AC 2008-2264: WHY A LIBERAL AND MULTIDISCIPLINARY EDUCATION IS NEEDED TO SOLVE THE ENERGY CRISIS

Matthew Heun, Calvin College

Matthew K. Heun received his Ph.D. in Mechanical and Industrial Engineering from the University of Illinois at Urbana-Champaign. He was a staff engineer at the Jet Propulsion Laboratory in Pasadena, California and a Senior Engineer at Global Aerospace Corporation in Altadena, California before joining the Engineering Department at Calvin College in Grand Rapids, Michigan.

Steven VanderLeest, Calvin College

Steven H. VanderLeest is a Professor of Engineering and currently the Engineering Department Chair at Calvin College. He has an M.S.E.E. from Michigan Technological University (1992) and Ph.D. from the University of Illinois at Urbana-Champaign (1995). He has been an officer in the Multidisciplinary Engineering and Liberal Education divisions of the ASEE. His research interests include responsible technology, embedded systems, and entrepreneurship.

Why a Liberal and Multidisciplinary Education is Needed to Solve the Energy Crisis

Abstract

One of the grand challenges for the current generation is the need for widespread use of clean and renewable energy sources. Rapid growth in demand for energy is likely to exceed our global ability to supply it moving forward. In addition, our current energy sources often carry heavy environmental tolls. Thus our current energy trajectory is not sustainable. Research and development of alternative energy sources, including renewable sources, has made good progress, but more work needs to be done with more urgency. New technologies and significant improvements in existing technologies are needed to address the looming energy shortage. Many of these non-traditional sources of energy have different social impacts from their more customary counterparts. Engineers working in the area of energy production must understand the technical aspects of these new energy technologies, but that alone is not sufficient. They must have a deep intuition and understanding of how these technologies impact the social-cultural milieu within which they will be embedded. Thus, engineering educators must provide a broad, multidisciplinary education – one that spans not only multiple technical disciplines, but also includes a strong liberal arts component. Such broad social problems require broad solutions. Given the critical and timely nature of this topic, one would assume that it would be receiving significant attention within engineering education scholarship. But it has not. Although increasing recently, the total number of relevant papers on energy education in the literature is quite small, and almost none address the essential need for a broader, contextual education. An examination of available textbooks on energy issues demonstrates a similar gap. We conclude with several recommendations to take initial steps toward rectifying this lack of sufficient scholarship in engineering education and lack of resources for engineering educators.

Energy Sustainability is a Grand Challenge

Energy sustainability is one of the grand challenges for this generation. It is a global, multifaceted, and extremely difficult problem: (a) energy demand is outstripping supply, (b) primary energy sources are heavy polluters, and (c) there is no clear solution. In this paper, we will refer to this triplet of difficulties as the "energy grand challenge."

Demand outstripping supply

Considering the significant problems facing our world today – AIDS, world hunger, war and terrorism, racial injustice, poverty, global warming – one issue, the looming energy crisis, seems particularly apt as a grand challenge for engineers. Consensus is growing to support the contention that our global demand for energy is outstripping our ability to supply it. Economics predicts that price will continue to increase to account for this supply shortfall. Significant economic and therefore social upheavals may likely result as some of our most prevalent sources of energy (oil and natural gas) dwindle to relative scarcity. Debate in the literature has transitioned from the question of *whether* a global peak (followed by a permanent downward trend) in oil and natural gas production will occur to the question of *when* the peak will occur. Hirsch, Bezdek, and Wendling summarize a variety of expert predictions regarding the peak and conclude: "Even the most optimistic forecasts suggest that world oil peaking will occur in less than 25 years."[1] They provide a similarly grim picture for natural gas: "Part of the attractiveness of natural gas was resource estimates for the U.S. and Canada that promised growing supply at reasonable prices for the foreseeable future. That optimism turns out to have been misplaced, and the U.S. is now experiencing supply constraints and high natural gas prices."[2] Global energy use will continue to grow: "…world marketed energy consumption is projected to grow by 57 percent over the 2004 to 2030 period."[3]

Primary energy sources are heavy polluters

Currently, our primary energy sources are fossil fuels that produce significant pollutants. While we continue to depend on these sources, we also are paying the price of environmental damage on a local and global scale. For example, global warming is widely attributed to increased emissions of greenhouse gases associated with burning of fossil fuels. The chart in Figure 1 shows the increase in worldwide carbon dioxide emissions and primary energy consumption (as a percentage of levels in 1980)[4].

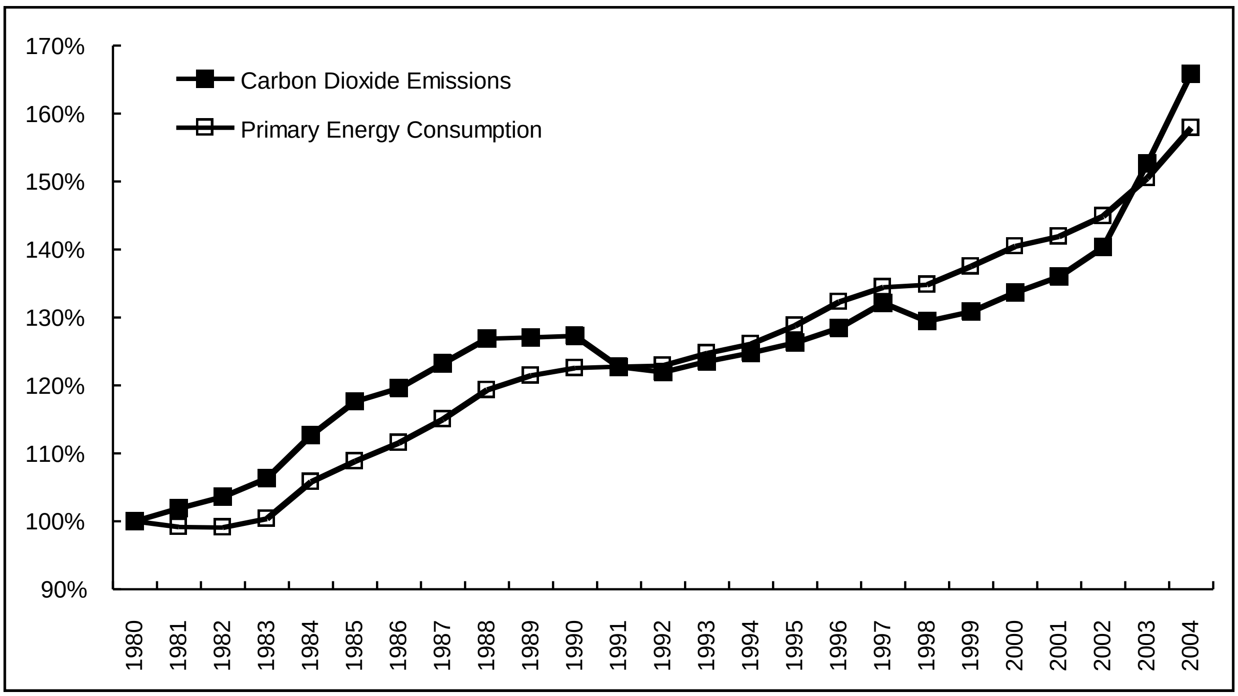

Figure 1: Worldwide Carbon Emissions and Energy Consumption.

No clear solution

There is no clear solution to the energy crisis on the near horizon. The literature is replete with pursuit of alternative energy sources to replace the sources on which we currently depend: wind, photovoltaic (solar), geothermal, hydrogen, biomass, nuclear fission (and even fusion). There is also much ongoing research to find more effective ways to use our current sources (e.g., to eke out more from existing deposits, to find ways to reduce pollutants either during or after production and use). However, none of these proposed solutions has yet fulfilled its promise. For example, wind energy has seen the most dramatic improvements in recent years, coming close to being cost competitive with traditional energy sources. But wind (and also solar) are intermittent supplies that produce energy in a form that is difficult to use for transportation. Fully electric and commercially viable vehicles are not yet available, and may never be for certain classes of vehicles: “There are no known near-commercial means for electrifying heavy trucks or aircraft, so related conversions are not now foreseeable.”[5] The issue of timeliness is a problem across the board: “Alternative energy technologies such as electric- or hybrid cars, hydrogen fuels, nuclear power, and renewable energy sources such as solar, wind, or biofuels still require considerable research and development before they evolve to the point of massive utilization.”[6]

Solving the energy crisis requires broad, contextual understanding

Breadth and Depth Points to Liberally Educating Engineers

Establishing reliable and long-term sustainable sources of energy is indeed a grand challenge. Furthermore, many potential fossil fuel replacements have significant issues to consider, including global warming impact, environmental impact, net energy balance, interaction with the existing energy infrastructure (electrical grid and liquid fuel distribution systems), geopolitical ramifications, and global justice impacts. Each of these issues requires broad contextual understanding and multidisciplinary skills to accurately assess and efficiently develop successful solutions.

To illustrate the importance of a multidisciplinary approach that requires broad contextual understanding, consider the technical factors involved in developing sustainable energy sources that have minimal impact on a single one of the above issues: global warming. Pacala and Socolow[7] note in their now-famous paper that “humanity already possesses the fundamental scientific, technical, and industrial know-how to solve the carbon and climate problem for the next half-century.” By “solve,” they mean limiting atmospheric CO_2 concentrations to less than 500 ppm, the level at which most scientists agree is an upper limit for Dangerous Anthropogenic Interference (DAI) with the global climate in the next 50 years. (The current CO_2 concentration is slightly less than 400 ppm. Without intervention, the atmospheric concentration of CO_2 is expected to more than double in the next 50 years.)

Pacala and Socolow’s paper evaluates a portfolio of technologies that have advanced beyond the laboratory and prototype stage: they have been successfully implemented technically, and in some cases, politically. Pacala and Socolow label these interventions “stabilization wedges,” and all of the wedges are related to the energy grand challenge. Their list of stabilization wedges is shown in the table below.

Each stabilization wedge eliminates 1 GtC/year (gigaton of carbon per year) increase in carbon emissions from 2004 levels. Implementation of any 7 of the stabilization wedges will limit CO_2 concentrations to 500 ppm by 2054. Humanity will still be increasing the carbon loading of the atmosphere, but we will avoid DAI with the climate in the next 50 years. Pacala and Socolow’s strategy buys time, but it does not solve the problem. Beyond 2054, elimination of CO_2 emissions altogether will be necessary.

Table 1. Climate Change Stabilization Wedges.

Category I: Efficiency and Conservation 1. Improved fuel economy: increase fuel economy from 30 to 60 mpg for 2 billion vehicles 2. Reduced reliance on cars: improve urban design to reduce miles driven from 10,000 to 5,000 miles per year for 2 billion vehicles 3. More efficient buildings: reduce energy consumption by 25% (half of potential energy savings can be obtained in developing countries) 4. Improved power plant efficiency: move coal plants from today's 40% to 60% efficiency
Category II: Decarbonization of Electricity and Fuels 5. Substituting natural gas for coal: replace 1,400 GW 6. Storage of carbon captured in power plants: 800 gigawatts of new coal plants 7. Storage of carbon captured in hydrogen plants: send hydrogen resulting from precombustion capture of CO_2 offsite to replace conventional fuels 8. Storage of carbon captured in synfuels plants: 30 million barrels per day 9. Nuclear fission: replace 700 GW of coal 10. Wind electricity: 2,000 GW of wind turbines that displaces coal 11. Photovoltaic electricity: 2,000 GW peak solar power that displaces coal 12. Renewable hydrogen: produced by 4 million windmills (1 MW each) 13. Biofuels: 34 million barrels of ethanol per day, provided the ethanol is carbon-free
Category III: Natural Sinks 14. Forest management: stop de-forestation and re-establish 300 million hectares of new tree plantations 15. Agricultural soils management: drill seeds into soil instead of plowing on 110 million hectares of cropland

The list of stabilization wedges has two important characteristics. First, energy is central to every item in categories I and II. Second, engineers and engineering design will play a significant role in implementing every one of the stabilization wedges. Moreover, all disciplines of engineering will be called upon to provide expertise to implement the stabilization wedges. This example illustrates the more general truth: significant depth of expertise in each engineering field will be required to meet the energy grand challenge.

The sheer breadth of engineering expertise required to address the energy grand challenge makes it clear that engineers with significant depth in one subdiscipline will be required to interface with engineers from many other subdisciplines as they develop solutions in the coming decades. Few engineers will be required to be experts in all engineering subdisciplines; but all must possess sufficient understanding of relevant engineering areas to contribute to design meetings, understand the impacts of design decisions, work well on design teams, and develop mental conceptual models of large systems.

New energy sources and technologies have different engineering needs from their customary counterparts

As we move forward to tackle the energy grand challenge, engineers will be required to possess different technical competencies and deeper understanding of societal impacts compared to our present energy economy.

<u>Different technical knowledge</u>

Each of the new energy technologies requires different technical knowledge from their customary counterparts (fossil fuels). Engineering related to electricity generation from fossil fuel sources demands knowledge of combustion processes and the thermal sciences. However, if our society is moving toward renewable technologies such as wind and solar, fluid mechanics and semiconductor electronics become increasingly important in the energy supply sector.

Whereas coal is used to generate electricity with large plants (hundreds to thousands of MW) in centralized locations near cities, wind electricity achieves an economy of scale with many smaller generators (ones of MW) not necessarily located near cities. Electricity generated from solar energy is likely to have even more distributed generation that is not located near cities. How will the existing distribution grid cope with these differences?

<u>Different social impacts</u>

Previous fossil fuel technologies certainly affected the environment, but society has learned to live with and, to some extent, has become accustomed to the negative effects of fossil fuel air pollution on quality of life and health. Alternative and renewable energy technologies bring different societal impacts. Turbines, for example, may minimize air pollution, but people are unaccustomed to the visual pollution and background noise of wind farms. Figure 2 shows the number of Google references to "visual pollution and smokestacks" as a percentage of the total number of reference to "visual pollution and wind turbines".[8] In addition, we cannot assume that alternative and renewable energy technologies will not affect the environment. For example, nuclear waste disposal is a significant concern that still lacks a suitable political solution.

Engineers today and in the future working on the energy grand challenge must design with these different societal impacts in mind, pointing to the need to provide both (a) multidisciplinary education among engineering subdisciplines and (b) a traditional liberal arts context for engineering education. Just as a traditional liberal arts education seeks to provide opportunities for students to obtain a fundamental level of knowledge for a broad range of existing disciplines, there exists a need to have all members of relevant engineering disciplines educated liberally within the broad field of engineering.

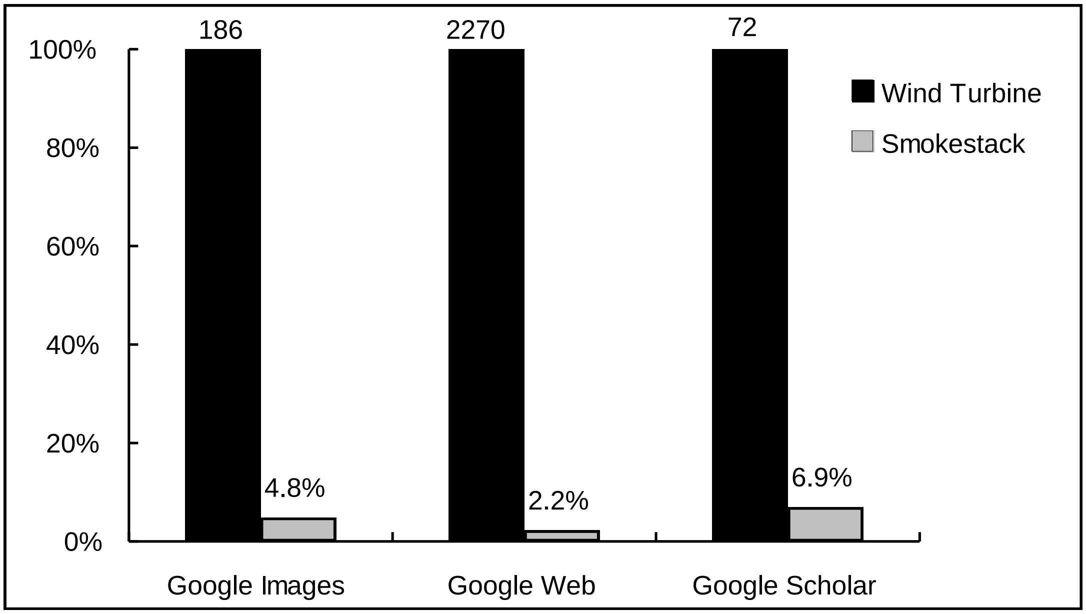

Figure 2: Number of Images, Web References, and Scholarly References for "Visual Pollution and Wind Turbine" Compared to "Visual Pollution and Smokestack".

Need multidisciplinary approach to address new technical knowledge needs

In addition to providing specialized education in specific engineering subdisciplines, multidisciplinary engineering knowledge will be required to meet the energy grand challenge. Future engineers will need to be broadly educated among engineering subdisciplines. Wind turbine generator designers will need to understand the effects of wind variability on turbine blade performance. Fluid mechanics will need to understand the impact that grid variations have on generator performance. Solar power system engineers will need to have detailed understanding of both electrical engineering and heat transfer.

To be sure, there are many places where engineers already work today across disciplinary boundaries; recent calls for change in engineering education reflect this reality (see below). The point here is that there will be no letup in the need for talented multidisciplinary engineers in the future. In fact, that need will accelerate. Narrow specialists are out. Specialists with broad knowledge of all engineering disciplines are in.

Need liberal arts context to evaluate different social impacts

Not only will the energy grand challenge drive an acceleration of the need for broadly educated engineers, it will drive the need for engineers educated within a liberal arts context. Making wise design decisions for developing sustainable energy sources requires broad understanding of the way society works, how political decisions are made, and how people respond to change. Technical issues can never be divorced from broader societal issues.

One example of the need for engineers to understand societal impacts is the sociological and psychological importance of how questions are asked. The question "Do you want a wind farm?" may receive a different answer from "Do you want a wind farm or a coal plant to meet your growing electricity needs?" An example of the former is the ongoing dispute over a proposed offshore wind farm in Nantucket Sound where opponents (The Alliance to Protect Nantucket Sound[9]) and proponents (Energy Wind Management a.k.a. "Cape Wind"[10]) both tout environmental arguments for their positions. Examples of the latter can be found in Maine[11] and Delaware[12], where residents weighed various energy options including wind and coal in light of costs and environmental impacts. The complexity of these choices is further illustrated in Kansas[13], where the rejection of two coal-fired plants doomed a wind farm project for lack of proper transmission lines.

Engineering education is moving too slowly

A growing chorus is calling for change in engineering education to meet the challenges of our modern world, one of which is the energy grand challenge. The landmark report from the National Academy of Engineering looks at the necessary attributes of an engineer in 2020 and calls for changes in engineering education: "The external forces in society, the economy, and the professional environment pose imperatives for change that may exceed those to come from the changes expected in the technology engineers will have at their disposal in 2020. Challenges will abound, but opportunities also will exist if engineering takes the initiative to prepare for the future."[14] James Duderstadt, former president of University of Michigan, has also pointed out the urgent need for reform: "During the past several years there have been numerous studies conducted by organizations such as the National Academies, federal agencies, business organizations, and professional societies suggesting the need for new paradigms in engineering practice, research, and education that better address the needs of a 21st century nation in a rapidly changing world."[15]

Numerous organizations and conferences are focusing on energy issues in engineering (but as we will show below, few are in the area of engineering education). For example, the "Engineers Forum on Sustainability"[16] meets three times yearly and publishes a periodic newsletter, with occasional articles on energy-related topics. The World Energy Engineering Congress[17] is an annual conference on a wide range of energy topics.

Lack of significant response (specifically for energy)

Despite an increasing need for multidisciplinary engineering education in a liberal arts context, the response to the energy grand challenge the engineering education community has been muted and slow to develop. Consider the number of papers published at the ASEE annual conference in the past decade. A search of the conference papers catalogued by Google Scholar from 1996 to 2006 reveals a total of only 100 papers that have any of the following key terms:

- "solar energy"
- "wind energy"
- "nuclear energy"
- "alternative energy"
- "renewable energy"

This pales in comparison to the total of over 10,000 ASEE conference papers in the Google database for this time period. While this represents less than 1% of the papers presented at the conference, the number has been increasing over the years, as shown in Figure 3.

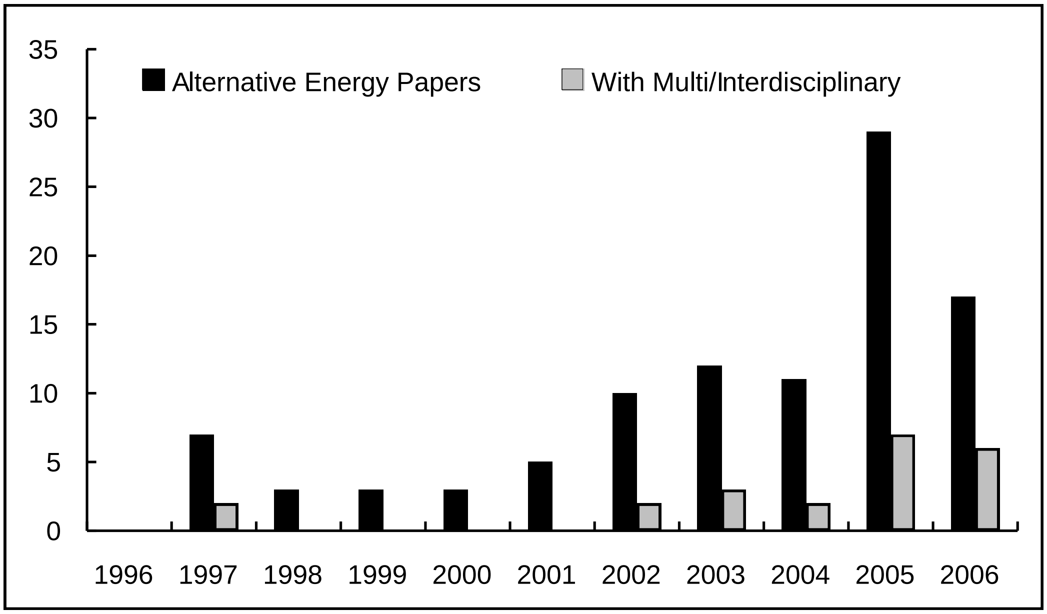

Figure 3: Number of ASEE Conference Papers on Alternative Energy Topics.

Most of these papers tend to be narrowly focused, viewing the broad problem of the energy grand challenge from the vantage point of a particular technical discipline. For example, consider that only 22 of the 100 papers shown in Figure 2 also contained the terms “multidisciplinary” or “interdisciplinary” somewhere within the paper. Only 18 of the papers contained technical details, only 11 considered more than one alternative technology, and only a handful considered any type of broader impact.

A similar review of the Journal of Engineering Education and the International Journal of Engineering Education for same period revealed only seven papers (out of over 600 articles in the two journals) that contained any of the search terms. Of those, none had any substantive discussion of multidisciplinary aspects – in fact most only mentioned energy issues in passing.

Not enough textbooks on energy issues (especially with broad approach)

Despite the importance of educating future engineers for the energy grand challenge, there are few textbooks on the subject that provide both contextual and multidisciplinary material related to the energy grand challenge. An ideal textbook for engineering education on this topic would (a) address technical issues associated with alternative and renewable energy technologies (design, efficiencies, interactions with environment and climate, scientific bases for assessing reserves of energy for multiple technologies), (b) show how alternative and renewable technologies exist within economic, policy, social, cultural, and climate contexts, and (c) do so for an undergraduate audience.

To investigate the availability of textbooks to assist instructors to educate engineering students about the energy grand challenge, we:

(1) searched amazon.com for related textbooks with the following terms

- "alternative energy" engineering
- "alternative energy" textbook
- "engineering design for alternative and renewable energy"
- "engineering and energy policy"
- "energy policy textbook"

(2) searched wiley.com (Wiley publishers)

- for publisher-categorized textbooks on "Wind and Solar Energy"
- with the term "alternative energy"

(3) searched mhhe.com (McGraw-Hill publishers)

- with the term "wind energy"
- with the term "solar energy"
- with the term "alternative energy"

These searches produced 86 books that were deemed to be relevant to the energy grand challenge. Of these, many (43%) are devoted to a *single* renewable energy technology. Many (45%) books were deemed to either lack significant information on societal impacts of energy or neglect societal issues at the expense of engineering design content. Finally, only 4 of 86 books could be considered textbooks suitable for undergraduate education with homework problems and detailed examples to assist student learning and instructor preparation. In the end, no textbooks simultaneously meet criteria (a), (b), and (c) above.

Why the disconnect between educational needs and educational resources?

The above sections indicate that a disconnect exists between educational needs for the energy grand challenge and the resources available for instructors to teach energy from a multidisciplinary point of view within engineering. In the sections below, we posit three potential reasons for the existing disconnect.

<u>Entrenched disciplinary boundaries</u>

Perhaps the most fundamental reason for the existing disconnect between educational needs and instructor resources is entrenched disciplinary boundaries. The energy grand challenge has emerged long after the present set of disciplinary boundaries (economics, engineering, business, political science, etc.) was established. The energy grand challenge exists between and among the disciplines as what philosopher Bruno Latour calls a "hybrid." "Hybrid[s] sketch out imbroglios of science, politics, economy, law, religion, technology, fiction. … All of culture and all of nature get churned up again every day. Yet no one seems to find this troubling.

[Newspaper] headings like Economy, Politics, Science, Books, Culture, Religion and Local Events remain in place as if there were nothing odd going on."[18]

The problems we face today are different from and larger than our old ways of thinking that are reflected in our disciplinary boundaries and newspaper headings. Yet, we naturally develop pedagogical resources that conform to our disciplinary boundaries. (Witness the dearth of textbooks that address multiple alternative or renewable energy technologies.) Thus, existing pedagogical resources are ill-matched to the immensity and pervasiveness of our largest problems, including the energy grand challenge.

Little reward for pursuing interdisciplinary work

Because the energy grand challenge is a "hybrid" that exists between and among disciplinary boundaries, engineers, scientists, economists, political scientists, and philosophers who work on the problem find few institutional rewards for doing so. Decisions about tenure and promotion can become additionally difficult when educators split their teaching and research time among several departments within the engineering field, and more so if work crosses boundaries between technical fields and social sciences. A researcher who shares time in both engineering and economics may not be perceived as a "real" engineer by the engineers or a "real" economist by the economists.

Renewable energy funding not commensurate with the scope of a "Grand Challenge"

There are many funding opportunities for renewable energy research in the US at the present time. However, the sum total of all funding on renewable energy technologies does not approach the scale for previous or current grand challenges.

The US Department of Energy (DOE) "Small Business Innovation Research" grants funding in the program area titled "Energy Efficiency and Renewable Energy" was awarded 38 out of total of 290 Phase I grants in 2005.[19] Those 38 Phase I grants (roughly $100,000 each, total roughly $3.8M) plus two Phase II grants (roughly $750K each, total roughly $1.5M) in the area of "Energy Efficiency and Renewable Energy" equals 5.3% of the annual grants of around $100M from the DOE[20] – which seems to be a rather small fraction of the funding from the federal department most likely to support efforts to address the energy grand challenge.

Although it is difficult to identify all the dollars in the US federal budget allocated for research and development on renewable energy, the largest distinct block of funding goes to the Office of Energy Efficiency and Renewable Energy (EERE), which is part of the US Department of Energy. This office oversees the National Renewable Energy Laboratory, for example. Over the last few budget cycles, the EERE is being funded at somewhat over $1 billion annually (FY06 allocation was $1.16 billion, FY07 request was $1.18 billion, FY08 request was $1.24 billion).[21]

To provide context for present funding levels for the energy grand challenge (approximately $1 billion annually), previous and current grand challenges have been funded at significantly higher rates. For example, the Apollo program cost about $103.5 billion in today's dollars.[22] President Johnson's "Great Society" cost a few billion dollars per year, initially.[23] (In today's dollars that would be about $10 billion annually.) President Reagan's Strategic Defense Initiative (more popularly known as Star Wars) "…has been estimated to cost nearly $120 billion."[24] Annual funding for the response to AIDS in low- and middle-income countries stands at $8.3 billion annually.[25] President George W. Bush's Moon-Mars initiative is projected to cost anywhere from $250 billion to $1000 billion.[26] The Iraq War has cost the US $480 billion as of the end of calendar year 2007.[27] The level of funding required to address a grand challenge is on the order of at least $10 billion annually (in today's dollars). To the extent that funding levels reflect priorities, it is clear that energy is not perceived by the US federal government as a grand challenge.

Recommendations

To begin developing resources for educating future engineers to face the energy grand challenge, we provide the following suggestions. Many of these suggestions arise from experiences at the authors' home institution, Calvin College, and represent, in most cases bottom-up, grassroots efforts to begin providing the kind of education required to prepare students to work on the energy grand challenge.

Curriculum and pedagogy (with case studies)

In the area of curriculum and pedagogy, there are several ways to introduce small initiatives that begin to expose students to the technical topics surrounding the energy grand challenge.

Multidisciplinary team projects, homework, mini-projects

Collaborations among engineering disciplines or between engineering and other departments can be effective ways to introduce students to the multidisciplinary nature of the energy grand challenge. This past semester the energy systems class of one author (Heun) collaborated with a biology class on a semester-long project that challenged students with the question "What would it take to make Calvin College carbon neutral?" Students worked together to assess carbon emissions and sequestration.

In addition to the semester-long project, participants simulated a cap-and-trade carbon market. At the beginning of the simulation, students (and professors) were issued credits that were retired based on self-reported activities. Market actors who retired all their credits could purchase credits (with cash) from others who forecast excess. Market winners (those with the most cash at the end of the simulation) were required to buy the pizza for an end-of-semester party. The combination of the semester-long project (which focused on institutional-level behaviors and policies) and the carbon trading simulation (which focused on personal-level actions) was extremely effective in leading engineering students to broader, contextualized understanding of the global societal effects of the power generation systems that were the topic of the course. The forced interaction between biologists and engineers underscored the need for reaching across disciplinary boundaries to develop solutions to big problems.

Courses on energy

Courses specifically devoted to energy, the energy grand challenge, and options for solutions to the energy grand challenge will be beneficial for educating future engineers. Unfortunately, as discussed above, there are precious few resources for instructors to develop such a course. The

EERE provides a list of institutions offering programs or courses[28], but offers nothing further to faculty hoping to develop one at their home institution.

Other resources

Nationally-organized educational initiatives, on-campus organizations, and grants provide additional resources for engineering educators to develop students ready to address the energy grand challenge.

One example of a nationally-organized educational initiative is the "Focus the Nation"[29] event held on 31 January 2008. Educators across the nation were organized to speak on their campuses about global warming (with a number of sessions related to energy). These events can provide a springboard for discussions of the energy grand challenge among students and faculty.

Calvin College has an example of a loosely-knit faculty organization called CEAP (the Calvin Environmental Assessment Program). This group of 10-15 faculty members meets occasionally to share information about the state of the campus and exchange curricular and pedagogical ideas. Although not much more than a "birds of a feather" group, CEAP serves as an organizing entity for many environmentally-related classroom projects on campus. Recently, energy and climate change projects have been planned in coordination with CEAP and have benefited from obvious connections between environment and energy. CEAP holds public poster sessions each semester wherein students present the results of in-class projects related to Calvin's ecosystem and resource utilization.

Many states offer grants for enhancing educational capacity related to alternative and renewable energy technologies. Calvin College has been successful in obtaining grant funding from the Energy Office of Michigan[30] to install a 1.8 kW demonstration wind turbine[31], and a 20 kW solar photovoltaic array[32] on a LEED-certified building.

Co-curriculum (with case studies)

Co-curricular education provides additional options for energy grand challenge education. Effective examples include student organizations, K-12 outreach, and intentional housing communities.

Student organizations

Student interest led to the formation of Calvin College's Renewable Energy Organization (REO), a student group devoted to increasing awareness about energy that is clean, renewable, and sustainable.[33] With guidance from faculty advisors, REO has hosted a seminar series, installed Calvin College's demonstration wind turbine, investigated residential energy efficiency, and investigated biofuel vehicle conversion.

K-12 outreach

Developing educational capacities related to the energy grand challenge can be done in a way that includes significant K-12 outreach. At Calvin College, a recent LEED certified eco-preserve interpretive center provides laboratory space for K-12 education via camps and enrichment activities for nearby students. Our demonstration wind turbine and solar photovoltaic systems have generated significant interest from nearby high school science teachers who want to expose young students to the benefits and challenges of alternative and renewable energy technologies.

Intentional living and learning communities

At the time of this writing, Calvin College is evaluating options for an intentional living and learning community to be housed on one floor of a new dormitory whose heating and cooling loads may be partially offset by a geothermal system. It is envisioned that the geothermal system and other innovative energy systems in the dormitory will be attractive to students interested in energy issues and provide a starting point for discussions of energy, sustainability, and climate issues on an ongoing basis.

Proposed initiatives for ASEE

There are several initiatives that ASEE could undertake to accelerate the process of equipping instructors to educate students for the energy grand challenge. We summarize a few modest proposals in the following sections.

Pre-conference Workshop on Energy Issues

None of the Sunday workshops at the last two ASEE conferences focused on energy issues. We propose an interactive half-day workshop to provide a forum for brainstorming and sharing creative ideas for teaching a broad, contextual, multidisciplinary and liberal education approach to solving the energy grand challenge. Such a workshop would be targeted to draw engineering educators from a diverse set of disciplines. An agenda workshop might include the following:

- Energy: a grand challenge of the 21^{st} century
- A survey of the multiple disciplines involved in the challenge
- Discussion of resources for educators
    - Peer-reviewed papers
    - Textbooks
    - Websites
    - Samples of homework and projects assignments
    - Sample curricula
- The challenges of teaching from an interdisciplinary perspective
    - Faculty versed in specific disciplines
    - Balkanized institutions

Joint sessions between MULTI, LED, and ECCD

An existing ASEE division focuses on issues of energy: the Energy Conversion and Conservation Division. While the division draws members from multiple disciplines, it may be able to reach a broader audience by jointly sponsoring conference sessions with the Liberal Education and Multidisciplinary Engineering divisions. We encourage the 2009 program chairs from these divisions to collaborate on a joint session of papers on the energy grand challenge.

Ways to institutionalize multidisciplinary approaches

As discussed above, one of the barriers to educating students for the energy grand challenge is entrenched disciplinary boundaries. One approach to reducing the significance of existing boundaries is to create institutional entities that, by design, cross and blur those boundaries. Educational institutions have used entities such as endowed chairs and multidisciplinary "centers" to encourage multidisciplinary collaborations. Other institutions have been successful in creating new offices and positions with titles like "Office of Sustainability" and "Director for Sustainability."[34]

A more-radical approach would be to demolish existing governance structures of educational institutions and replace them with new institutional entities that reflect new priorities. Industry calls this process "reorganization" and often uses "re-orgs" to signal significant priority shifts to customers and employees. In addition, reorganizations become opportunities to fast-track talented young employees into positions of significant responsibility and sideline ineffective workers. Colleges and universities often seem less able than businesses to effect significant organizational adjustments in response to priority changes.

In the end, it is necessary to assess the environment at each institution to determine the best route to making the organizational changes that are often required to provide the space to address new issues like the energy grand challenge. In some cases, bottom-up approaches (like faculty birds-of-a-feather organizations) will be most effective. In others, top-down approaches (like an institutional reorganization) will work best.

Conclusion

Development of sustainable energy sources for the future is a grand challenge. We have tried to show that the engineering education community should be moving in two important directions to prepare young engineers for future engagement with the energy grand challenge: toward (a) multidisciplinary education in (b) a liberal arts context. Our initial assessment shows that extremely limited resources exist to support educators in these directions: hardly anyone is talking about the energy grand challenge in the engineering education community (witness the meager number of ASEE papers on the topic) and few if any undergraduate multidisciplinary resources are available (witness the dearth of textbooks that provide multidisciplinary engineering design information on responses to the energy grand challenge for undergraduates). We provided several modest suggestions in the areas of pedagogy, institutional structures, and national ASEE initiatives to begin the process of providing resources for educators to help future engineers meet the energy grand challenge.

There is a significant amount of work that could yet be done to fully characterize the extent of the disconnect between educational needs and resources for instructors. Some areas that appear ripe for further study include:

- Analyzing details of funding (including trends) for multidisciplinary energy education
- Expand our survey to explore the literature in specific engineering disciplines to look for connections to the engineering education community

- Survey major initiatives in this area to assess which are more successful: bottom-up or top-down approaches to initiating multidisciplinary engineering education programs

Beyond that, it seems imperative to begin broader discussions within ASEE. Workshops and seminars could become places where the conversation expands. Thereafter, curricular materials should be developed to help instructors prepare future engineers to meet the energy grand challenge.

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