AC 2007-3099: PROJECT-BASED PEDAGOGY TO ENHANCE TEACHING AND LEARNING IN ENERGY AND THE ENVIRONMENT FOR HONORS STUDENTS

Yaw Yeboah, Pennsylvania State University

Yaw Yeboah is Professor and Head of the Department of Energy and Geo-Environmental Engineering at The Pennsylvania State University. Prior to joining Penn State, he was Professor of Chemical Engineering and Associate Dean for Science and Engineering in the School of Arts and Sciences at Clark Atlanta University. He has over 25 years of research (academic and industrial), teaching and project management experience.

Sarma Pisupati, Pennsylvania State University

Sarma Pisupati is Associate Professor of Energy & Geo-Environmental Engineering Department and a Faculty Fellow of the John A. Dutton e-Education Institute of the College of Earth and mineral Sciences. He is Chair of the General Education Program of the EGEE Department and has been teaching undergraduate and graduate courses at Penn State University since 1992.

Project-based Pedagogy to Enhance Teaching and Learning in Energy and the Environment for Honors Students

Abstract

The paper presents a project-based teaching pedagogy for an honors level freshman course on energy and the environment. In addition to class lectures and discussions, students select from among a menu of energy-related topics for their project. The projects cover various aspects of the in-class discussions on energy fundamentals, renewable energy, fossil fuels, environmental impact, and energy policy. Each student prepares a 30 minute presentation on their topic to be given in class. The key criteria are for the lecture and data presented to be substantially different from the in-class lectures, up-to-date, and extend beyond the US (i.e., internationalized or globalized). Students are expected to be the experts on the topic after completing and presenting their project. Sample student topics include: wind, geothermal, hydroelectric, solar, biomass, ocean and tidal energy, coal, petroleum, natural gas, oil shale and tar sands, electric power, fuel cells, environmental impact of energy, energy supply and demand, materials for energy applications, and the 2005 US Energy Act.

The class, over a two year period 2005-2006, has shown a remarkable level of growth, excitement and interest of students. The presentations followed by questions and answers have shown enhanced teaching and learning of students. Student evaluations have indicated the project to be one of the key aspects of the course students liked most. It was concluded that project-based pedagogy significantly enhances teaching and learning.

Introduction

To meet the ever increasing energy demand, the nation and the world need a well trained and diverse workforce to develop process, utilize and manage both conventional and renewable energy sources in an environmentally safe and economically viable manner. Unfortunately, many of the academic programs that provided such workforce (e.g., chemical engineering) have redirected their focus to the health or bio-related areas leaving many energy producing and consuming industries with a high average technical workforce age and growing workforce demand. There is also renewed emphasis on the development of alternative sources of energy to conventional fossil fuels. The increasing demand for energy and trained energy workforce calls for innovative methods to increase enrollments and graduation rates of students in energy-focused disciplines.

Penn State University has significant resources and expertise in energy especially within the College of Earth and Mineral Sciences (EMS) through the departments of Energy and Geo-Environmental Engineering (EGEE), Material Science and Engineering and Geosciences as well as the Energy Institute (EI)[1]. The EMS College, in collaboration with other Colleges, is uniquely positioned to assist in this area of national importance: *energy*. The EGEE Department[2], for example, is committed to educating the student body at Penn State with regard to energy and energy concerns. This department is currently

educating 4,000 students per year in energy outside of our departmental majors, compared to less than 300 four years ago. In particular, the education of non-science students in energy is vital to the national debate on energy and security.

The high enrollments were achieved with dedicated faculty through innovative teaching styles and interactive learning objects[3]. Two of the popular general education courses that have contributed to the education of the large number of students on energy are EGEE 101 Energy and the Environment and EGEE 102 Energy Conservation. The innovative approaches used in these classes have attracted higher representations of minorities (19% in "Energy & the Environment") and women (56% in "Energy Conservation"). The regular sections of these classes typically have enrollments of 100-200 per section. However, the honors sections of these classes are limited to 20-30 per section. This allows more group discussion and interaction as well as individual projects and presentations by students. This paper covers aspects of the honors sections of the two classes taught by the authors; in particular the honors section of EGEE 101 Energy and the Environment taught by the lead author in Fall 2005 and 2006.

EGEE 101H: Energy and the Environment

This course satisfies the general education natural science requirement of Penn State University. It is typically taken by non-science majors as most science majors would have already satisfied this requirement with required courses in chemistry, physics and biology. However, a significant number of science-based majors still take this course. The course has no prerequisites and is offered in the Fall and Spring semesters.

The main objectives of this course are to:

- provide basic understanding and appreciation of energy and environmental concerns
- analyze energy consumption patterns
- discuss various energy resources that power the modern society
- examine energy conversion processes
- explore interrelationships between energy use and industrial progress and environmental consequences
- discuss sustainable future energy alternatives and conservation methods

The course is typically broken into four units:

Unit 1: Energy fundamentals that covers forms and uses of energy, supply and demand, and energy conversion and efficiencies

Unit 2: Nuclear and renewable energy that covers nuclear energy and such renewable options as wind, geothermal, hydropower, ocean and tidal, solar, biomass, and hydrogen and fuel cells.

Unit 3: Non-renewable energy- coal, petroleum, natural gas, oil shale and tar sands

Unit 4: Environmental impact that discusses the environmental and health and safety impacts of non-renewable and renewable energy options.

A sample schedule for a course that meets twice a week for 75 minutes per class session is shown in Table 1.

Table 1: Sample EGEE 101H Class Schedule

Weeks	Unit	Topic(s)
1-3	1 (Energy Fundamentals)	Introduction to Energy; Forms of Energy; Uses of Energy; Energy Efficiency Supply and Demand
4-7	2 (Renewable Energy)	Wind and Geothermal; Hydro, Ocean, Tidal; Solar; Biomass; Fuel Cells; Nuclear Energy
8-11	3 (Fossil Fuels)	Fossil Fuels Overview; Coal; Petroleum/ Crude Oil; Natural Gas; Oil shale & tar sands
12-15	4 (Environmental Impact and Project Presentations)	

In the honors section class, in addition to the enhanced interaction and open discussions on the topics, each student is required to develop expertise in one subject area of the class. Students are required to prepare a 30-minute PowerPoint presentation (20 minutes presentation and 10 minutes question and answer session) on their project topic and to deliver it in class. The presentation is evaluated by their peers and the instructor. An electronic copy of the presentation is submitted through a drop box in the course management site (ANGEL) that is accessible to all students. The quality of the student document and presentation material is judged especially on how **current or up-to-date** the data/information is and the extent or level of **internationalization/globalization** of the data (i.e., how far the data presented goes beyond the US and incorporates information/data on the rest of the world). Typically the project is weighted 20 % of a students overall grade. As the instructor and student presentations are accessible to all students, they are responsible for all material covered by the instructor and students for all exams including the final exam. This encourages students to attend class and participate in the class presentations and discussions.

Sample topics or projects that students have previously chosen from are given in Table 2.

Table 2: Sample EGEE 101H Student Project Topics

1. Energy Supply and Demand	2. Wind Energy	3. Geothermal Energy
4. Hydroelectric Energy	5. Solar Energy	6. Tidal and Ocean
7. Biomass/Bioenergy	8. Fuel Cells	9. Coal
10. Petroleum/Crude Oil	11. Natural Gas	12. Oil Shale & Tar sands
13. Environmental Impact	14. Nuclear Energy	15. 2005 US Energy Act
16. Materials for energy applications	17. Electric power	18. Other

Students are expected to make presentations that are substantially different from the class lecture notes provided online to all students. They may however expand on the lecture notes provided in ANGEL, if available, and focus in their presentations on such topics as:

- The cause or source of the energy
- The reserves and resources of the energy
- The mechanism/technology for conversion of the energy
- Production rate
- Consumption/usage rate (e.g., total and per capita) relative to other sources of energy
- Specific applications or uses of the energy and their percent distribution
- The historical trend in cost and usage
- Historical setbacks or accidents on its production and usage
- Future of the energy source
- Societal or environmental impact
- Relation of the supply and demand to population and industrialization
- Personal statement or impression/summary after completing the project and developing expertise on the specific topic studied.

Students are encouraged to consult with the instructor as much as possible and to strive to be the expert and most current and reliable resource for information on their topic. The project based learning is to promote independent thinking and analysis, creativity, and the organization and presentation of thoughts and material learned.

Sample Student Projects/Presentations

Sample student project presentation on the 2005 US Energy Act is given at the end of the paper in Figure 1. Also shown in Figure 2 is a project on Biomass/Bioenergy. A summary of some of the personal opinions/conclusions provided after their research is given in Figure 3. Before each presentation, students were given an evaluation sheet shown in Table 3 to evaluate their peers on the project and presentation.

Student Evaluations of Projects and Course

Shown below are the mean values of the student's feedback reported at the end of the course in Fall 2005 semester on a scale of 1 to 7 with seven being the highest score.

1. Overall quality of the course:	6.00
2. Overall quality of the instructor:	6.33
3. Clarity of the instructor's presentations:	5.83
4. Instructor's willingness to help students make progress:	6.17
5. Instructor's skill creating a climate conducive to learning:	6.17
6. Adequacy of the instructor's knowledge of the subject matter:	7.00
7. Instructor's preparation for class:	6.67
8. Course organization in terms of logical arrangement of material and activities:	6.67
9. Instructor's skill in encouraging students to think:	6.50

Table 3: Evaluation Sheet for EGEE 101 H Student Project and Presentations

Name of Student Presenting_____ Project Title_____

Grade each of these on a scale of 1 (poor) – 5 (Excellent).

	Poor				Excellent
1. How informative was the presentation?	*1*	*2*	*3*	*4*	*5*
2. How knowledgeable and confident was the presenter?	*1*	*2*	*3*	*4*	*5*
3. How much do you think the presenter put in the preparation?	*1*	*2*	*3*	*4*	*5*
4. How effective was the presentation?	*1*	*2*	*3*	*4*	*5*
5. How current was the data/information presented?	*1*	*2*	*3*	*4*	*5*
6. How global or international was the data presented?	*1*	*2*	*3*	*4*	*5*

7. Circle the words you would you use to describe the presenter? You may circle more than one.

Nervous Uncomfortable Lacks knowledge Unprepared

Confident Comfortable Knowledgeable Prepared

8. Circle the words you would you use to describe the presentation. You may circle more than one.

Unorganized Duplicates class notes Old Data Little data outside US

Organized Detailed Informative Presented sufficient data outside US

(New data) (Global/International)

9. Other comments

Typically comments and responses to three specific questions asked students at the end of the course included:

a. What did you like most about the course?

Student presentations; independent research projects; small class size and interactions; wide range of interesting topics; learning new materials; great instructor; online notes; the professor; in class demonstrations; fun, friendly and interesting learning environment; puzzles, homework and exam format

2. What did you like least about the course?
Tedious/lengthy homework; fast pace sometimes; too much material (but interesting); no book; math and equations; exam format

3. What suggestions do you have for improving the course?
More movies/films, videos, and in class demonstrations; have textbook; less homework; less math; make it more challenging

Some of the comments sound contradictory. This reflects the mix and wide range of backgrounds of the students. In particular, non honors students are allowed to register for the course after registration of honors students. Clearly, however, the positive experiences far outweigh the negative experiences in terms of number and intensity.

Summary and Conclusions

In summary, through project-based pedagogy, teaching and learning in an energy and the environment general education course were enhanced as evidenced by student evaluations. The class, over the two year period 2005-2006, showed a remarkable level of growth, excitement, and interest of students. Student presentations showed enhanced teaching and learning. Student evaluations and comments indicated the project to be the part of the course students liked and enjoyed most. The approach enabled students to develop expertise in an aspect of energy and the environment, through project-based pedagogy, while learning from the professor and peers. In particular, the course structure enabled a broad range of topics such as the 2005 US Energy Act and aspects of some topics that would not have been covered in class to be researched and presented by students. This significantly broadened the depth of knowledge gained by students and the overall effectiveness of the course.

References:

1. College of Earth and Mineral Sciences, Penn State University Accessed January 10, 2007, http://www.ems.psu.edu/
2. Department of Energy and Geo-Environmental Engineering, Penn State University, Accessed January 10, 2007, http://www.egee.psu.edu/
3. Pisupati, S. V., Deluca, M., Gutowski, M., Mahan, W. and Victor, B., Impact of innovative and highly interacted online activities on energy efficiency education, *American Society for Engineering Education Annual Conference, June 12-15*, 2005, Portland, OR,

Figure 1. An Example of Student's presentation on 2005 Energy Act

Biomass

- Improved Biomass Use Grant Program:
  - Research and development costs associated with improving the use of biomass energy will be subsidized partly by the government
  - Grants are available up to $500K and the total amount for each year between 2006 and 2016 is $50 million.
- Grants of $20 per "green ton of biomass" are also available to people who use biomass to produce electricity, substitutes for petroleum products or transportation fuel.

Geothermal, Solar, Wind and Ocean Energy

- Over the next five years, $3Billion is being devoted to renewable energy.
- $210Million of that amount is devoted to funding Solar energy
  - Specifically solar energy that is used in the production of hydrogen and electricity
- Other funding is available for studying ocean and wave energy
- State and local governments that construct buildings that utilize renewable energy are entitled to grants up to 40% of the costs of installation.

The Energy Bill and Fossil Fuels

- Over the next five years, $2.9Billion is going to be used to fund a number of initiatives related to fossil fuels.

Coal

- The Clean Coal Power Initiative is the main piece of legislation concerning coal
- Goals by 2020:
  - remove 99% of sulfur dioxide
  - Cut emissions of NOx to .05lbs per million Btu
  - Reduce mercury emissions
  - Increase thermal efficiency of coal to nearly 60%

Coal cont.

- Funding Coal Technologies:
  - Loan guarantees are available to firms which operate power plants which use coal gasification and produce at least 400 megawatts of power
  - Loan guarantees are available for petroleum coke gasification projects
  - $5million towards researching electron scrubbing technology to reduce sulfur emissions
- Overall, in the next five years, $1.422Billion will be spent on coal technology R&D

Petroleum and Natural Gas

- Expands the capacity of the Strategic Petroleum Reserve from 700million barrels to 1billion barrels.
- Calls for an increase in petroleum refining capacity
  - US is currently operating at 95% refining capacity and demand for gasoline is going to rise by 4million barrels per day by 2025
  - Encourages expansion of refining capacity by promoting the revitalization of idle refineries
  - Identifies geographic areas as refinery revitalization zones based on previous refining activity in the area and unemployment
- Encourages the prohibition of offshore drilling in the Great Lakes and in the Finger Lakes

Petroleum and Natural Gas cont.

- In the next five years, $140Million will be allocated to studies concerning exploration, gas hydrates, reservoir life, transportation, ultra clean fuels and environmental research.
- $450Million is going to be allocated specifically towards the Ultra-Deepwater and Unconventional Natural Gas and Other Petroleum Research fund.
  - This basically provides subsidies to companies which engage in deepwater exploration

Nuclear Energy

- Over the next five years, $2.05Billion has been set aside for R&D, commercial application, engineering, security, and waste storage associated with Nuclear energy.
- Nuclear Power 2010 Program:
  - A roadmap which promotes engineering and designing new nuclear plants and encourages new nuclear plants to be built

Hydrogen Fuel Cells

- The bill allocates money for "research and development on technologies relating to the production, purification, distribution, storage, and use of hydrogen energy, fuel cells, and related infrastructure."
- With the goal of "commercialize the use of hydrogen for transportation,…utility, industrial, commercial, and residential applications"
- Establishes an interagency task force composed of more than 8 government agencies with the goal of promoting the use of hydrogen fuel cells.

Hydrogen Fuel Cells cont.

- Funding: The Energy Bill calls for $1.06Billion over the next five years and for additional money for 2011 through 2020 allocated specifically for development of the hydrogen supply
- Funding: Calls for $860million over the next five years for development of fuel cell technologies, plus additional money for 2011 through 2020.

The Energy Bill and Transportation

- By 2015, the automobile industry should be able to sell hydrogen powered vehicles in the "mass consumer market"
- This also involves the construction of infrastructure to support hydrogen vehicles. Including: refueling stations, hydrogen production facilities, transmission of hydrogen and viable storage.

The Energy Bill and Transportation cont.

- Hybrid Vehicles: The bill encourages production and consumption of hybrid vehicles in a number of ways
  - There are various tax credits ranging from $8K to $40K for fuel cell vehicles
  - $1k to $4K for fuel efficient cars
  - $400 to $2,400 for Hybrid vehicles that reach a certain fuel efficiency

The Energy Bill and Transportation cont.

- Establishes a grant program which allocates money to municipalities that participate in pilot programs that utilize new transportation technology
- Other programs take aim at reducing engine idling, encourage bicycle usage, aviation fuel conservation, railroad efficiency, and fuel cell school buses

The Energy Bill and Pollution

- Part of the Coal initiative sets aside money for reducing pollution associated with burning coal
  - In 2006: $300million for pollution control equipment for controlling mercury, NOx and SO2, and particulates. (more money is set aside for following years)
- Other methods for reducing pollution involve making the products we use more energy efficient (Energy Star Products)

Global Impact of the Energy Bill

- "Set America Free Act of 2005"
  - Sets up a commission which will try to develop an energy policy for the US which would make it possible for North America to be "energy self sufficient" in 20 years.
  - $10million over the next two years to set up the commission

Global Spending on Energy R&D in 2004

- US: $2,850 Million
- Germany: $460 Million
- Japan: $3,963 Million
- UK: $66 Million
- Canada: $263 Million
- Turkey: $5.9 Million
- France: $517 Million (2002)

Source:
http://www.iea.org/rdd/engTableViewer/wdsview/dispviewwo.asp

My Personal Opinion

- I think that the US Energy Bill is very important for the country. After not having an energy policy for over 10 years it was important for the government to push through this legislation. I think it does a lot in terms of providing funding towards new technology that will make energy production more efficient and ecologically friendly. Furthermore, I think it addresses a key concern which is energy dependence on foreign sources of energy. Two key areas are hydrogen fuel cells and nuclear technology. I think that these two sources of energy are the future of our country.

My personal Opinion cont.

- Restarting the nuclear power industry will vastly improve air pollution (reducing sulfur, mercury and NOx) and will also cut down on green house gas emissions. This is particularly important because we already possess the nuclear technology and are comfortable with it which makes it a safe alternative.
- In regards to hydrogen, we possess the technology to produce hydrogen fuel cell cars, but I feel as if the infrastructure to support hydrogen energy is still at least 25 years away. I feel that the funding towards hydrogen supply and infrastructure is a step in the right direction.

My personal Opinion cont.

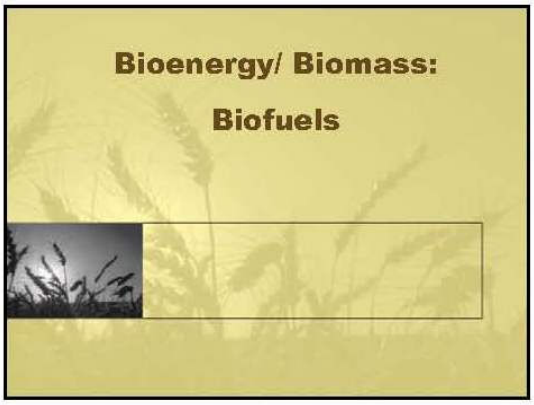
- There is one issue that I have with the energy bill, this is the vast amount of money that is seemingly being given away to the oil industry. Hurricane Katrina showed that our petroleum/gasoline supply is fragile; however, it also showed that the skyrocketing price of gasoline and oil as a result of supply shortages provides oil companies and executives with billions of dollars of profits. I think that it is unnecessary for Congress and the Bush administration to continuously pump money into the oil and gas industry when those companies are profiting so much off of the American people as it is. The energy bill has no policy regarding high gasoline prices, but still provides billions in subsidies to the oil and gas industry.

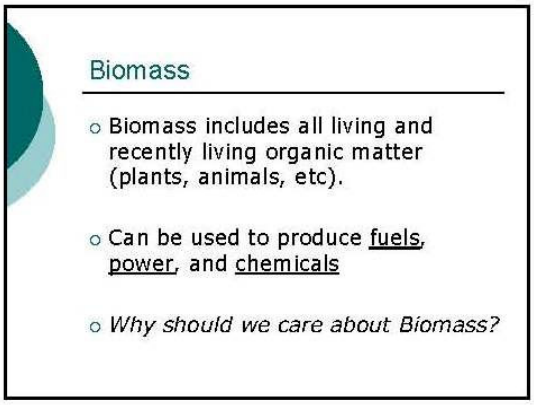
Bibliography

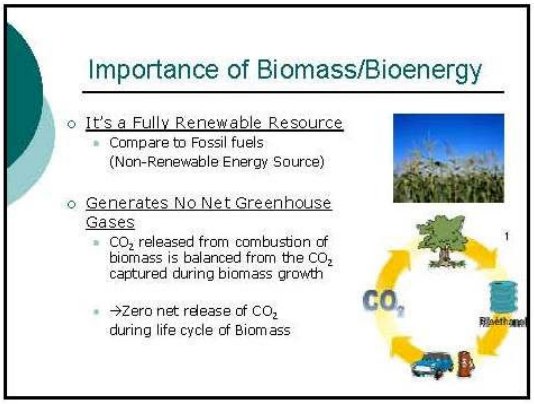
- "Energy Policy Act of 2005." THOMAS: Library of Congress. 08 Aug. 2005 <http://thomas.loc.gov/cgi-bin/bdquery/z?d109:h6:>.
- "IEA Energy Statistics." International Energy Agency. 5 Dec. 2005 <http://www.iea.org/Textbase/stats/rd.asp>.
- "President Signs Energy Policy Act." WhiteHouse.gov. 08 Aug. 2005. The White House. 4 Dec. 2005 <http://www.whitehouse.gov/news/releases/2005/08/20050808-6.html>.

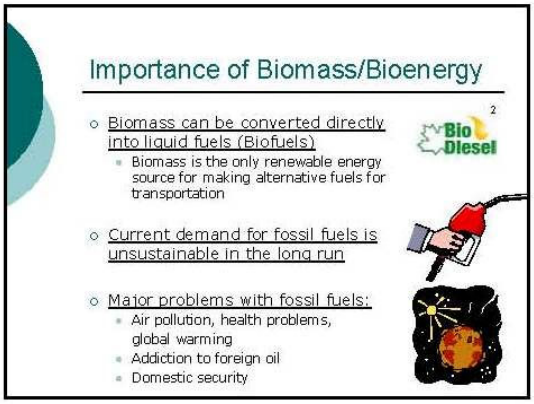
Questions?

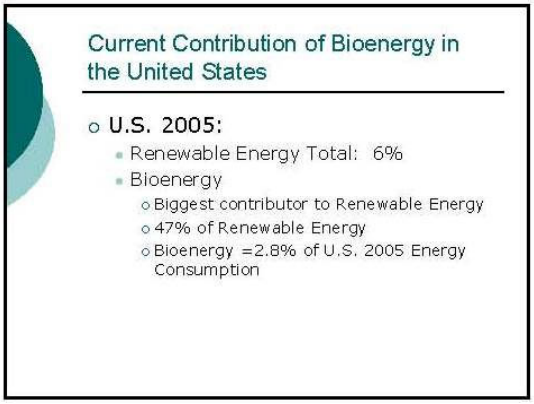
Figure 2. A Student's Presentation Illustrating the Depth of Research

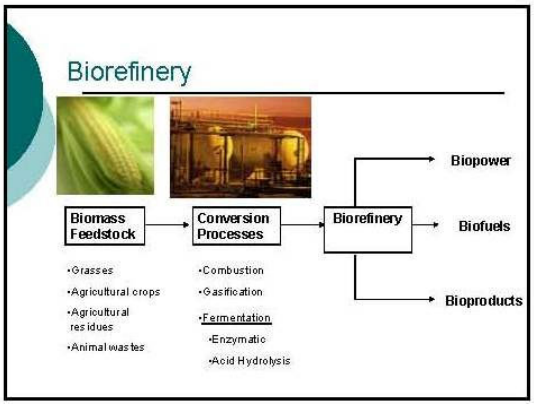












Biopower

- **Biomass Fuelled Power Plants**
- Combustion of Biomass produces Electricity, Heat, and Process Steam for:
  Paper Mill and 2 neighboring towns

Kvaerner Power Co.
Fluidized Bed Bio-Boiler:[3]
- Power Generated: 269 MW_{th}
- Location: Kymin Voima, Finland
- Start-Up: 2002

Bioproducts

- Chemicals and chemical products from biological sources (instead of petroleum)
  - Adhesives
  - Plastics
  - Solvents
  - Paints
  - Dyes, Pigments, Ink
  - Many more products

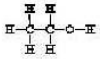
Biofuels

- Biomass can be directly converted into liquid fuels (Biofuels)
  - Helps meet transportation energy needs
  - Burns cleaner than gasoline
  - Reduces air pollution
  - Decreases dependence on foreign oil
  - Are biodegradable

- Two most common Biofuels
  1. **Bioethanol**
  2. **Biodiesel**

Bioethanol

- **Ethanol:** A 2-Carbon Alcohol
  - Same chemical that's in beer and wine
  - Produced by fermentation of any Biomass high in Carbohydrates



- **Bioethanol:**
  - *Denatured:*
    Chemicals added to make it unfit to drink (Methanol, Acetone, etc)
  - Derived from renewable biomass materials (corn, sugar, etc)

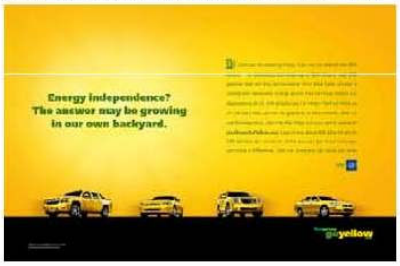
Bioethanol

- Can be used as either:
  - Alternative Fuel
    - **E100:** Pure Ethanol
    - **E85 Blend:** (85% Ethanol, 15% gasoline)
      - Major decrease in greenhouse gases (CO2, etc)
      - Horsepower increased by about 5 hp*
  - Additive to Gasoline
    - Boosts Octane # (Ethanol O.N. = 100-105)*
    - Reduces emissions of CO and other smog-forming pollutants
    - **E10 Blend:** (10% Ethanol, 90% gasoline)

*http://www.edmunds.com/advice/fueleconomy/articles/109194/article.html

General Motors Flex Fuel Vehicles

"Live Green, Go Yellow" Campaign: E85 fuel made from corn



Currently, GM has 1.5 million Flex Fuel vehicles on the road

In U.S., as of 2006, 5 million Flex Fuel vehicles owned*

Chevrolet Avalanche Flex Fuel truck:

Can run on E85 or gasoline[5]

* http://www.edmunds.com/advice/fueleconomy/articles/109194/article.html

Current Flex Fuel Vehicles

- Chevrolet 5.3L Avalanche (2005-2006)
- Chevrolet 3.5L Impala (2006)
- Chevrolet 3.5L Monte Carlo (2006)
- Chevrolet 2.2L S-10 (2000-2002)
- Chevrolet 5.3L Silverado (2002-2006)
- Chevrolet 5.3L Suburban (2002-2006)
- Chevrolet 5.3L Tahoe (2006)
- Chrysler 2.7L Sebring Sedan (2003-2006)
- Chrysler Town & Country (1998-2003)
- Chrysler/Plymouth 3.3L Voyager (1998-2003)
- Dodge 3.3L Caravan (1998-2000; 2004-2006)
- Dodge 3.3L Cargo (2003)
- Dodge 4.7L Durango (2006)
- Dodge 3.3L Grand Caravan (2004-2006)
- Dodge 2.7L Stratus (2003-2006)
- Dodge 4.7L Ram 1500 (2004-2006)
- GMC 4.3L Sierra (2002-2006)
- GMC 2.2L Sonoma (2000-2002)
- GMC 5.3L Yukon and Yukon XL (2002-2006)
- Ford 4.6L Crown Victoria (2006)
- Ford 4.0L Explorer (2002-2005)
- Ford 4.0L Explorer Sport Trac (2004-2005)
- Ford 5.4L F-150 (2006)
- Ford 3.0L Ranger (1999-2000)
- Ford 3.0L Ranger SuperCab (2001-2003)
- Ford 3.0L Taurus (1995-2006)
- Isuzu 2.2L Hombre (2000-2001)
- Lincoln 4.6L Town Car (2006)
- Mazda 3.0L B3000 (1999, 2001-2003)
- Mercedes-Benz 2.6L C240 (2005)
- Mercedes-Benz 3.2L C320 (2003-2005)
- Mercury 4.6L Grand Marquis (2006)
- Mercury 4.0L Mountaineer (2002-2005)
- Mercury 3.0L Sable (2002-2004)
- Nissan 5.6L Titan (2005-2006)

A variety of Cars, Pick-up Trucks, Minivans, and SUV's

2007 GM FlexFuel Vehicles

- As of 2006 GM producing 400,000 Flex Fuel Vehicles per year
- Other FlexFuel Vehicle Manufacturers:
  - Ford, Chrysler, Mazda, Dodge, others
- E85 Filling Stations*
  - Currrently 1075 in U.S.
  - Diagram of E85 locations on http://www.e85refueling.com/

*Data from National Ethanol Vehicle Coalition

States in U.S. with E85 Filling Stations

States in yellow contain E85 stations

Interactive Map on http://www.e85refueling.com allows the location of individual refilling stations

www.e85refueling.com

Bioethanol Stats

- In 2004, the use of ethanol as a fuel reduced the emissions of greenhouse gases in the U.S. by about 7 million tons *
  - →Equivalent of taking 1 million cars off the road
- In 2005, annual production of ethanol in U.S.: 3.25 billion gallons **
- 2005 Renewable Fuels Standard:
  - Mandates annual U.S. ethanol production double by 2012 to 7.5 billion gallons

*Study by Department of Energy's Argonne National Laboratory

** http://www.edmunds.com/advice/fueleconomy/articles/109194/article.html

Bioethanol: Current Feedstocks

- Current Feedstocks:
  - **Starches** (Corn)
  - **Sugars** (Sugar Cane)
    - →Sources: Crops which have to be grown
    - →*Fossil fuels required in agricultural processes of planting, growing, and harvesting*

- Can be directly fermented and processed into Ethanol

What is the Future of Bioethanol ?

- Corn ethanol is considered to be a "transition" biofuel.
- "To have ethanol make a dent in gas consumption and global warming, we'll need a wide-scale switch from corn to cellulosic ethanol"

Dr. Daniel Kammen
Professor in the Energy and Resources Group
Director of Renewable and Appropriate Energy Laboratory
University of California, Berkeley

Bioethanol: Future Feedstocks

- New Feedstocks: **Advanced Bioethanol Technology** (R&D Phase)
  - Cellulose
  - Hemicellulose
  - Lignin

  > Three main components of plants (fibers, structural components of cell walls)

  - → Vast majority of plant biomass is composed of these substances!
  - → Sources: Waste products!
    - Agricultral residues (leftover materials from crops)
      - **stalks, leaves, husks, straw,** etc.
    - Forestry residues (wastes from lumber mills and forests)
      - **wood chips, sawdust, dead trees, tree branches**

R&D Bioethanol Feedstocks

6

Cedar woodchips

7

Leftover sawdust from cutting logs at sawmill

Challenges with New Feedstocks

- Compared to Starch and Sugar:
  - Harder to break the cellulose and hemicellulose polymers into component sugars (monomers)
    - Cellulose has crystalline structure→ Insoluble, resistant to attack
  - Hemicellulose has some component sugars which are difficult to ferment
  - Lignin is composed of monolingol monomers, not sugar monomers

Process for Making Bioethanol

1. **Convert biomass into useable fermentation feedstock (some form of sugar)**

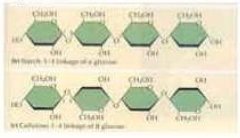
   Polysaccharide → Glucose, Fructose, Galactose, etc

Hydrolysis: ("water splitting") of polysaccharides (polymer) into sugars (monomers)

- H_2O molecules attack and split the bonds between monomers in the polymer chain
- Acid Hydrolysis (Acid acts as a catalyst)
- Enzymatic Hydrolysis (Cellulase enzyme catalyst)

Polysaccharides

8

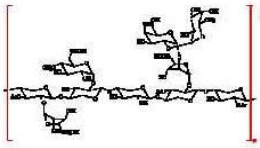


Starch and Cellulose

•Straight chain Polymers composed only of glucose (6-carbon sugar) monomers

•The bonding between glucose units in the chain is different

9



Hemicellulose

•Brached polymer composed of several different 5 and 6-carbon sugar monomers (xylose, galactose, mannose, glucose, etc)

Cellulosic Ethanol

18

Mr. Stavros Dimas, Commissioner for Environment, European Commission, visits logen facility, fuels up with cellulose ethanol - September 22, 2005

Problems with Ethanol as a Fuel??

1. Higher concentrations of ethanol (E85, E100) could corrode pumps and fuel lines (corrodes metal, makes plastic brittle)
   - Today, Flex-Fuel vehicle's fuel delivery system is typically replaced with stainless steel or Teflon-coated components to ensure the E85 does not corrode them*
   - Automakers only warrant the use of E10 in non-Flex Fuel vehicles
     →However, recent studies by the American Coalition for Ethanol have shown that E10, E20, and E30 do not cause damage when run in non-Flex Fuel vehicles*
2. Slight drop in fuel economy (~10%) for E85 compared to pure gasoline*
   - Ethanol has a lower energy content than gasoline
   - Therefore, more of it has to be burned

*http://www.edmunds.com/advice/fueleconomy/articles/109194/article.html

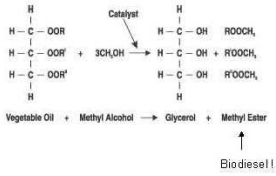
Projection of Contribution of Bioethanol to U.S. Energy Consumption

- By 2025:
  - Oil Replaced: 8 million barrels/ day
  - CO_2 Displaced: 500 MMT/ year *
  - Transportation Needs Met: 30%

- MMT = million metric tons
- Tom Cline. Study by Popular Science **"STEP TO END AMERICA'S FOSSIL-FUEL ADDICTION" July 2006**

Biodiesel

- **Fatty Acid Methyl Esters**
- Produced from Transesterification reaction of Triacylglycerols (from Fat or Vegetable Oil) and Methanol
- Reaction is catalyzed by base (NaOH, KOH, etc)



Biodiesel !

Advantages of Biodiesel as an Alternative Fuel

1. Clean burning
   - Significantly less emissions when burned than Petroleum Diesel (CO, Unburned Hydrocarbons, Particulate Emissions)
2. Produced from domestic, renewable resources
   - vegetable oil from soybeans
   - yellow grease from animal fats, etc
3. Contains no petroleum, but can be blended with petroleum diesel
4. Can be used in diesel engines with little or no modification
5. Biodegradable, nontoxic
6. Essentially free of sulfur and aromatics
7. Excellent lubricating qualities

Common Fuel Blends:
- B100 (Pure Biodiesel)
- B20 (20% Biodiesel, 80% Petroleum Diesel)

U.S.: Biodiesel Retail Fueling Sites

(Data as of 12/4/06)

From National Biodiesel board

18

Cellulosic Ethanol

18

Mr. Stavros Dimas, Commissioner for Environment, European Commission, visits logen facility, fuels up with cellulose ethanol - September 22, 2005

Problems with Ethanol as a Fuel??

1. Higher concentrations of ethanol (E85, E100) could corrode pumps and fuel lines (corrodes metal, makes plastic brittle)
   - Today, Flex-Fuel vehicle's fuel delivery system is typically replaced with stainless steel or Teflon-coated components to ensure the E85 does not corrode them*
   - Automakers only warrant the use of E10 in non-Flex Fuel vehicles
     →However, recent studies by the American Coalition for Ethanol have shown that E10, E20, and E30 do not cause damage when run in non-Flex Fuel vehicles*
2. Slight drop in fuel economy (~10%) for E85 compared to pure gasoline*
   - Ethanol has a lower energy content than gasoline
   - Therefore, more of it has to be burned

*http://www.edmunds.com/advice/fueleconomy/articles/109194/article.html

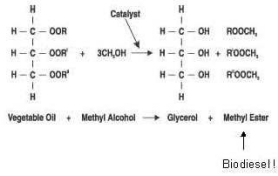
Projection of Contribution of Bioethanol to U.S. Energy Consumption

- By 2025:
  - Oil Replaced: 8 million barrels/ day
  - CO_2 Displaced: 500 MMT/ year *
  - Transportation Needs Met: 30%

- MMT = million metric tons
- Tom Cline. Study by Popular Science **"STEP TO END AMERICA'S FOSSIL-FUEL ADDICTION" July 2006**

Biodiesel

- **Fatty Acid Methyl Esters**
- Produced from Transesterification reaction of Triacylglycerols (from Fat or Vegetable Oil) and Methanol
- Reaction is catalyzed by base (NaOH, KOH, etc)



Biodiesel !

Advantages of Biodiesel as an Alternative Fuel

1. Clean burning
   - Significantly less emissions when burned than Petroleum Diesel (CO, Unburned Hydrocarbons, Particulate Emissions)
2. Produced from domestic, renewable resources
   - vegetable oil from soybeans
   - yellow grease from animal fats, etc
3. Contains no petroleum, but can be blended with petroleum diesel
4. Can be used in diesel engines with little or no modification
5. Biodegradable, nontoxic
6. Essentially free of sulfur and aromatics
7. Excellent lubricating qualities

Common Fuel Blends:
- B100 (Pure Biodiesel)
- B20 (20% Biodiesel, 80% Petroleum Diesel)

U.S.: Biodiesel Retail Fueling Sites

(Data as of 12/4/06)

From National Biodiesel board

18

U.S. Biodiesel Sales Volume

- 2005 -- 75 million gallons
  2004 -- 25 million gallons
  2003 -- 20 million gallons
  2002 -- 15 million gallons
  2001 -- 5 million gallons
  2000 -- 2 million gallons
  1999 -- 500,000 gallons

Estimates from National Biodiesel Board

Biofuels Filling Station (Bioethanol and Biodiesel)

19

Biofuels in the World

- Biofuels can be made practically worldwide.
- In several countries, they comprise a significant portion of their transportation needs

Brazil

- World's leader in production of sugar and sugarcane-based ethanol
- Produced 4.4 billion gallons of bioethanol in 2005
- Requires a 20% blend of ethanol in <u>all</u> gasoline sold in the country (E20)
- Recent introduction of Flex-Fuel vehicles has increased domestic consumption of bioethanol and spurred increased investment in ethanol production
- The use of baggase (residue left after extraction from sugar cane) to generate power in sugar/ethanol mills.
  - Lower energy usage in ethanol production
  - Major cost savings

***Phil Jarrell and Mary Rekas. "Biofuels Coming Online: International Biofuel Use Expands"**
Foreign Agricultural Service. U.S. Department of Agriculture. July 2006
http://www.fas.usda.gov/info/fasworldwide/2006/07-2006/BiofuelsOverview.htm

European Union

- EU has established a Biofuels mandate for Fuel Consumption
  - From voluntary target of 2% in 2005 to 5.75% in 2010
  - In 2005 biofuel use was below the 2% target, but is growing significantly
- Main biofuel in the EU: <u>Biodiesel</u> (80% of EU biofuel usage)

***Phil Jarrell and Mary Rekas. "Biofuels Coming Online: International Biofuel Use Expands"**
Foreign Agricultural Service. U.S. Department of Agriculture. July 2006
http://www.fas.usda.gov/info/fasworldwide/2006/07-2006/BiofuelsOverview.htm

Finland

- Bioenergy accounts for
  - 20% of primary energy consumption
  - 10% of electricity demand
  - These are the highest levels for any industrialized country
- Goal: increase bioenergy usage by 35% over next decade

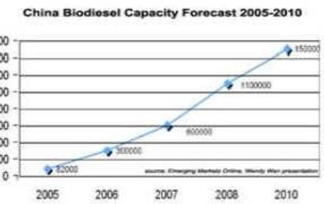
http://www.unep.org/GC/GCSS-IX/Documents/FINLAND-bioenergy.pdf

Nepal

- Currently have 137,000 biogas plants built by Biogas Sector Partnership (with Dutch and German support)
- Biogas plants use bacteria to generate methane gas from cattle dung in underground digesters The gas is burnt in kitchen stoves instead of wood or kerosene.
- Biogas burns cleaner and decreases smoke pollution risk in homes.
- 400,000 tonnes of firewood and 800,000 litres of kerosene are no longer needed each year, avoiding 600,000 tonnes of greenhouse gases
- BSP plans to build 200,000 more in the next 5 years.

http://biopact.com/2006/10/small-is-bountiful-in-nepals-energy.html

China



http://biopact.com/2006/11/chinas-growing-thirst-for-biodiesel.html

Zimbabwe

- Has major potential to produce ethanol from molasses
- Study in 2000 says that capacity to produce ethanol from all sugars available could account for 43% of their annual gasoline consumption

http://www.carensa.net/PDF/CarensaScenarios%20WBC%20Poster%5B2%5D.pdf

Images References

1. http://www.surrealiste.org/modules/wfchannel/images/Fiches-wiki/bioethanol/co2.gif
2. http://www.bcsea.org/images/se-biodiesel.gif
3. http://www.metsoautomation.com/automation/index.nsf/FR?ReadForm&ATL=/automation/ep_prod.nsf/WebWID/WTB-041029-2256F-57194
4. http://www.gm.com/company/onlygm/livegreengoyellow/index.html
5. http://www.edmunds.com/advice/fueleconomy/articles/109194/article.html
6. http://www.spi-ind.com/Sales/Bark_Fiber_Prod.htm
7. http://www.sentex.net/~mwandel/sawmill/sawdust.jpg
8. http://faculty.uca.edu/~johnc/starch%20and%20cellulose%20compared.jpg
9. http://members.lycos.fr/nico911/images/hemicell.gif
10. http://www1.eere.energy.gov/biomass/biomass_today.html
11. http://www1.eere.energy.gov/biomass/dilute_acid.html
12. http://www.diversa.com/Pages/Products/AlternativeFuels/AltFuelsCellulosic.html
13. http://www.diversa.com/
14. http://www.iogen.ca/news_events/media_resources/index.html
15. http://www.genencor.com/wt/home
16. http://www.novozymes.com/en/MainStructure/ProductsAndSolutions/Fuel+ethanol/Fuel+ethanol.htm
17. http://www.iogen.ca/news_events/media_resources/index.html
18. http://www.biodiesel.org/buyingbiodiesel/retailfuelingsites/
19. http://www1.eere.energy.gov/biomass/abcs_biofuels.html

Source References

- http://www1.eere.energy.gov/biomass/abcs_biofuels.html
- http://www1.eere.energy.gov/biomass/understanding_biomass.html
- http://www1.eere.energy.gov/biomass/biomass_basics_faqs.html#bioethanol
- http://www.biodiesel.org/
- http://www1.eere.energy.gov/biomass/renewable_diesel.html

Questions?

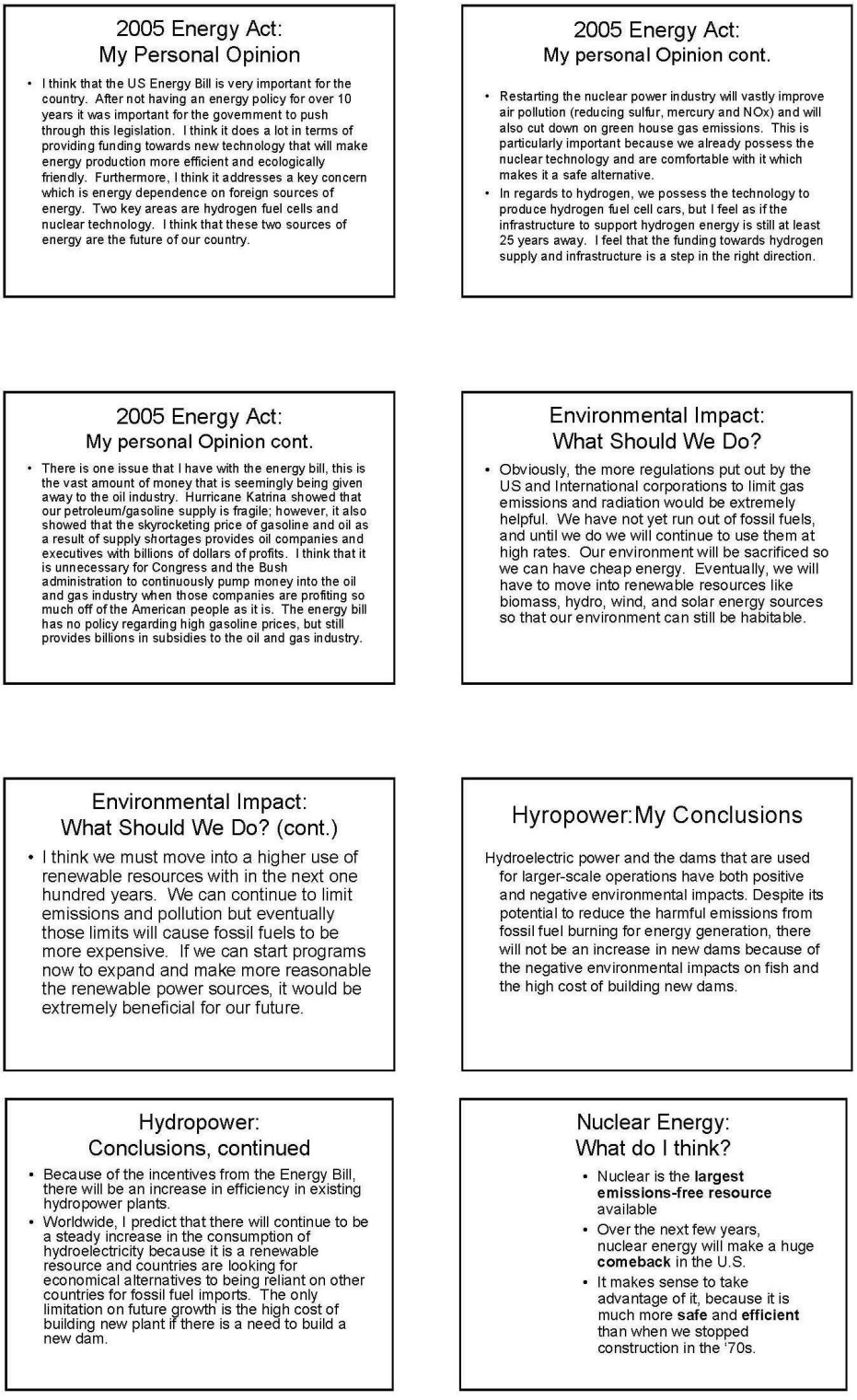


Figure 3. Summary of some of the personal opinions/conclusions provided by students