Green Design Educational Modules and Case Studies

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Abstract

We report on the content and use of a series of course modules, case studies, homework assignments, and software developed at Carnegie Mellon University. The course materials illustrate the principles of green design - the environmentally-conscious design of products and processes. The materials are available on the world wide web at: http://www.ce.cmu.edu/GreenDesign/education.html. The course materials are suitable for use in upper level undergraduate and graduate level engineering programs. A number of the modules/case studies are also suitable for use in business curricula or in technology oriented courses in public policy and history. The materials were developed from industry-oriented research in green design and pollution prevention conducted at Carnegie Mellon University over the past 5 years. Topics highlighted in the educational materials include: 1) green design, 2) life cycle assesment, 3) full cost accounting, 4) design for disassembly and recycling aids, 5) recycling and waste management, and 6) material flows and mass balance calculations. These modules are in regular use - during the six month period, April – September 1999, each module on the web was accessed an average of 126 times by users not affiliated with Carnegie Mellon University.

Introduction

Engineering is concerned with the creation of products and processes, hence design and manufacturing are essential components of engineering education. Prospective engineers need to know how to make products and processes that have desired properties. Traditional properties of interest have included operational functionality, reliability, and cost, among many others. In the past decade, minimizing environmental impact has become an increasingly important attribute as a result of increasingly stringent regulation, widespread public concern, and new corporate environmental policies. Of particular importance for implementing environmentally-conscious "green" engineering and design are appropriate knowledge, tools, production methods, and incentives that can be applied during design and manufacturing. This change represents a substantial engineering challenge for both practitioners and the educational system (Hendrickson and McMichael, 1992, Conway-Schempf and Lave, 1996).

Researchers at Carnegie Mellon University have developed a series of course modules, case studies, and software that illustrate the principles of green design - the environmentally-conscious design of products and processes. The course modules are suitable for use in upper level undergraduate and graduate level engineering programs. A number of the modules are also suitable for use in business curricula or in technology oriented courses in public policy and history. The modules were developed from the results of industry-oriented research in green design and pollution prevention conducted at Carnegie Mellon University over the past 5 years.

Modules include:

- introduction to green design,
- full cost accounting (and teacher's guide),
- radioactive waste management,
- disposition of personal computers (and teacher's guide),
- reverse engineering for green design, and
- rechargeable battery management and recycling.

Case studies include:

- a case study in environmental input-output life cycle assessment,
- a case study in full cost accounting at a plastics molding facility (and teacher's guide),
- a case study of full cost accounting at a semiconductor manufacturing facility.

An educational software program that aids in life cycle assessment was also developed and is available at http://www.eiolca.net/.

The modules have been designed as stand-alone units that can be inserted into course curricula where appropriate. The case studies can be used along with module material or as separate units.

This paper summarizes the modules and their application and use. The modules are available on the web (http://www.ce.cmu.edu/GreenDesign/education.html). The educational effort is also linked to the NEEDS digital library for engineering education (http://needs.org).

Background to the principles and objectives of Green Design

Green design attempts to develop more environmentally-conscious products and processes. The application of green design involves developing a systematic framework for considering environmental issues and the application of relevant analysis and synthesis methods. This is a challenge to traditional procedures for design and manufacturing.

The challenge of green design is to alter conventional design and manufacturing procedures to incorporate environmental considerations systematically and effectively. This requires changes in existing procedures. Change for any existing process is difficult. Changing design procedures is particularly difficult because designers face many conflicting objectives, uncertainties, and a work environment demanding speed and cost effectiveness. Environmental concerns must be introduced in practical and meaningful fashions into these complicated design processes. For the future, the goal is to prepare consumers and designers to think proactively and concurrently about the environment.

There is no widespread consensus or agreement on the particular goals to be pursued by green design. Some argue that green design and pollution prevention should be pursued solely to reduce costs. In this view, any waste from a process or product is an opportunity. Others focus on particular strategies, such as recycling to conserve raw materials, and develop goals specifically for these strategies. Another approach is to direct all attention to a particular environmental problem, such as global warming, or a particular media, such as air pollution, and ignore other environmental effects.

Each of these approaches is too focused. Some pollution may be socially undesirable but might not be economical to prevent. Some recycling may have environmental burdens larger than the savings, especially if long distance transport is involved. Focusing upon a single issue, such as air pollution, may result in transfer of pollution to another media such as water. We need a more general approach.

We advance three general goals for green design in pursuit of a sustainable future. The objective of green design is to pursue these goals in the most cost-effective fashion.

Green Design Goals

- Reduce or minimize the use of non-renewable resources
- Manage renewable resources to insure sustainability; and
- Reduce, with the ultimate goal of eliminating, toxic and otherwise harmful emissions to the environment, including emissions contributing to global warming.

With these three overarching goals, specific objectives can be defined and pursued. For example, more energy efficient devices can reduce the use of non-renewable resources and toxic emissions, as long as the energy efficient changes do not have excessive environmental burdens. Thus, building insulation may save heat but it entails some environmental costs from manufacturing and installation procedures.

It is also important to remember that a green product or process is not defined in any absolute sense, but only in comparison with other alternatives of similar function. For example, a product could be entirely made of renewable materials, use renewable energy, and decay completely at the end of its life. However, this product may not be the grrnest alternative if, for example, a substitute product uses fewer resources during production and use, or results in the release of fewer hazardous materials. Other things being equal, a car that gets 50 miles per gallon is greener than one that gets 30 miles per gallon— unless the owner family cannot fit into the more fuel efficient car necessitating two trips. A fully loaded bus is greener than either car, but a bus with one passenger is not at all green.

Rarely is one product greener in every dimension (resource and energy use, emissions, reyclability etc.) than other products; there are usually tradeoffs among characteristics. For example, making cars more fuel-efficient generally requires making them lighter. This can be accomplished by substituting aluminum or plastic for steel. Both aluminum and plastic require more energy during production than does steel. How should we compare the energy required during production with the energy required for operation? One approach is to calculate how many miles the car must go to "pay back" the energy required during production. Another example is that some new materials and composites, such as carbon fibers, have many advantages, but cannot be recycled. Which is more important, the ability to recycle or the lighter weight and strength? Finally, if petroleum is in extremely short supply, saving gasoline may be desirable even if the result is increasing total energy use, e.g., cars powered by methanol from coal.

A central concept in green design is the notion that the systems effects of design decisions should be considered. In designing a new product, the environmental burdens associated with material supply, manufacture, use and disposal may all be relevant. Thus, while one product may seem greener than another, the more important attribute has to do with the overall system in which each product is used.

The Educational Modules and Cases

The examples discussed in the reminder of this paper outline some of the main types of methods and tools used in green design efforts along with a description of an educational course module, case study, or software program designed to illustrate the method. The modules are stand alone discussions of the issue in question and would form the basis of a class session. The case studies are drawn from interactions with industrial partners and are based on industry data (although the data may have been adjusted to protect confidentiality). The case studies can be used to further illustrate a concept outlined in a module, or as stand-alone exercises themselves. The software application can be used as an exercise in life cycle assessment to accompany any upper level or graduate level engineering course on environmental management. The software can also be used effectively in business or public policy courses on environmental management. Most of the modules and case studies include suggested student assignments or homework problems.

1) Green Design

Green Design Educational Module- The module on green design discusses the general principles of environmentally-conscious product/process/service design and stresses the systems approach to solving environmental problems. The module also provide a good introduction to the other modules and case studies can be used as a starting point for the use of the other modules.

2) Life Cycle Assessment

Environmental Life Cycle Assessment (LCA) is a technique for tracing out all the environmental effects and resource needs of a new product or process through the material suppliers, through manufacture, use and disposal. It is intended to provide a comprehensive assessment of environmental effects (US EPA, 1993). LCAs aim to show the major environmental problems of a material, product, or process. The act of doing the assessment builds awareness about environmental impacts and focuses improvement efforts. This has led companies, such as AT&T, to develop internal LCA tools for their product lines (Graedel and Allenby, 1995) and Government agencies, such as the EPA to provide generic guidelines for conducting LCAs (USEPA, 1993).

LCA Educational modules and materials:

Software- We have developed an LCA software program called Economic Input-Output Life Cycle Assessment (EIOLCA, available at www.eiolca.net) which provides a method of estimating the environmental consequences of all economic activities associated with the provision of a good or service, such as product manufacturing, resource extraction, materials processing etc. The model has been the basis for a total of 6 Ph.D. theses in the engineering, business, and public policy schools at Carnegie Mellon University. The model represents a simple, rapid, and relatively noncontroversial way of estimating the supply chain implications for a change in demand for a particular product or service. The EIO-LCA approach has been used as a research tool to examine the environmental impacts of various industrial sectors (Cobas et al, 1995, Lave et al, 1995, Lave et al, 1998), automobile use (MacLean and Lave, 1998), automobile components (Joshi, 1997) and construction materials (Horvath and Hendrickson, 1998a, b; Hendrickson and Horvath, 1998). The software is also being used to assess the external or full costs associated with providing goods and services. The software has been used in undergraduate and graduate level civil and environmental courses and in the MBA program at Carnegie Mellon University, in environmental engineering courses at Duquesne University in Pittsburgh, MIT in Massachusetts, and the University of California at Berkeley, in California. The software was accessed over 6000 times between April and October of 1999.

Module and Project – Life Cycle Analysis: A Learning Guide For Professors and Students of Design, Environment and Ethics. This module has been used extensively at Carnegie Mellon in a capstone course for environmental engineering minors. The module discusses LCA and the idea of "Concept Mapping", a technique useful for determining the entire system relevant to a product/process/activity. The module then outlines a life cycle assessment project to be conducted by students. The project can be short or extensive in range depending on the class. This module is suitable for humanities-based courses, in addition to science and engineering programs.

Case Study – "Economic Input-output Life Cycle Assessment of Asphalt versus Steel reinforced Concrete for pavement construction". This case study describes life cycle assessment and then discusses the EIOLCA approach in detail, including a description of the mathematical basis to the model. The case study then requires the user to use the EIOLCA model (available free on the web) to assess the environmental implications of two alternative pavement construction materials – this is the type of decision an LCA user would typically be considering. The case study takes students through the use of the model in a step-by-step approach and demonstrates how to set up the assessment. The student is then required to complete the assessment and to comment on the results. The case study has been used in upper undergraduate and graduate level course in environmental management at Carnegie Mellon University.

Module – "Rechargeable Battery Management and Recycling: A Green Design Educational Module". This module introduces rechargeable battery characteristics and use, focusing on nickel-cadmium batteries and was developed to illustrate issues associated with recycling , waste management, and life cycle assessment. The module is discussed in greater detail in section 4. The LCA assignment included in the module sets up a framework for the assessment and estimates emissions and energy use for NiCd batteries and includes an NiCd battery LCA assignment which can be carried out using the EIOLCA software. The assignment includes all the data required to carry out the assessment. The module has been used in a graduate level environmental management class at Carnegie Mellon University.

3) Full Cost Accounting Methodologies

Many corporations and consumers want to support green products and sustainability but do not know how to make greener decisions. Designers and plant managers are specialists who cannot be expected to be environmental experts capable of estimating the environmental and sustainability implications of their decisions. As a result, a company often incurs high costs from using a material or process that creates environmental problems when an environmentally benign material or process alternative exists. Similarly, consumers purchase products that create environmental problems because they may not know about green alternatives.

Companies need assistance in the form of management information systems that reveal the total cost to the company of decisions about materials, products, and manufacturing processes. This sort of system is called a "full cost accounting" system. For example, when an engineer is choosing between protecting a bolt from corrosion by plating it with cadmium versus choosing a stainless steel bolt, a full cost accounting system could provide information about the purchase price of the two bolts and the additional costs to the company of choosing a toxic material such as cadmium. In many cases, the choices that a designer or consumer makes also impose costs on society. For example, choosing a cadmium coating increases the possibility of human exposure to a toxic substance. The designer and consumer might be informed by showing them this social cost of the cadmium, i.e., the cost of preventing the exposure and the potential health risks of exposure. This information might be communicated by having a "social" cost listed on the price tag. A still stronger step would be to actually charge the designer and consumer for the social costs of environmentally damaging materials or products. Thus, the government might add an environmental tax or effluent fee that would account for the social damage.

We have developed a course module and two case studies described below, which illustrate the concepts of full cost accounting. They have been used in two MBA courses and in a graduate and upper level undergraduate environmental engineering course at Carnegie Mellon University.

FCA Educational Modules and Materials

Module - " Full Cost Accounting" describes the three types of accounting (national accounting, financial accounting, and managerial/cost accounting). The module then describes the shortcomings of each type of accounting with regard to environmental issues and discusses methods to incorporate environmental costs into each accounting framework. The bulk of the module focuses on incorporating environmental costs into cost accounting systems and refers extensively to EPA work on the topic.

Case Study – "True Costs of Plastic Scrap: An Environmental Cost Accounting Case Study". This case study was developed as part of a master's thesis from data gathered at an automobile plastic parts molding facility. The case goes through a step-by-step analysis of determining the full "private" costs of scrap at the plastics facility. The case describes a simple mass balance to demonstrate where scrap occurs. The case then explores the full costs of this scrap to the company in terms of materials loss, parts loss, labor requirements, electricity requirements etc. The real life case demonstrates the significant cost savings that could be realized if the scrap rates could be reduced.

Case Study – "Semiconductor Fabrication Facility". This case study was developed as part of an undergraduate honors thesis and describes the chemical accounting and environmental management system in place at a semiconductor fabrication facility. The case discusses the facility's "Value Added Operations Model" which helps to determine the material inputs and machine costs of each fabrication step for each wafer. The case then describes how it would be beneficial for the company to expand the model to include items such as energy consumption and waste measurement in order to understand better the additional environmental costs being generated during wafer fabrication.

4) Design for disassembly and recycling aids

Design for disassembly and recycling (DFD/R) means making products that can be taken apart easily for subsequent recycling and parts reuse. For example, Kodak's 'disposal' cameras snap apart, allowing 87% of the parts (by weight) to be reused or recycled. Unfortunately, the economic costs associated with physically taking apart products to get at valuable components and materials often exceeds the value of the materials. Reducing the time (and thus cost) of disassembly might reverse this balance. Thus DFD/R acts as a driver for recycling and reuse. DFD/R software tools generally calculate potential disassembly pathways, point out the fastest pathway, and reveal obstacles to disassembly that can be "designed out".

Disassembly Educational Modules and Materials Material

Module – The module on "Reverse Engineering for Green Design of Products" discusses the motivation and goals for green design and then elaborates on the theme of reverse engineering with a goal of environmental improvements. The idea is to take things apart in order to determine how to design them for easier disassembly, reuse, and recycling etc. The module is full of detailed images of products such as a coffee maker and a disposal camera in various stages of disassembly. The module then demonstrates how reverse engineering of these products highlights potential areas of improvement in terms of reduced environmental impacts. This module has been used in a capstone design course in mechanical engineering.

5) Recycling and Waste Management

Recycling, remanufacturing, and reuse are strategies for green design that aim to reduce resource use and waste disposal requirements. There are many products which have the potential to be reused, remanufactured or recycled if the economic costs associated with the reuse strategy are low. For example, many of the components of a washing machine are still functional if the machine breaks down, and the parts could be reused or remanufactured if the machine can be brought to a recycling facility and the components removed. However, this strategy is only economically viable if the costs associated with transporting the machine and removing the parts are less than the revenues generated for the sale of the part.

We have developed two course modules and a case study that discuss different aspects of recycling and waste management issues. The module on battery management and recycling issues focuses on a specific product (one with a high toxic material content) and discusses the issues associated with developing effective recycling options. The module on radioactive waste management uses history to show how environmental problems change over time, and attempts to solve environmental problems may sometimes make matters worse. The case study on end-of-life options for products describes a method to develop models of product life and obsolescence in order to plan either efficient product disposal or product recycling strategies. These modules have been used in discussions of recycling and waste management in undergraduate history and policy courses in the college of social sciences, and in an upper undergraduate/graduate-level course on environmental management in the engineering school at Carnegie Mellon University.

Recycling/Waste Management Educational Materials and Modules

Module – "Rechargeable Battery Management and Recycling: A Green Design Educational Module". This module was discussed in section 2. In the context of recycling the definition of a green battery is developed which reinforces other modules and materials on green product development. The module discusses the development of a life cycle assessment of nickel cadmium batteries (NiCd). Current battery collection and recycling strategies are also discussed and a method for estimating NiCd battery recycling rates are also given. Public policy and consumer education issues are also mentioned. Then case includes an NiCd battery LCA assignment which can be carried out using the EIOLCA software described in Section 1.

Module – "Radioactive Waste Management: An Environmental history lesson for Engineers (and Others)". This module is a historical perspective of the issues associated with radioactive waste management, the extent of the problem, and a discussion of how the problems have developed over time. The module demonstrates that management of radioactive solid waste is not a single task but is a multidimensional issue that needs to be understood and addressed physically, socially, and economically. This course has been used to an undergraduate humanities and social sciences course entitled Science, Technology, and Policy'.

Case Study – "Disposition and End-of-life Options for products: A Green Design Case Study".   This case study (which includes a teacher's guide) aims to introduce a general method for modeling the disposal fate of products. This type of model could be used to predict the volume of material that will enter a landfill or to predict the amount of material available for recycling or remanufacturing etc.   The case focuses on the fate of personal computers (PCs) and describes the development of an excel-based model to estimate the potential fate of obsolete computers (such as landfilling, recycling, storage etc). The case study also discusses business management and public policy issues and strategies to alleviate disposal problems. Many of the requests for this module are from corporate users.

6) Material Flows and Mass Balance Calculations

Materials flow analysis and mass balance calculations are techniques for tracing material use and location over time. Understanding where material is wasted or misused is important in reducing resource use. In recycling materials, there is a distinction between closed-loop (re-use for the same function) and open loop (re-use in a different function, typically with lower quality requirements). In tracing materials flows, it is important to be clear about the boundaries of analysis and the uncertainty of mass measurements. Mass balance analysis involves tracing the materials or energy in and out of the system. Ideally, mass balances are based on measurements of inflows, inventories, and outflows (including products, wastes and emissions). In actuality, all the data needed is rarely available or even consistent.

Material Flow/mass balance Educational Modules and Materials:

Module on Rechargeable Battery Management and Recycling. This educational module discusses the technical attributes of batteries and issues associated with the handling and recycling of batteries. It is summarized in sections 2 and 5.

Module on Disposition and End-of-Life Options for products

This module (see section 5) can also be used to illustrate material flow diagrams as the calculations and model for estimating product disposal fates are basically applied forms of materials flow assessments.

Case Study – "True Costs of Plastic Scrap: An Environmental Cost Accounting Case Study". This was discussed detail in section 3 where the emphasis is on the costs associated with wasted material. The case can also be used in a discussion of materials flow and balance calculations – in this context, the discussion emphasis would be on the development of the mass balance and the variety of decisions that can be supported by mass balance or materials flow calculations.

Summary

We have described a series of educational modules, case studies, assignments, projects, and software which are suitable for courses on environmental management in engineering, business, policy, and social sciences curricula (See Table 1). The educational materials were derived from research undertaken with industry partners over the past 5 years. The materials have been used extensively thoughout Carnegie Mellon University in a wide variety of coruses. Non-Carnegie Mellon users are also using the materials with an average of 126 downloads per module/case study.

Table 1. Summary of Green Design Themes and Complementary Modules/Case Studies

Theme

Module/Case Study	**Green Design**	**LCA**	**FCA**	**Design for Disassembly**	**Recycling, Waste**	**Materials Flows**
EIOLCA Software	X	X	X			
LCA learning Guide	X	X			X	X
EIOLCA Case study of Pavements	X	X	X			
Intro to GD	X	X	X	X	X	X
FCA	X		X			
FCA Plastic Strap Case	X		X			X
FCA Semiconductor Case	X	X	X			
Reverse Engineering Module	X			X		
Rechargeable Battery Management Module	X	X			X	X
Radioactive Waste Management	X				X	
Disposition and End-of Life Options	X				X	X

Acknowledgements

The educational modules were developed with support from the National Science Foundation (**EEC-9700568**). The research underlying the modules was supported by the NSF (Grants 111-9319731 and DMI 9613405), the NSF/EPA Environmental Technology Grants Program (#R 826740-010), the Department of Energy Office of health and Environmental research, and the Green Design Consortium at Carnegie Mellon University.

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