AC 2009-1867: EDUCATING ENGINEERING STUDENTS ON ENERGY SYSTEMS THROUGH INVESTOR-DRIVEN CLASS PROJECTS

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Educating Engineering Students on Energy Systems Through Investor-Driven Class Projects

Abstract

Efficient use of energy resources is becoming increasingly important with respect to minimizing climate change, decreasing financial burdens associated with energy use, and enabling national goals of energy independence. This can only be achieved, however, if engineers of *all* disciplines have a sound understanding of energy issues as they design their systems. Such facets include not only conversion technology, but also resource availability, energy delivery, policy, reliability, and short and long-term financial, social, and environmental costs.

This paper will describe class projects in energy conversion that attempt to raise awareness in these areas, and do so with respect to a diverse group of senior and graduate engineering students. For the projects, students chose a conversion technology primarily for electric power generation, wrote a paper outlining why they supported or opposed its implementation, and then presented their research to their peers. Meanwhile, the entire class was split up into groups of short and long term investors and given a pool of money to allocate to a variety of technologies and sources to create a true energy portfolio. They could then make their investment decisions as they listened to each of the presentations.

The quantifiable results of the course comprise two snapshots of the students' perceptions. At the beginning of the class, students completed a survey about general energy issues. The students' perceptions were also compiled upon completion of the project through their investment decisions and a set of associated questions. The results were analyzed with respect to engineering major and also compared to the general population and professionals with a background in energy issues from publicly available surveys and/or governmental energy forecasts. In addition to these results, this research will illustrate the implementation of such class projects, describe common student strengths and weaknesses relative to energy conversion, and explain the importance of defining appropriate prerequisites for a diversity of engineering majors.

1. Introduction

Energy touches every aspect of human behavior, spanning a spectrum of use that ranges from powering the human body to satisfying creative and recreational needs. The complexity of its various uses, forms, and means of transport is complicated further by the level of required investment, lengthy planning and implementation timelines, and public policies (including environmental protection). Public awareness on energy is continuously shaped by the media – by way of both journalism and the advertising messages of special interest entities – and is sometimes shaped with incorrect or misleading information (a survey of journalists found that over 70% of the respondents believed that sources such as lobbying organizations and special interest groups were not credible sources[6] even though they account for a significant quantity of advertising on broadcast, cable, and the Internet). If the United States and indeed all countries of the world are to develop long-term, strategic, sustainable policies on energy, we must involve the best and brightest in the process. Who better to separate technical fact from fiction and to serve as ambassadors to the public at large on energy issues than our next generation of engineers?

1.1. Course Description

It is this very question that prompted a new engineering course in energy conversion at the University of Minnesota Duluth - open to seniors and graduate students in three engineering majors: Chemical (ChE), Electrical and Computer (ECE), and Mechanical and Industrial (MIE) Engineering – tailored to measure awareness and then shape it through lecture, individual and group assignments, invited speakers, and research papers and presentations. The course was designed to provide the students with exposure to the same three facets of the engineering discipline that drive energy decisions in the real-world: technology, investment, and public policy. A secondary objective for offering the course was to stimulate interest in energy-related careers, a field that today lacks adequate personnel with expertise and will have vastly increased needs for such talent in the future[3, 7].

Throughout the course, frequent references are made to the engineering elements involved in a given conversion technology, as well as the engineering issues latent in existing and proposed energy policies. It is stressed that the discipline of engineering is often viewed as the application of science and technology to the needs of society, which reinforces to the students that engineering energy solutions go beyond technology to include such aspects as economics, finance, and policy. Discussion of each conversion technology also addresses certain basic engineering elements, such as developing a conceptual design, evaluating available components and materials, developing budgets and schedules, and consideration of the system's operability and maintainability.

The semester-long course primarily targets electric power generation. It addresses energy basics, such as units, conversions, and formulae at the outset to ensure that the diverse backgrounds represented in the class are on a common footing. National and global energy reserves, and consumption and conversion statistics are also examined, highlighting the sheer size of the quantities and impact of consumption rates on proven reserves. Other topics discussed include the earth-sun energy balance, combustion chemistry (to place carbon dioxide effects in context), the status of climate change and predicted impacts, electrical energy systems, convergences with other energy consuming sectors (such as transportation, industry, and agriculture), delivery systems and reliability considerations, and the latest statutes and policies governing energy. The course concludes with each student giving a 10-minute presentation on a chosen conversion technology, arguing either for or against it. An abbreviated course syllabus is included in Appendix B.

Given this knowledge and insights, students are then expected to allocate US $100 billion to various conversion technologies, acting as either U.S. government energy czars or as private investment advisors. They are encouraged to change their allocations as presentations occur, using both what they see presented as well as material from the course to shape their decisions.

The course emphasizes the diversity that exists in energy availability by region, diversity in energy use due to geopolitical factors, and diversity in supply of the system components. Single-technology solutions are compared to a future having a portfolio of solutions. A web-based calculator developed specifically for the class allows students to explore combinations of conversion technologies by adjusting component weights to determine cost and greenhouse gas impacts. Resource plans of several utilities are then used to supplement lectures to support students' calculator findings.

Each of the three engineering majors eligible for this elective course has their own distinct set of prerequisites, resulting in the prerequisite requirement for this course necessarily narrowing to that of completion of lower division coursework and status as a senior or graduate student. Lectures and exercises were structured with special consideration to four important theoretical topics within energy in which students in the three majors may not be universally well versed; namely, heat transfer, thermodynamics, electrical circuit theory, and chemistry.

1.2. Results Discussed in this Paper

The objectives of this paper are to share an approach used to educate a diverse group of engineering students on energy conversion and to summarize the efficacy of the process used in both quantitative and subjective terms. Discussion tracks the students as they progress through the semester, starting with a Likert-style survey[9] of their perceptions on energy on the first day of class. During the first few weeks, as students select an energy conversion technology to research and defend, some sense is gained on what this forthcoming generation of engineers finds interesting and feasible, in spite of external influences. As the course wraps up, a comparison unfolds between the short and long-term investment thinking of the respective private investor and government camps. The details within each of these camps provide additional conclusions on student mindset as they complete the class.

Summarizing the impact of the class on perceptions is more of a qualitative exercise that uses quantitative inputs, rather than a strictly data-driven exercise. The course was as much about students developing the ability to converse about energy as it was about understanding its theories and systems, and so some observations will be offered here as well.

1.3. Organization of Paper

A brief discussion of the field of energy conversion and the need for a portfolio approach to future choices is followed by a description of the student research project. Project guidelines and the pedagogical reasoning behind the assignment are then summarized. After this, the results of the initial class survey are presented, along with a discussion of the final investment choices made by students. The paper concludes with observations on potential improvements and student responses to the class generally, as well as thoughts on future research opportunities.

2. Energy Conversion and Imminent Critical Decisions

The U.S. electric power system, or "grid" as it is often referred to, has been referred to by industry insiders as the most complex machine ever developed, yet its thousands of generators and hundreds of thousands of miles of transmission and distribution facilities usually operate in unnoticed support of our economy and way of living. So important is electricity to our daily lives that electrification was named the number one technological achievement of the 20^{th} century by the National Academy of Engineering (NAE) - more important than the introduction of the automobile, the telephone, the microprocessor or even aviation[15]. As we explain to students, *all* of the technologies considered by the NAE ranking are either integral to grid operations or are supported in some way by electrical energy. This interdependent technological mix makes reliability and quality of electric supply a critical requirement. And unlike other energy systems, electrical energy cannot be inventoried in any meaningful quantity; the energy demanded by loads must always be in balance with the energy converted to electrical form.

A previous generation of engineers worked largely with a grid architecture involving large generators, all capable of having their outputs varied in accordance with overall demand. This central-station, highly dispatchable era (that still dominates today) involved public policy issues such as nuclear plant safety and waste storage, reducing particulates and other emissions from fossil-fueled plants, siting of generation and transmission facilities, deregulation at both state and Federal levels, and escalating costs. Graduates of today's engineering programs will enter the field in a new era of rapid change driven by renewable energy mandates and greenhouse gas concerns. This new era is characterized by distributed generation, the potential of more nuclear facilities, the growing presence of non-dispatchable wind and solar, reinvestment in transmission facilities, new control systems in the delivery system, and streamlined siting processes.

Adding to this complexity is the shear size of investments required - large plant projects described in billions of dollars, not millions; transmission facilities costing a million dollars or more per mile – with planning horizons that can easily span a decade. The national and global response to global warming may need to occur prior to a tipping point[8]. And to top it all, the energy moves at near the speed of light so that poor choices made with policy or during the planning or engineering phases can increase the chances of instantaneously placing millions of citizens in the dark.

It is this very state of affairs that serves as the impetus for expanding coursework in energy and preparing engineering graduates to leading society through the complex set of issues. All of the aforementioned issues and characteristics are elements of the course described herein, and the surrounding discussion arguably forged the awareness and opinions of the class participants. Each student registering for the class had to first obtain permission from the instructor, a process where an informal interview revealed the student's interest in energy and provided some assurance that some pre-existing attraction to the topic existed (beyond simply a need for credits). Those admitted to the class had their first academic opportunity to learn why the complex mix of technology, investment, and policy makes the field one of the most exciting to consider working in.

3. The Student Research Project

The project is introduced to students as one where they must argue for or against a particular energy conversion technology. It is stressed that, in graduate school or in an engineering career, they will very likely encounter the need to research a topic and defend a position. They are asked to research, write and present as though they are the single person advising management or policy makers on an energy decision that will involve substantial amounts of capital. In other words, papers and presentations must be based in fact and convincing with their conclusions.

Technical content must also be sufficient to effectively communicate with other engineers while simultaneously explained in terms and at conceptual levels understandable by non-technical audiences that hold decision-making authority. This emphasis on effectively translating complex energy topics into a message graspable to a wider audience is not only a skill important in the real world, but is equally important to convincing other classmates with diverse backgrounds to invest their US $100 billion funds appropriately. Another pedagogical reason is that both the accreditation board and the ECE Department's industrial advisory board have consistently recommended that a continued emphasis be placed on providing opportunities wherever possible for students to write, speak, defend, and engage in critical decision making on complex topics[1]. Energy, it is argued, is among the most pertinent subject areas to offer such opportunities.

In addition to the above discussion, students are given guidelines that include the following (a full set of guidelines with the pedagogical reasoning can be found in Appendix A):

- The project steps comprise topic selection, abstract, rough and final drafts, and a presentation.
- Projects must relate to the conversion of energy for the production of electricity in the context of proposing to construct a conversion facility, as part of a broader portfolio expansion, or research and development (R&D) effort.
- Technology options: Biomass, oil, natural gas, propane, nuclear fission, nuclear fusion, coal, integrated gas combined cycle (clean coal), hydro, wind, solar photovoltaic, solar thermal, tidal, geothermal, and fuel cells.
- The paper must describe the energy conversion process, its economic, social, and environmental sustainability issues and the policies and incentives that promote its use, and make a recommendation of where in the portfolio it should reside.
- Papers and presentations are given appropriate page and time limits, respectively.

3.1. Pedagogical Reasoning behind Each Guideline

The guidelines described above are derived from formats used widely in business and industry. The electrical energy emphasis is used to enable a broad range of technologies and thus student choices. Student choice has been shown to have a high correlation with students' self-efficacy and motivation to learn[4, 16]. Students are also deliberately exposed to the broader aspects of engineering, such as the need to be able to advise co-workers, organizations, and/or employers with high-level recommendations developed through extensive analysis, the ability to analyze a technology in terms of its non-technical impacts economically, socially, and environmentally, and the capability to communicate findings effectively in written and oral formats within the given constraints to audiences with varying backgrounds[1]. Within the area of environmental impact, students are to be conversant not only with CO_2 emissions of a particular technology, but also with respect to greenhouse gases and global warming generally.

The investment allocation process draws on the student's biases, knowledge gained during the course, and personal research. Students are surprised initially at the size of the capital they receive, until it is shown that the real investments will be even larger. The exercise also forces students to allocate a scarce resource (capital) to many possible choices, each having unique short and long-term implications for the adequacy and reliability of energy supply, and on society.

4. Survey Results

4.1. The Initial Survey

Students received as their first homework assignment a Likert-style survey on energy-related topics that consists of 36 statements (see Appendix C). Students were asked to indicate their agreement with each statement on a 9-point scale, where a "1" indicates "Strongly Disagree and a "9" indicates "Strongly Agree." This relatively simple survey style was selected to make it as easy as possible to ascertain perceptions, compared to a non-quantitative approach where they might be asked to write a short response on each topic. The results of this survey style were relatively easy and fast to compile with some basic measures. Means and standard deviations for each question were computed. The mean values were used to conclude how the class felt generally about a particular statement, while the deviation suggested how similar or diverse the class was in its perception.

Sharing these results was deemed as an essential pedagogical step in the class, a step intended to emphasize to a given student how their own perceptions on energy might compare to others, and that the educational content of the course may very well change their views. Giving them a sense of how their classmates viewed topics lays a foundation of tolerance that would be needed for several in-class group projects later in the course.

Survey statements cover energy consumption, resource dependency, climate change, cost, sustainability of technologies, elimination of technologies, and transmission barriers. Statements are briefly reviewed in class when first distributed, and students are encouraged to use their intuition to rank statements on topics that are unfamiliar (instead of not assigning a ranking). The survey was administered to two energy conversion systems classes that were offered during the spring and fall semesters of 2008. Enrollment in each were 23 and 18 students, respectively, with each drawing more heavily from ECE and MIE seniors and graduate students than from ChE.

Results were predictable in some areas and surprising on other aspects. As shown in Table 1, several topics showed distinct polarization. Both classes *strongly disagreed* with 1) eliminating all nuclear generation, 2) that coal-fired generation is sustainable, 3) that the public is sufficiently educated on energy to guide policymakers, and 4) that celebrities are credible sources on energy matters. Similarly, both classes *strongly agreed* that the United States uses much more energy per capital than other countries and that the concentration of carbon dioxide in the atmosphere is increasing.

Table 1: Mean of Responses

Statement	**Spring**	**Fall**
All nuclear generation should be eliminated	2.4	2.3
Public is sufficiently educated on energy & environment to guide policy	2.6	2.0
Celebrities are credible sources on energy & environment	2.8	2.0
Coal-based electrical generation is a sustainable technology	2.8	2.0
U.S. uses more energy per capita than any other country	8.2	5.8
Concentration of CO_2 in the atmosphere is increasing	7.2	6.0

In contrast to the similarity between classes on polarizing topics, there appeared to be no correlation between the classes on topics that had the greatest or least consensus (shown in Tables 2 and 3, respectively). For example, the Spring 2008 class had the lowest standard deviation on statements involving U.S. energy consumption and the role of the Earth's albedo in climate change, while the Fall 2008 class was most consistent in their responses on the public having sufficient energy education and increasing levels of carbon dioxide.

Table 2: Greatest Consensus (Standard Deviation)

Statement	**Spring**
The United States uses more energy per capita than any other country	1.2
Variations in the Earth's reflectivity impact climate change	1.4
Celebrities are credible sources of advice on energy and the environment	1.5
Energy transmission is a significant barrier to efficient energy choices	1.5
	Fall
Public is sufficiently educated on energy & environment to guide policy	1.1
The concentration of carbon dioxide in the atmosphere is increasing	1.4
Tidal power is a sustainable technology	1.6

Table 3: Least Consensus (Standard Deviation)

Statement	**Spring**
Cost of gas, heating, & electricity is a reasonable % of my monthly budget	6.4
Solar is a sustainable technology	4.8
Global warming poses life-threatening risk in the next 100 years	4.6
	Fall
All nuclear electrical generation should be eliminated	6.2
The United States uses more energy per capita than any other country	5.7
Celebrities are credible sources of advice on energy and the environment	5.7

4.2. Observations

By examining the responses to statements on the sustainability of various technologies, it was clear that solar, wind and tidal are all popular in this regard, although the spring class was far more committed in their opinions (means ranged from 6.7 to 7.0) compared to the fall class (means were midrange between 5.0 and 5.5). One possible explanation for this result might be linked to the fact that the fall class was dominated by ECE majors (56%) who may have better understood the difficulties of integrating these technologies with the grid, relative to the spring class that was dominated by MIE majors (52%). Interestingly, biomass, currently a close second to hydroelectric generation as a source of total renewable energy in the United States[13], was consistently ranked near the bottom of renewable alternatives for electrical generation. Discussions with students during the semester revealed widespread concern over what they termed "inappropriate use" of crops and other biomass for fuels, due to the resulting impacts on food prices and desertification.

Responses on four statements linked to economics consistently showed a very strong belief that world economies are tied to the availability of energy. But at the same time, students in both classes moderately disagreed with the notion that the environmental impacts of energy conversion are less important than the benefits derived from electricity. As with the opinions on biomass, students in both classes showed impressive sensitivity to the environment. They were consistently and strongly opposed, however, to eliminating those major conversion technologies using hydrocarbons or nuclear fuel. While coal was consistently and strongly viewed as unsustainable, students felt strongly that it is too important to the overall generation mix to eliminate in the immediate future. These results are encouraging, as they suggest that the seniors and graduate engineering students entering the course have a sense for the complexity of the matter, understand that the generation mix must change significantly, but that change must occur methodically.

On matters of policy, students felt very strongly that the United States does not have a clear energy policy, and that friends and neighbors are insufficiently educated on energy to provide guidance to elected officials and regulators (policymakers). The positive sentiment toward nuclear generation was accompanied by tepid, mid-range responses on its sustainability. As subsequent feedback from lectures would bear out, students were willing to consider nuclear as a sustainable technology if policy permitted the use of breeder reactors *and* if the debate over waste storage were resolved.

Finally, regarding climate change, students were solidly convinced that carbon dioxide levels in the atmosphere are rising, and were almost as strongly convinced that the earth is warming and that CO_2 is the primary driver. Responses also indicated a very high level of awareness that the current warming is not the first for the planet[10].

Taken together, these results suggested that students were entering the class with some basic knowledge of energy and some well developed opinions about its future. Lectures were modified accordingly to focus on those topics where perceptions may contain hidden engineering obstacles. For instance, the very positive attitudes toward wind as a sustainable technology suggested that some time be devoted to explaining the issues of integrating wind with the existing grid, the response of wind turbines during grid disturbances, and the operational impacts of powering the grid with large percentages of non-dispatchable generation[11].

4.3. The Investment Exercise

Presentation of papers and investment decisions occurred in the final weeks of each class. Students were encouraged to view the allocation of their US $100 Billion as a dynamic process influenced by the presentations before them. It was clear that students unanimously embraced the concept of a diversified generation portfolio after 12 weeks of the course, as no student allocated all of their funds in a single technology.

Government and private equity investment choices for the spring semester 2008 class are shown in the charts below. Hydroelectric investment was noticeably less for private investors, perhaps due to the material presented during class on relicensing risks facing existing hydro facilities in the United States. Development of distributed generation was also perceived as a government function, unattractive to private investors. Nuclear fission was embraced more by the private investors; presentations lauded the lack of greenhouse gases and new incentives which likely influenced the large allocation. In contrast, nuclear fusion was deemed to be much more attractive to government funding.

Figure 1A: Government Energy Funding
of $100 Billion (US)
(As selected by twelve ECE 5995 Students, Spring 2008)

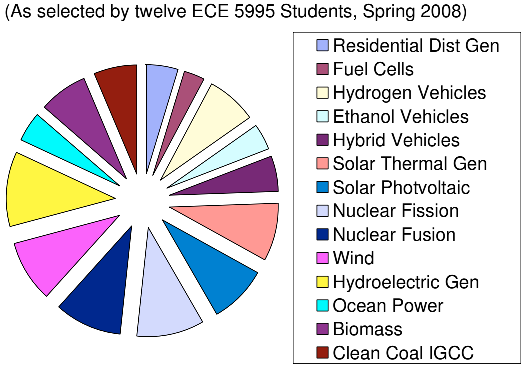
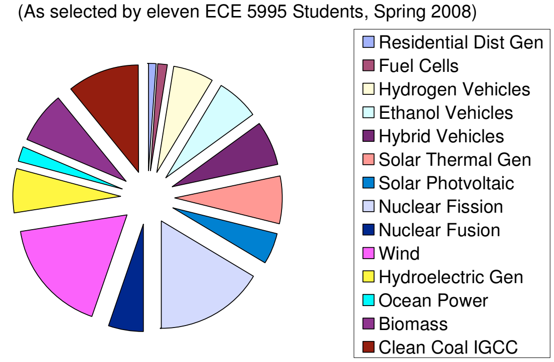
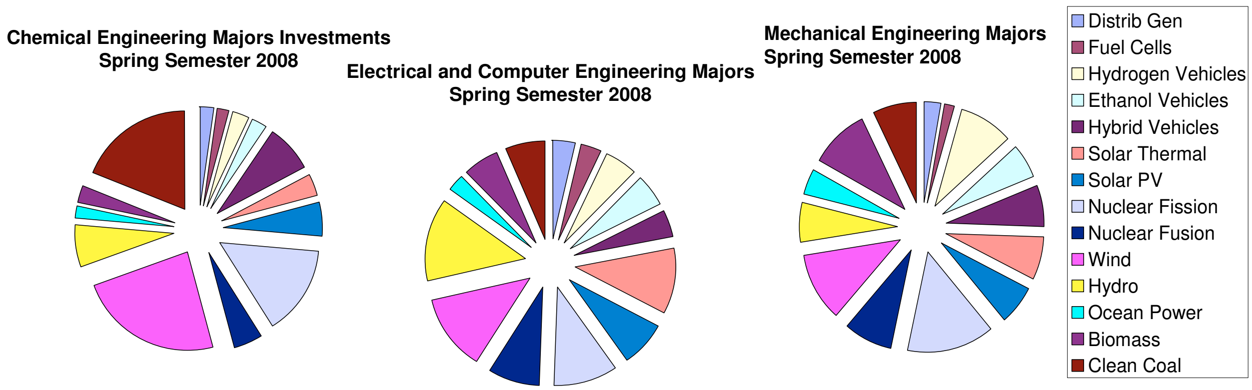


Figure 1B: Private Equity Investment
of $100 Billion (US)
(As selected by eleven ECE 5995 Students, Spring 2008)



Allocation of funds by major (ChE, ECE, and MIE) are shown below. ChE students favored clean coal, wind and nuclear fission, comprising 55% of their total investment. ECE majors emphasized hydroelectric, wind and solar thermal electric, constituting 38%. And MIE students placed 34% of their investment in fission, wind and biomass. Across the majors, ChE students showed much more interest in clean coal, and much less in nuclear fusion, than the others. ECE majors were noticeably more interested in hydroelectric, while MIE students were much more enamored with hydrogen-powered vehicles.

Figure 2: Investments by Major (Spring, 2008)



Results for the fall semester 2008 class, for government and private equity investment, are shown below. Note that the investment opportunities are not fully identical to those for the spring class due to the research interests of the students.

Figure 3A: Government Energy Funding
of $100 Billion (US)
(As selected by ten ECE 5995 Students, Fall 2008)

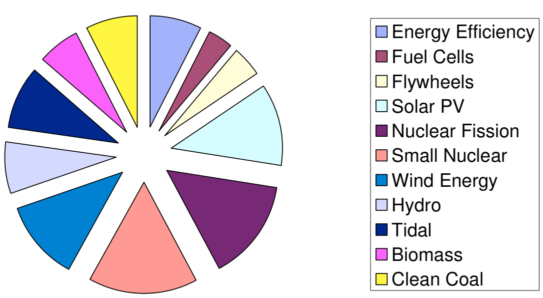
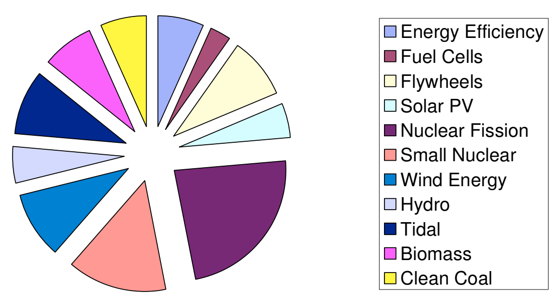
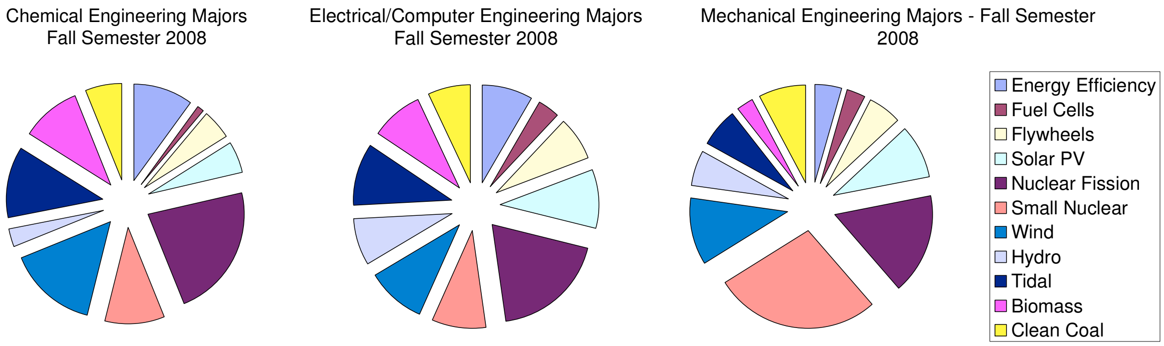


Figure 3B: Private Equity Investment
of $100 Billion (US)
(As selected by eight ECE 5995 Students, Fall 2008)



By major, the results are shown in Figure 4. For this second class, both the government and private investors were cool to fuel cell investment, and both were about equally interested in nuclear fission. Notable between the investor types is the much greater emphasis on solar photovoltaic (PV) technology by government, and the relatively higher interest of private investors in regenerative storage systems.

Figure 4: Investments by Major (Fall, 2008)



Across majors, ChE students favored nuclear fission, wind, and tidal (59% in total). The top picks of ECE majors were nuclear fission, wind, tidal and solar PV (57%), while MIE students favored nuclear fission, wind and solar PV (64 % in total). ChE majors were much less impressed with fuel cell technology. MIE students were much less supportive of biomass conversion and industrial energy efficiency investments, and much more interested in nuclear in total (and especially small-scale nuclear fission).

4.4. Perceptions of the Public and those with Technical Backgrounds

Many of the public perception studies in the areas of energy and the environment that have been completed in recent years focus on the broader topics of global warming and climate change[5]. There is relatively little data, however, on specific energy policies relating to the use of alternative energy sources. A 2007 survey did discuss the use of different energy sources as a comparison for the public's perception about nuclear energy[2].

The study showed a strong preference for renewable energy sources (over half thought that solar and wind should be increased a lot) as compared with coal, gas, nuclear, and oil (two-thirds of the participants thought that each of the latter should not be increased with less than one-sixth being in favor of more oil or coal). Furthermore, over half of those surveyed also thought that the amount of hydroelectric power should be increased[2]—this is opposed to the long term estimates of the EIA, for which the amount of hydroelectric power is essentially stable for the foreseeable future[12, 14]. The participants also had a highly optimistic view of the cost of renewable energy sources. In this study, the public viewed solar and wind as relatively inexpensive whereas oil and nuclear are perceived as relatively expensive[2].

As mentioned, the primary purpose of the study was to explore the perceptions about the use of nuclear power. While the general public is less opposed to the use of nuclear energy now than it was 5 years ago, resistance still remains high as compared with other fuel sources[2, 5]. This opposition is especially strong when the construction of a nuclear facility is proposed within a person's local area (75% of the participants opposed such construction)[2].

In contrast, the opinions of editors and reporters whose focus was in energy, agriculture, and the environment were more evenly split within the realm of alternative energy sources (i.e. less heavily weighted towards solar and wind)[6]. This came in response to the question “which of the following alternative energy sources…hold[s] the most promise in easing US dependence on fossil fuels over the next ten years?”[6] Within the responses, hydropower also received negligible results. A couple of important differences to note were that nuclear energy was not listed as its own source (possibly due to the 10 year time frame) and that biomass was provided as an option while it did not appear in the MIT survey.

Part of this discrepancy might arise from the views of the editors and reporters about the credibility of different sources when determining their opinions. Over 90% of those surveyed rated academic institutions and governmental agencies as either “very credible” or “somewhat credible.” Meanwhile, more mainstream sources of information such as corporations, non-governmental organizations, and special interest blogs were considered significantly less credible[6]. This is an aspect that the general public might not consciously think of when viewing information about energy sources.

4.5. Value of this Course in Influencing Public Perceptions on Energy

From the views expressed in Subsection 4.4., it can be hypothesized that given similar investment options, the public would likely invest significantly in renewable energy sources (including dams), moderately in gas and nuclear, and minimally in coal and oil[2]. The students in the class, however, understood that even though renewable energy source development will increase, there will still be a need to invest in other areas to maintain the necessary *capacity*. This was one of the crucial concepts that students learned because even if the nominal power rating of a solar panel or wind turbine seemed relatively high, dispatchability and capacity factor issues often cause renewable energy sources to have larger costs than would seem at first glance. This insight about capacity requirements is specifically aligned with the EIA’s future estimates for the next two decades[12, 14]. Student investments were also aligned with the view that hydroelectric power is not going to be an area of growth.

5. Discussion and Improvements

5.1. Student Strengths and Weaknesses

Students in both classes exhibited a somewhat surprisingly high level of awareness of current energy and environmental issues. They frequently watched the media for events pertaining to the subject and were anxious to later share impressions with the class. They were exceptionally confident speaking before others and exhibited strong writing and persuasion skills. Also notable in both classes was the strength of knowledge on heat transfer basics, regardless of major, perhaps rooted in pre-engineering physics courses.

Prerequisites for the class were limited by the varied backgrounds of the three eligible majors, with lectures recognizing the potential variation with brief tutorials when needed to establish a common foundation. That said, several opportunities exist for improvement in all three majors. First, both classes showed a general weakness in applying chemistry and calculus to energy theory, a shortcoming that could be mitigated by including in those pre-engineering courses more examples involving energy. And although calculus is almost always completed within the first two years, chemistry was regarded by some of the non-ChE students as a nuisance requirement that was often delayed until the senior year. Knowledge of basic theory on solar dynamics was another notable weakness in both classes; basic concepts were widely understood, but many had not been exposed to the analytical aspects of the subject.

5.2. Course Strengths and Weaknesses

Rescheduling the course from three 50-minute weekly sessions to two 75-minute sessions enabled more thorough development of topics and room for class discussion. The research papers, presentations, and investment exercises aroused substantial interest. Course evaluations confirmed this observation. Hands-on operational and engineering knowledge was frequently shared with the class; the vast majority found these tangents of great value. A portfolio approach to meeting future energy needs was a course theme, emphasized with several exercises that utilized a generation portfolio calculator designed specifically for the course. The calculator allowed students to immediately see how their generation choices affected capacity, energy, reliability, cost, and carbon dioxide emissions, and was essential in demonstrating the latest operational status of all conversion technologies. To stimulate interest in the future of energy, convergence of energy sectors was frequently discussed, especially the potential convergence of the transportation sector (e.g., plug-in electric hybrids) with the electrical sector. A course website was very helpful for posting lecture notes, summarizing key energy issues, and providing links for further exploration.

The course could be improved by adding more discussion on the electromechanical properties of rotating machinery (i.e., electrical generators), as over 93% of the U.S. generation in 2006 utilized this technology[12]. Consideration should also be given to using multiple instructors to cover their respective areas of expertise. Finally, a case study involving actual distribution of capital across conversion technology choices, perhaps led by a finance faculty, would complement the portfolio calculator and investment exercises.

6. Future Research

One area of future research is to align the manner in which perceptions are gauged at the beginning and end of the class. This could be done via completion of the Likert-style survey at the end of the semester in addition to at the beginning and/or having students make investment decisions at the beginning of the semester in addition to after having heard their peers and instructor present on energy issues and technologies throughout the semester. Upon completion of the latter, a greater statistical analysis of the progression of thought could be performed.

Another area of possible expansion is the inclusion of business majors into course-related special projects. The effects of their persuasion skills could then be monitored to determine the relative impacts of those with a greater background in the technical aspects (i.e. the engineering majors) versus those with expertise in the financial and business side of the projects. Proper screening of such students would again be necessary.

7. Summary

The primary objective for this senior elective course in energy conversion systems was to raise awareness of the complex variety of issues in the field. While the course outcomes were largely met in the opinion of both faculty and students, the experience revealed that additional emphasis on energy-related problems could be incorporated in pre-engineering coursework. Expanded coverage of rotating machine basics is necessary to complete the energy conversion process. Perhaps a team-teaching format with faculty from each of the majors represented in the class would enhance the learning experience.

Results described in this paper are based on two offerings of the semester-long course, attended by seniors in Chemical, Electrical and Computer, and Mechanical and Industrial Engineering. Perception surveys at the start of each class showed students to be well grounded in basic energy awareness. Investment decisions showed a very strong preference by students in both classes to invest in a diversified mix of solutions. Support was consistently strong across classes and majors for nuclear fission and wind, along with government support of solar development. These results are at odds with surveys of public perception that show greater favorability for renewable sources and little support for nuclear, as well as the belief that solar and wind are the least expensive solutions. Students certainly understood the need for expanding renewable participation, but also understood that additional conventional generation will be needed to maintain reliability of power supply.

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Appendix A: Complete Project Guidelines and Pedagogical Explanation

1. Project Steps: Topic Selection, Abstract, Rough & Final Drafts, & Presentation.

2. Topics should relate to the conversion of energy for the production of electricity; under the correct circumstances, energy for transportation may be considered acceptable.

3. Potential choices include specific technologies within biomass, oil, natural gas, propane, nuclear fission, nuclear fusion, coal, integrated gas combined cycle (clean coal), hydro, wind, solar photovoltaic, solar thermal, tidal, geothermal, and fuel cells.

4. Projects focus on a particular technology as if proposing the construction of a specific energy conversion facility, or as part of a broader portfolio expansion or research and development (R&D) effort.

5. Text and tables, without graphics, should not exceed 20 pages, and shall contain a short table of contents, abstract, executive summary, body, and conclusion with recommendation.

6. The paper shall describe an energy conversion process (what it is, how it works, mathematical descriptions of energy quantities, status or maturity of technology), fuel sources, emissions, wastes, environmental impacts, costs to build, energy busbar costs, integration with grid, policies and incentives that promote its use, recommendation of where process should be reside in a portfolio of energy conversion choices.

7. If the selected technology produces CO_2, include a discussion on capture, sequestration, and costs.

8. Each presentation will range strictly between 8 and 10 minutes.

9. The assumed audience is a board of directors or panel of lawmakers that understand nothing beyond algebra, and have limited exposure to acronyms. Most of the audience should be assumed to not have an engineering background. However, the few that do will want more than a grade school-level discussion. The correct balance must be struck, and the need will arise at times to describe complex thoughts in simpler terms.

10. As students listen to each presentation, their task will be to assign $100 billion among energy conversion alternatives, acting as either a government energy czar or an investment banker.

Pedagogical Reasoning behind Each Guideline

1. Paper structure: This is the format graduates will find widely expected in business.

2. Electrical energy emphasis: Provides the broadest possible inclusion of energy technologies and engineering disciplines.

3. Conversion technology choices: As open as possible to appeal to individual student interest. Several students were allowed to select topics outside of electrical energy, such as human energy conversion processes, flywheel storage systems, and fuel-cell powered transportation, provided they discussed interactions or convergences with electrical energy systems.

4. Argue for or against: Engineers are frequently called on to advise organizations with high-level recommendations developed through extensive analysis. This aspect of the projects affords an opportunity to develop and practice this skill.

5. Paper structure: Guidance and limitations on structure keeps the project to a reasonable effort among a student's other demands for time.

6. Paper elements: Emphasizes the breadth of research expected, forces the exploration of the complexity of the topic, and emphasizes that energy decisions are highly influenced by investment and policy (including environmental) issues.

7. Carbon dioxide discussion: Emphasizes the ability of graduates to be conversant not only with CO2 emissions and capture of a particular technology, but conversant on greenhouse gases and global warming generally.

8. Time limit: Students are surprised to learn that management presentations and government hearings often have strict limits on presentation length, similar to that found in the proceedings of professional organizations such as the IEEE. Condensing a message to an 8 to 10 minute length required extensive work with several students, which revealed how difficult this requirement can be for some to meet. The strictness of this requirement is also an attempt to model respect for others by not boring audiences and not forcing subsequent speakers to shorten their presentations to keep proceedings on schedule.

9. Prepare for a mixed audience: Emphasizes the need to not speak only as a scientific researcher to most audiences. Emphasizes that, even among an all-engineer audience, basic descriptions are essential building blocks for more in-depth technical material.

Appendix B: Abbreviated Course Syllabus

Description: A three-credit, semester-long senior elective course open to seniors and graduate students in electrical and computer engineering, chemical engineering, and mechanical and industrial engineering. Offered through the Department of Electrical and Computer Engineering.

Textbook: *Sustainable Energy – Choosing Among Options*, Tester, et al, MIT Press, ISBN 0262201534.

Course Outline/Topics:

1. Fundamental energy concepts
2. Greenhouse gases, carbon dioxide cycle, and earth/sun radiation balance
3. Environmental aspects of energy conversion
4. Theory, planning and operational aspects of conventional and alternative energy conversion systems for electric power generation
5. Development of generation portfolios
6. Relationship and convergence of electrical energy systems with other energy sectors
7. Deliverability and reliability issues
8. Storage systems
9. Case studies with technical, economic and policy content
10. Current energy issues
11. Oral presentations of term papers

Appendix C: Initial Perception Survey

During the first week of the course, students were asked to indicate their agreement or disagreement with the following statements on a scale from 1 (strongly disagree) to 9 (strongly agree).

1. The United States uses more energy per capita than any other country
2. We can and should end all dependency on foreign sources of energy
3. The earth's climate is warming
4. Global warming poses life-threatening risk in the next 100 years
5. Variations in the Sun's intensity impacts climate change
6. Variations in the Earth's orbit impacts climate change
7. Variations in the Earth's reflectivity impact climate change
8. The methods for measuring Earth's temperature changes are highly accurate and representative of the "big picture"
9. Variations in cosmic radiation impact climate change
10. Variations in photosynthesis activity impact climate change
11. This is the first time humankind has encountered global warming
12. The concentration of carbon dioxide in the atmosphere is increasing
13. Increased CO2 concentration is the primary driver of global warming
14. Celebrities and politicians are *credible* sources of advice on energy and the environment
15. Celebrities and politicians are *influential* on energy and the environment
16. The United States has a clear plan for its energy future
17. The amount I pay for gasoline, heating, and electricity is a reasonable percentage of my monthly budget
18. The environmental impacts of electric power are less important than the work and convenience that electricity provides to our lifestyle
19. Hydroelectric power is a sustainable technology
20. Coal-based electric power is a sustainable technology (sustainable economically, environmentally, and in its availability of fuel)
21. Wind is a sustainable technology
22. Solar is a sustainable technology
23. Nuclear fission is a sustainable technology
24. Biomass is a sustainable technology
25. Geothermal is a sustainable technology
26. Tidal power is a sustainable technology
27. Natural gas generation is a sustainable technology
28. Nuclear fusion is the ultimate answer
29. All coal electrical generation should be eliminated
30. All natural gas electrical generation should be eliminated
31. All nuclear electrical generation should be eliminated
32. Transmission of energy from its source to its point of use is a significant barrier to making efficient choices
33. The U.S. and global economies heavily rely on economically priced energy
34. Economic growth requires growth in energy usage
35. My friends, family and neighbors are sufficiently educated on energy and the environment to properly guide our policymakers
36. Model-based predictions of long-term climate changes are accurate and supported with good science