120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013
ATLANTA

Paper ID #7866

A Graduate Engineering Technology Online Course in Sustainable and Green Manufacturing

Dr. Richard Chiou, Drexel University
Prof. Tzu-Liang Bill Tseng, University of Texas, El Paso
Dr. Yalcin Ertekin, Drexel University (Tech.)
Mr. M. Eric Carr, Drexel University

Mr. Eric Carr is currently the Laboratory Technician for Drexel University's Engineering Technology program. Eric assists faculty members with the development and implementation of various Engineering Technology courses, and enjoys finding innovative ways to use microcontrollers and other technologies to enhance Drexel's Engineering Technology course offerings. Eric holds an MS in Computer Engineering from Drexel University and is an author of several recent technical papers in the field of Engineering Technology Education.

A Graduate Engineering Technology Online Course in Sustainable and Green Manufacturing

Abstract

This paper describes the development of a new graduate engineering technology online course in sustainable and green manufacturing. The course is intended to provide an in-depth overview of environmental issues in manufacturing and industrial resources to reduce the environmental impact of their produced products and services. Green manufacturing is an emerging field in recent years and is also the sustainable development model for modern manufacturing industries. Sustainable green manufacturing encompasses the concept of combining technical issues of design and manufacturing, energy conservation, pollution prevention, health and safety of communities and consumers. The goal of this paper is to assess the current graduate engineering technology online program curriculum at Drexel University (DU) with regard to sustainable and green manufacturing predominantly metal working based manufacturing curriculum. In this paper we will discuss key environmental topics that can be integrated into manufacturing coursework at DU to include sustainability principles. Finally, the graduate online course has been evaluated and reviewed to indentify barriers and inclusion of sustainable green manufacturing course into current curriculum.

1. Introduction

The United States (U.S.) is on the cusp of transformational changes in how green industry is developed. Accelerating U.S. clean innovation, green manufacturing, and sustainability is an environmental necessity. Without new innovations and a robust clean technology policy, the United States will not be able to reduce greenhouse gas emissions (GHG) to needed levels, unless the price of GHGs rises to politically unsustainable levels. As important as these environmental objectives are, clean innovation is also an economic imperative. Investments in the global clean industry are expected to grow from $200 billion in 2010 to reach $600 billion by 2020. Government policy and public investment will be critical determinants of which countries become leaders in the race to attract that clean technology investment and the economic and job creation benefits these investments will bring[1-4].

Despite decline in recent years, manufacturing remains a critically important sector of the U.S. economy. U.S. manufacturing firms employ 13 million workers; represent two-thirds of total U.S. research and development investment, and account for more than 80 percent of U.S. exports. While developing a globally competitive manufacturing sector is important in general, it also offers a major new export opportunity in the fast-growing green manufacturing industry. Sustainability has been identified as one of the global grand challenges of the 21st century. In order for future generations to enjoy a satisfactory quality of life, the current generation must find ways to meet humanity's needs for energy, shelter, food and water in ways that are environmentally, economically, and socially sustainable[5-8].

This paper describes the development of a new online graduate engineering technology course in sustainable and green manufacturing at Drexel University. The goal of the engineering technology program is to develop advanced level practitioners in industry who are interested in developing green knowledge to meet evolving workforce demands, seeking professional development, expanding opportunities for professional advancement, or pursuing a managerial position[9-12]. To support this goal, the new course is intended to enable students to make green decisions when selecting and implementing a sustainable design plan for a particular industrial application through an in-depth understanding of currently available and newly emerging green manufacturing. The course is currently offered entirely online. One of the key challenges in developing the online course is an emphasis on life cycle assessment simulation experience for enhancing online student learning on green manufacturing. To provide online simulation experience with network protocols, experiments with an industry-standard modeling tool GaBi 4 is used. Hence the teaching of green and sustainable manufacturing is an excellent opportunity to teach about research and innovations in industrial setting[13-15].

2. Overview of the Online Course Development

The course ET 755 Sustainable and Green Manufacturing provides the students with a comprehensive knowledge of sustainable and green manufacturing. The course objectives are: 1. to provide the students with comprehensive knowledge of environmentally conscious manufacturing, design for environment, and environmental regulations, 2. to acquaint students with the environmental issues surrounding product and process design decisions for reuse, recycling, and remanufacturing, 3. to identify/develop strategies, techniques, and methods that can be used for minimization of hazardous waste and prevention of pollution, and 4. to understand the system nature of environmental challenges and develop student's skills in performing life cycle assessment of manufacturing processes.

The course has an applied learning focus, offering flexibility to the students through an online learning environment. Since the concepts of online course are best conveyed through application-based learning, the course is divided into two components: a blackboard lecture component and an associative virtual LCA laboratory component. The virtual laboratory component is central to the course and is available to the students. This allows the students the freedom to explore the concepts of LCA without time constraints inhibiting learning. In order to provide an enhanced virtual laboratory experience, the students work with real world industrial case studies associated with green manufacturing. The below table provides an overview of lecture and virtual lab series in ET 755 Sustainable and Green Manufacturing.

Table 1: Overview of lecture and virtual labs

WEEK	Lecture and Lab Topic
1	Introduction to Environmentally Benign Manufacturing
2	Design for the Environment
3	Life Cycle Assessment (LCA)

4	Life Cycle Assessment Simulation
5	Prevention of Metalworking Fluid Pollution Midterm exam
6	Prevention of Metalworking Fluid Pollution
7	Air Quality in Manufacturing
8	Metal Finishing and Electroplating
9	Disassembly for End-of-life Electromechanical Products
10	Industrial Energy Efficiency Final Exam
11	Class end

Environmentally Benign Manufacturing

Students learn the introduction of the Environmentally Benign Manufacturing in the first week. Specially designed assignments and projects have been developed for the course as a part of this practicum, and are necessary to complete many of the exercises in the course. Generally speaking, manufacturing is to convert materials into products. The manufacturing processes provide the job opportunities for people. The products made by manufacturing are to improve our standard of living. To increase the value and quality of the products, supply chain and services have to be involved with the manufacturing processes. One of the outputs must include waste from manufacturing processes. The shadow side of manufacturing needs to be addressed first, such as environmental issues and excess of energy used in industry.

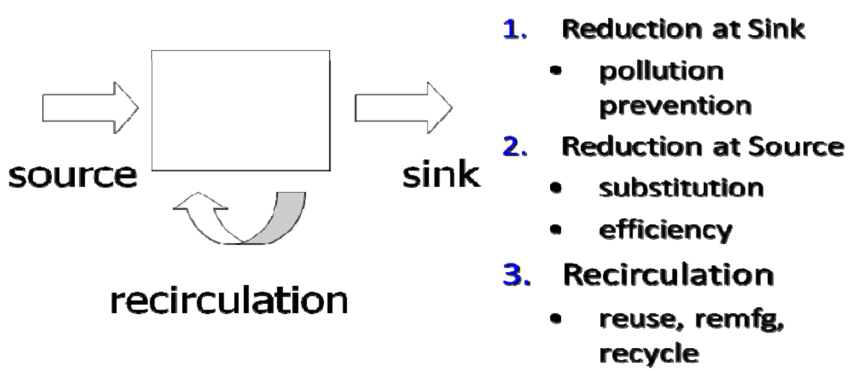

Figure 1: Green engineering strategies

As shown in Figure 1, the fundamental issue in environmentally conscious manufacturing is to align manufacturing needs with environmental issues. That is, how do we manufacture market-competitive products without harming the air, water, or soil on planet Earth? How do we motivate companies to behave unilaterally to adopt environmentally benign manufacturing practices? Will nation-states unilaterally recognize the need to impose environmental standards on companies manufacturing products within their national boundaries? Recent experience informs us that progress is being made on each of these fronts, but that we have a long way to go to fully protect the environment from the offenses committed by the worldwide manufacturing community.

There are two types of manufacturing processes: traditional and non-traditional.
The traditional manufacturing itself is perhaps the most important stage in the supply chain in terms of overall environmental impact. Here we shall consider traditional manufacturing processes that apply to metals and plastics, such as: (1) machining, (2) metal casting, (3) metal forming, (4) metal joining, and (5) plastics injection molding. In the past, people were only concerned with the sink or the output in the manufacturing processes with an emphasis on reduction of pollution. Today, the engineering strategies for design and manufacturing are changed due to environmental issues. Recirculation has been added in the new and innovative manufacturing processes, including reuse, remanufacture, and recycle.

Design for the Environment

Students have to learn what the Design for Environment (DfE) is in the course. Design for Environment has the common known acronym DfE and can be viewed in different ways. DfE is a philosophy that advocates that consideration be given to the environment when developing new products and processes. DfE is an engineering design initiative that promotes environmentally sound decisions at every step of the production process from chemical design, process engineering, procurement practices, and end product specification to post-use disposal. The concept is developing in the environmental /engineering fields and is beginning to gain public recognition. Therefore, DfE is about industry improving and optimizing the environmental performance of products, impacts on human health, associated risk, product and process costs, efficient use of materials, waste and pollution prevention, and energy conservation.

During the past years, growth of interest and initiatives around the concept of pollution prevention and toxics use reduction has been significant. Firms around the world are beginning to recognize that it is far more efficient to prevent the generation of industrial wastes than to manage the wastes once they are produced. In the U.S., environmental engineers increasingly are engaging production engineers around reduction of waste streams from manufacturing processes. Yet this is only one avenue for bringing about environmentally sound production processes. The opportunity to consider environmental effects at the earliest design points in the development of new products or the redesign of current production processes opens up an exciting new area of professional work.

The industrial ecology view promotes sustainable manufacturing through the modeling of industrial processes after the material and energy flows of the natural environment. An industrial ecosystem follows a cyclic model in which the consumption of energy and materials is optimized, waste generation is minimized, and the byproducts of one process become raw material for another. DfE pursues industrial ecology principles by requiring that industrial designers and managers think in terms of cycles or complex systems rather than traditional linear process flow diagrams. Industry is beginning to consider the environmental impact of a product throughout its life cycle, primarily because of regulatory trends, rising treatment and disposal costs. Corporations are also recognizing the potential economic advantage of DfE. But more training, technical information, and industry-specific knowledge of DfE are needed to bring about its broad-scale implementation. Efforts to develop and integrate DfE with life cycle assessment (LCA) into the production of products and services are under way in the public and private sectors.

Life Cycle Assessment

From the outline of the lecture, students learned what LCA is, Why use LCA, and what it can be used for business benefits. LCA is a tool to measure, assess, and manage the environmental performance of a product from raw material through production, use and end-of-life phase. As environmental awareness increases, industries and businesses are assessing how their activities affect the environment. Society has become concerned about the issues of natural resource depletion and environmental degradation. Many businesses have responded to this awareness by providing “greener” products and using “greener” processes. The environmental performance of products and processes has become a key issue, which is why some companies are investigating ways to minimize their effects on the environment. Many companies have found it advantageous to explore ways of moving *beyond* compliance using pollution prevention strategies and environmental management systems to improve their environmental performance. One such tool is LCA. As shown in Figure 2, this concept considers the entire life cycle of a product. Every year, more and more companies are becoming concerned with the environmental impact of their activities. Currently, the main driving force is the need for companies to stay competitive in the marketplace.

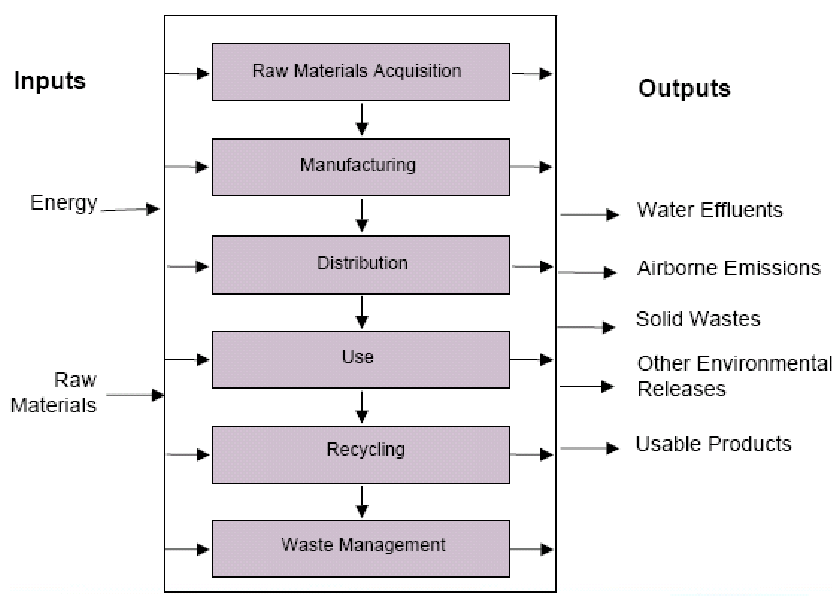

Figure 2: The Product Life Cycle

LCA practitioners define how data should be organized in terms of a *functional unit* that appropriately describes the function of the product or process being studied. Careful selection of the functional unit to measure and display the LCA results will improve the accuracy of the study and the usefulness of the results. The life cycle of a product begins with the removal of raw materials and energy sources from the earth. For instance, the harvesting of trees or the mining of nonrenewable materials would be considered raw materials acquisition. Transportation of these materials from the point of acquisition to the point of processing is also included in this stage. During the manufacturing stage, raw materials are transformed into a product or package. The product or package is then delivered to the consumer. The manufacturing stage consists of three steps: Materials manufacture, Product fabrication, and Filling/packaging/distribution. For Use /Reuse /Maintenance, this stage involves the consumer's actual use, reuse, and maintenance of the product. Once the product is distributed to the consumer, all activities associated with the useful life of the product are included in this stage. This includes energy demands and environmental wastes from both product storage and consumption. The product or material may need to be reconditioned, repaired or serviced so that it will maintain its performance. When the consumer no longer needs the product, the product will be recycled or disposed. Finally, the recycle/waste management stage includes the energy requirements and environmental wastes associated with disposition of the product or material.

Students learned LCA to assess product development options and establish baseline information for a process. A key application of LCA is to establish a baseline of information on an entire system given current or predicted practices in the manufacture, use, and disposal of the product or category of products. In some cases, it may suffice to establish a baseline for certain processes associated with a product or package. This baseline would consist of the energy and resource requirements and the environmental loadings from the product or process systems that are analyzed. The baseline information is valuable for initiating improvement analysis by applying specific changes to the baseline system. Therefore, LCA can be used to inform industry, government, and consumers on the tradeoffs of alternative processes, products, and materials. The data can give industry direction in decisions regarding production materials and processes and create a better informed public regarding environmental issues and consumer choices.

With features refined through experience on thousands of PE consulting projects, GaBi 4 supports every stage of a LCA, from data collection and organization to presentation of results and stakeholder engagement. GaBi 4 updates all material, energy, and emissions flows, as well as defined monetary values, working time and social issues, giving instant performance accounting in environmental impact categories. GaBi allows rapid modeling of complex processes and different production options with a modular architecture. This architecture makes it easy to add other data such as economic cost or social impact information to a model, making GaBi a useful tool for life cycle assessment. The GaBi 4 platform is complemented by the most comprehensive, up-to-date Life Cycle Inventory database available. The databases maintained by PE provide over 2,000 cradle-to-gate material data sets, 8,000 intermediary chemical process models, and thousands of LCA projects from quality-controlled industry projects. The data set contained in this educational version of GaBi 4 Education, which is a small fraction of the available data within the professional engineers. The simulation software GaBi 4 provides an extensive introduction to LCA methodology and outlines step by step procedures for building a model with GaBi 4. The students had one example (a paper clip) for life cycle assessment throughout the software tutorial series posted in website.

Prevention of Metalworking Fluid Pollution

The topic on process modification for prevention of metalworking fluid pollution was given for a week. In addition to near dry machining, The students studied the dry machining issues, including Vortex Tube Cooling, Cryogenic Machining, Diamond Film, and Heat Pipe Cooling. Case studies from the recent research results were discussed. It was emphasized in the lecture that we worked on more advanced topics on product life with 3R: reuse, remanufacture, and recycle. Recycling can be used to organize the environmental issues of the industry and employ the life-cycle stages of a product. A typical life cycle consists of four principal stages presented: (1) materials processing, (2) manufacturing, (3) use, and (4) recovery. The materials processing and manufacturing stages are largely concerned with creation of a finished product. The use stage considers the actual use of a product, in this case the operation of a vehicle. The recovery stage of the product includes both product recovery as well as its subsequent disposition via reuse, remanufacturing, recycling, or disposal.

A study in the automotive industry revealed that workpiece-related manufacturing costs associated with metalworking fluids (MWFs) 7–17% were several times higher than tool costs (2–4%). These costs would be eliminated if machining processes could be conducted without MWF. Environmental impact and health risks directly associated with MWFs would also be eliminated. These opportunities have encouraged research into machining without MWF (dry machining) and into minimizing MWF usage. Both Dry machining and Minimal MWF application strategies were discussed. These process modifications currently under active research aim to reduce worker exposure to MWF mist and to reduce the health risks and environmental impact of MWF chemistries.

A case study for a project on dry machining using heat pipe cooling was presented. This project seeks not only to develop new tool design with embedded heat pipe, but also to improve heat transfer behavior and prolong tool life. Embedded heat pipes in cutting tools on workpiece to eliminate cutting fluids, thermal damage and tool wear can be a solution to meet all of the machining industry's needs in traditional machining. The use of embedded heat pipes can effectively carry away the heat generated during machining and cool the high temperature that occurs at the cutting tool in high speed machining, thus reducing tool wear and prolonging tool life. The operation of a heat pipe is understood by using a cylindrical geometry. The components of a heat pipe are a sealed container (pipe wall and end caps), a wick structure, and a small amount of working fluid which is in equilibrium with its own vapor. The length of the heat pipe is divided into three parts: evaporator section, adiabatic (transport) section, and condenser section. The configuration rapidly conducts thermal energy away from the heat source in machining, thereby significantly improving the storage of thermal energy in the heat sink as well as providing a means for later dissipating thermal energy from the heat sink to an ultimate heat sink.

Design for Disassembly *(DfD)*

After the students have learned the product life cycle many times in the class, they continued to learn how the DfD is related to the product life cycle. Since 1960s, the world economy has been developing faster than ever before. The rapid development of technology effectively shortens the useful life of the industrial products causing enormous consumption of natural resources. Take, for example, the computer. According to US environmental Protection Agency (EPA), more than 300 million computers are projected to be discarded in the United States every year. It is expected that the waste of 8.5 million of these, which contains harmful elements such as lead, mercury, and cadmium, would end up in landfill. In order to solve the environmental problems, a green approach - design for disassembly for electronic products must be developed. It should strive to minimize the negative impact of the product on the environment throughout the entire life cycle and to have the highest utilization ratio of recovery. Consequently, the final dismantlement of electronic products occupies a very important position in green manufacturing system.

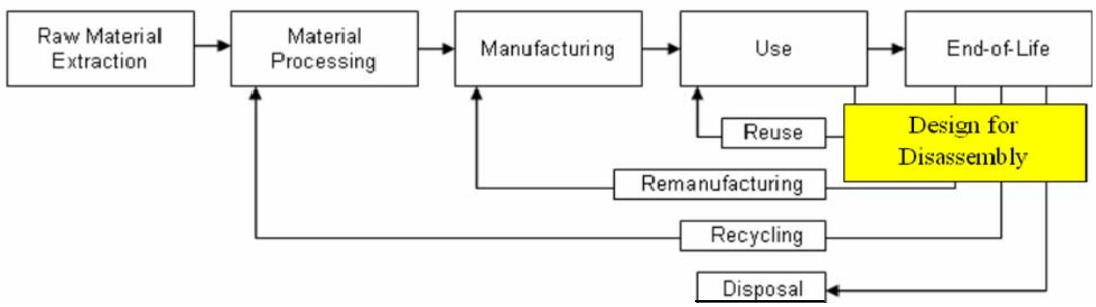

Figure 3: DfD in Product Life Cycle

As shown in Figure 3, recycling, remanufacturing, and reuse are the last three key segments of the lifespan of products and they are the most difficult segments to address. The degree to which these three segments are fully realized influences resources and environment directly. The primary factors complicating recycling, remanufacturing, and reuse are as follows: 1. Methods of joining: In general, the connection methods for component parts are chosen in order to simplify assembly and make safe connections. 2. Material variety: Economical efficiency and best performance dominate the material selection, which generally results in adopting large number of different materials, many of which are nonrecoverable and carry a high cost for dismantlement. 3. Process design: The processes selected to provide optimal function and assembly efficiency can create a large number of unnecessary dismantlement steps.

To improve process design, for examples, the students learned and used mechanical fasteners instead of glue for modularizing products and isolating hazardous materials.

DfD is a new concept for the design and manufacturing community and is an important contributor to Design for Environment (DfE). There are three goals for DfD:

1. Reutilization of the products: Reutilization encompasses both Direct and Indirect reutilization. Direct reutilization is suitable when the parts expensive to produce, take a long time to be improved, or have a long performance life, such as the bottles used for beverages, which can be reused directly for holding other liquids. Indirect reutilization is suitable for parts that cannot be reused directly but can be reused directly after some treatment. For example, discarded main boards of computers can be reconfigured for use in game machines.

2. Reclamation of components and parts: This is especially suitable to electronics products because they contain numerous materials and obsolescence is very rapid. Special methods are often necessary to retrieve component parts.

3. Recovery of materials: When the material used to produce a product or component is expensive, but the price of the single part is low because of large-scale production and short producer lifespan, it is often more efficient to recycle the material.

Air Pollution

In recent years, increased attention has been devoted to the environmental performance of products and their associated manufacturing processes. One of these waste streams, process generated airborne particulate, has received much emphasis within the scientific literature of the industrial hygiene and safety engineering communities. Emphasis has been placed on the origins of the particulate and the potential hazards that it represents; the role of traditional control technologies in addressing particulate and more environmentally conscious approaches that focus on dealing with particulate at its source are also examined.

Regulations limit emissions from particular types of coating operations, such as those coating metal furniture, miscellaneous metal parts, plastic parts, and large appliances. Coating facilities affected by these regulations may need to obtain permits, control and monitor air emissions, and submit reports. The Clean Air Act requires EPA to set National Ambient Air Quality Standards for six common air pollutants. These commonly found air pollutants (also known as "criteria pollutants") are found all over the United States. They are particle pollution (often referred to as particulate matter), ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead.

A number of different words and phrases are used to describe aerosols. The American National Standards Institute (ANSI) has published definitions for dusts, fumes, and mists. Table 2 describes the origin and typical size of above aerosols. These types of aerosols, which are frequently found in an industrial environment, include: dust, fumes, mist, smoke, spray, and aerosol. The six principal pollutants, which are called "criteria" pollutants by the EPA have been mentioned and listed in the previous slides. Their units of measure for the standards are parts per million (ppm) by volume, parts per billion (ppb

- 1 part in 1,000,000,000) by volume, milligrams per cubic meter of air (mg/m3), and micrograms per cubic meter of air (µg/m3).

In 2004 the manufacturing industry represented less than 14% of the private employment sector and accounted for 42% of the non-fatal work place illnesses as published by the U.S. Bureau of Labor Statistics. A portion of work-related illnesses is lung diseases, which are associated with poor air quality conditions. Some statistics complied in 2004 are: i) inhalation and accumulation of dust were responsible for 2,860 deaths in 2000, ii) about 20-30% of asthma cases in adults are caused by work-related exposure, and iii) the fourth national leading cause of death, chronic obstructive pulmonary disease, was estimated to be 15% related to workplace exposure. It is evident that the manufacturing sector still has a significant impact on the health of workers. Inhaled particles have also been linked to increased lung cancer cases.

The human respiratory system takes in air from the atmosphere and the air passes through the nose, pharynx, larynx, trachea, bronchi and bronchioles, and enters the alveoli. Gas exchange takes place in the alveoli, with oxygen passing into the bloodstream and carbon dioxide entering the alveoli; upon exhalation, CO_2 is removed from the body. As has been noted, particulate matter (or PM) differs in terms of chemical composition and size. Bioaerosols are aerosols of biological origin. Different types of aerosols can be found in the occupational environment including: viruses, bacteria, fungal spores, and pollen. Common settings for exposure to viruses and bacteria are hospitals and health clinics. Tuberculosis is an example of an occupational related disease cause by the bacterium *mycobacterium tuberculosis*. Bioaerosols can contain very small components; for example, viruses exist at the nanometer scale. In manufacturing environments, bioaerosols might originate from HVAC systems, machining operations that use metalworking fluids (MWF), or manufacturing biotech applications.

Industrial Energy Efficiency

In the last week, students focused on the energy efficiency associated with the reduction of waste energy, energy consumption, undesirable quantities of emission, and unwanted environmental effects by manufacturing. Manufacturing processes include a wide variety of operations, from subtractive processes such as machining and grinding, to net shape processes such as injection molding, to additive processes such as chemical vapor deposition (CVD) and rapid prototyping. All of these manufacturing processes take material inputs, including working materials and auxiliary materials, and transform them into products and wastes. Similarly, the energy inputs into these processes (primarily from electricity) are transformed into useful work, some of which is embodied into the form and composition of the products and wastes, and waste heat. In addition, the energy inputs usually require fuels and produce emissions. For electrical energy inputs, this occurs at the power station. A manufacturing process goes along with material and energy flows to and from the process. It was attempted in the course to enhancing an understanding of the time-of-use costing of electrical energy and how to take advantage of it. The analysis of the database reveals interesting energy profile and savings potential for various types of manufacturing facilities. Some key components were discussed in electricity and natural gas energy bills. The required energy cost mainly has three components: (1) fixed costs, $/month (consumer/customer charges, administrative costs), (2) electricity costs, the real cost of electricity that is consumed by the process (variable costs); and (3) demand costs – that is, the cost of maintaining a level of energy to run the operation (investment costs, $/kW).

Manufacturing processes are made up of a series of processing steps. Whatever for mass production situations are usually automated. For some processes each of these steps can be integrated into a single piece of equipment. For example, a modern milling machine can include a wide variety of functions including work handling, lubrication, chip removal, tool changing, and tool break detection, all in addition to the basic function of the machine tool, which is to cut metal by plastic deformation. The result is that these additional functions can often dominate energy requirements.

For the immediate purposes of this class, the focus is placed on the electrical energy requirements of the manufacturing process. It is convenient to think of a manufacturing process as being made up of a collection of equipment needed to perform the steps of the process. The energy efficiencies of manufacturing processes are determined by the total number of conversion processes that are classified as c-chemical, e-electrical, m-mechanical, r-radiant, and t-thermal. Whatever for mass production situations are usually automated with a wide variety of functions including work handling, lubrication, chip removal, and tool changing. These functions can often dominate energy requirements. After a manufacturing process is rearranged for the specific energy, it can be found that the specific energy can be minimized as the process rate increases to infinite.

3. Conclusions

The online course ET 755 Sustainable and Green Manufacturing is a green concept and its usefulness is provided an understanding in terms of students' point of view in sustainability. Towards this, weekly lecture and assignment were incorporated within the online course that students need to complete at the end each week session. In addition to the weekly discussions, the facility is equipped with collecting facility usage data. The course is intended to provide an in-depth overview of sustainable and green manufacturing. Upon successful completion of the course in this discipline, the students were able to achieve learning outcomes: 1. Understand life cycle analysis and clean manufacturing, 2. Understand recycling, hazardous materials, and pollution prevention, 3. Identify the characteristics of hazardous substances and waste materials, and 4. Understand the design for the environment by improving and optimizing the environmental performance of products, impact on human health, associated risks, and product and process costs. Course reviews by students were very positive. The benefits of an active online learning model were derived. Students mentioned appropriate time involved with the homework assignments and exams. Many commented positively about their knowledge gained related to their current jobs in their own companies. Students commented that they enjoyed working in the LCA virtual lab. Students' evaluation was conducted at the last week of the class (4.5/5.0). The results showed the highly supportive evidence towards the intended online course outcomes.

4. Acknowledgement

Students used the GaBi 4 software package for learning life cycle assessment (LCA). A free a-year trial version was available to all students. The package is well-documented and supported with instructive material.

Bibliography

1. Rob Atkinson and Scott Andes, "Atlantic Century: Benchmarking EU and U.S. Innovation and Competitiveness," *Information Technology and Innovation Foundation*, February 2009, www.itif.org/!les/2009-atlantic-century.pdf.
2. Jim Duderstadt et al, "Energy Discovery-Innovation Institutes: A Step toward America's Energy Sustainability." Brookings Institution, 2008, www.brookings.edu/reports/2009/0209_energy_innovation_muro.aspx.
3. Jesse Jenkins, "National Institutes of Energy Needed to Fill Energy R&D Gap," Breakthrough Institute, October 9, 2009, www.thebreakthrough.org/blog/2009/10/national_institutes_of_energy.shtml.
4. Rob Atkinson, "8 Ideas for Improving the America COMPETES Act," Information Technology and Innovation Foundation, March 2010, www.itif.org/!les/2010-america-competes.pdf.
5. "Current and Potential Green Jobs in the U.S. Economy," U.S. Council of Mayors, 2008, www.usmayors.org/pressreleases/uploads/GreenJobsReport.pdf.
6. Office of U.S. Senator Ron Wyden. "Major Opportunities and Challenges to U.S. Exports of Environmental Goods," December 9, 2009, http://wyden.senate.gov/newsroom/120809jw_enviro_goods_report.pdf.
7. Deborah Stine, "America COMPETES Act and the FY2010 Budget," Congressional Research Service, June 11, 2009, www.fas.org/sgp/crs/misc/R40519.pdf.
8. "Future of the Hollings Manufacturing Extension Partnership," National Institute of Standards and Technology. December 2008, www.nist.gov/mep/upload/MEP_ExecSummary72dpi.pdf.
9. Davidson, Cliff I.; Matthews, H. Scott; Hendrickson, Chris T.; Bridges, Michael W.; Allenby, Braden R.; Crittenden, John C.; Chen, Yongsheng; Williams, Eric; Allen David T.; Murphy, Cynthia F.; and Sharon Austin. "Adding Sustainability to the Engineer's Toolbox: A Challenge for Engineering Educators." *Environmental Science & Technology*, **2007**, pp. 4847-4850.
10. Vest, Charles. "Context and Challenge for Twenty-First Century Engineering Education." *Journal of Engineering Education*, July **2008**, pp. 235-236.
11. Heidi A. Taboada, Jose F. Espiritu, Olivia Moreno and Abril Vasquez. (2011). Experiences While Incorporating Sustainability Engineering into the Industrial Engineering Curricula. Proceedings of the ASEE Annual Conference and Exposition. Vancouver, B.C., Canada, June 26-29, 2011.
12. Connie Gomez, Heidi A. Taboada Jose F. Espiritu & Noe Vargas (2010). Increasing Sustainability Engineering in Education and Research. In Proceedings of the 2010 ASEE Annual Conference and Exposition. Louisville, Kentucky. June 20 - 23, 2010.
13. Myer Kutz (Editor), Environmentally Conscious Manufacturing. ISBN: 978-0-471-72637-1, John Wiley & Sons, March 2007.
14. Timothy G. Gutowski, **"**Teaching Environmentally Benign Manufacturing, United Nations, *Life Cycle Assessment:What it is and How to do it*. United Nations Environmental Program, 1996.
15. GaBi 4 learning center: http://www.GaBi-software.com/support/GaBi-4-learning-center.