# AC 2008-574: NOT JUST INFORMATIVE, BUT NECESSARY: INFUSING GREEN AND SUSTAINABLE TOPICS INTO ENGINEERING AND TECHNOLOGY CURRICULA

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# Not Just Informative, but Necessary:
# Infusing Green and Sustainable Topics into
# Engineering and Technology Curricula

## Abstract

Generally accepted duties of engineers and technologists encompass designing and implementing solutions to problems. When so doing, it is their responsibility to be cognizant of the impacts of their designs on, and thus their accountability to, not only society in general, but also subsequent effects upon the environment. They need to be able to concurrently satisfy these competing needs, as well as constraints specific to the design challenges at hand. Responding to these requirements are the growing fields of green engineering and sustainable engineering. Both of these areas encompass many concepts, ideas, and tools, all of which are essential information for graduates to know and understand. Many degree programs do not offer this type of information to their students. It is true that modifying curricula can be challenging, especially as pressure mounts to teach the students more information, but not extend their tenure at the university.

Toward that end, the goal of this paper is to discuss three key topics that can be readily infused into existing coursework with minimal disruption: *raw materials*, *process efficiencies*, and *wastes/byproducts*. These three themes are essential to any engineering field or application, whether discussing design, manufacturing operations, management, service operations, or energy production, to name only a few. These concepts apply to traditional engineering materials and even to organic and biological processing, and they extend fully across the engineering spectrum, from product conception to end-of-life. Indeed, these three topics are multidisciplinary in nature.

In this paper we will discuss each of these topics in turn, and how to infuse each of them into engineering and technology coursework (there are a variety of ways to successfully incorporate them into existing curricula). We will also provide a resource base that educators can use when pursuing such an endeavor. Augmenting undergraduate and graduate instruction is a strategy that can reap profound rewards, not only because trained graduates will enter the workforce equipped with this knowledge, but bolstering curricula can raise awareness of these topics on many levels, ranging from the students themselves to the public at large.

## Introduction

In recent years there has been growing interest in environmental concerns across a broad spectrum of our society. This has been reflected in publications such as[1, 2, 3]. Most recently, “An Inconvenient Truth” has captured the attention of the public, and has brought the environment, and the effects of human activities, to the forefront of many people’s minds[4]. Now, the media is routinely filled with articles discussing these topics. Some of these have begun to focus on technologies, manufacturing practices, and the products which are produced. A few examples include industrial chemicals[5], green solvents[6], green consumer products[7], and environmentally-benign separations processes[8].

Not only is the public paying attention to environmental topics, but interest is growing in industry and academia as well. Engineers, and thus engineering educators, need to be cognizant of how their specific disciplines interact with, and ultimately impact, the environment. This includes not only waste management practices, which traditionally fall into the domain of environmental engineering, but also green and sustainable subjects as well[9]. Relevant topics must also include product design and material selection, end of life management (including reuse, recycling, and reverse manufacturing) and environmental impact assessment methods[10, 11].

In order to understand what topics may be most appropriate to pursue for augmenting engineering and technology coursework, in order to meet the need for increased sustainability education, it is useful to consider what industry is looking for in terms of employees. An online search reveals that there is definite interest by employers in sustainability issues, especially as they relate to engineering positions. As shown in Table 1, the keywords "efficiency" and "environmental" appeared most frequently for the search that was conducted. "Sustainability" and "waste byproducts" were part of many job descriptions as well, but at a much lower frequency.

**Table 1.** Number of job postings for the given keywords ("Monster.com" search conducted on October 30, 2007).

| Keyword | # |
|---|---:|
| Raw Materials | 19 |
| Bio | 51 |
| Design Engineers | 83 |
| Waste Byproducts | 112 |
| Service Management | 156 |
| Service Engineer | 712 |
| Sustainability | 749 |
| Manufacturing Engineer | 1,328 |
| Environmental | 1,517 |
| Process (AND Efficiency) | 2,708 |

It is also useful to examine the published scientific literature to gage the interest of faculty in these topics. It appears that interest in sustainability is growing in this arena. As shown in Table 2, a brief search indicates that nearly 14% of the articles published on sustainability and engineering were published last year alone. On the other hand, approximately 13% of articles published on sustainability and management were published within the last year. Searching by single keywords only (Table 3), many articles have been published on raw materials and energy production, but considerably fewer have been published on other sustainability-related keywords. Not surprisingly, there have been very few articles published on curriculum development – which is unfortunate because higher education sets the stage for coming generations of employees, employers, and citizens.

**Table 2.** Number of publications for the given keyword combinations between years 1900 – 2007.*
("Web of Science" search conducted on October 30, 2007).

| Keyword \ Keyword | Engineering | Management |
|---|---|---|
| Service | 100 (21) | 684 (131) |
| Manufacturing | 204 (24) | 143 (10) |
| Design | 407 (36) | 277 (44) |
| Energy | 101 (10) | 1277 (174) |
| Sustainability* | 362 (51) | 4682 (622) |

* Indicates the number of publications containing the keyword "Engineering" or "Management" within the search results initiated with the keyword "Sustainability". () indicates number of publications between 2006 – 2007 only.

**Table 3.** Number of publications for the given keywords between years 1900 – 2007.
("Web of Science" search conducted on October 30, 2007).

| Keyword | # | # |
|---|---|---|
| Sustainability curriculum development | 46 | (7) |
| Biological processing | 119 | (14) |
| Waste byproducts | 268 | (49) |
| End-of-life process | 526 | (151) |
| Process efficiency | 735 | (152) |
| Energy production | 4,325 | (740) |
| Raw materials | 9,881 | (1413) |

() indicates number of publications between 2006 – 2007 only.

It is true that many articles have been published and presented over the years that have discussed bringing green and sustainable engineering concepts into the engineering curriculum. For example, several have reviewed appropriate knowledge domains[12, 13, 14, 15, 16]; have explored incorporation throughout the entire curriculum[17, 18, 19, 20, 21, 22]; have discussed specific courses that have been successfully implemented[23, 24, 25, 26, 27, 28, 29]; have described whole degree programs[30]; have explained various projects and experiences for students[31, 32, 33, 34]; and have discussed educational modules[35]. All of these are very informative, and the reader is referred to them for more information. Even though these articles do provide much insight, there is still considerable room for innovative methods for achieving the aim of curriculum enhancement. Our goal was not to repeat these studies, but rather to provide a unique perspective on three topics which, even though they may sound simple, can have profound implications for industrial practice (across all engineering disciplines), and these concepts can readily be infused into existing curricula without adding substantial burdens to instructors.

## Essential Green and Sustainable Topics

As indicated by our brief examination of job postings and published articles, it appears that raw materials, process efficiencies, and wastes/byproducts could logically be topics that, if given more emphasis in the curriculum, could pay great dividends in terms of increasing green engineering and sustainable engineering knowledge in our students. By addressing these topics in the classroom, we hope to help fill three gaps that have become apparent: between the current needs of industry and the educational experience of graduates (Gap I), between academic/faculty interests and course content (Gap II), and between industry's needs and faculty interests (Gap III).

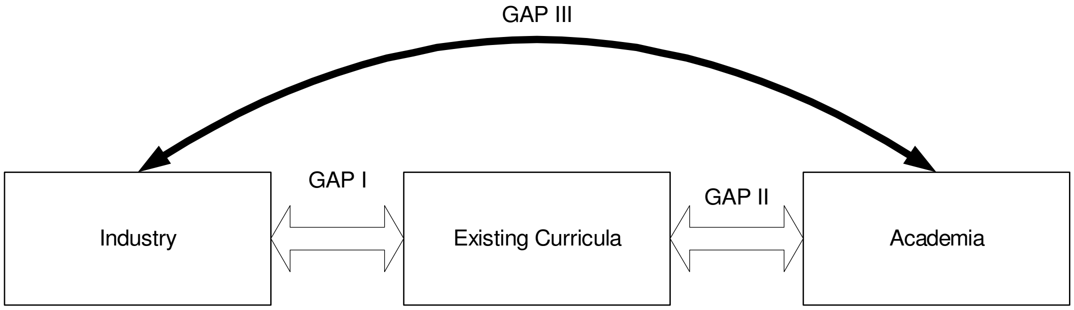
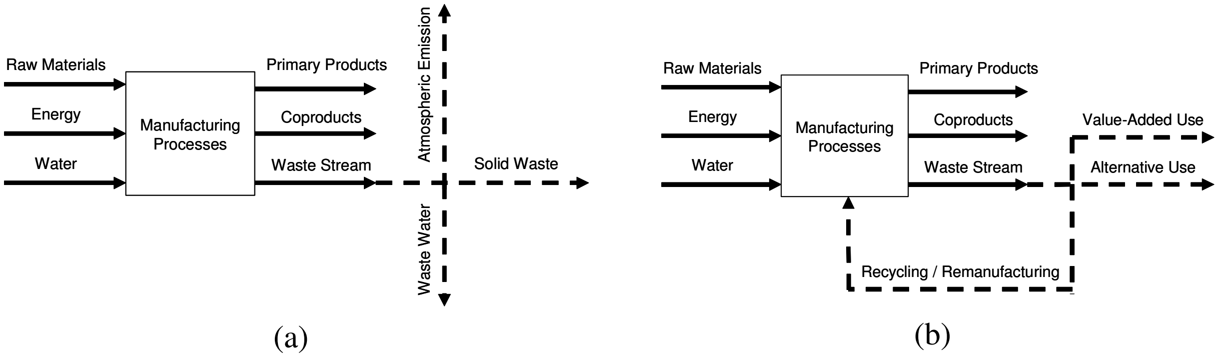


**Figure 1.** Gaps between Industry-Curricula-Academia that can be crossed by curricular enhancement.

In a broad sense, the impetus for this work is to help faculty provide additional perspectives to their students by emphasizing the interactions between industrial systems and the environment. By considering and addressing these three core topics, students should, upon entering the workforce, be able to help transform the inherent unidirectional character of most systems and enterprises, which have traditionally produced output that has dichotomously consisted of either finished products or waste materials (Figure 2a). Modern enterprises are beginning to respond to the need for change due, in part, to increased environmental regulations as well as operational economics, and are starting to recognize the benefits of systems where selecting the appropriate raw materials can decrease environmental burdens of products throughout their entire lifecycle, where increasing process efficiencies can drastically reduce both energy consumed as well as waste products produced, and where waste streams can be minimized, reused as energy feedstocks, or as input streams for other products or processes (Figure 2b). Addressing these three topic areas can ultimately help to reduce impact on the environment, and thus can help close the ecological loop.



(a) (b)

**Figure 2.** General flowcharts for traditional (a), and sustainable (b), enterprises.

### *Raw Materials*

When raw material usage is one of the initiating processes for a manufacturing operation, discussions regarding the disadvantages of virgin material usage, including impacts on the environment, and related production/consumption statistics, should be provided to the students. Furthermore, alternative ways of creating input material to processes via recycling, reusing, and remanufacturing should be explained, including the technological and economical aspects of such end-of-life (EOL) operations. In this regard, disassembly, an operation that is partially or wholly required to regain a material's added value to the EOL products should be investigated in detail.

Providing a systems approach to discuss these topics would aid students in understanding the product life cycle in an encompassing manner. Figure 3 illustrates the physical state of a product for Forward and Reverse Supply Chains. Introducing students to take-back processes, as well as brief information regarding all possible EOL options for the given material, will be helpful in increasing awareness regarding manufacturing decisions in terms of virgin material usage versus diminishing natural resources. Implementing this approach will be dependent upon the material of interest, with each material resulting in unique information and processes which may be appropriate.

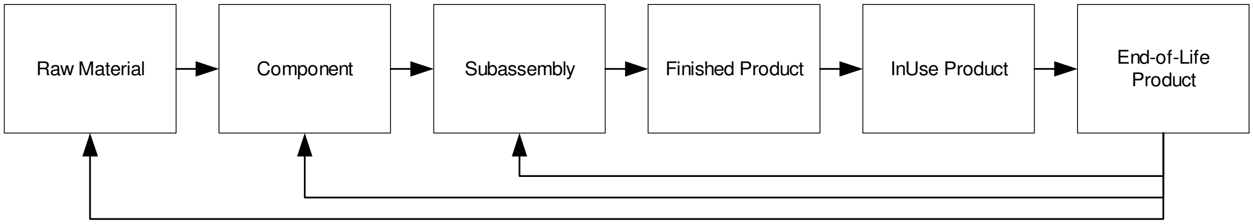


**Figure 3.** Product structure a typical Forward and Reverse Supply Chain.

Figure 3, depicts a simplified generic scenario for any product. When the concern is on the national and/or international scale, students can also be educated regarding material life cycles in a more generalized manner, as shown below.

A useful way to address these topics is illustrated in Figure 4, which depicts each stage in the life of a given material. As shown, all stages in the lifecycle of a material need to be examined, from raw products (stages 0 and 1), all the way to end of life, including landfilling (stage 6) and reprocessing/disassembly for reuse in production (stage 2). This diagram also illustrates material flows between stages, which are represented by $A_{ij}$, where A denotes material flow, i denotes "flow from", and j denotes "flow to". This approach can be used to discuss a given raw material (such as iron, copper, etc.), and can be discussed on a local, national, or even international scale. Hence, regarding the nature of the problem at hand, students can be provided with appropriate information for specific material flows, and can be made aware of the overarching environmental consequences of the engineering solutions they provide.

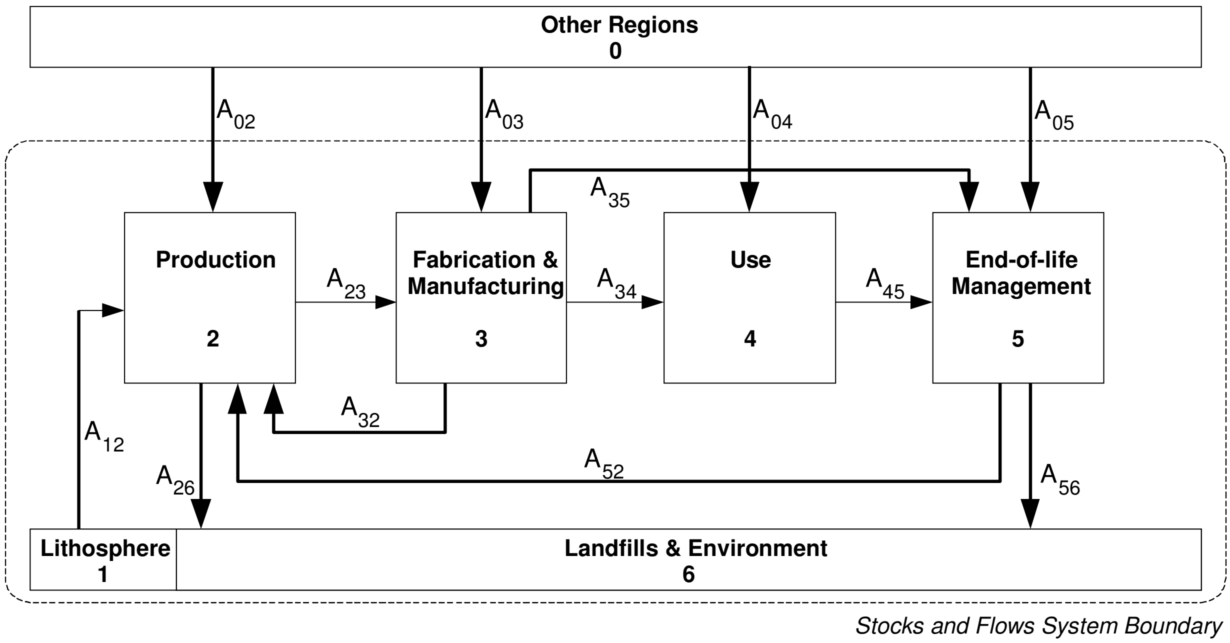


**Figure 4.** Simplified schematic diagram of an anthropogenic cycle for a given material, with successive life stages[37].

*Process Efficiencies*

When discussing various processes and operations in any setting (e.g., design, manufacturing, maintenance, or even the service sector), the efficiency of each step in the process will impact the capability of the overall system. In a general sense, efficiency quantifies process losses (which are wastes or byproducts) compared to process inputs. And, when discussing various operations in engineering and technology classes, it is essential that efficiencies are part of the educational experience; in other words, coursework should not just focus on traditional theoretical work and problem solving skills, because in real life losses will occur.

To examine process efficiencies requires mathematically quantifying each specific operation in that process. As an example, consider an overall process mass balance (which could readily be utilized in conjunction with Figures 3 and 4), which is a macro-scale viewpoint, and may consist either single or multiple flow streams:

$$\sum \dot{m}_{in} + \sum \dot{m}_{gen} - \sum \dot{m}_{des} - \sum \dot{m}_{out} = 0 \qquad (1)$$

where $\dot{m}_{in}$ is mass flow rate entering a specific process, $\dot{m}_{gen}$ is mass flow rate of material generation within the process, $\dot{m}_{des}$ is the mass rate of material destruction within the process, and $\dot{m}_{out}$ is the rate of mass exiting the process. In other words, a first-law analysis is key to understanding process efficiencies. Moreover, the outbound material stream is typically composed of final product and process waste, or residue (which ultimately we want to minimize). This term can be rewritten as:

$$\sum \dot{m}_{out} = \sum \dot{m}_{product} + \sum \dot{m}_{residual} \tag{2}$$

Depending on the process which is being analyzed, it may be possible to further decompose this macro-scale view into individual constituent streams. Rewriting the overall mass balance, and accounting for each component stream, which in sum ultimately constitute the overall product streams of the process leads to:

$$\sum_i \dot{m}_{in} + \sum_i \dot{m}_{gen} - \sum_i \dot{m}_{des} - \sum_i \dot{m}_{out} = 0 \tag{3}$$

where i represents the specific constituents of interest. Moreover, the mass flow rate exiting the process can also be rewritten on an individual component basis:

$$\sum_i \dot{m}_{out} = \sum_i \dot{m}_{product} + \sum_i \dot{m}_{residual} \tag{4}$$

Once the mass balances have been developed, it is very easy to determine process efficiencies. For example, the overall process mass transfer efficiency (η) which can be used to account for overall processing losses can be defined as:

$$\eta = \frac{\sum \dot{m}_{out} - \sum \dot{m}_{gen} + \sum \dot{m}_{des}}{\sum \dot{m}_{in}} \tag{5}$$

The overall process conversion (i.e., conversion of raw products into final products vs. waste products) efficiency (ε) can be determined as:

$$\varepsilon = \frac{\sum \dot{m}_{product} - \sum \dot{m}_{residual}}{\sum \dot{m}_{in} + \sum \dot{m}_{gen} - \sum \dot{m}_{des}} \tag{6}$$

To account for processing losses for each constituent (if the flow streams can be decomposed into constituent parts), the component process mass transfer efficiency ($\eta_i$) can thus be defined as:

$$\eta_i = \frac{\dot{m}_{i_{out}} - \dot{m}_{i_{gen}} + \dot{m}_{i_{des}}}{\dot{m}_{i_{in}}} \tag{7}$$

And the process conversion efficiency for each constituent ($\varepsilon_i$) can be determined as:

$$\varepsilon_i = \frac{\dot{m}_{i_{product}} - \dot{m}_{i_{residual}}}{\dot{m}_{i_{in}} + \dot{m}_{i_{gen}} - \dot{m}_{i_{des}}} \tag{8}$$

The above discussion has focused solely on mass flow rate, as this can be readily be utilized with the approach illustrated in Figures 3 and 4. A similar type of analysis could easily be established for other process parameters as well, but instead of using mass flow, other variables would be utilized. This could include product flows, information flows, employee flows, or other parameters that may incur losses as they flow from one aspect of the process to another. Regardless of what type of scenario is examined, an overall balance of that parameter will be necessary, and the equations developed will be specific to that type of operation. And this approach can be applied to any engineering or technology discipline and subject area, not just manufacturing environments.

Further, this type of analysis would readily prove to be a challenging, yet very appropriate mathematical modeling exercise when studying various processes in the classroom. Ultimately, the focus of these discussions should revolve around methods for increasing process efficiencies, which thus will reduce the wastes and byproducts that are produced.

*Wastes and Byproducts*

A skill that should be taught to students is that of identifying waste and byproduct streams. Because all processes and operations produce waste (whether discussing manufacturing, food processing, or even service industries), this topic is relevant to most engineering and technology courses. And it is up to the faculty that teach these courses to help students understand where specifically these streams originate, why they originate, and how to minimize their generation. If waste products cannot be eliminated, then they will require some type of remediation or disposal.

Additionally, students need to know how to quantify waste generation. This could entail calculating potential waste generation, given appropriate information on specific unit operation equipment and setting, and if process efficiencies are known. Ultimately, however, this means physically measuring how much waste is generated by a given production process, on either a volumetric ($m^3$/hr) or a mass (kg/hr) basis, and determining what fraction of process inputs are actually converted into waste materials vis-à-vis finished products (i.e., calculating conversion process efficiencies). Furthermore, it is important that waste generation be quantified using a short-term, or cross-sectional, approach (e.g., over one production run), but must also be determined on a long-term, or longitudinal, basis (e.g., over several months or even years). This information is essential because it enumerates exactly how much waste must ultimately be managed. Moreover this type of data analysis is appropriate for quality control analysis, which could further augment the educational material in a classroom.

Students also need to know how to characterize waste streams. In other words, they should know how to quantify several key physical and chemical properties of the waste stream under consideration. Properties of the waste stream will depend in large part on the raw materials used, but also on the processing steps employed in a given production process. Depending upon the nature of the waste material (solid, liquid, sludge, fines, etc.) essential physical properties could include the nature and size of the waste materials, including particle size and shape, moisture content, mass density, yield stress, apparent viscosity, thermal conductivity, thermal diffusivity, heat capacity, and even electromagnetic properties. It is also important that students are aware of the importance of chemical constituents, including potentially toxic compounds, and how to measure them. Characterization of waste streams is important because it provides data that are necessary for storing, handling, and disposing of these materials, or for developing value-added options, thus eliminating the need for disposal. In fact, physical and chemical properties can actually dictate which potential avenues are most appropriate for a given waste stream. Some of these options include reprocessing, recycling, incinerating, composting, using as an energy source (i.e., combustion, gasification, pyrolysis), applying to land, feeding to livestock, or reusing via other value-added procedures. Furthermore, material properties are critical to the engineering of equipment and facilities, and also to the design and optimization of specific processing operations.

## Infusion into Curricula

Many opportunities currently exist to infuse undergraduate curricula with green engineering concepts, and the benefits are not only in terms of curricular augmentation alone, but they also provide a chance for faculty to develop new, innovative teaching materials.

It is true the green and sustainable concepts can be incorporated into an engineering or technology degree program via a full-semester, stand-alone course dedicated to this general area, and all of the topics this would entail. But, that is not what the authors are proposing. With all other programmatic requirements currently in place, few academic programs are able to accommodate the addition of another course. Therefore, it is beneficial to examine other mechanisms for incorporating the three topics discussed in this paper, either as individual topics, components, or units that can be used as specific learning modules, into existing coursework.

In fact, many approaches have been found to be quite successful for augmenting engineering and technology instruction by inserting additional materials into mainstream instruction[38]. Addressing engineering ethics is a prime example of how specific topics can be infused into curricula without adding additional courses. Some avenues that have been shown to work well include integrating focused components (theory as well as case study analyses) into specific technical courses[39-43], examining issues during technical problem solving in specific technical courses[44], issues and topics for review during capstone experiences[45-46], specific components in coursework dedicated to professionalism[47-48], topical seminars[49], as well as integration throughout the entire curriculum[50-52]. In fact, the authors feel that it would be most appropriate to infuse these three topics (raw materials, efficiencies, and waste products), using a variety of the aforementioned techniques, in all courses that engineering and technology students take, as they are germane to almost every subject that is offered in a degree program.

Ultimately, the successful inclusion of these concepts in undergraduate engineering and technology education will be dependent upon individual faculty interest, motivation, and implementation, and will be heavily influenced by the creativity of the individual instructor.

## Resources for Educators

Information regarding green and sustainable engineering is quite dispersed; no single comprehensive literature source exists that would appropriate for use in an engineering or technology curriculum that would adequately cover all three topics that have been discussed in this paper. So, for instructors who are interested in incorporating individual, specific topics or modules based on the ideas discussed in this paper at appropriate locations during the semester, as well as those who may design and implement entire courses devoted to green and sustainable engineering, supporting teaching materials will be critical to these endeavors. Therefore, a thorough listing of recent textbooks and online publications has been compiled and is provided below in Table 4.

**Table 4.** Green and sustainable engineering resources for educators.

**Books**

| *Authors* | *Year* | *Title* |
|---|---|---|
| Allen, D. T., Shonnard, D.R. | 2001 | Green Engineering: Environmentally Conscious Design of Chemical Processes |
| American Society of Civil Engineers | 2004 | Sustainable Engineering Practice: An Introduction |
| Brissaud, D., Tichkiewitch, S., Zwolinski, P. | 2006 | Innovation in Life Cycle Engineering and Sustainable Development |
| Camarinha-Matos, L. M. | 1997 | Re-engineering for Sustainable Industrial Production |
| Doble, M., Kumar, A. | 2007 | Green Chemistry and Engineering |
| Gupta, S. M., Lambert, A. J. D. | 2007 | Environment Conscious Manufacturing |
| Kutz, M. | 2007 | Environmentally Conscious Mechanical Design |
| Kutz, M. | 2007 | Environmentally Conscious Manufacturing |
| Lambert, A. J. D., Gupta, S. M. | 2004 | Disassembly Modeling for Assembly, Maintenance, Reuse and Recycling |
| Lancaster, M. | 2002 | Green Chemistry |
| Lankey, R. L, Anastas, P. T. | 2002 | Advancing Sustainability through Green Chemistry and Engineering |
| McDonough, W. | 2002 | Cradle to Cradle: Remaking the Way We Make Things |
| Stevens, E. A. | 2001 | Green Plastics: An Introduction to the New Science of Biodegradable Plastics |
| Takata, S., Umeda, Y. | 2007 | Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses: Proceedings of the 14th CIRP Conference on Life Cycle Engineering |
| Talaba, D., Roche, T. | 2005 | Product Engineering: Eco-Design, Technologies and Green Energy |
| Wool, R., Sun, X. S. | 2005 | Bio-Based Polymers and Composites |

**Websites**

| *Title* | *URL* |
|---|---|
| A Guide to Sustainable E-waste Management | ewasteguide.info |
| Campaign Earth! | www.campaignearth.org |
| Department of Environmental Protection | State web sites (e.g., www.ct.gov for the State of Connecticut) |
| Environmental Education Resource for Teachers | eelink.net |
| Federal Emergency Management Agency | www.fema.gov |
| ISO 14000 Essentials | www.iso.org/iso/iso_14000_essentials |
| National Geographic Environment News | news.nationalgeographic.com/news/environment.html |
| National Recycling Coalition | www.nrc-recycle.org |
| National Safety Council | www.nsc.org |
| New York Times Environmental News | environment.about.com/ |
| Online Environmental Community | envirolink.org |
| Scorecard | www.scorecard.org |
| The Environment Directory | www.webdirectory.com |
| US Environmental Protection Agency | www.epa.gov |
| World Environmental Organization | www.world.org |

## Conclusions and Future Research

Diminishing natural resources and increasing amount of waste have been the concern of governments and institutions for the last couple of decades. For example, the National Safety Council estimates an accumulation of 500 million Personal Computers between the years 1997 and 2007 which corresponds to 7.5 million tons of potential waste.

In order to be able to come up with environmentally-benign solutions for business and manufacturing operations, sustainability issues need to be a part of the every engineering decision. This includes every step, from the design phase until the product reaches to its end-of-life, and continues even after that, when the efforts to regain the material's value may take place.

In addition, not only manufacturing operations but also service businesses can also be structured in an environmentally-friendly manner, reorganizing the flow charts and embedding environmental rules and regulations into the work environment.

This can only be achieved in an efficient manner if the potential work force is trained accordingly. In this regard, this study presented an outline summarizing three important topics that can easily be embedded into the existing curricula without major changes. Some helpful literature and internet resources are also provided for the use of educators.

Future research will be looking into a case example in a U.S. educational institution. Furthermore, the gaps between industry, academia and educational institutions will be further investigated via surveys.

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