Green Engineering: A Multidisciplinary Engineering Approach

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Abstract

Virginia Polytechnic Institute and State University (Virginia Tech) is entering its 131st year. Founded in 1872 as Virginia's land-grant college with an initial enrollment of 43, Virginia Tech has grown to become the commonwealth's largest university with enrollment at roughly 26,000. The University offers over 200 degree programs through its seven undergraduate academic colleges. Its annual research expenditures exceed $150 million.

Introduction

Virginia Tech's College of Engineering accounts for about one quarter of university students, both undergraduate and graduate, as well as the lion's-share of research expenditures. The College of Engineering consists of 10 degree granting departments plus the Division of Engineering Fundamentals – the home of engineering's common-first-year program. Virginia Tech's College of Engineering is unusual in that, in addition to the multitude of special interest groups, labs and research areas, the college contains a Green Engineering Program. Green Engineering encompasses all of the engineering and science disciplines, focusing on the design and synthesis of materials, processes, systems, and devices with the objective of minimizing overall environmental impact (including energy utilization and waste production) throughout the entire life cycle of a product or process. Green engineering might be considered environmentally conscious attitudes, values and principles combined with sound science, technology and engineering practice. Green engineering is, inherently, inter- and cross-disciplinary in nature. Each department within the College of Engineering includes this information to a greater or lesser degree as an imbedded and generally non-specific part of its curricula.

This paper examines the potential of green engineering in a multidisciplinary environment. Not only is green content appropriate for most, if not all, disciplines within engineering, but it is also appropriate for non-engineering majors. "A technically literate society must be educated on what issues to evaluate, or be resigned to being the victim of snake-oil sales people in the form of politicians, telemarketers, and other guises."[1]

The National Council for Science and the Environment in their *Recommendations for Education for a Sustainable and Secure Future* make the case for a new paradigm in education:

> 'Education strategies are being considered now that prepare a new professional to feel comfortable in a multidisciplinary framework. Individuals cannot have all the specialized knowledge relevant to decisions they make in their private, work, or civic life. They must realize through the education process, however, that such information is relevant and available. Even if they are not experts in everything, they can appreciate the work of

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others, and they can collaborate with others to achieve integrated solutions. Such an approach would enable graduates to apply their learning to the needs of real world problems and real people. Cross disciplinary education enlarges students' awareness of issues and methods beyond their own disciplinary inquiry, enabling them to explore the relationships among these issues and encouraging students to view their studies from a broader social and ecological perspective that takes into account human values and environmental, social, and economic sustainability.' [2]

Green Engineering

Engineers, engineering faculty and engineering students need to realize that they typically do not have all the relevant knowledge needed to make decisions, and that those decisions typically have a broad impact the world in which we live. Jeremy Rifkin, in The Hydrogen Economy, states the case in this fashion: 'Unfortunately, while every school child is tutored in the laws governing gravity and why apples fall from trees the way they do, few are ever introduced to the laws governing the transformation of energy. Yet these laws are far more helpful in instructing us about the ebbs and flows of existence, including the passage of time and the workings of the Earth's chemical, biological, and social systems.'[3] Ray Anderson, the embattled CEO of Interface, Inc., simply notes that 'The truth is, we have an essentially illiterate populace when it comes to the environment.'[4] Making the energy, environmental, social and global impacts of engineering solutions an important consideration is the essence of green engineering. Implementing them across the engineering curricula represents a challenge. Frank Splitt, McCormick Faculty Fellow at Northwestern University, has spent the past several years lobbying ABET, successfully, to include environmental considerations in ABET Criterion 3, Program Outcomes and Assessment.[5] Although a one word addition to the criteria may appear superficially minor, the required effort to make the change reflects on it's importance. In Dr. Splitt's words 'Engineering programs must then demonstrate that their students attain an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability, as well as demonstrate the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.'[6]

'Green' engineering is the terminology currently in use to describe the process of designing and producing goods, services, or processes, taking into consideration the effect of these items on the environment. To those of us active in the engineering profession, this is not a new concept. Part and parcel of the design process is an analysis of overall product cost, which normally involves waste disposal and/or reclamation. This perhaps more traditional approach to the environmental impact of an engineering design is being supplanted by an approach that is less dependent on costs -- green engineering. Green engineering, in short, involves analyzing the environmental impact of the designed product throughout the product/process life. Not only are the raw materials analyzed, but also the impact of the product's use, any by-products or waste streams generated, and the disposal/reclamation cost. A separate branch of 'green' engineering, possibility pre-dating the use of that term, is Design for Recylability, DFR. DFR implies the conscious analysis of product recycling by the design engineer. Although this generally involves the product itself, it also includes the manufacturing process as well.

The current interest in green engineering topics is driven by a number of forces. Companies, with the exception of charitable organizations, are in business to make profits, and, as a result, to provide a reasonable return to their investors, and provide salaries and benefits to their employees. The world marketplace determines the value placed on the product, and also determines the material, labor, and, increasingly, regulatory costs of that product. Raw materials, process equipment, packaging materials, and other items are also subject to the same market forces. It is in the companies' best interest to keep these costs as low as possible, while still maintaining the requisite product quality, durability, safety, marketability. Eliminating waste streams in the manufacturing processes will reduce raw material costs, but perhaps at an increase in manufacturing cost. Recycling materials from these waste streams can be effective in reducing product cost and increasing product competitiveness.

A second force moving companies toward more concentration on the environmental impact of their products is public awareness. Although the price of a product in the marketplace is a major factor in purchasing decisions by the consumer, companies are finding that consumers are now more willing to pay a premium for products with a 'green' label[7,8]. These products are those that are advertised as including 'recycled' or 'reclaimed' materials (paper products); minimize packaging (laundry detergent refills); contain no dyes (PEPSI 'clear'); minimize energy usage (fluorescent lights); use naturally occurring materials (woodstoves; cotton fabrics); use recycled materials (Patagonia's 'polarfleece' fabric); have minimal noise impact (electric lawnmowers); minimize manufacturing waste steams (unbleached fabrics); minimize hazardous wastes (re-chargeable batteries); and in other ways appeal to the purchaser's own environmental awareness.

The third impetus behind green engineering is legal/regulatory. As disposal of products becomes more expensive, governments are more apt to force this cost on the consumer rather than on the general public. Waste disposal has historically been a service provided by communities and supported by taxes. As waste streams have increased and the availability of landfills decreased, 'tipping' charges have increased or been implemented, and recycling has become more economic. As manufacturing processes have become more technically complex, their waste streams have likewise become less benign, more concentrated, and less likely to be compatible with public treatment facilities. The costs, both direct and indirect, of operating these facilities have increased, and the operating authorities have had to regulate the incoming waste streams. Laws and regulations have been changed to limit or reduce the materials which may be discharged, forcing industries to pay the cost of in-house discharge treatment. On the state and national level, laws have been passed regulating the energy efficiencies of products, and specifying penalties for non-compliance. The implementation of CAFE standards (corporate Average Fuel Economy) standards on the automotive industry has. arguably, had a major impact on the fuel efficiency of the US automobile fleet. Similar discharge legislation has substantially reduced automobile emissions. California's strict emission requirements have influenced emission standards in other states, at the federal level, and have forced manufactures to revise their product mix. In addition to regulatory action, civil lawsuits against companies force these companies to re-evaluate their products/processes.

These three driving forces - the economics of the marketplace, regulatory action, consumer preferences - are pushing Americans to examine the 12 billion tons of waste that we produce annually. In addition to this tangible waste steam of solid waste, liquid wastes and air pollution, add the less tangible environmental discharges of noise pollution, thermal pollution, electromagnetic fields, or visual pollution. American industry, while not having a particularly admirable historical concern for the environment, has been moving in the 'green' direction recently - due to the driving forces just described. The 1995 era automobile is a product

designed using DFR. Roughly 70% of that automobile will be eventually recycled into steel, aluminum, plastics and fluids that may be used in next generation vehicles. Some European countries require the manufacturer of an automobile to be responsible for the disposal/recovery of that vehicle at the end of its product life. In this country market forces determine the value of these vehicles - often requiring the owner to pay for its eventual disposal.
Numerous authors have addressed the issues of green engineering, of note Anastas and Zimmerman.[9] Dr. Robert Hesketh of Rowan University has provided an overview of green engineering and green programs in a forthcoming book *Sustainability Science and Engineering: Defining Principles,* an outcome of the conference "Green Engineering: Defining the Principles" held in Sandestin, Florida, in May 2003. The EPA has solicited proposals for a survey of colleges and universities offering 'green' or 'sustainable' programs; that grant should be announced prior to this ASEE meeting. The results of that study should provide considerable insight into the extent and diversity of green engineering curricula. Those institutions with the most visible programs would likely include Carnegie-Mellon University, the University of Pittsburgh's Mascaro Center, Georgia Tech, University of Texas – El Paso, and Virginia Tech. Many other programs exist under various guises, often making identification difficult. Many schools offer courses in green topics although do not offer related certificates or degrees. Although each institution takes a slightly different approach, the following reflects the situation at Virginia Tech.

Virginia Tech's Green Engineering Program

In 1992, five faculty members and administrators within Virginia Tech's College of Engineering began the quest to establish a program which would stress the environmental and societal implications of engineering activities. The program was given a two-fold mission: 1) establish a concentration in Green Engineering and 2) ensure that every Virginia Tech engineering graduate had an understanding of the environmental and societal ramifications of engineering activities. The University's subsequent decision to provide substantial annual funding for this program was praised within the College of Engineering. Department heads, deans and university administrators agreed to provide cross-disciplinary support for the fledgling program.

This program was established with a part-time director and a seven-member steering committee. Funding for the part-time directors position was secured from the University's annual program support. Members of the steering committee serve as unpaid "volunteers", contributing their time and effort in support of the overall mission of the college. Although the director's "home" department continued to fund his/her full salary, the Green Engineering Program reimbursed that department by providing whatever funding was required to hire a teaching replacement.

Green engineering is, inherently, inter- and cross-disciplinary in nature. Each department within the College of Engineering includes this information to a greater or lesser degree as an imbedded and generally non-specific part of its curricula. In order to provide students an opportunity to pursue a more in-depth and broader study of the environmental ramifications of engineering activities, the Green Engineering program developed a concentration in green engineering. The development of a green engineering minor was considered. University regulations required that such a minor be offered by the department conferring the green major, and the development of a green major was not an option. The concentration is identical to the minor in content. Students pursuing the concentration are required to complete eighteen credit hours in courses approved for that concentration.

Establishment of the concentration thus required the development and/or identification of appropriate courses. The concentration specifically identified three areas: 6 credit hours in 'core' green engineering courses; six credit hours in courses with substantial green content within a student's major (in-discipline); and six credit hours of courses with substantial green content outside the student's major (inter-disciplinary). Establishing this curriculum required three steps: the development of the core green engineering courses; the identification of existing in-discipline and inter-disciplinary courses; and the modification of other existing courses to add green content. The two core green engineering courses were designated as an introductory course (Introduction to Green Engineering, ENGR3124) and a course dealing with life cycle assessment of products, processes and services (Environmental Life Cycle Assessment, ENGR3134). Funding was provided from the Green Engineering budget for the development of these core courses.

Establishment of the concentration satisfied part of the mission of the Green Engineering Program. It was recognized by members of the steering committee that a limited number of Virginia Tech's roughly 6000 engineering students would pursue this concentration; therefore the second part of the program's mission was to ensure that all engineering students had some exposure to green engineering principles. To satisfy this portion of the mission, the program submitted a request for proposals from engineering faculty to add green content to existing courses. Proposals were requested annually, reviewed by the steering committee, and awards were granted in those areas most beneficial to the growth of the program. This portion of the Green Engineering Program used the bulk of the annual budget, but in turn led to the development of scores of courses with substantial green content. Financial and other limitations led to the elimination of the requests for these proposals in academic year 1999.

Core Courses

The two core courses of the Green Engineering Program are ENGR3124 – Introduction to Green Engineering and ENGR3134 – Environmental Life Cycle Assessment. The courses may be taken in any sequence, however the introductory course is offered only during the fall semester and the LCA class only in the spring semester. Each course is a three credit hour course and is limited to students who have completed their freshman year academic requirements.

ENGR3124 is designed to introduce engineering students to global environmental issues – those issues that engineers should be cognizant of as world citizens and environmentally conscious engineers. Students in this course examine ways in which human and engineering activities impact the environment, and they are exposed to environmentally conscious design techniques. Enrollment in this courses ranges from 10 to 30 students and, as such, is conducted not as a lecture class but more as a colloquium. As a three-thousand level class it is appropriate to expect students to take an active part in the development and direction of class discussions. This approach becomes more difficult as class size exceeds twenty. As expected outcomes or learning objectives of this class, the successful student should be able to:

- List and discuss the major environmental problems, their causes and potential solutions
- Discuss how the engineering profession can take a proactive role in minimizing environmental problems

- List the principal environmental issues facing their particular engineering discipline and discuss how these issues can or are being addressed by professionals in that discipline.
- Utilize spreadsheets and simple simulation/programming techniques to analyze environmental problems and alternative solutions
- Discuss the importance of interdisciplinary teamwork in the solution of environmental and environmentally conscious design and manufacturing problems.

Topical coverage in this class includes the following:

- Global Environmental Issues
- Sustainability
- Environmental History
- Science, Systems, Matter and Energy
- Ecosystems: Components, Energy Flow, and Matter Cycling
- World Summit discussion and review
- Matter Cycling
- Evolution and Biodiversity
- Population Dynamics, Carrying Capacity and Conservation Biology
- Various Guest Speakers
- Food Resources
- Soil Resources
- Geological Resources: Nonrenewable Minerals and Energy Resources
- Energy Efficiency and Renewable Energy Resources
- Risk, Toxicology and Human Health
- Air and Air Pollution
- Water Pollution
- Climate Change and Ozone Loss
- Solid and Hazardous Wastes
- Economics, Environment and Sustainability
- Sustainable Cities: Urban Land Use and Management.

ENGR3134, Environmental Life Cycle Assessment, introduces students to the practical application of life cycle assessment (LCA) techniques for engineering products, processes and systems. LCA methodologies including inventory, impact assessment, improvement analysis and streamlining procedures are introduced. Other LCA applications including life-cycle design, ecolabeling, costing and public policy in the United States and abroad are addressed. Enrollment in this class ranges from fewer than ten to forty-plus. The smaller class size is much more conducive to discussion of issues whereas the larger class sizes are limited, logistically, to a lecture format. As expected outcomes or learning objectives of this class, the successful student should be able to:

- Apply LCA principles to products, processes and services
- Apply streamlining techniques to LCA applications
- Describe the benefits and limitations of an environmental life-cycle assessment
- Conduct an environmental life-cycle inventory
- Evaluate data sources
- Utilize available LCA software

Topical coverage in this class includes the following:

- Introduction to Life Cycle Assessment
- LCA Methodology
- LCA Software Systems
- Streamlining Techniques
- LCA Data Quality
- LCA Case Studies
- LCA Applications
- Life Cycle Design
- LCA in Public Policy
- LCA in Europe
- Materials Issues in LCA
- Business Uses of LCA
- Systems Analysis
- LCA Valuation
- Product Development
- Waste Management
- Integrating LCA
- LCA – Future Directions.

Implementation

Virginia Tech's approach to green engineering has been one of diffusion. Its core courses are accepted by the departments of Biological Systems Engineering, Electrical and Computer Engineering (plus Computer Science), and Mechanical Engineering as technical electives. The Department of Industrial and Systems Engineering accepts these courses as science electives. The departments of Material Science and Engineering, and Aerospace and Ocean Engineering accept the courses as technical electives for individual students, subject to a departmental approval process. The other departments within Virginia Tech's College of Engineering (Civil and Environmental Engineering, Mining and Minerals Engineering, Chemical Engineering, and Engineering Science and Mechanics) accept these courses as free electives.

The enrollment in these courses has steadily increased in the past five years. While they were initially taught as undergraduate seminars with enrollments of 12-15 engineering students, current enrollment has peaked at 50 students for the Life Cycle Assessment course, 65 for the Introduction to Green Engineering Course. These numbers are somewhat deceptive however. The LCA class has been assigned a classroom with a capacity of 50 students and has since changed to a computer equipped classroom to facilitate the use of LCA software. That computer-equipped classroom holds 34. Although additional sections of the class might be offered, the Green Engineering Program does not have the resources to support more than two classes per academic year. More telling, however, is the lack of financial support by the faculty member's home department. Individual departments are struggling to meet the obligations of their own missions and can not afford to devote scarce resources to programs which may not be in their immediate interest. A clear understanding of the enrollment trends is further distorted by the acceptance by individual departments of these courses as either technical or science electives. Students faced with selecting a technical elective from, for example, thermodynamics and heat transfer, mechanical behavior of materials, solid and structural mechanics, or Environmental Life Cycle Assessment might well opt for the latter. For the Green Engineering Program, however, exposing all students, not just those pursuing a concentration, to the concepts of green engineering is a substantial part of its mission.

The two core courses suffer somewhat in not having individual faculty regularly dedicated to them. As the Green Engineering Program does not have a 'home' or ownership department, departments do not perceive this teaching assignment as high priority. The Introduction to Green Engineering class has been taught by a senior faculty member to excellent reviews, and more recently by an adjunct engineer with less favorable reviews. The Life Cycle Assessment class is taught by the program director. Students in this class are required to complete an open-ended cradle-to-cradle analysis of the energy and material needs, and the waste products produced, by a product or process of the instructor's choosing. Products selected for analysis have included bicycles, snow-boards, mattresses, reading glasses, one-mile of interstate highway, and bottled water, among many others. Difficulty in obtaining usage data, the necessity of making many assumptions regarding data and its quality, and the open-ended nature of the process poses organizational and time-management difficulties for some students. Other students are challenged by these same factors and relish the opportunity to investigate new areas and ideas. Students are therefore not ambivalent about this course – they like it or dislike it – there is little middle-ground. The numeric 'student perception of teaching' is typically three on a scale of four.

Virginia Tech's Green Engineering Program is, by design, an undergraduate program, although the elimination of annual funding in 2003 has provided impetus to develop a research and graduate component. In the author's view, this is unlikely due to the broad scope of green engineering concepts. Green research is currently and continually being performed at Virginia Tech in most of the engineering disciplines: however the titles, funding, and rewards revert, rightfully, to the department, not to the 'green' program. A specific program to pursue legitimate green research would likely infringe upon or duplicate efforts by individual departments and their faculty. In terms of engineering education, 'green' senior design projects are options in each of the departments.

The departments of Biological Systems Engineering, and Materials Science and Engineering have recently agreed to jointly oversee the Green Engineering Program. These departments will not be contributing financially to the program, but will provide what might be described as moral support to those faculty contributing to the program. The current director of the program serves as an unpaid volunteer and a national search is underway for a full- or part-time replacement.

Although no rigorous statistical analysis of the recipients of the 'green concentration' has been attempted, a cursory review of that data indicates that six students should receive that concentration this academic year, about the norm for the preceding five years. Of greater interest, however, in a college where the female population represents about 15% of enrollment and students of under-represented racial groups represent about 4% of enrollment, over half of the green concentrations are awarded to women and roughly one-fifth awarded to minorities. Clearly the green engineering concentration is not a seminal achievement that an employer might use to differentiate between job applicants. In fact it might be suggested that the 'green' reference on their resume might give some employers justification for not considering a candidate – the perception of 'green' in the United States is substantially different than in European countries. If this rationale holds, then women and under-represented minorities must be pursuing the concentration because the engineering involved is not only more palatable to them, but clearly is of personal and professional interest. Although Virginia Tech and its College of Engineering have failed to appreciate this unique appeal, it would appear to be an ideal vehicle for increasing the numbers of women and minorities in this profession.

Summary

The future for green engineering is established, generally. With the world population exceeding six billion, the desire to raise the standard of living for all people, and limited world resources, green engineering principles must be incorporated widely. The future of the Green Engineering Program at Virginia Tech is less certain. Annual funding for the program has been eliminated, due in large part to the fiscal pressures facing Virginia and her colleges and universities. The program will continue with funding carried over from prior years; however the Green Engineering Program is targeted for elimination under the current budget. This targeting is understandable, fiscally. As an undergraduate program it does not generate revenue for the university. It does, however, confer a handful of concentrations in green engineering each year and does so at a minimal cost. In addition, it annually exposes hundreds of engineering students from all engineering disciplines to the concepts of green engineering and sustainability. In addition, efforts are beginning to be made to open these classes to non-engineering majors, pending prerequisite approval. A more far-reaching goal is to implement a university core requirement that all graduates of the university have an exposure to the concepts of sustainability. The inclusion of 'environment' in ABET's engineering criterion should certainly provide legitimacy to this and other approaches to green engineering education.

[1] Dr. Mary Kasarda, Virginia Tech, in 'Last Word', *PRISM*, October 2005

[2] Recommendations for Education for a Sustainable and Secure Future, A Report of the Third National Conference on Science, Policy and the Environment, January 30-31, 2003. p.12. Washington D.C. National Council for Science and the Environment

[3] Jeremy Rifkin, *The Hydrogen Economy*, p.43. Penguin-Putnam Inc., 2002

[4] Ray Anderson, in Recommendations for Education for a Sustainable and Secure Future, *op.cit*., p. 67

[5] Criteria for Evaluating Engineering Programs, 2005-6, ABET, Baltimore, Md. 11/01/04

[6] Frank G. Splitt, McCormick Faculty Fellow, McCormick School of Engineering and Applied Science, Northwestern University, Evanston, IL, email correspondence 11/23/04

[7] C.F. Mason, On *the Economics of Eco-Labeling*, University of Wyoming, 2002

[8] R. Sedjo and S. Swallow, *Eco-Labeling and the Price Premium*, Resources for the Future, Washington, D.C., 1999

[9] Paul Anastas and Julie Zimmerman, *Design through the 12 Principles of Green Engineering*, Environmental Science and Technology, March 1, 2003, p. 95, American Chemical Society.

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