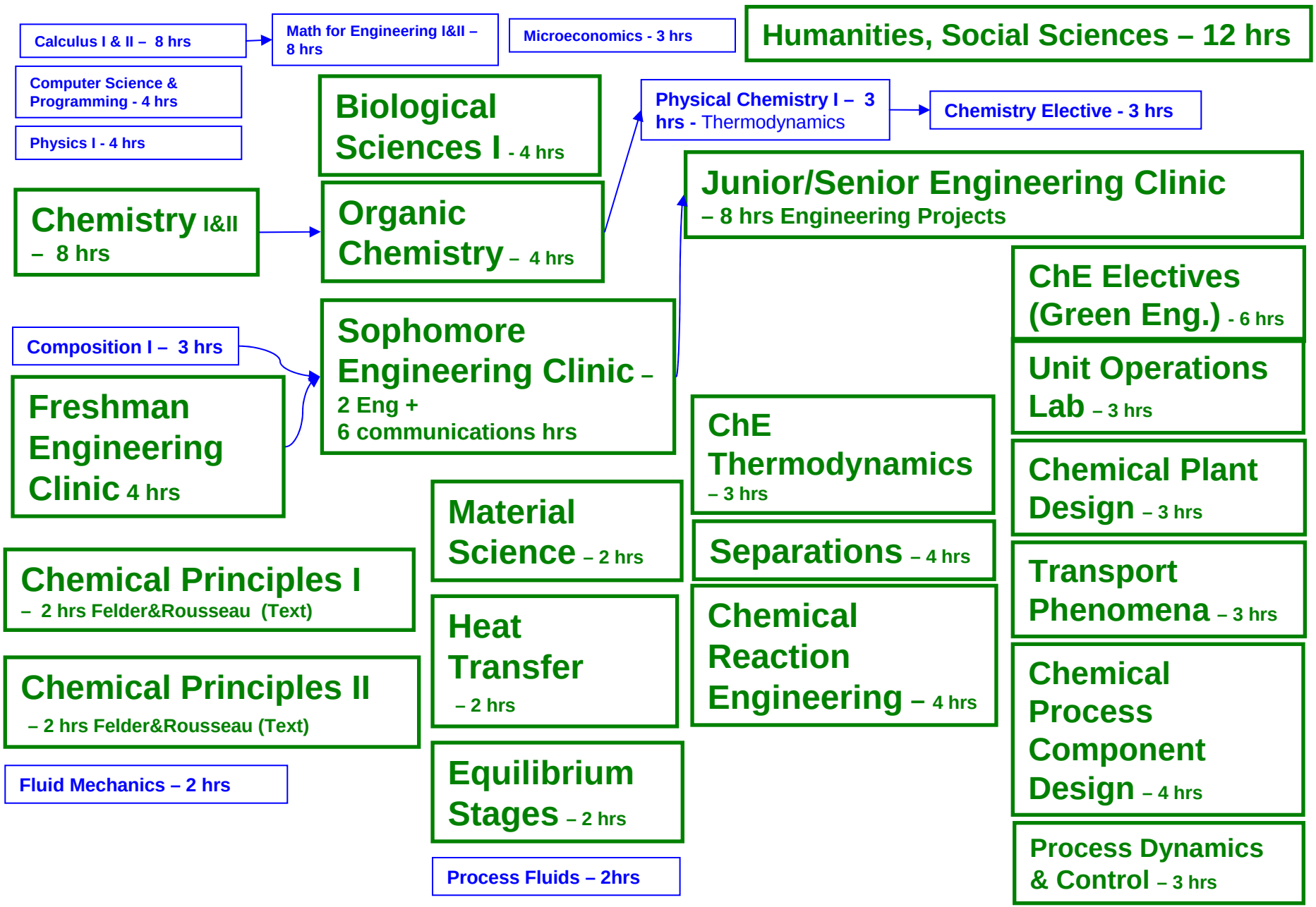
- **Environmental and sustainability perspective:**
  - **Included in the vision and strategies of Integral Program for Institutional Strengthening (PIFI-UASLP).**
  - **Established in the Institucional Development Plan.**
  - **Financial support by UASLP, SEP-SESIC, Conacyt, Semarnat and other agencies.**
  - **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)


SPECIALIZED PROGRAMS
UASLP Academic Entities
Services, laboratories,
Consulting, Specific Studies on Demand
Outreach
Alumni,
undergrad studies
training
Teaching and
Training
Research and
Graduate
Studies
Programs, lines of
research,
projects, products
Promotion and
Administration
Norms, organization, transversal programs,
resources, procedures
AUMA
SMA (EMS)
PMPCA
STRATEGIC PROGRAMS
Coordination of Agenda Ambiental and multidisciplinary programs
SPECIAL PROGRAMS
Outreach: Institutions and organizations
GENERAL SUPPORT PROJECTS
Networks
Courses and events
Internet

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.

Green CHEMICAL ENGINEERING CURRICULUM – 131 hrs



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?**

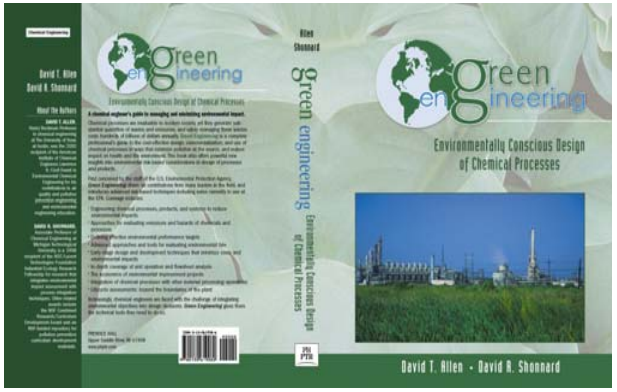
IMPLEMENTATION

- **Sustainable/Green Engineering Champion**
- **Sustainable/Green Engineering Text for 4 years**
- ***Modules* prepared for each course**
- **Strong Support of Chair & Dean**
- **Excited & Cooperative Faculty**

engreen ineering

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

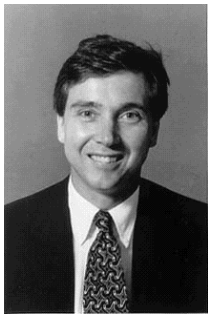
Green Engineering: Environmentally Conscious Design of Chemical Processes

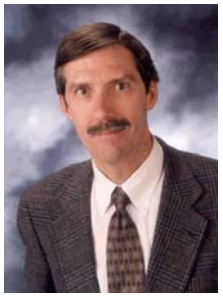


Allen, David T and D. R Shonnard

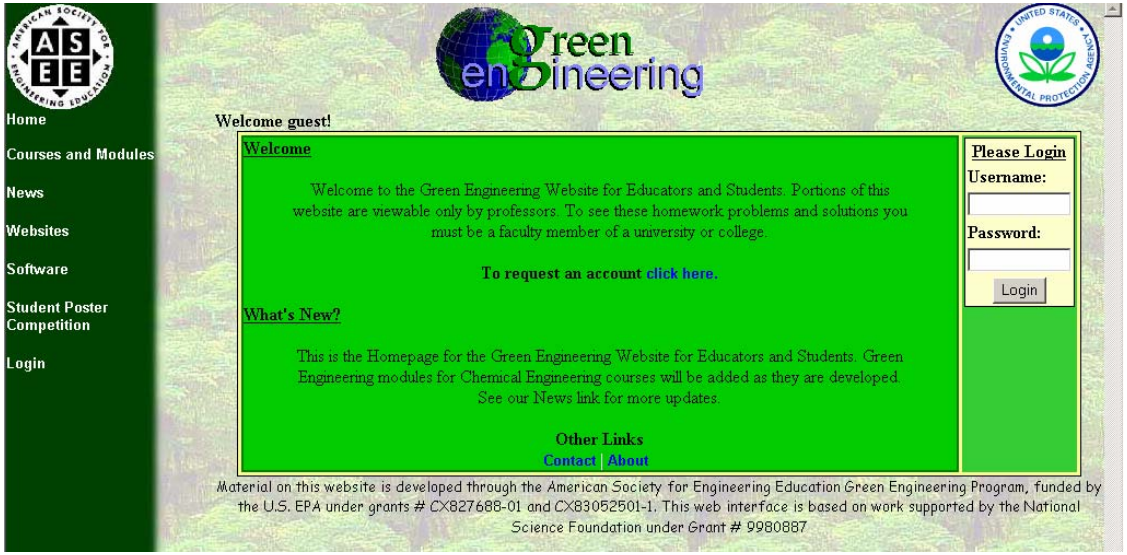
- **Easy to Utilize for a Green Engineering course**
- **Modules Created for Engineering Courses:**

www.rowan.edu/greenengineering





Rowan Green Engineering WEBSITE



Modules Prepared

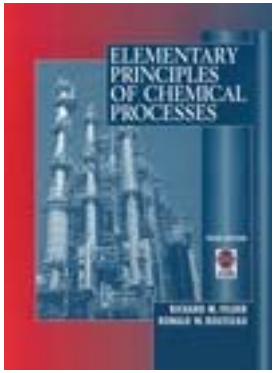
- Freshman Engineering
- Material and Energy Balances
- Design
- Material Science and Engineering
- Heat Transfer
- Process Dynamics and Controls
- Separation Processes
- Transport Phenomena
- Reaction Engineering
- Thermodynamics
- Life Cycle Analysis

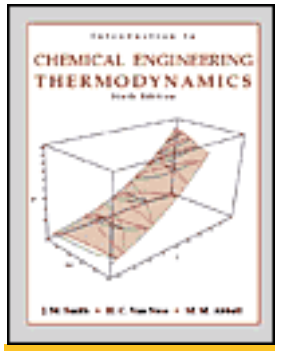
http://www.rowan.edu/greenengineering

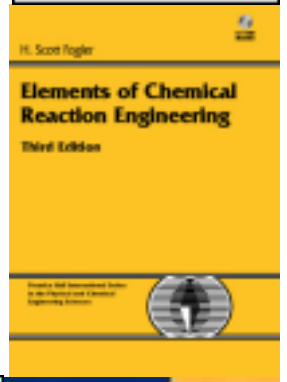
Need New Linked Modules

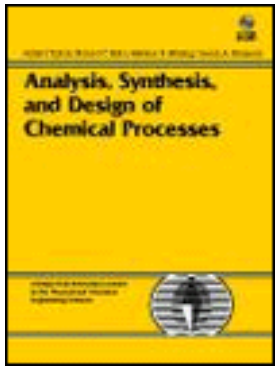
Mapping of Green Engineering Subjects with Course Text & Green Engineering Principles

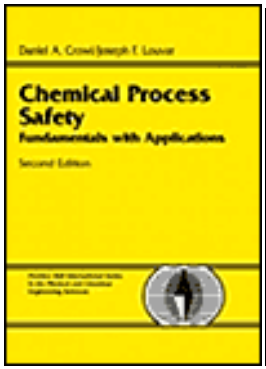
- Selected Readings from Text
- Example Problems
- Homework Problems
- Case Studies

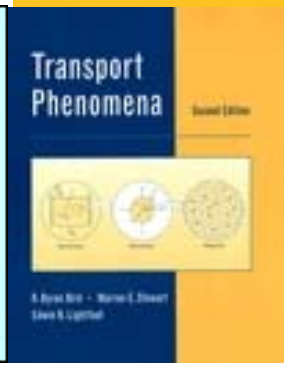




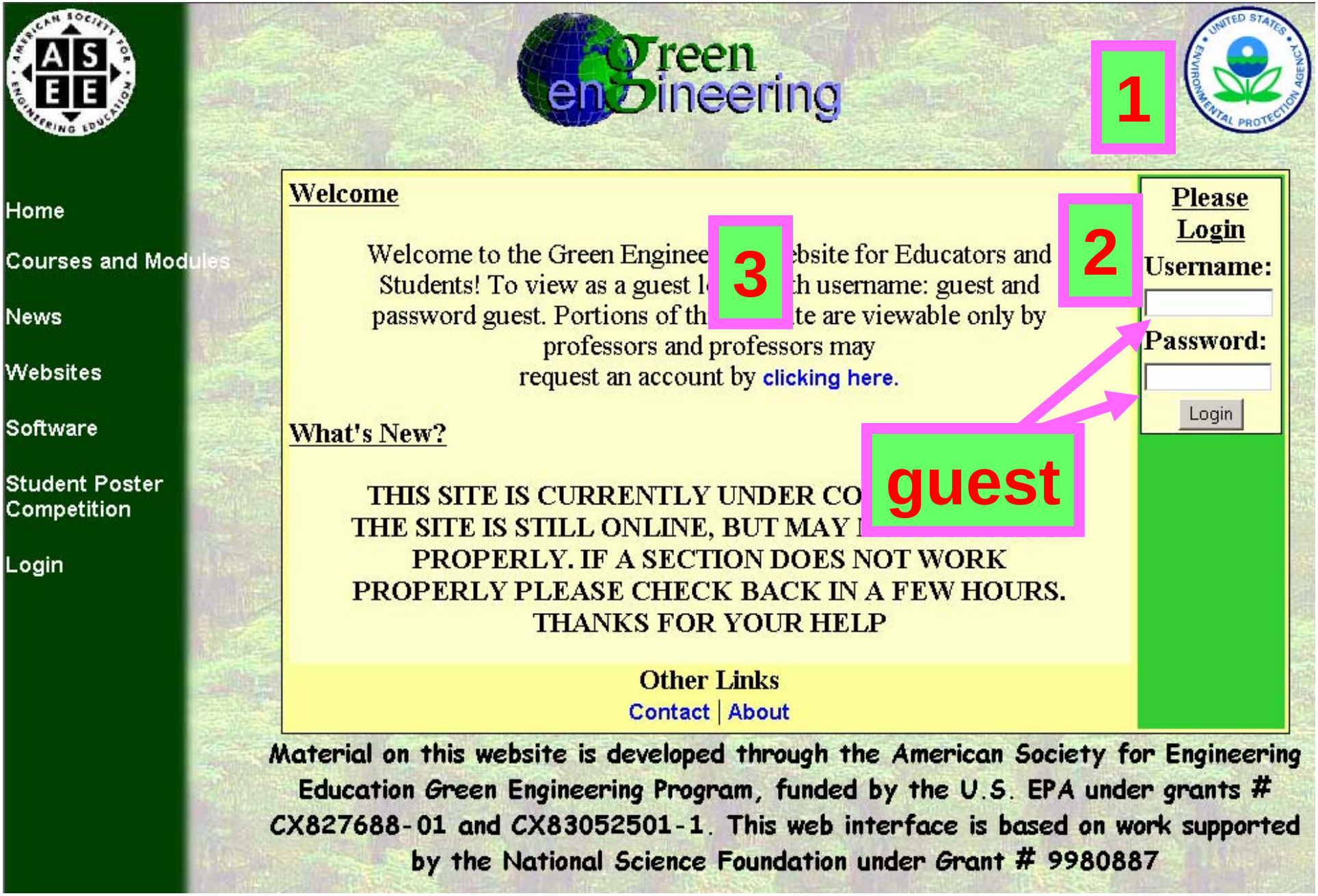








www.rowan.edu/greenengineering



www.rowan.edu/greenengineering

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 frien
Mellon.

- *Personal Environmental Impact Log Project* (Guest)

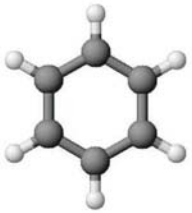
Water, Paper, and Electricity Use Inventory Project from Carnegie

- *Role Playing Debate Project* (Guest)

Salmon Management in the Pacific Northwest Conflict Resolution
Carnegie Mellon.

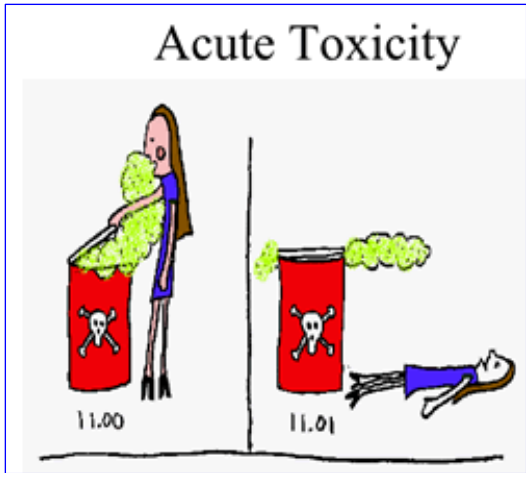
www.rowan.edu/greenengineering

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?)

Freshman/General Engineering Course Material ⊞

Principles of Chemical Processes ⊞

Materials Science ⊞

Separations Processes ⊞

Design ⊞

Life Cycle Assessment ⊞

System Dyn

Heat Trans

Chemical R

Transport P

Chemical Reaction Engineering ⊞

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

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)

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

Calculate energy required and emissions produced

Examine the effect of reusing the sacks

Make Conclusions

LCA in Courses

Carnegie Mellon
GREEN DESIGN INITIATIVE
www.eiolca.net

SimaPro6.0

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

Freshman/General Engineering Course Material

Principles of Chemical Processes

Materia

Separat

Design

Aligned with Text:
Fogler: Elements of Chemical Reaction Engineering
by Martin Abraham & Neil Schweitzer

Life Cycle Assessment

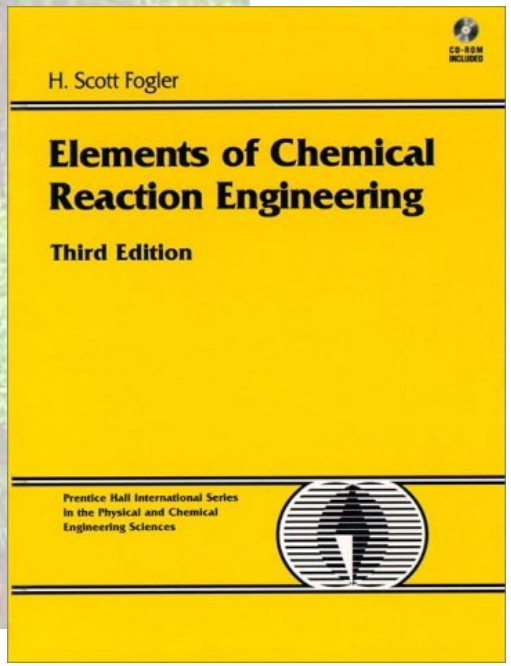
System Dynamics and Control

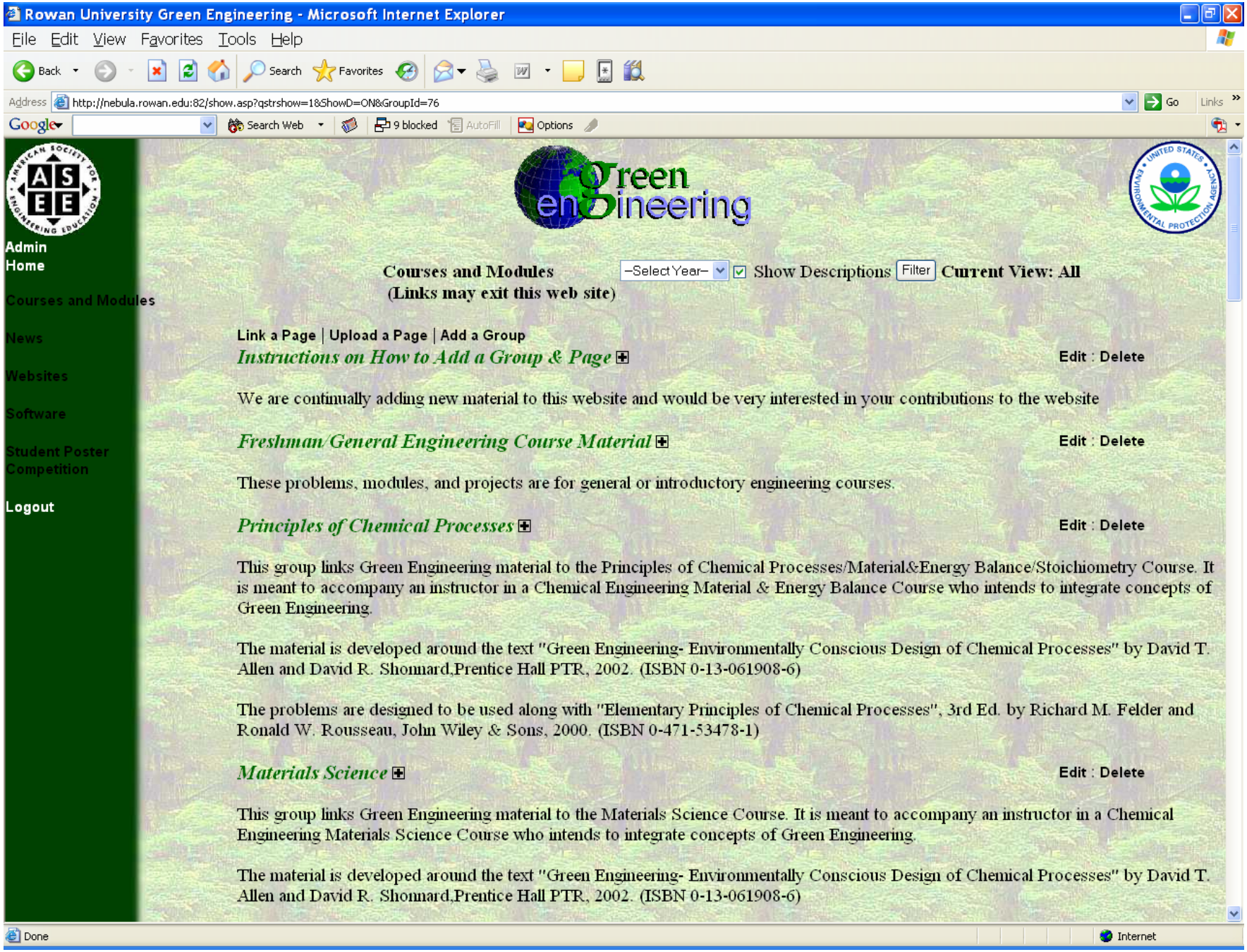
Heat Transfer

Chemical Engineering Thermodynamics

Transport Phenomena

Chemical Reaction Engineering

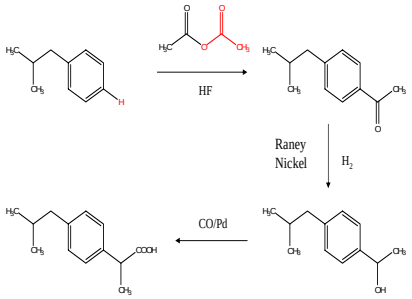



Rowan University Green Engineering - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Search Favorites
Address http://nebula.rowan.edu:82/show.asp?qstrshow=1&ShowD=ON&GroupId=76
Go Links
Google Search Web 9 blocked AutoFill Options
Admin
Home
Courses and Modules
News
Websites
Software
Student Poster Competition
Logout
Green engineering
Courses and Modules
(Links may exit this web site)
–Select Year–
Show Descriptions
Filter
Current View: All
Link a Page | Upload a Page | Add a Group
Instructions on How to Add a Group & Page
Edit : Delete
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
Edit : Delete
These problems, modules, and projects are for general or introductory engineering courses.
Principles of Chemical Processes
Edit : Delete
This group links Green Engineering material to the Principles of Chemical Processes/Material&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.
The material is developed around the text "Green Engineering- Environmentally Conscious Design of Chemical Processes" by David T. Allen and David R. Shonnard,Prentice Hall PTR, 2002. (ISBN 0-13-061908-6)
The problems are designed to be used along with "Elementary Principles of Chemical Processes", 3rd Ed. by Richard M. Felder and Ronald W. Rousseau, John Wiley & Sons, 2000. (ISBN 0-471-53478-1)
Materials Science
Edit : Delete
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.
The material is developed around the text "Green Engineering- Environmentally Conscious Design of Chemical Processes" by David T. Allen and David R. Shonnard,Prentice Hall PTR, 2002. (ISBN 0-13-061908-6)
Done
Internet

Instructor Guide

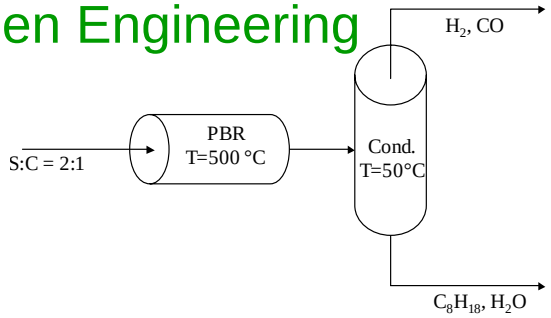
Problem	Reaction Engineering Element	Green Engineering Element
Automotive Catalytic Converter	Sec. 1.4.3 describes the mole balance for the packed bed reactor, and provides an example for a first order reaction.	Sec. 1.5 describes criteria air pollutants and begins to put the issue of pollution reduction into an appropriate context.
Aerated Bioreactor Lagoon	Sec. 1.3 and 1.4.1 describe batch and continuous stirred tank reactors, and describe the methodology for deriving the reactor design equation.	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.
Membrane Reactor System	Sec. 1.2, the general mole balance, is required to complete a mass balance on this reactive system.	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.

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



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

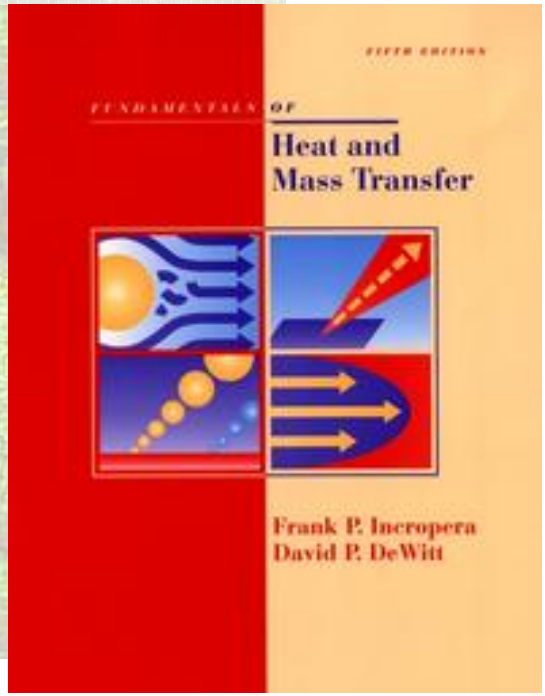
Heat Transfer

Chemical Engineering Thermodynamics

Transport Phenomena

Chemical Reaction Engineering

24 problems
For 13 chapters
of Incorpera & DeWitt



Ecuador Pipeline

Heat Transfer

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

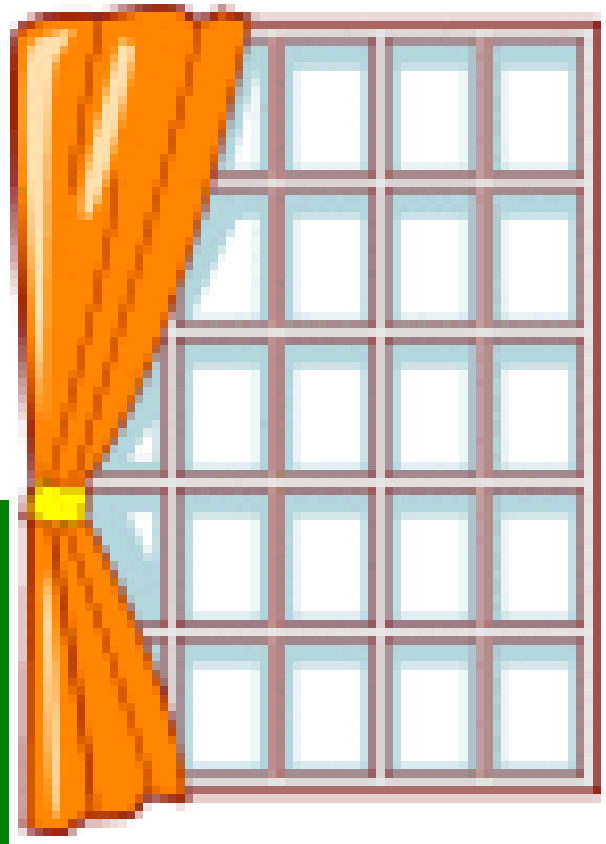
www.rowan.edu/greenengineering

Replacement Windows

Heat Transfer

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

Lighting for the Home

Heat Transfer

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

Heat Transfer

TAKE-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

Heat Transfer

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

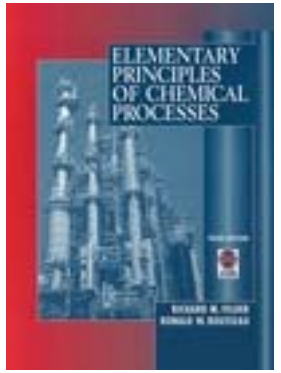
Critical Elements to Teaching Green Engineering

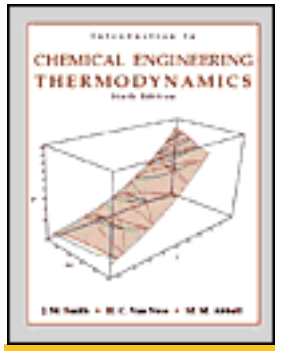
- Provide students with a short, introductory text.
- Periodically test students on their green engineering knowledge.
- Include significant classroom discussion before and after homework assignments have been completed.
- Assign group research projects.
- Include homework assignments that address world issues and are industry-based.

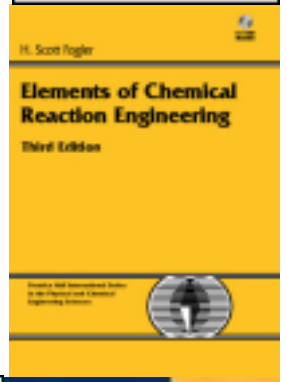
Need New Materials & Modules

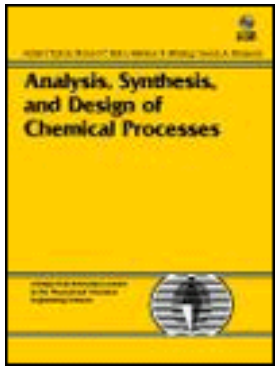
Mapping of Green Engineering Subjects with Course Text & Green Engineering Principles

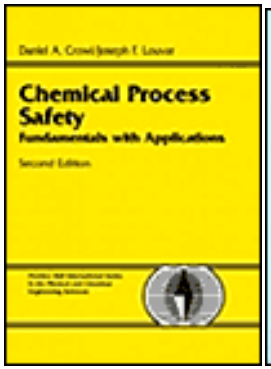
- Selected Readings from Text
- Example Problems
- Homework Problems
- Case Studies

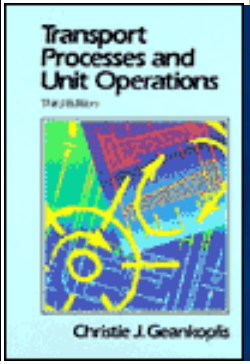


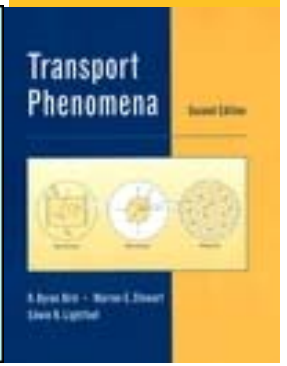






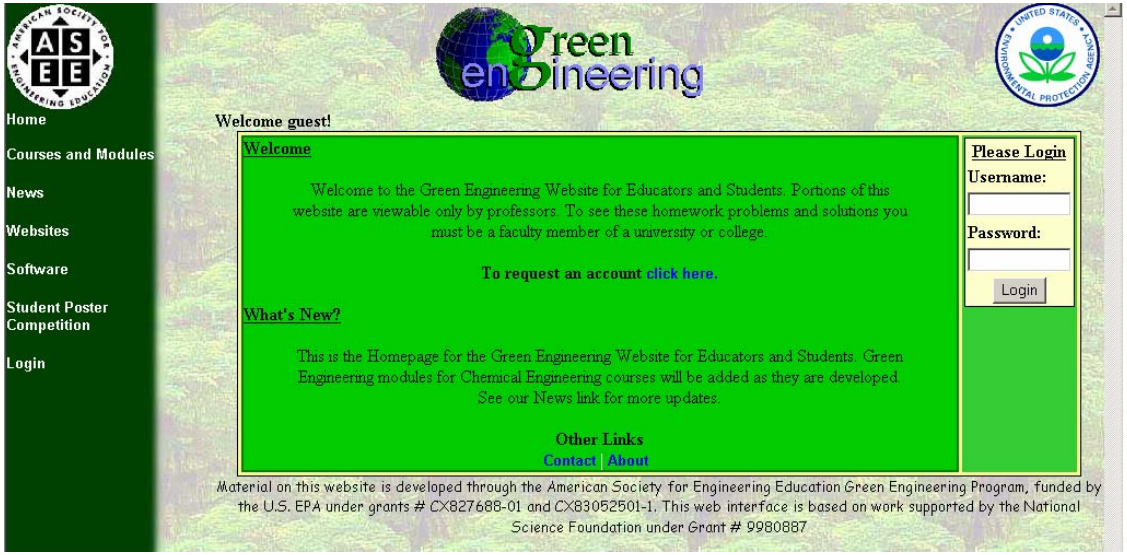






www.rowan.edu/greenengineering

Rowan Green Engineering WEBSITE



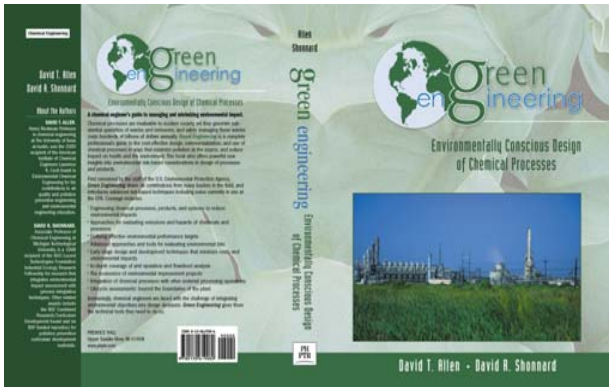
Modules Prepared

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

http://www.rowan.edu/greenengineering

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**



www.rowan.edu/greenengineering

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)
- *Khashruzzamen 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