

AC 2008-2289: INCORPORATING ENERGY ISSUES INTO ENVIRONMENTAL ENGINEERING

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Incorporating Energy Issues into Environmental Engineering

Abstract

No single engineering discipline has integrated renewable and sustainable energy topics into their core curriculum. Environmental engineering programs may benefit from including sustainable energy in their curriculum. Many students in a freshman-level introductory Environmental Engineering (EVEN) course viewed EVEN as a potential major to study renewable energy, but many have since indicated that they plan to switch into other majors. Twelve of the 46 students in the class indicated that “energy” was their primary specialty choice (second only to 14 students stating an interest in water). Student interest in energy related topics was also strongly apparent among the applicants to a summer Research Experience for Undergraduates (REU) program in EVEN, with 42 of 84 applicants stating an interest in working on research related to energy topics. These energy projects were the most popular among all of the 15 different research topics advertised. This paper describes the existing energy-related courses at the University of Colorado at Boulder. It also describes ways to incorporate sustainable energy into existing courses. Environmental engineering needs to determine what its niche will be in relation to sustainable energy topics, and train students in this important area.

Background

Energy-related issues are important to the sustainability of the planet, due to links with global climate change which has been associated with the combustion of fossil fuels. Energy issues are currently receiving a lot of news coverage. This is exciting many students about the possibilities of working in a career that would develop sustainable energy sources with fewer pollution effects. Meeting this challenge will require the efforts of scientists, engineers, and policy makers. Students with an interest in this field are currently struggling to determine the best major to pursue in college to enable them to pursue a career in this area.

Catherine Peters proposed that civil/environmental engineering curricula should “teach students the fundamentals of sustainable energy, in addition to incorporating sustainable engineering and global warming issues¹⁴. To effectively engineer sustainable systems, energy flow must be understood. For example, the Electric Power Research Institute (EPRI) has estimated that about 4% of all electricity consumption in the U.S. is consumed by water and wastewater treatment and transmission, and that electricity accounts for 80% of municipal water treatment and distribution costs². Environmental engineers have the potential to lead systematic analysis of products and processes from a life-cycle perspective. Environmental engineers may be the best suited of all the engineering disciplines to conduct these life-cycle analyses due to broad training in fundamentals that span almost the broadest range fundamental science and engineering disciplines. These topics include physics, chemistry, biology, mathematics, and economics. Life cycle analyses (LCA) are also an important tool in traditional environmental engineering disciplines. Various water and wastewater treatment processes have undergone LCA by including energy, raw materials, pollution, and toxicity factors, with results published in peer reviewed literature⁶. This paper describes energy related curriculum and courses, and with how they relate to environmental engineering.

Survey of Energy Related Programs

Web research is a common way that students gather information. Energy-related majors and courses at a variety of colleges and universities can be easily found using a simple web search. A few programs in energy are highlighted below.

At Stanford University, energy and the environment have been coupled as a strategic area for research. The web page for this initiative highlights the Civil and Environmental Engineering Department, and discusses sustainability as a key theme. This major offers courses such as 'Energy Efficient Buildings' and 'Electric Power: Renewables and Efficiency'. There is also an Atmosphere and Energy major, which is not ABET accredited (<http://soe.stanford.edu/initiatives/energy.html>). At Washington University in St. Louis, there is a Department of Energy, Environmental & Chemical Engineering. Despite the unique department name, they only offer a B.S. degree in chemical engineering (CHEN). The University also offers a minor in Environmental Engineering Science, which is jointly provided by Chemical, Civil (CVEN), and Mechanical (MCEN) Engineering (<http://eec.wustl.edu/>). At the University of California - Berkeley there is an energy and resources group, which offers an undergraduate minor (<http://socrates.berkeley.edu/erg/index.shtml>).

At the Massachusetts Institute of Technology (MIT) there are energy related research and/or courses highlighted by both CHEN and CVEN. Chemical Engineering emphasizes its energy and environmental research (<http://web.mit.edu/cheme/research/energy.html>). The Civil and Environmental Engineering department offers a B.S. degree in EVEN. This degree requires the course Ecology II: Engineering for Sustainability. The catalog description for this course indicates that topics such as renewable energy and green buildings are illustrated through case studies. Other energy related courses offered at MIT include: Fundamentals of Energy in Buildings; Applications of Technology in Energy and the Environment which includes fossil fuels, nuclear, solar, wind, fuel cells, energy conservation, and global climate effects (<http://web.mit.edu/1.149/www/>); and Alternate Energy Sources that covers geothermal, wind, natural gas, and solar energy. A search on "energy" in the MIT course catalog yielded 79 courses (<http://student.mit.edu/catalog/m1a.html>).

The University of Florida offers an ABET accredited B.S. degree in Environmental Engineering (<http://www.ees.ufl.edu/current/undergrad/default.asp>). Courses offered by this major that incorporate energy include an elective junior-level Energy & Environment course taught by Mark T. Brown. The course covers the principles of energy analysis, systems ecology and public policy. Dr. Brown also offers graduate level courses on Energy Analysis, Advanced Energy & Environment, and Energy Analysis (<http://www.ees.ufl.edu/homepp/brown/default.asp>). These courses use textbooks by Odum^{12,13}.

At Humboldt State University (http://www.humboldt.edu/~ere_dept/) the Environmental Resources Engineering curriculum "combines traditional environmental engineering with management of natural resources in applications such as ecological restoration and energy resource management." The major components of the program are energy resources, water quality, water resources, and air quality. All students are required to take a basic

thermodynamics course. In addition, students can select their major electives to include the following energy related courses: Thermodynamics and Energy Systems II, Building Energy Analysis, Renewable Energy Power Systems, and Solar Thermal Engineering (http://www.humboldt.edu/~catalog/courses/engr_crs.html#anchor577817).

Some international programs also offer energy-related programs. At Osaka University there is a Division of Sustainable Energy and Environmental Engineering, established in 2005. This division resides in the Department of Environmental Engineering (<http://www.env.eng.osaka-u.ac.jp/senko/english/index.html>). The Division of Environmental Engineering and Energy Systems was created in July 2007 at the University of Toronto (<http://www.energy.engineering.utoronto.ca/>). This grew out of the previous Environmental Engineering division. This division sponsors an Environmental Engineering option that is open to undergraduate students in Chemical or Civil Engineering. With the exception of an “Energy and the Environment” seminar, no specific courses focusing on energy were found listed on the website; this may be due to the newness of the program.

Energy Related Programs at the University of Colorado at Boulder

At the University of Colorado at Boulder (CU-B), there is no single curriculum with a strong emphasis on energy. The University of Colorado has a task force to study energy, with a Renewable and Sustainable Energy Initiative started in 2006 (<http://www.colorado.edu/insidecu/editions/2006/2-28/chancellor.html>; <http://engineering.colorado.edu/industry/Energy.htm>). A variety of activities at the University that are related to energy are described briefly below.

The Joint Center for Energy Management (JCEM) in the Department of Civil, Environmental, & Architectural Engineering (CEAE) was established in 1987. The center conducts research aimed at improving the energy efficiency of buildings and industrial sectors, and on the practical applications of renewable energies. The JCEM was integrated into both the undergraduate and graduate programs. Because key faculty in the center have recently retired, its activities have been absorbed into the Building Systems Program (<http://ceae.colorado.edu/bsp/>). As a result, two graduate-level courses listed in the catalog have not been taught recently: Advanced Passive Solar Design and Computer Simulation of Building Energy Systems.

The Colorado Center for Biorefining and Biofuels (C2B2) is a cooperative research and educational center devoted to the conversion of biomass to fuels and other products. C2B2 is supported by state, institutional, and industry funds. The center includes the three primary state universities and the National Renewable Energy Laboratory (NREL). At CU-B most of the efforts associated with this center are located in the Department of Chemical Engineering (<http://www.colorado.edu/che/c2b2/index.html>). Recently, the CHEN degree added an option to allow students to gain competence in energy-related areas. The Energy Option allows students to select one of three core concentrations: fossil fuels or petroleum, photovoltaics, and biofuels. Course requirements for each option are shown in Table 1. Note that students pursuing these curriculum options have no remaining free technical electives in their 4-year B.S. degree.

In the Department of Mechanical Engineering, a Joint Center for Combustion and Environmental Research (JCCER) is listed on the web (<http://me-www.colorado.edu/centers/combustion/>

ccr.html). However, there is a general lack of detail about their activities. Because the key faculty member conducting research in this area recently retired, it is unclear if the center is currently active. The Electrical Engineering department lists power electronics and renewable energy systems among its focus areas. The courses listed under the renewable energy focus are: ECEN 1000 Special Topics Energy 101, ECEN 3170 Energy Conversion I, ECEN 4167 Energy Conversion II, and ECEN 4517 Power Laboratory (<http://ece.colorado.edu/academics/ugrad/HelpGuide0708.pdf>). The Center for Energy and Environmental Security (CEES) at the University of Colorado Law School is an interdisciplinary research and policy center (<http://www.colorado.edu/law/eesi/>). The above discussion illustrates that there are a number of energy related activities on-going at the University.

Table 1. Courses in the Energy Options in the Chemical Engineering B.S. Degree at CU-B

Option:	Fossil Fuels/Petroleum	Photovoltaics	Biofuels
Required courses for each option:	CHEN 4838 Energy Fundamentals - 3 credits		
	PHYS 3070 Energy and the Environment - 3 credits		
	Introduction to Geology 1	Circuits & Electronics	Principles of Genetics and lab
	Physical Chemistry 2	Modern Inorganic Chemistry	
		General Physics 3 + lab	
	CHEN 3000+ Independent Study - 3 credits		
Technical elective courses for each option:	2 of the following: MCEN Energy Conversion, MCEN Intro to Combustion, CVEN Engrg Geology, GEOL Intro to Hydrocarbon Geology, GEOL Intro to Mineralogy, GEOL Intro to Petrology, GEOL Intro to Geochemistry	1 of the following: MCEN Energy Conversion, ECEN Semiconductor Devices, ECEN Introduction to Solid State	3 of the following: MCEN Energy Conversion, CHEN Metabolic Engineering, CHEN Catalysis and Kinetics, CHEN 3000+ Independent Study

(<http://www.colorado.edu/che/undergrad/documents/helpguide07-08.pdf>)

Energy Related Courses at the University of Colorado at Boulder

A variety of courses related to energy are taught at CU-B, as summarized in Table 2. Note that many of the courses taught over the past 3 years have been offered as special topics (“Sp Tps”). These special topics courses have not been fully approved for listing in the CU-B course catalog. New material is generally taught as a special topics course for 1 to 3 times, and then successful courses are proposed to be regular courses published in the catalog. In the College of Engineering new courses must submit a course proposal that is approved by the department (generally via a curriculum committee), and then approved by the Dean. To date, few EVEN students have taken these courses, which would count as technical electives toward the ABET accredited B.S. degree. The physics course has been the most popular among EVEN students, likely because it has been reliably offered and has no pre-requisites. Textbooks used in the courses are also listed. Many of the courses use reading packets or notes developed by the instructor rather than a published text book.

Table 2. Energy Related Courses that have been offered at CU-B

Course	Enrollment per semester 2005-present	# EVEN students	Text-book Used (ref)	Pre-requisites
CVEN 5830 Sp Tps: Bldg Energy Sys	7	0	n/a	Instructor consent
CVEN 5050 Advanced Solar Design	15	0	5	Instructor consent
CVEN 5020 Building Energy Audits	22	0	7	Mech. systems for buildings
Physics/ENVS 3070 Energy and the Environment	60-70 ⁺²⁰	12	15	None
ENVS 4/5100 Sp Tps: Energy Policy	21-32	1	Notes	None
ENVS 5100 Sp Tps: The Nuclear West	3 - 5		1	None
ENVS 5820 Renewable Energy Policy	16	0	Notes	Instructor consent
ENVD 4035 Solar and Sustainable Design	30-53 ⁺⁹	0	notes	General physics 1
ECEN 2060 Sp Tps: Renewable Energy	36	0	11	None
ECEN 3170 Energy Conversion 1	41-51	0	notes	Circuits & Electronics ³
ECEN 4167 Energy Conversion 2	9-20	0	notes	ECEN 3170
CHEN 4838 Sp Tps: Energy Fundamentals	52	8	9	Senior standing
MCEN 4228 Sp Tps: Sustainable Energy	42-70	4	8	MCEN, SRS
MCEN 4228: Sp Tps: Wind Energy	24 ⁺¹⁰ - 51	0	10	MCEN, SRS
MCEN 4162 Energy Conversion	25 (last taught in fall 2005)	2	Unk	thermodynamics
MCEN 4152 Intro to Combustion	Not taught in fall 2005 or later	2	Unk	thermodynamics

⁺ There was a waitlist for the course, due to more student interest than the maximum enrollment limit.

Unk = unknown because the course has not been offered recently.

Incorporating Energy Issues into a Freshman Course

Incoming engineering freshmen at the University of Colorado at Boulder generally take a 1-credit introductory course to learn about their selected major. EVEN students enroll in EVEN1000, Introduction to Environmental Engineering. Similar courses are offered by the other engineering majors and for general engineering (GEEN) students who have not yet selected a specific major. The demographics of students enrolled in the first-year EVEN course in 2006 and 2007 are summarized in Table 3.

Table 3. Demographics of Students Enrolled in the EVEN1000 Course

Year	Total # of students	% Women	% Minority	% 1 st Year	% Non Engineering Majors	% EVEN Majors
2006	29	48	28	55	38	48
2007	46 start 44 end	35 34	9 7	74 73	20 20	61 61

In 2007, energy issues were incorporated in a variety of ways into the EVEN1000 course. In the initial lecture that provided an overview of environmental engineering, an “energy” slide was added; energy was not highlighted in the 2006 opening lecture. In the first homework assignment, students could then identify “energy” as a sub-discipline area of environmental engineering (alongside water, remediation, air, etc.) and look up information about this sub-topic on the internet. In the team design project (homework 3), groups of 4 to 5 students considered energy issues related to solid waste and landfill design. The students used the U.S. EPA LandGEM model¹⁶ to determine the amount of methane that would be generated from the landfill, then determined the energy equivalent of the methane, and decided if they believed methane recovery was a good option. LandGEM is an Excel-based model that can be downloaded for free (<http://www.epa.gov/ttnecat1/products.html>). The students also computed the amount of fuel used by waste collection vehicles for trash and recyclables collection, then discussed if biodiesel versus standard diesel was a good option for the vehicles. Energy issues could also be discussed when the students discussed whether it was worthwhile and cost effective to collect different portions of trash for recycling. The landfill project was also completed by students in 2006. Finally, an entire lecture at the end of the semester was devoted to a special topic presentation on sustainable energy. This lecture was given by the mechanical engineering professor teaching the MCEN 4228 course (listed in Table 2).

Student Interest in Energy: Freshman Course

The first lecture to introduce EVEN indicates sub-specialties in air, water, remediation, and ecology. Student questions in fall 2006 indicated some interest in energy, but confusion as to which major would be the best fit for their interests. Therefore, energy was added as another listed sub-specialty in 2007. Immediately following this first lecture, students complete homework one (HW1). The HW1 assignment asks students to indicate the sub-specialty area of EVEN that they find most interesting. After they have identified an area, the student finds a company or organization that employs engineers in this area and a current news “event” pertaining to this topic. The percentage of the EVEN students stating an interest in the various sub-discipline areas of EVEN are summarized in Table 4. Students who identified two areas of interest were counted as “half” a student for each topic. In fall 2006, no student selected “energy” as their area, probably because it wasn’t identified as a sub-specialty area in the course slides. A few 2006 students did verbally state an interest in energy during in-class discussions. The areas of student interest in 2007 were significantly different compared to 2006, with high interest in energy. Among the 2006 students, the primary interest was air. In the minds of the students, air pollution may have been linked to energy due to the problems related to global warming from greenhouse gases. Another reason for the difference may have been stronger media focus on global warming in 2006 compared with increased focus on energy in 2007.

Over the semester in 2007, students worked on the landfill project that included solid waste, air pollution, and energy issues. There were also 4 guest speakers who were working in the areas of ecology, water, remediation, and air. Each of the guest speakers had a B.S. degree and/or M.S. degree in EVEN. The students then completed the 4th homework assignment (HW4). In HW4 the students mapped out the courses they needed to take to earn a B.S. degree in EVEN at the University of Colorado at Boulder, including the selection of a specialization option. The option areas that the students selected in this assignment differed significantly from the interest areas that they identified on the first homework. The difference could be due to content covered in the course between the first and 4th assignments. In addition, the HW4 assignment would be more difficult if the student did not select one of the five published “options” in air, ecology, remediation, water, or chemical processing. The focus on energy would require special paperwork. Four students noted that they selected the option they felt was closest to their energy interest (and were counted at 50% for energy in Table 4). Two students received extra help outside of class to create an energy option. Students in 2006 completed a similar assignment, but the options that they selected were not recorded.

Table 4. Percentage of students in EVEN1000 course interested in different sub-specialties of Environmental Engineering, based on various homework assignments in the course

EVEN Specialty Area:	Year: Assignment:	2007 HW1	2007 HW4	2007 HW6	2006 HW1	2006 HW6
Air Quality		9	18	7	34	17
Applied Ecology		9	21	13	2	9
Environmental Remediation		20	19	17	16	0
Water Resources and Treatment		24	19	18	34	11
Energy		26	10	15	0	0
Other: Engineering for Developing Communities (EDC), sustainability, etc.		13	13	7 EDC 23 uncertain	14	15 EDC 48 uncertain

The final assignment in 2006 and 2007 (HW6) required students to write a reflective essay on EVEN. The students were asked to indicate if they were interested in earning a degree in EVEN, and the sub-topic of greatest interest. The percent of the students stating an interest in various sub-discipline areas is shown in Table 4. In 2006, 21% of the students stated that they were unlikely to select EVEN as their major. Of those interested in EVEN, results indicated a significant shift in stated areas compared to homework 1, although almost half were simply uncertain about a specific area of interest. In the 2007 class, 32% of the students stated that they were no longer interested in earning a degree in EVEN and another 20% were possibly interested in earning an EVEN degree or maybe switching to another major such as CVEN or CHEN. Of the students interested in EVEN, the areas of greatest interest are similar to those the students identified in HW1. However, there is a noticeably lower interest in energy on HW6. This difference is primarily because many of the students interested in energy on HW1 indicated that they were switching out of EVEN and into another major. The large difference in HW4 may be because students were forced to select an option, with associated courses.

In the 2007 class, the fate of the 13 students who initially stated an interest in energy (or energy and a second topic) was of particular interest. At the end of the semester, 5 of those students indicated they would select a major outside of EVEN; either chemical or architectural engineering, architecture, engineering physics, or biology. Four students were uncertain of the best major. Four students stated an interest in pursuing an EVEN degree, but with more broadly defined interests than energy, including air, EDC, water, and “helping the world” in their interests. One additional student noted an interest in energy, and stated that he was changing his major to Mechanical Engineering. In their final essay, students noted that none of the four professional guest speakers worked in the energy field. Over the course of their careers, the speakers worked to some extent in the sub-areas of air, ecology, water, remediation, chemical processing, and engineering for developing communities (EDC). If EVEN wants to send a strong message to students that they can successfully practice in the area of energy with an EVEN degree, it will be important to bring in a guest speaker pursuing this path. However, of the EVEN graduates from our own program to date, only one works in the area of energy (for Black & Veatch). He lives in California, which is too far to travel.

Energy Issues in Other Required Courses

Energy issues are currently covered in some of the other courses that EVEN students are required to take. EVEN students take one of three different thermodynamics courses offered by chemical, mechanical, or architectural (AREN) engineering. Both civil and architectural engineers are required to take the AREN version of thermodynamics, which is taught by two professors affiliated with EVEN (<http://civil.colorado.edu/~silverst/aren2110/syllabus.html>). One of the four stated objectives of the course is to: “Identify applications of thermodynamic concepts in Civil, Environmental & Architectural Engineering such as sustainable energy technologies, conservation, and maintaining the global environment”. Environmental thermodynamics was the subject of two lectures, which is one full week of the course. This material was supported by course notes, since the topic is outside the information covered in the textbook⁴. The course also included two guest lectures on: (1) the thermodynamics of weather and climate, and (2) sustainable energy.

The capstone design course that all EVEN seniors are required to take often incorporates energy issues. Many of the projects in the course are service learning projects to serve local communities and businesses. One example of a project that incorporated energy challenges was the upgrade of a lagoon used to treat wastewater from a Native American community³. No power was locally available at the existing lagoon site and the client desired a solution that was highly sustainable and environmentally friendly. As such, students evaluated various natural systems or aeration/mixing equipment that was wind or solar powered. The solution eventually recommended by the students and implemented by the community was the SolarBee, a solar powered circulator that both increases evaporation and enhances biodegradation due to better oxygen transfer in mixed lagoons. Another service learning project determined appropriate solutions to handle by-product waste generated from a community scale biodiesel production facility. In addition, most traditional environmental engineering projects -- such as wastewater treatment plant upgrades, drinking water treatment, and remediation -- all require some analysis of energy requirements in order to compute annual operating costs.

Energy Specialization Option

The EVEN degree program at the University of Colorado at Boulder requires that students select an “option” that provides more depth in a selected focus area. Options have been established in air, water, remediation, ecology, and chemical processing. Each option consists of a list of regularly offered courses, from which the students select a total of 9 credits (generally 3 courses). When student interest and course availability warrants, new options are added. For example, the EVEN program began in 2000 with only 3 options available. To date, four EVEN students have petitioned for a special option in energy; one has graduated and three are in progress. Eight other current EVEN students have expressed interest in an energy related option, but have not yet submitted any paperwork to make it official. The curriculum committee in EVEN is discussing adding energy as a new specialization option. The only barrier is that many of the courses that offer the best content are currently “special topics” rather than courses that are reliably offered each year. Any of the courses listed in Table 2 could be included in the option, although students would probably be limited to a single policy oriented course to ensure that the option courses were primarily technical. ABET review of our options in the past has indicated that each set of option courses selected by the students needs to include some design content.

Student Interest in Energy Research

At CU-B we have a summer Research Experience for Undergraduates (REU) site in Environmental Engineering. In the years 2002-2004 and 2006, the available projects advertised to the applicants were in the traditional EVEN areas of water, air, ecology, and remediation. For the summer 2007 program, additional projects related to energy were advertised. A comparison of applicants to our REU program is shown in Table 5.

Table 5. Applicants to the REU site in Environmental Engineering

Year	# Applicants/ Year	% Minority	% Female	% Non Host Institution
2002-2004	35	13	53	92
2006	42	19	60	81
2007	84	20	57	94
<i>energy</i>	42	14	55	95

In their application essays, students are encouraged to discuss specific research projects that they find interesting. This facilitates matching of students and projects. Most students (71% in 2007) discuss more than one project in their essay. A few students said that they were interested in any of the projects (6% in 2007). The energy-related projects were popular, with 8% of the students solely interested in those projects and another 42% interested in the energy projects among others. The energy related projects were the most popular of all the advertised projects. The next most popular topic were projects related to acid mine drainage (AMD), with 29% of the students specifically discussing AMD in their essays. Twenty-five percent of student applicants wanted to research point-of-use water treatment for the developing world. The demographics of students interested in the energy-related research projects were not significantly different than the overall applicant pool. These data provide some indication that energy-related topics may draw students to environmental engineering.

The University of Colorado at Boulder has a College-wide research apprentice program during the academic year. Professors can propose research projects and pay half of the hourly pay rate for the students, with the College paying the remainder. Students apply in spring to work on projects the following academic year, and each student can apply for up to 4 projects. Students may apply to any of the advertised projects, not only those offered by professors in their major. Professors from Civil, Mechanical, and Chemical engineering have had environmental and energy related projects. Since 2005, energy-related projects have been available from professors in chemical and civil engineering. In 2005, the projects were offered from CHEN professors on biorefining and modeling cathode reactions in hydrogen fuel cells. In 2006, CHEN offered projects on biorefining and photochemical conversion of natural gas feedstock, and CVEN a project on membrane processes for energy and water sustainability. In 2007, a CVEN professor offered a project on membrane processes for sustainable transportation fuels. The number of students applying for each project is a rough indicator of project popularity, although this is also influenced by the number of projects available in a particular discipline and number of students from the discipline that apply. The data in Table 6 indicates that the energy-related projects are generally not more popular than other types of environmental engineering research projects. Students interested in the energy projects were primarily majoring in CHEN (21 students), EVEN (3 students), and CVEN (3 students). In 2006 and 2007, more students were interested in research projects related to EVEN than the average project. The difference in the relative popularity of energy projects found among the REU applicants and the CU-B students may be related to a low availability of energy projects nationwide, such that the REU program attracted these students nationwide.

Table 6. Applicants to College of Engineering Undergraduate Research Intern Program

Year	Total # projects	Total # student applicants	# EVEN student applicants	Average # student applicants / project	# energy related projects	Ave # Apps / energy project	Ave # apps / even project	# other EVEN projects available
2007	54	56	5	3.8	1	4.0	5.9	7
2006	56	65	3	4.0	3	4.7	6.0	4
2005	37	49	0	4.5	2	6	3.7	7

Conclusions

In summary, if EVEN wants to retain students who are interested in energy-related topics, we face stiff competition from other majors and we have an image problem. Environmental engineering needs to define how its students are uniquely suited to contribute to solving energy related problems. For example, most EVEN graduates will not be designing the next generation of solar panels or wind turbines. A core strength that EVEN students may be able to build upon is an integration-level understanding of systems that enables life cycle analysis of energy and mass flow. The availability of educational materials such as case studies may help facilitate the integration and emphasis of energy topics in EVEN courses. Programs may also need to develop new courses to train EVEN students to contribute to solving energy-related problems.

Bibliography

1. Ackland, L. 1999. *Making a Real Killing: Rocky Flats and the Nuclear West*. University of New Mexico Press.
2. Appelbaum, B., Principal Investigator at ICF Consulting. 2002. *Water & Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply and Treatment – The Next Half Century*. EPRI Technical Report 1006787. R. Goldstein and W. Smith, Project Managers. Palo Alto, CA.
3. Bielefeldt, A.R. and R. Malhotra. 2006. "Wastewater Treatment for a Native American Tribe." In: *Case Studies in Environmental Engineering and Science*. Prepared by the AEESP Education Committee. Ed. A. Bhandari and M.A. Butkus. <http://www.aeespfoundation.org/publications.html#CaseStudies>
4. Cengel, Y.A., R.H. Turner, and J. Cimbala. 2007. *Fundamentals of Thermal-Fluid Sciences*, 3rd Edition McGraw-Hill, New York.
5. Duffie, J.A. and W.A. Beckman. 2006. *Solar Engineering of Thermal Processes*. 3rd Edition. John Wiley & Sons. Hoboken, New Jersey.
6. Friedrich, E., S. Pillay, and C.A. Buckley. 2007. The use of LCA in the water industry and the case for an environmental performance indicator. *Water SA*. 33(4): 443-451.
7. Krarti, M. 2000. *Energy Audit of Building Systems: An Engineering Approach*. CRC Press. Boca Raton, FL.
8. Kreith, F. and D.Y. Goswami. *Handbook of Energy Efficiency & Renewable Energy*. CRC Press. Boca Raton, FL.
9. Kruger, P. 2006. *Alternative Energy Resources: The Quest for Sustainable Energy*. John Wiley & Sons. Hoboken, New Jersey.
10. Manwell, J.F., J.G. McGowan, and A.L. Rogers. 2002. *Wind Energy Explained: Theory, Design, & Application*. John Wiley & Sons. West Sussex, England.
11. Masters, G.M. 2004. *Renewable & Efficient Electric Power Systems*. Wiley-IEEE Press.
12. Odum, H. T. 1996. *Environmental Accounting: Energy and Environmental Decision Making*. John Wiley & Sons, New York.
13. Odum, H.T. and E.C. Odum. 2001. *A Prosperous Way Down: Principles and Policies*. University Press of Colorado. Boulder.
14. Peters, C. 2007. *Sustainable Energy in the CEE Curriculum*. Presentation at the NSF-sponsored workshop *Frontiers in Environmental Engineering Education*, Jan 8-10, Tempe, Arizona.
15. Ristinen, R.A. and J.P. Kraushaar. 2005. *Energy and the Environment*, 2nd Edition. John Wiley & Sons.
16. U.S. EPA. 2005. *Landfill Gas Emissions Model (LandGEM) Version 3.02 User's Guide*. US EPA Office of Research and Development. Washington D.C. EPA-600/R-05/047. <http://www.epa.gov/ttnecat1/dir1/landgem-v302-guide.pdf>