Session 3251

Environmental Life Cycle Analysis for Engineers

Michael H. Gregg
Division of Engineering Fundamentals
Virginia Polytechnic Institute and State University

Abstract

Environmental Life Cycle Analysis, EF3134, is one of the core courses in Virginia Tech's 18 credit hour Green Engineering concentration as well as an engineering elective. This paper describes the difficulties associated with presenting this complex software driven class in an undergraduate curriculum. Main elements include LCA concepts, databases, available software, assumptions and simplifications, limitations and applicability.

Introduction

Virginia Tech, a land grant institution, is well into its second century. Its objectives are education, research, and community service. Virginia Tech has grown over the past 130 years from an institution with a student body of 43 to its current enrollment of over 25,000, comprising about 5000 new freshman each year. Of these entering freshmen, roughly 1500 will enter the College of Engineering. The College offers ABET accredited Bachelor of Science degrees in Aerospace, Biological Systems, Chemical, Civil/Environmental, Computer, Electrical, Engineering Science and Mechanics, Industrial and Systems, Materials Science and Engineering, Mechanical, Mining and Minerals, and Ocean Engineering.

Virginia Tech's engineering program puts an emphasis on immediately involving its entering engineering students in engineering topics. These introductory topics are structured to give these students a taste of engineering curricula and to expose them to problem solving techniques. Early involvement in engineering problem solving helps stimulate, refresh and/or retain the interest that these students have already shown in the engineering profession. Virginia Tech's success in maintaining a respected and rigorous engineering program is combined with an exceptionally high retention rate of its freshman in engineering. Although admission standards to the engineering program are reasonably high (average 1256 combined SAT, top 10% of class, 3.6/4.0 GPA), the latest figures indicate that nearly 70 percent of freshman engineering students graduate from Virginia Tech with an engineering degree; an additional 20 percent graduate from Virginia Tech with other than an engineering degree, and the remainder transfer to another institution or take on other challenges.[1]

Green Engineering

'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 products 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 more and more willing to pay a premium for products with a 'green' label. 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. An example is California's requirement of a minimum level of 'zero impact' and electric vehicles by 2000. 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, 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 current 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.

Carnegie Mellon, Berkeley, Georgia Tech and the University of Windsor all have green engineering WEB sites, and either formative or mature green engineering programs. Virginia Tech began its Green Engineering Program a decade ago. In 1992, the College of Engineering at Virginia Tech established a "Green Engineering" program. Green Engineering is defined within the context of the Virginia Tech program as environmentally conscious attitudes, values, and principles, combined with science, technology, and engineering practice, all directed toward improving local and global environmental quality. Its program 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. An ABET impetus for green engineering is contained in Criterion 3 Program Outcomes and Assessment, Item [h] of the EC200 requirements, requiring that 'Engineering Programs must demonstrate that their graduates have: ……………….the broad education necessary to understand the impact of engineering solutions in a global and societal context.' [5] Some efforts are underway to have the ABET language of item [f] 'an understanding of professional and ethical responsibility' modified to include the word environmental.

Virginia Tech's Green Engineering program has two major goals. First is to ensure that every Virginia Tech engineering graduate is fully aware of environmental issues and understands the environmental consequences of engineering systems. The second goal is to provide a concentration in green engineering for those students interested in pursuing this course of inquiry. The 'concentration' has all the requirements of a 'minor' but without much of the administrative overhead. Students pursuing this concentration must take 18 credit hours of approved courses. Six credit hours are in-discipline courses as approved by their department and the Director of the Green Engineering Program. Six credit hours are interdisciplinary electives approved by the Director with the concurrence of the Green Engineering Steering Committee. The remaining six credit hours consist of the 'core' course of the concentration: ENGR 3124 Introduction to Green Engineering, and ENGR 3134 Environmental Life Cycle Assessment.

ENGR 3134 Environmental Life Cycle Assessment

As one of the two core courses in the Green Engineering Program, this course is offered only during the spring semester; its counterpart, Introduction to Green Engineering, is offered during the fall semester. It has attracted mostly engineering students interested in obtaining the concentration, but has also attracted non-engineering students as well. Enrollment in this class peaked at 24; its last three semesters had 9, 24 and 12 students enrolled. Its popularity was enhanced by its professor, Dr. Ron Kander, certainly one of Virginia Tech's finest and most popular professors. Since Dr. Kander's departure to head James Madison University's fledgling Integrated Science and Technology Department, this ENGR 3134 class has been designated a technical elective by at least one of the departments within the College of Engineering. This designation elevates the class to the status of counting toward a student's engineering degree, in some cases. Enrollment for the spring semester 2002 is forty students, with many students on a burgeoning waiting list. This enrollment change requires, for all practical purposes, the class to be taught in a more traditional manner; with fifteen students it could be taught in the form of an engineering seminar with individual projects. Life Cycle Analysis (LCA) is best described by its ISO 14040 definition:[11]

> LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by:
> - Compiling an inventory of relevant inputs and outputs of a product system;
> - Evaluating the potential environmental impacts associated with those inputs and outputs;
> - Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study. (ISO 1996, p.iii)

The goal of this course is to introduce students to the practical application of LCA, to include products, processes and services. This course is project and case study based, its syllabus comprising the following elements:

- History of LCA
- LCA Methodology

- Streamlining the LCA Process
- Available Software and Databases
- Life Cycle Design
- Life Cycle Costing
- Materials in LCA
- Applications and Case Studies
- Individual and Team Projects

Life cycle assessment is essentially an elaborate accounting mechanism. One author traces the roots of LCA to an 1865 study of coal depletion in Great Britian.[10] Most, however, acknowledge the first attempts at LCA in its current form to the work of the U.S. Department of Energy in its early work in the development of the Energy Consumption Database and other fuel cycle studies of the sixties and seventies. Much more development and application work has been performed in the European countries, however, than in the United States. ISO standards are either in place (ISO 14040) or in preparation and review for LCA procedures and policies. Although LCA is perceived is some venues as product oriented, a more macroscopic view of life cycle assessment includes systems, services and, perhaps more importantly, policies. An institutions first uses of LCA were often productive and simple, helping to identify those areas of their product or process which most affected the environment. These were fairly obvious decisions, supported by LCA. As the 'pickings' became slimmer, LCA efforts became much more involved and laborious. "Performing a life cycle inventory/assessment for a design, product or process is a daunting task. It attempts to identify and quantify environmental impacts and costs over acquisition, operation and decommissioning/disposal phases."[7] A 'daunting' task for an industrial organization is even more so in terms of a one semester undergraduate course.

LCA tasks typically involve goal setting, scope determination, the inventory analysis, environmental impact analysis and interpretation of results. As with any project, whether product design, system analysis or service, goal setting and scope determination are critical to the project's success. Goal setting and scope determination, however, are best defined and established based on experience with life cycle analysis….experience that the students do not yet have. Often, then, these tasks (particularly the goal setting) fall to the LCA instructor. If the scope of the LCA is too narrowly defined then the results may be trivial. On the other hand a scope that is too sweeping or ambitious may result in an LCA project which could not realistically be completed in the course of one semester. Much of what is done in ENGR 3134, therefore, involves the life cycle inventory and the subsequent analysis and interpretation of the environmental impact.

The life cycle inventory is driven, typically, by the available LCA software. Software and databases have been discussed by numerous authors[6-13]. ENGR 3134 has used Battelle Memorial Institutes Life Cycle Advantage™ and is considering the use of SimaPro™ by PRe' Consultants. Spreadsheet software such as QuattroPro™ or EXCEL™ is also suitable for the inventory, however the LCA specific software typically includes the necessary database, an essential ingredient in the inventory. The main disadvantage to the use of LCA software is the learning-curve lead time required to become proficient. ENGR 3134 students are generally struggling with the software throughout the semester. Given forty-eight classroom contact hours per semester, combined with perhaps an additional ninety-six homework hours, a student would have, at most, about four full work-weeks of LCA contact. LCA practitioners spend multiple two-thousand hour work years gaining their expertise.

ENGR 3134 has been, and will continue to be, a project/case study driven course. Students work in instructor-selected or self-selected teams of two to four on various LCA projects over the course of the semester. Teams present the results of their life cycle assessments both orally and as written assignments. Assigned projects must be realistic in goal and scope, of interest to the students diverse engineering backgrounds, have readily available data sources for the inventory analysis, and not have solutions which are available on the web (or in other forms.) Projects have included soft drink manufacturing, reverse engineering to obtain 'green' toys, analysis of disposal of computer components, and a comparison of transportation alternatives. This semester's projects may include low-flow toilets, fuel cells, 'plastic' wood, hybrid vehicles, public transportation and others as proposed by students or teams. Grading in this class has previously relied heavily on written projects and oral presentation, with no formal written tests. With the increased enrollment for Spring 2002, however, the course will include 'quiz-a-week' testing to ensure that all students are keeping abreast of the course material and are not relying on their project teammates to carry the load. It is anticipated that a great deal of additional information concerning the conduct and success of this course will be available at the end of the spring term.

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Biographical Information

MICHAEL GREGG is an Associate Professor in the Division of Engineering Fundamentals at Virginia Polytechnic Institute and State University (Virginia Tech) in Blacksburg, Virginia. Mr. Gregg is the Director of Virginia Tech's Green Engineering Program and is a past chair of the Freshman Programs Division of ASEE.