AC 2012-4575: CHALLENGES IN DEVELOPING A NEW ENERGY ENGINEERING MAJOR

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Challenges in Developing a New Energy Engineering Major

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Abstract

With the world's thirst for energy continuing to grow, there is now an urgent demand for a well trained workforce to develop, process, utilize and manage conventional, unconventional, and renewable energy sources in an environmentally safe and economically feasible way. To move The Pennsylvania State University to the forefront in energy, the Department of Energy and Mineral Engineering has developed for the first time in the US, a formal undergraduate degree program (Bachelor of Science) in the growing field of energy engineering. Through collaboration and cooperative arrangements with other departments and colleges, and flexibility in the program, science and engineering students with special interests in energy are able to obtain a BS degree in Energy Engineering on its own or dual/concurrent degrees, minors, options or general education in energy engineering. Along with the basic engineering skills, the program integrates skill sets in the physical sciences (chemistry, engineering, mathematics, and physics) and social sciences (economics, policy, and management).

The first two years of the program are similar to traditional engineering disciplines. Thereafter, one takes a series of courses that introduce Energy Engineering concepts and fundamental energy engineering principles that involve material and energy balances, thermodynamics, fluid mechanics, heat and mass transfer operations, and physical and chemical processing as applied to energy industries. In addition to these engineering principles, students enroll in required courses in renewable/sustainable energy principles. Students are trained in basic chemistry of fuels – coal, petroleum, natural gas and biomass; combustion; petroleum and natural gas processing; electrochemical energy conversion; and energy conversion processes including chemical, nuclear, biological and catalytic. Students also choose departmental electives from courses such as green energy engineering and environmental compliance, hydrogen and fuel cell technology, materials for energy applications, physical processes in energy engineering, and air pollutants from combustion sources. Professional electives allow students to gain exposure to business, legal and ethical issues related to energy. Technical electives can be chosen to provide specialization or breadth and depth in renewable or non-renewable energy and/or mechanical or chemical aspects of energy.

This paper discusses the program, the rationale in developing the program, and the details of the novel curriculum.

Introduction

World population and energy consumption both continue to grow significantly. Also, due to global uncertainties, energy is becoming increasingly important. The United States, for example, increasingly relies on imported energy (32.9 % in 2006)[1]. Projections from DOE's Annual Energy Outlook indicate that primary energy use in the United States will climb to 134

Quadrillion Btu in 2030 from 98 in 2010[2]. Despite increases in electricity generation efficiencies, total electricity consumption is also predicted to increase. President Obama has called for energy initiative based on the development of clean coal technologies, renewable energy (solar, wind, geothermal, biomass etc), advanced automotive batteries, and building and process energy efficiency. Concurrently, there is an aging workforce. Refinery operations are very close to maximum capacity and any terrorism or natural disasters could weaken our ability to ensure an affordable supply of energy. New challenges, such as converting coal and gas to liquids, transporting more fuel across the nation as gas, liquid or electricity, and extracting and converting non-traditional (renewable) fuel sources, are facing the energy industry.

Rationale

To meet the increasing energy demand, the nation and the world will require a well trained diverse workforce to develop process, utilize and manage conventional, unconventional and renewable energy sources in an environmentally safe and economically viable manner. Unfortunately, many of the academic programs that provided such workforce have either closed (e.g., petroleum and mining engineering programs) or redirected their focus to the health or bio-related areas (e.g., chemical engineering) leaving many energy producing and consuming industries with an aging technical workforce and growing workforce demand. There is also renewed emphasis on the development of alternative sources of energy to conventional fossil fuels. The increasing demand for energy and trained energy workforce calls for innovative methods to increase enrollments and graduation rates of students in energy-focused disciplines. Such a workforce is essential for the future of America, our energy security, and is a strategic issue of great importance to the nation.

With society's growing need for energy and energy-related workforce, many institutions are vying to take advantage of these opportunities and challenges. Some academic institutions with traditional engineering programs (e.g., chemical, civil, mechanical, electrical and nuclear engineering) have created departments and/or programs in energy-related areas to reflect the growing need and trend. To move The Pennsylvania State University to the forefront in energy, the Department of Energy and Mineral Engineering proposed a formal undergraduate degree program (Bachelor of Science) in the growing field of energy engineering. The program benefits students of several colleges at The Pennsylvania State University. Through collaboration and cooperative arrangements with other departments and colleges, and flexibility in the program, science and engineering students at The Pennsylvania State University with special interests in energy are able to obtain dual or concurrent degrees, minors, options or general education in energy engineering.

The plans for this program were initiated in Fall 2005 and the major was approved to start in Fall 2007. The program is consistent with the University 2006 Energy Task Force report and the recommendation for the University to "develop an exciting new undergraduate and graduate curriculum in energy". The undergraduate program in energy engineering is designed to reflect the growing impact and demand for energy in society and to equip students with the knowledge necessary to achieve the following career and professional accomplishments or program educational objectives: become valuable contributors in addressing society's energy needs and demands; successful leaders in advancing the technology and management of energy; innovators and entrepreneurs in the energy sector; and educators, practicing engineers, and national leaders on energy and associated environmental, health and safety, and policy and economics issues. The program integrates skill sets in the physical sciences (chemistry, engineering, mathematics and physics) and social sciences (economics, policy, and management) to ensure successful career opportunities and growth within energy-related industries, government agencies, and academia.

The courses are structured to enable students to understand engineering fundamentals and apply the knowledge to solve problems in the production, processing, storage, distribution, and utilization of energy using multiple techniques as synthesis, analysis, design and case studies. Inquiry-based teaching methods and lab experiences are emphasized. The faculty research and scholarly activities are integrated into the curriculum. The program is designed to train students to be lifelong learners, problem solvers, and energy industry leaders. The educational opportunities are sufficiently flexible, broad, and diverse to enable students to tailor their educational experiences to particular interests, background, and expected role in society. Flexibility in the curriculum allows other students in energy related programs such as agricultural and biological, chemical, civil, electrical, environmental, mechanical, mining, nuclear, and petroleum engineering, materials science and engineering, industrial health and safety, and energy business and finance to have dual or concurrent degrees, minors, or options (e.g., dual degrees in chemical engineering and energy engineering).

Program Objectives:

The integration of knowledge and skills acquired during the course of study enables graduates of the program to achieve the following program educational outcomes:

1. Employed in the public or private sectors in the areas of energy science, energy engineering or energy business management or pursuing an advanced degree.
2. Contributing in addressing society's energy needs and the technological challenges in meeting these needs;
3. Engaged in individual and multi-disciplinary teams designing, evaluating and recommending methods and strategies for the efficient production, processing and utilization of renewable and non-renewable energy and the associated environmental challenges;
4. Effective written and oral communicators as well as community and professional leaders through service and outreach;
5. Engaged in life-long learning process to maintain adaptable professional competency through training, and participation in professional activities.

Curriculum

The sequences of courses required for the BS in energy engineering degree are outlined in Table 1. Students may select their Departmental, professional, and technical electives from a list that includes courses from Chemical, Mechanical, Electrical, Nuclear, Agricultural and Chemistry departments. The technical electives are energy-related courses outside the major that are offered by various colleges across The Pennsylvania State University. Substitutions must be made by petition.

Table 1
Bachelor of Science in Energy Engineering Program

1 Semester		**2nd Semester**	
CHEM 12 (GN) Chemical Principles	3	**CHEM 13** (GN) Chemical Principles	3
CHEM 14 (GN) Experimental Chemistry	1	**MATH 141** (GQ) Calculus With Analytic Geometry II	4
MATH 140 (GQ) Calculus With Analytic Geometry I	4	**PHYS 211** (GN) General Physics: Mechanics	4
EM SC 100S (GWS) Freshman Seminar *	3	**ENGL 015** (GWS) Rhetoric and Composition or ENGL 030 (GWS)	3
ECON 02/14 or ENNEC 100 (GS) Economics **(GA/GH/GS Elective 1)**	3	**GA/GH/GS Elective 2**	3
Health and Physical Activity (GHA)	1.5		
	15.5		**17**
3rd Semester		**4th Semester**	
CHEM 38 Organic Chemistry	3	**EE 211** Electrical Circuits and Power Distribution*	3
MATH 251 Ordinary and Partial Differential Equations	4	**MATH 231** Calculus of Several Variables	2
PHYS 212 (GN) General Physics: Electricity And Magnetism	4	**CMPSC 201C**	3
GA/GH/GS Elective 3	3	**PHIL 103** (GH) Ethics **(GA/GH/GS Elective 5)**	3
GA/GH/GS Elective 4	3	**GA/GH/GS Elective 6**	3
		Health and Physical Activity (GHA)	1.5
	17		**15.5**
5th Semester		**6th Semester**	
EGEE 012 Energy Engineering Lectures	1	**EGEE 304** Heat and Mass Transfer	3
MATSE 201 Intro. to Material Science	3	**EGEE 430** Intro. to Combustion	3
EME 301 Thermodynamics for Energy Engineering	3	**FSC 431** Chemistry of Fuels- coal, petroleum, gas, biomass	3
EME 303 Fluid Mechanics of Energy Systems	3	**EGEE 411** Energy Engineering Laboratory	3
EGEE 302 Principles of Energy Engineering			
Professional Elective 1	3	**EGEE 438** Wind and Hydro Energy Engineering	3
	16		**15**
7th Semester		**8th Semester**	
ENGL 202C (GWS) Technical Writing	3	**EGEE 494A** Research Projects	2
FSC 432 Petroleum and Natural Gas Processing	3	**EGEE 437** Solar Energy Engineering	3
EGEE 441 Electrochemical Energy Conversion	3	**EGEE 464W** Energy Design Project	3
EGEE 451 Energy Conversion Processes: Chemical and Nuclear	3	**EGEE Elective**	3
IE 302 Engineering Economy or **PNG 489** Engineering Evaluation	3	**Technical Elective 2**	3
Technical Elective 1	3	**Professional Elective 2**	3
	18		**17**

Students also choose electives from courses such as green energy engineering and environmental compliance, hydrogen and fuel cell technology, materials for energy applications, physical processes in energy engineering, and air pollutants from combustion sources. Professional electives allow students to gain exposure to business, legal and ethical issues related to energy. Technical electives can be chosen to provide specialization or breadth and depth in renewable or non-renewable energy and/or mechanical or chemical aspects of energy.

All students in the program take an energy engineering lab course, engage in a supervised independent research project, and participate in an integrative interdisciplinary design project/course. The design project is carried out as part of The Pennsylvania State University's Learning Factory that engages students on multidisciplinary teams to address industrially challenging problems. This paper will discuss the new energy engineering initiative, the novel curriculum, and the seamless integration of research into the training and education of students to help to produce the next generation of skilled workforce for the energy industry.

Research Integration

Integration of research into the program is carried out at three levels: in the required energy lab class (EGEE 411); the independent research projects class (EGEE 494), and the integrative design project (EGEE 464W) course. In the energy engineering lab, students engage in lab research in fuel characterization, engine testing, boiler efficiency determination, proximate and ultimate analysis, and renewable energy efficiencies.

Research Project: The independent research project varies with the interest of the student and the expertise of the advisor. The project may cover conventional fossil fuels (coal, oil and natural gas) or renewable energy options such as solar, wind, biomass or geothermal. It may also cover unconventional sources as shale oil, tar sands, coal bed methane and methane hydrates. A student typically performs an independent research in one of these areas under the supervision of a faculty. The focus of the work may include aspects of the production, processing and utilization of energy. It may also cover the environmental, health and safety, and business/management issues. In the methodology and analysis, probability, statistics and experimental design methods may be employed. An economic evaluation of the project may also be undertaken. The student submits a final report and defends his/her work through a technical presentation on the work.

Learning Factory. The mission of The Pennsylvania State University Learning Factory is to integrate design, manufacturing and business realities into the engineering curriculum. It is an industry-university partnership that involves multidisciplinary students working on real-life industrially sponsored problems. Since 1995, over 500 sponsored projects have been completed for 140 companies. The Learning Factory was awarded the 2006 Gordon Prize by the National Academy of Engineering. The Bernard M. Gordon Prize — recognizes innovation in engineering education — "for creating the Learning Factory, where multidisciplinary student teams develop engineering leadership skills by working with industry to solve real-world problems."

The energy engineering curriculum was designed to enable students in the program to carry out their capstone design project through The Pennsylvania State University Learning Factory. The students are able to work with teams of students from chemical, mechanical and other engineering disciples on common energy-related problems giving them broad exposure to how they are expected to operate as part of the energy workforce.

The experiences gained from the integration of research into the curriculum, enhance students' understanding of concepts learned in the classroom, prepare students for the real life working environment, and promote teamwork. Students are better able to see the interrelationships between the disciplines and how they are expected to collaborate in industry for the common good of the company.

The capstone design course is to be a culmination of the knowledge and skills learned in earlier courses as well as a writing intensive course which means students are expected to learn to write and be given ample opportunity to practice writing. The work culminates in a final written report and technical presentation to a public audience. The projects are judged by a panel of industry and faculty experts and awards made to the top place finishers.

Changes in the Curriculum Courses

Some improvements made so far to the curriculum based on instructor and student feedback include:

EGEE 301 (5 credits) to EGEE 301 (6 credits)

An increase in course credits (from 5 to 6) for EGEE 301 was recommended and implemented to allow additional laboratory experiments that demonstrate the interrelationships of thermodynamics, heat flow and fluid mechanics concepts. The six credit EGEE 301 was subsequently split into EME 301 (Thermodynamics) and EME 303 (Fluid Mechanics) each for three credits. This allowed coverage of the thermodynamics of electrochemical systems and provided flexibility for students who have covered the equivalent of one of the two subject matters elsewhere and wished to only cover the other subject matter to be able to do so. It also allowed flexibility to cover thermodynamics and fluid mechanics as two back-to-back courses to provide flexibility in scheduling. CHEM 112 was added as a prerequisite to enhance course understanding and success. This change was approved by the Faculty Senate, effective Spring 2008. MATH 251 was added as a prerequisite in line with the fluid mechanics courses in other Engineering departments.

EGEE 437:

The proposed course changes included the course content, title, and prerequisite. The title of the course was changed from "Renewable Energy Fundamentals" to "Design of Solar Energy Conversion Systems". These changes were based on the experience of teaching this course for the first time in Spring 2008. The principal change in content included narrowing the scope of the course to cover photovoltaic and thermal solar energy conversion with the exclusion of a generic introduction to renewable energy and biomass energy. During the first two offerings of the course, it became clear to the instructors that more time was necessary for an effective teaching/learning of the solar energy conversion concepts. Student comments also pointed to the need of spending more time particularly on photovoltaic solar conversion. The biomass energy was included in EGEE 451.

EGEE 438:

The proposed course changes include the course content, title and prerequisite. The proposed changes will take effect from spring of 2012. The title of the course will be changed from "Sustainable Energy Options "to" Hydro and Wind Energy Engineering." These proposed changes are based on the experience of teaching this course twice in Spring of 2009 and 2010 and are made in concert with feedback from the students from both offerings. The change in content involves sharpening the course focus to cover in more technical detail the renewable conversion of energy from moving fluid (wind and hydropower) and eliminating coverage of the temperature gradient driven power conversion processes (geothermal and OTEC). This change allows for a richer technical exposure to the wind and hydropower technology areas building upon the foundations of fluid mechanics taught in the suggested prerequisite change to EME 303, which is generally taken concurrent to the current prerequisite, EME 301.

Current Status:

This major was approved and started in fall 2007. Therefore, incoming students who entered in fall 2007 were not informed about this major through the admission catalogues/brochures. By the end of 2011, the program had 250 students who had declared Energy Engineering as their major. The first cohort of students graduated in May 2009. As of December 2011, a total of 35 students have graduated from the program. The program is seeking accreditation as a General Engineering Program by the Engineering Accreditation Commission of ABET in the 2011-2012 academic year.

REFERENCES

1. USDOE *Annual Energy Review 2006*; DOE/EIA-0384(2006); 2007.
2. USDOE *Annual Energy Outlook 2008*; DOE/EIA-0383(2008); 2007.