Educating the 2030 Global Energy Engineer

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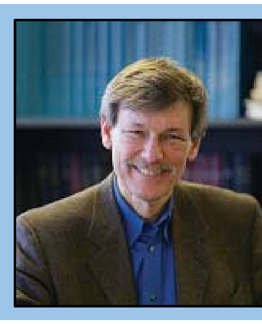


Abstract

The changing landscape for engineering practice in general necessitates significant structural transformation in engineering education to enhance the system perspective and innovation/entrepreneurship skills of future engineering practitioners. The demands for such a transformation are nowhere more evident than in the global energy industry that poses numerous interdisciplinary challenges to a rapidly aging workforce. This paper opens with a discussion of the educational needs of engineers in this new century, continues with a description of the unique challenges facing the energy industry, and closes with a brief introduction of a sample proposed innovative Energy Systems Engineering graduate program designed to respond to these needs.

1. Introduction

Most recent research in engineering education explores the ways current engineering education practices must change to meet the needs of a twenty-first-century workforce and marketplace. Because of the complexities of current and future technologies, engineering professionals and engineering educators must increasingly adopt a systems approach. Furthermore, due to the "customerization" of engineering—the consumer-driven market for technological goods—engineers need to become accustomed to working with customers in a more public role than engineers have traditionally played.

Within the energy industry, demand for skillful engineers is higher than ever. Regardless of which scenario, the "plenty-of-oil" or the "peak-oil" scenario, becomes reality it is clear that we have reached an era where the "black gold" is simply more difficult to find and too precious to burn for low temperature applications such as heating and cooling needs. In the years to come we will see the oil and gas increasingly used to produce value-added products, such as plastics and chemical derivatives. Moreover, as "easy" oil continues to be less available, more-advanced technologies are required to find the oil and to utilize it in value-added products with minimal adverse impact on the environment. Twenty-first-century energy engineering education must prepare students to face these new challenges. This talk, therefore, considers possible reforms for engineering education, the unique needs of and challenges for energy engineering in general, and in the Middle East in particular.

2. Engineering Education in the New Century

The engineering education system involves such elements as the teaching, learning, and assessment processes; the faculty and students; curricula, laboratories, and informational technologies; and the external environment that shapes marketplace demands for engineers.

In pursuing a more student-oriented system, most recent research findings focus on two major tasks: "better alignment of engineering curricula and the nature of academic experiences with the challenges and opportunities graduates will face in the workplace;" and "better alignment of faculty skill sets with those needed to deliver the desired curriculum in light of the different learning styles of students." Some of the main recommendations to accomplish these tasks are documented in a recent report on adapting engineering education to a new century [2] and include the following:

- The B.S. degree should be considered a pre-engineering or "engineer in training" degree.
- Engineering programs should be accredited at both the B.S. and M.S. levels, so that the M.S. degree can be recognized as the engineering "professional" degree.
- Colleges and universities should endorse research in engineering education as a valued and rewarded activity for engineering faculty and should develop new standards for faculty qualifications.
- In addition to producing students who have been taught the advances in core knowledge and are capable of defining and solving problems in the short term, institutions must teach students how to be lifelong learners.

- Engineering educators should introduce interdisciplinary learning in the undergraduate curriculum and explore the use of case studies of engineering successes and failures as a learning tool.
- National Institutions in both the developed and developing countries should establish additional incentives to further encourage domestic students to obtain M.S. and/or Ph.D. degrees in order to improve the training of the future skilled work force and to have a greater impact on resources devoted to the research and development frontiers.

3. Educational Needs of the Global Energy Industry

While the education of the global energy engineer is strongly influenced by the changing educational landscape for all engineering disciplines, the specific needs of the global energy industry must also be addressed.

Based on the latest estimates, by the year 2030 nearly 80% of the world's energy requirements will most likely be provided by fossil fuel sources. With further energy demands by the developing economies, including India and China, adding to the still growing energy needs of the developed economies, fossil fuels will continue to rise in value. However, with the maturation of fossil fuel reservoirs around the globe, we are approaching ''peak easy oil'' and sustaining production levels in the coming era will require advanced measures for improved oil recovery (IOR) and enhanced oil recovery (EOR). Among the various EOR and IOR techniques, capture and injection of CO_2 is being considered and is already in pilot studies in a number of locations, including Abu Dhabi which aspires to assume a leading role in this area. It is, nevertheless, clear that to sustain long term production of the reservoirs at current levels till year 2030 and well beyond, requires careful reservoir modeling at the pore scale and multi-scale, leading to full mathematical modeling of the reservoir. Such understanding requires a multi-disciplinary approach, involving advanced skills in geology and geophysics, mathematics, chemistry, materials science and engineering, petroleum, mechanical and electrical engineering, as well as production and supply chain management and optimization. Moreover, while maintaining high levels of fossil fuel production, it is imperative that the adverse environmental effects of hydrocarbon-driven fuels and energy production be minimized. This need creates an opportunity for the synergetic use of CO_2 and lends additional importance to energy-efficient capture and storage of CO_2 from various sources, such as from air, flue gas, and from exhaust of various power generation equipment including gas turbines.

Although by the year 2030, and possibly well beyond that, the majority of energy for transportation and other critical industries will come from fossil fuel sources, the oil/gas industry has already charged itself with the broader mission of providing energy from all possible sources, with a focus on sustainability and minimization of adverse environmental effects. Sustainability of the energy supply thus requires training of an innovative and skilled work force that can transform an accelerated shift to environmentally sustainable future energies and future fuels. Regrettably, the low energy prices in the past three decades have resulted in low investment of the energy industry in education and development of highly skilled workforce. A great portion of the skilled work force is expected to retire in the next decade and create a huge gap in the skill and knowledge base, with only limited overlap of the highly experienced and the novice work force. Accordingly, a focus on innovation and leadership in the modern energy curriculum will be necessary, requiring accelerated investment in the educational domains of significance to the energy industry. In the global economy environment teamwork, interdisciplinary collaborations and knowledge of world economies, finance, and supply chain management and optimization, along with exposure to the science and technology underpinning alternative energy sources, are among qualities that will be increasingly impotent.

While low oil prices introduce their own challenges, such as reduced investments and expansion plans, very high oil prices will present challenges that could be detrimental, if not dealt with effective planning. For example, in the past two years we have seen sever cost escalations in all sectors of the energy industry, new resource development challenges both from technical geopolitical aspects, and more importantly the raging war for talent and skilled work force.

4. A Sample Proposed Graduate Education in Energy Systems Engineering

4.1 Motivation

Informed by the changing landscape in engineering education and the global energy industry, many institutions are embarking on an innovative graduate program in Energy Systems Engineering (ESE), offering M.S. degrees to researchers and practitioners alike. Such programs will focus on the science and engineering that underpins energy production and utilization from a systems perspective, and will address engineering, science, and societal issues in the three broad areas of fossil, nuclear, and renewable power generation, including attention to conservation, hydrogen generation and utilization, energy conservation and optimization, and sustainable development.

Research and education in the science and engineering of fossil, nuclear, and renewable energy production, as well as energy conservation, are perceived by many faculty members as being of critical local as well as global importance. The proposed ESE program will provide a coherent approach to energy engineering; equipping its graduates with the tools needed to conceptualize, analyze, and design advanced energy systems, informed by a broad perspective on production/transmission trade-offs and an appreciation for public policy and regulatory issues. The ESE graduates will be uniquely qualified to participate in the formulation and implementation of future energy strategies, as well as to perform the needed engineering research and development, and will provide a leadership cadre for the energy engineering community.

In addition to the graduate education provided by ESE, it is anticipated that the program will develop and offer an honors course and an “energy engineering” concentration area for undergraduate students in the Clark School of Engineering. Growing public concern over energy sufficiency and independence can be expected to make such courses highly attractive to undergraduate students and to enhance the future employability of students participating in such courses and concentration areas.

Students can enter this program with a bachelor’s degree or higher in engineering, mathematics, or physical sciences. Also, students in any of the 5-year B.S./M.S. Engineering programs can choose the ESE program for their M.S. degree, with appropriate arrangements with their B.S. degree granting Department.

4.2 Curricular Framework

The available (or under development) ESE courses are listed in the section that follows, showing a common set of “core” courses, an inner ring of shared “advanced tools” courses, and an outer ring of elective courses in each of the three specialization areas: fossil, nuclear, and hydrogen/renewable power generation. Graduate students entering the ESE program with a BS degree, will be expected to take three, 3-credit core courses and, at least, two courses from the inner ring of “advanced tools” courses that will prepare them for courses and research in any of the three specialization areas. Enrolled students will then be required to select a specialization area and complete three, 3-credit courses in this specialization area, i.e. fossil, nuclear, or renewable power generation. Courses offered by other Departments within the College of Engineering, that relate specifically to the student’s needs and interests, may also be included among these “specialization” courses.

To complete the requirements for a M.S. degree, following completion of these eight ESE courses, participating students will be required to complete a 6-credit Thesis, with an Advisor selected from among the ESE faculty. A total of 30 credits, including the 6 Thesis credits, will be required to earn an M.S. in Energy Systems Engineering.

It is anticipated that M.S. and Ph.D. students in Mechanical Engineering and Reliability Engineering, as well as in Material Science and Engineering and other Departments in the College, whose research deals with specific aspects of energy systems, will also find the ESE courses of interest.

4.3 ESE Graduate Courses

Listed below are courses for the proposed curriculum. All listed courses are offered at the graduate level.

4.3.1 Core Courses

ENESE 601: Fundamentals of Energy Systems. This course introduces a common framework for analyzing various available energy systems, including energy production, transport, conversion, utilization, and storage.

ENESE 601: Fundamentals of Energy Production and Utilization. This course reviews the major sources and end-uses of energy in our current society, as well as treating the sources and end-uses that are expected to become important in the near term.

ENME 632: Advanced Convection Heat Transfer. This course addresses conservation of mass, momentum and energy. Laminar and turbulent heat transfer in ducts, separated flows, and natural convection. Heat and mass transfer in laminar boundary layers. Boiling, two-phase phenomena and industrial applications such as cooling towers, condensers. Heat exchanger design.

ENME 633: Advanced Thermodynamics. This course will focus on developing physical and mathematical insight into the properties of matter and the interactions between molecules, which govern macro-scale processes relevant to energy engineering as well as other fields.

ENME 635: Energy Systems Analysis. The course introduces students to the analysis of entire energy systems, beginning with simple components, such as heat exchangers, compressors and turbines, and the integration of these components into subsystems and finally into complex power generation and energy conversion systems.

4.3.2 Advanced Tools

ENRE 602: Reliability Analysis - Principal methods of reliability analysis.

ENRE 620: Mathematical Techniques for Engineers - Probability and statistics, mathematical techniques for analysis and solution of energy engineering problems.

ENRE 670: Risk Assessment for Engineers - Sources of risk, probabilistic risk assessment procedure, risk benefit assessment.

ENME 712: Measurement and Instrumentation - Methodologies for measurement and data analysis of thermal and fluid processes.

ENESE 715: Modeling and Simulation of Energy Systems - (in preparation).

4.3.3 Energy Production and End Use

4.3.3a Fossil

ENME 707: Combustion and Reacting Flow - Thermochemistry and chemical kinetics of reacting flows.

ENESE 710: Advanced Combustion technologies-evaluating steady-flow and cyclical combustion devices.

ENESE 718: Production of Fossil Fuel - in preparation.

ENME 750: Boiling and Multi-Phase Flow - phase change heat transfer phenomenology, analysis and correlations.

4.3.3b Nuclear

ENESE 670: Nuclear Reactor Analysis - Nuclear reaction rates, energy distribution of neutrons, diffusion theory, fuel depletion, reactor kinetics, neutron transport.

ENESE 671: Thermalhydraulics in Nuclear Systems - Thermal analysis of fuel elements; flow loops scaling methodologies; two-phase flow instabilities;

ENESE 675: Advanced Nuclear Reactor Systems - in preparation

ENESE 764: Radiation Engineering - Analysis of radiation applications, such as synthesizing chemicals, preserving foods, control of industrial processes, and chemonuclear reactors

4.3.3c Hydrogen and Renewable

ENESE 625: Utilization of Renewable Energy Sources - in preparation.

ENME 684: Thermochemistry and Physics of Hydrogen Energy - fundamental understanding of the thermodynamics of materials and physical chemistry needed for hydrogen-based energy infrastructure.

ENME 706: Impact of Energy Conversion on the Environment - energy production, transportation and consumption; evaluation of environmental, infrastructure and cost impacts.

ENESE 771: Energy Conservation Technologies - energy conversion systems/practices, cost/benefit analysis financial impact of the proposed energy-saving concepts.

5. Conclusions

With further steep demand for energy around the globe, the energy industry of today and the future requires changes in the way engineers are prepared for and are expected to perform their jobs in the twenty-first century. The global energy engineer of the future needs to be well-rounded, with solid knowledge of fundamentals, as well as skills to be prepared to face the realistic work environment upon commencement. This means in most cases that a four-year bachelorette degree may no longer be sufficient, and students may have to pursue a master's degree. While technical excellence remains the key factor in an engineering education, graduates should also "possess team, communication, ethical reasoning, and societal and global contextual analysis skills, as well as understand work strategies." These areas are necessary for a university to produce engineers who can communicate with the public and "engage in a global engineering marketplace," and who will become lifelong learners. Educating the Energy Engineer of 2030 introduces additional challenges that must be addressed and are briefly discussed in this Keynote address. The curriculum of an innovative Energy Systems Engineering graduate program was presented for consideration and interactive discussions.

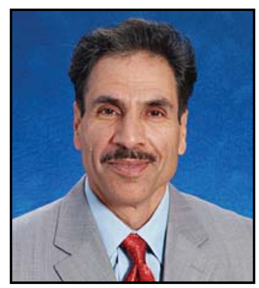
6. References for Additional Related Information

1. National Research Council, 1999. *How People Learn: Brain, Mind, Experience, and School.* Washington, D.C., National Academies Press.
2. National Academy of Engineering, 2005, "Educating the Engineer of 2020: Adapting Engineering Education to the New Century." Washington, DC, National Academies Press, www.nap.edu/catalog/11338.html

Author Biographies

Dr. Avram Bar-Cohen is Distinguished University Professor and Chair of Mechanical Engineering at the University of Maryland. He is an internationally recognized leader in the field of thermal design and thermal management of electronic systems, an Honorary member of ASME, and Fellow of IEEE. His work has served to create the scientific foundation for the thermal management of electronic components and systems. Bar-Cohen is the general chair for the 2010 International Heat Transfer Conference and the incoming President of the Assembly of International Heat Transfer Conferences.

Bar-Cohen's was most recently recognized with the ASME's InterPack Achievement Award (2007) and was previously honored with the Worcester Reed Warner Medal (2000), Heat Transfer Memorial Award (1999), the Edwin F. Church Medal (1994) and the IEEE CPMT Society's Outstanding Sustained Technical Contributions Award (2002). Bar-Cohen co-authored (with A.D. Kraus) *Design and Analysis of Heat Sinks* (John Wiley & Sons, Inc., 1995) and *Thermal Analysis and Control of Electronic Equipment* (Hemisphere Pub. Corp., Wash. D.C.; McGraw-Hill, N.Y., 1983), and has co-edited 13 books in this field, while currently serving as co-editor for the Elsevier book series *Advances in Heat Transfer*. He has authored/co-authored some 300 journal papers, refereed proceedings papers and chapters in books; and has delivered more than 60 keynote, plenary and invited lectures at major technical conferences and institutions. Bar-Cohen and he holds four shared US patents.



Dr. Michael M. Ohadi is a Professor of mechanical engineering, and the Provost and Acting President of The Petroleum Institute in Abu Dhabi, UAE. Previously he served at the University of Maryland as a professor of mechanical engineering and co-director of Center for Environmental Energy Engineering. His field of expertise is thermal and fluid systems with applications to design and optimization of advanced heat exchangers and energy systems. An internationally recognized authority in his field, he has conducted many research projects for both industry and the government agencies, which have included sponsors in the U.S., Japan, Germany, Denmark, South Korea, and Taiwan. He has published over 140 refereed technical papers, and currently serves as Associate Editor for two journals in his field of expertise. He is the past chairman of ASME Process Industry Division, as well as past chairman of ASME Potter Medal Awards committee. He is a fellow member of both ASME and ASHRAE, and has won numerous awards from both societies.