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Greening the Curriculum: Augmenting Engineering and Technology Courses with Sustainability Topics

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Abstract: Duties of engineers and technologists often entail designing and implementing solutions to problems. It is their responsibility to be cognizant of the impacts of their designs on and thus, their accountability to society in general. They must also be aware of subsequent effects upon the environment. They need to be able to concurrently satisfy these often competing priorities as well as constraints specific to the technical challenges at hand. Responding to these contending forces 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 for graduates to know and understand. Unfortunately, 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 time at the university. Toward that end, the goal of this study is to discuss three key topics that can be readily infused into existing coursework with minimal disruption: raw materials, process efficiencies and wastes by products. The researchers have determined that these three themes are essential to any engineering field or application, whether discussing design, manufacturing, management and even service operations to name but a few. These concepts apply to the application of traditional engineering materials as well as organic and biological systems and they extend fully across the engineering spectrum from product conception to end-of-life. Indeed, these three topics are multidisciplinary in nature and have multiple dimensions to consider. In this study, 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 several resources 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 a greater knowledge base and skill set but bolstering curricula can raise awareness of these topics on many levels, ranging from the students themselves to the public at large.

Key words: Curriculum enhancement, education, efficiency, green engineering, raw material, sustainable engineering, waste

INTRODUCTION

Over the years, there has been growing interest in environmental concerns across a broad spectrum of the society. This has been reflected in publications such as Brown (2002), Gore (1993) and Pahl (2001). This concern has gained momentum of late. 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 (Gore, 2006). Now, the media is routinely filled with articles discussing these topics, especially climate change, global warming, resource consumption, energy supplies and pollution. Some of these stories have even begun to focus on technologies, manufacturing practices and the products which are produced. A few examples include industrial chemicals (Kongar and Gupta, 2006a), green solvents (University of Notre Dame, 1999; Gaughran *et al*., 2007), green consumer products and environmentally-benign separations processes (Geldermann and Rentz, 2005).

Not only is the public paying more attention to environmental topics but interest is growing in industry and academia as well. Engineers and technologists and thus educators need to be cognizant about how their specific disciplines interact with and can ultimately impact the environment. Practitioners and educators alike should at least understand waste management practices which traditionally fall into the domain of environmental engineering but also green and sustainable subjects as

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Table 1: Number of job postings for the given key words (monster.com search conducted on October 30, 2007 and May 4, 2009)

Key words	2007	2009
Raw materials	19	673
Bio	51	546
Design engineers	83	3944
Waste byproducts	112	1
Service management	156	5 000+
Service engineer	712	4 460
Sustainability	749	342
Manufacturing engineer	1,328	3,063
Environmental	1,517	5,000+
Process (and efficiency)	2,708	5,000+

Table 2: Number of publications for the given keyword combinations between years 1900-2009. *[Web of Science search conducted on October 30, 2007 and May 4, 2009]

	1900-2007		1900-2009	
Analysis	Engineering	Management	Engineering	Management
Service	100 (21)	684 (131)	395 (45)	2,946 (341)
Manufacturing	204 (24)	143 (10)	629 (32)	996 (85)
Design	407 (36)	277 (44)	5,193 (314)	3,257 (343)
Energy	101 (10)	1,277 (174)	500 (32)	2,108 (187)
Sustainability**	362 (51)	4,682 (622)	200 (35)	1,536 (252)

*[ ] indicates number of publications between 2006-2007 only and ( ) indicates number of publications between 2008-2009 only. Data without parentheses include all publications. **Indicates the number of publications containing the keyword Engineering or management within the search results initiated with the keyword sustainability

well (Bower *et al*., 2006). Relevant knowledge domains must include product design and material selection, end of life management (including reuse, recycling and reverse manufacturing) and environmental impact assessment methods (Wittig, 2006; Lynch-Caris and Redekop, 2007). Of course, the challenge is to provide this additional background without excessive burdens to instructors or the need for increasing the number of required courses in degree programs.

In order to understand specifically which topics may be most appropriate to use to augment engineering and technology coursework 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. In addition, Table 1 shows the significant increase in the number of environment and sustainability related jobs in the last 2 years. It is also useful to examine the published scientific literature to gage the interest of faculty and researchers in these topics. It appears that interest in sustainability is growing in this arena as well.

Table 3: Number of publications for the given topic keywords between years 1900-2009. *[Web of Science search conducted on October 30, 2007 and May 4, 2009]

Key words	1900-2007	1900-2009
Sustainability curriculum development	46 (7)	89 (26)
Biological processing	119 (14)	152 (12)
Waste byproducts	268 (49)	391 (55)
End-of-life process	526 (151)	844 (148)
Process efficiency	735 (152)	1,158 (160)
Energy production	4,325 (740)	6,011 (806)
Raw materials	9,881 (1,413)	13,430 (1,602)

*[ ] indicates number of publications between 2006-2007 only and ( ) indicates number of publications between 2008-2009 only. Data without parentheses include all publications

As shown in Table 2, a brief search shows 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, policy makers and citizens.

Literature review: Bearing these search results in mind, one must ask: have not these topics already been addressed. It is true that many articles have been published and presented over the years that have discussed bringing green and sustainable engineering concepts into engineering and technology curricula. For example, several articles have reviewed appropriate knowledge domains (Carew and Mitchell, 2001; Foroudastan and Rappold, 2004; Bosscher *et al*., 2005; Legg *et al*., 2005; Lynch *et al*., 2007); explored incorporation throughout the entire curriculum (Turner *et al*., 2001; Hesketh *et al*., 2002; Robinson and Sutterer, 2003; Hadgraft *et al*., 2004; Slater *et al*., 2005; Bajwa and Chen, 2006) discussed specific courses that have been successfully implemented (Richter *et al*., 2007; Sukumaran *et al*., 2004; Gregg, 2005; Ciocci, 2006; Matthews and Heard, 2006; Hey *et al*., 2007; McAloone, 2007) described whole degree programs (Johnson *et al*., 2006) explained various projects and experiences for students (Turner *et al*., 2001; Beckman *et al*., 2006; Paterson *et al*., 2007; Scott and Ahmad, 2007) and discussed specific educational modules (Gaughran *et al*., 2007).

All of these are very informative and the reader is referred to them for more information. Even though, these published works do provide much insight, the end goals have not yet been universally met and thus there is still considerable room for innovative methods for achieving the aim of curriculum enhancement. The goal is not to repeat these studies but rather to add to the overall discussion by providing a unique perspective on three topics which if introduced into curricula and given appropriate emphasis can have profound implications for industrial practice (across all engineering and technology disciplines). These concepts can readily be infused into existing curricula without adding substantial burdens to instructors.

MATERIALS AND METHODS

Three key green and sustainable topics: As determined by the brief examination of job postings and published articles. Three key topics emerged: raw materials, process efficiencies and wastes by products. These could logically be topics that if given more emphasis in the curriculum could pay dividends in terms of increasing green/sustainable engineering knowledge in students and ultimately in industrial practice.

By addressing these topics in the classroom, we hope to help fill three gaps (Fig. 1) that have become apparent between the current needs of industry and the educational experience of graduates (Gap 1) between academic/faculty interests and course content (Gap 2) and between industry's needs and faculty interests (Gap 3). In a broad sense, the impetus for this work is to help faculty provide additional awareness, perspectives and

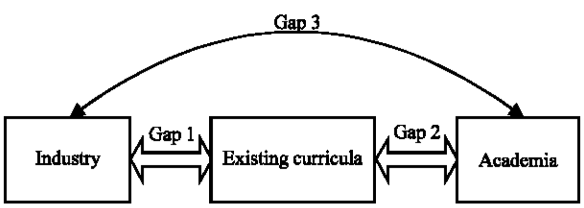

Fig. 1: Gaps between Industry-Curricula-Academia that can be crossed by curricular enhancement

knowledge to their students by emphasizing the interactions among design, industrial systems, business operations and the environment. By considering and addressing these three core topics (raw materials, efficiencies and waste products), 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 generally consists of either finished products or waste materials (Fig. 2a).

Modern enterprises are beginning to respond to the need for change due in part, to increased environmental regulations as well as operational economics. Many are starting to recognize the benefits of systems where selecting appropriate raw materials can decrease environmental burdens of products throughout their entire life cycle 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 (Fig. 2b). Addressing these three topic areas can ultimately help to reduce impact on the environment and thus can help close the ecological loop.

Raw materials: When raw material usage is one of the initiating processes for a manufacturing operation (i.e., product or process design), discussions regarding the disadvantages of virgin material usage (including impacts on the environment such as extraction and preparation for usage-including the resulting waste products or potential pollution which may be generated and related production/consumption statistics) should be provided to the students. Alternative ways of creating input material to processes via recycling, reusing and emanufacturing wither whole parts or components thereof should also be explained including the technological and economic aspects of such End-of-Life

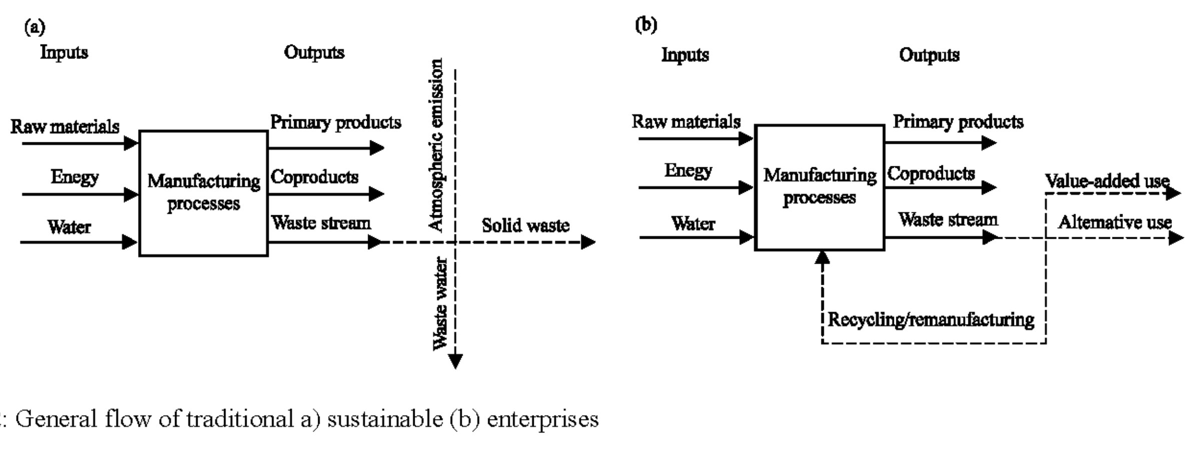

Fig. 2: General flow of traditional a) sustainable (b) enterprises

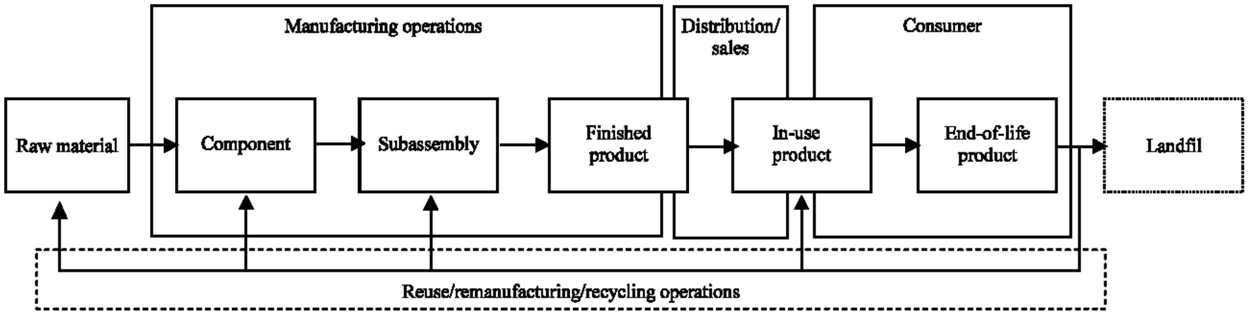

Fig. 3: Product structure for a typical forward and reverse supply chain which attempts to utilize products in an environmentally-efficient manner (Kongar and Gupta, 2006b)

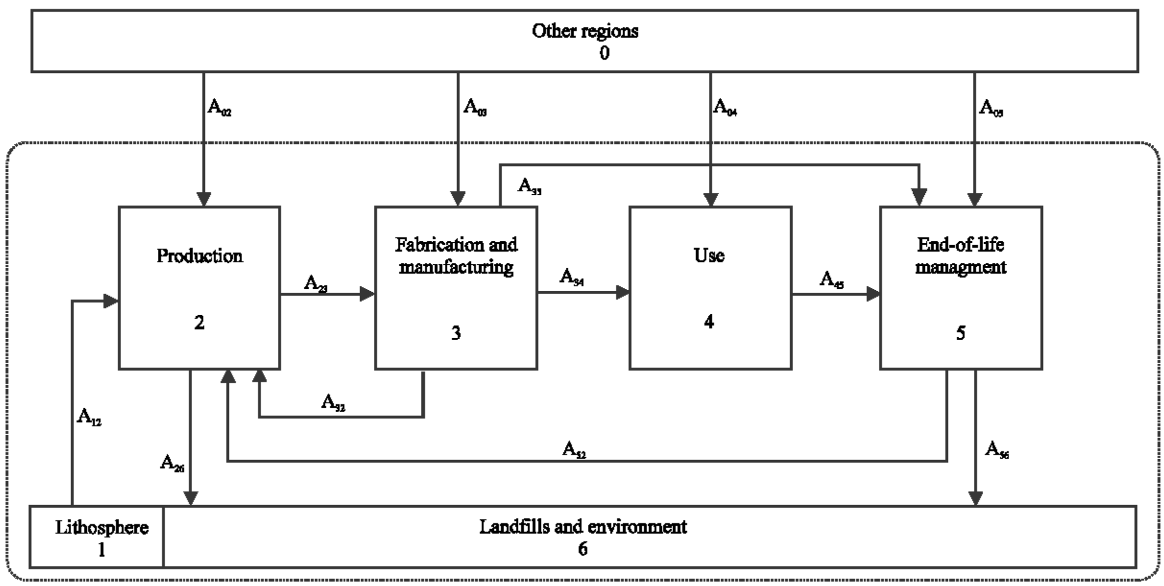

Fig. 4: Simplified schematic diagram of an anthropogenic cycle for any given material, incorporating successive life cycle stages (Wang *et al*., 2007)

(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. Key topics should include sequence of demanufacturing steps, costs of operations, as well as costs for receiving/take-back operations (if material is brought into a plant for reuse instead of landfilling). In other words, students need to be introduced to forward and reverse supply chains.

Providing a systems approach to discuss, these topics will aid students in understanding the product life cycle concept in an encompassing manner. For example, Fig. 3 shows the physical state of any given product throughout its life cycle. Introducing students to take-back processes (to achieve reuse) as well as brief information regarding all possible EOL options for a given material will be helpful in increasing awareness regarding manufacturing decisions in terms of virgin material usage versus diminishing natural resources. Of course, implementing this approach will be dependent upon the material of interest with each material resulting in unique information and processes which may be appropriate. Food manufacturing will not have the same materials, products or processes as automobile manufacturing but the overall concept is appropriate for any industrial scenario.

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. A useful way to approach these topics is shown in Fig. 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 the end of life including landfilling (stage 6) or 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, corn, wheat, petroleum, etc.) and can be discussed on a local, national or even international scale, depending upon where the boundaries are defined.

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 using raw materials for various applications.

Process efficiencies: When discussing various operations (e.g., design, manufacturing, maintenance or even the service sector), the efficiency of each step in a given process will impact the capability of the overall system. In a general sense, efficiency quantifies losses (which are wastes or byproducts) compared to inputs. And, when discussing operations, equipment and products 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 and cannot be ignored.

To examine process efficiencies requires mathematically quantifying each specific step in that process. For each unit operation, construct a mass balance using a macro-scale viewpoint. It may consist of either single or multiple flow streams:

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

Where:

$\dot{m}_{in}$ = Mass flow rate entering a specific process

$\dot{m}_{gen}$ = Mass flow rate of material generation within the process

$\dot{m}_{des}$ = The mass rate of material destruction (i.e., utilization or conversion) within that process

$\dot{m}_{out}$ = The rate of mass exiting the process

In other words, a thermodynamic first-law approach is key to understanding process efficiencies. The outbound material stream is typically composed of final product and process waste (which ultimately we want to minimize). This term can be rewritten as:

$$\sum \dot{m}_{out} = \sum \dot{m}_{product} + \sum \dot{m}_{waste} \quad (2)$$

Depending on the system which is being analyzed, it may be possible to further decompose this macro-scale view into individual constituent streams. For example, biological materials are composed of water, proteins, lipids, carbohydrates and inorganic materials. Further proteins are composed of specific amino acids; lipids are composed of specific fatty acids. The level of decomposition which is necessary will depend upon the specific topic. 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:

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

$$\sum_i \dot{m}_{out} = \sum_i \dot{m}_{product} + \sum_i \dot{m}_{waste} \quad (4)$$

Once the mass balances have been developed, it is easy to quantify 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:

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

For a steady-state scenario with no processing losses, then $\eta = 1$ because $\Sigma\dot{m}_{in} = \Sigma\dot{m}_{out}$. The overall process conversion (i.e., conversion of raw materials into final products vs. waste products) efficiency (ϵ) can be determined as:

$$\varepsilon = \frac{\sum \dot{m}_{product} - \sum \dot{m}_{waste}}{\sum \dot{m}_{in} + \sum \dot{m}_{gen} - \sum \dot{m}_{des}} \quad (6)$$

Thus for the case where there is no waste generated, at steady-state conditions $\epsilon = 1$ because $\Sigma\dot{m}_{in} = \Sigma\dot{m}_{product}$. To account for processing losses for each constituent (if the flow streams can be decomposed into constituent parts), the component process mass transfer efficiency (η_i) can thus be defined as:

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

And the process conversion efficiency for each constituent (ϵ_i) can be determined as:

$$\varepsilon_i = \frac{\dot{m}_{i_{product}} - \dot{m}_{i_{waste}}}{\dot{m}_{i_{in}} + \dot{m}_{i_{gen}} - \dot{m}_{i_{des}}} \quad (8)$$

In real life situations, there are no perfect processes thus, the transfer efficiency and the conversion efficiency are never 100%. How do you reduce the waste which is generated. You need to improve the process operations. How you do this is dependent upon what type of industrial scenario you are discussing, the equipment which is used, raw materials, etc. Lean manufacturing tools can help with this. There is a very large and continually growing, literature base which is focused on lean concepts.

The reader is referred to them for more information. If the course where this topic is discussed (efficiencies) is not focused on lean manufacturing, then this would be an ideal opportunity to introduce students to these concepts. The above discussion has focused solely on mass flow rate as this can be readily be utilized with the approach shown in Fig. 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 could 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 or business 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. 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 or the laboratory. Ultimately, the focus of these discussions should revolve around methods for increasing process efficiencies which can reduce the wastes and byproducts that are produced.

Wastes and byproducts: A skill that should be taught to students (but is currently often neglected in most classrooms) is that of identifying waste and by product 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.

It is up to the faculty that teach these courses to help students understand specifically where, how and why waste streams originate and how to minimize their generation. If waste products cannot be eliminated, then they will require some type of remediation or disposal perhaps they can be reused or recycled within the plant or perhaps they can be upgraded and used for other purposes.

Additionally, students need to know how to quantify waste generation. This could entail estimating or calculating potential waste generation, given appropriate information on specific unit operation equipment and settings and if process efficiencies are known.

This could also mean physically measuring how much waste is generated by a given production process, on either a volumetric ($m^3 h^{-1}$) or a mass ($kg h^{-1}$) basis (or some other equivalent unit basis) and then determining what fraction of process inputs are actually converted into waste materials vis-à-vis finished products (i.e., calculating conversion efficiencies).

This type of exercise would be appropriate for laboratory or field experiences. Furthermore, it is important that waste generation be quantified using a short-term or cross-sectional approach (e.g., over a single production run) but must also be determined on a long-term or longitudinal basis (e.g., over several weeks, months or even years).

This information is essential because it enumerates exactly how much waste must ultimately be managed. For a given system, this type of data is appropriate for quality control analysis which could further augment the educational material in a classroom. Students also need to know how to characterize various 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 and on the processing steps employed in a given production process. Depending upon the nature of the waste material (solid, liquid, sludge, powder, etc.,) essential physical properties could include the nature and size of the waste materials (including 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 in the laboratory. Table 4 shows a comprehensive list of properties which are necessary in order to fully characterize waste materials. 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 often used options include reprocessing, recycling, incinerating, composting, using as an energy source (i.e., heat exchangers, combustion, gasification, pyrolysis), applying to land as fertilizer, feeding to livestock or reusing via other value-added

Table 4: Properties essential for comprehensive characterization of waste streams (Rosentrater, 2005)

Chemical attributes	Physical attributes
Moisture content	**Moisture relationships**
Solids content	Equilibrium moisture contents
Organic solids content	Water activity
Nitrogenous solids content	Drying analysis
Protein (N) content	**Physical attributes and structure**
Nitrogen solubility index	Volume and surface area
Protein dispersibility index	Particle size and shape
Protein digestibility (*in vitro*)	Particle size distribution
Amino acid profiles	Cellular structures
Non-protein N content	Micro structures (morphological)
Fat (lipid) content	Macro structures (morphological)
Carbohydrate content	**Bulk transport properties**
Nitrogen Free Extract (NFE) content	Mass density
Starch content	Unit density
Sugar content	Bulk density
Crude fiber content	Standard density
ADF content	Pail density (compact bulk density)
NDF content	True density
Lignin content	Porosity
Cellulose content	Durability
Hemicellulose content	Angle of repose (filling)
Inrganic solid content	Angle of repose (emptying)
Ash content	Coefficient of static friction
P content	Flow through orifices
S content	Flow through spouts and ducts
Ca content	**Rheological properties**
Na content	Surface tension
Cl content	Viscosity (apparent and dynamic)
Mg content	Yield stress
K content	Small strain rheology
Fe content	**Thermal properties**
Aggregate chemical properties	Thermal conductivity
Appearance	Thermal diffusivity
Color	Specific heat capacity
Acidity	Glass transision
Alkalinity	Enthalpy
Conductivity	Thermal behavior and response
Fioatabies	**Aerodynamic properties**
Solids	Terminal velocity
Total solids	Airflow resistance
Total dissolved solids	**Electromagnetic properties**
Total suspended solids	Resistance
Fixed and volatile solids	Capacitance
Settleable solids	Color (L-a-b tristimulus)
Total, fixed, volatile in solids and	**Deformation properties**
particle counting and size	Compression
Distribution sludge testing	Tension
Settled sludge volume	Bending
Sludge volume index	Shear and 3-point bending
Specific gravity	Torsion
Time-to-filter	Viscoelasticity
PH	Penetration
Dissolved Oxygen (DO)	
Aggregate organic properties	
Biochemical Oxygen Demand (BOD)	
Chemical Oxygen Demand (COD)	
Total Organic Carbon (TOC)	
Surfactants	
Tannin and lignin	
Organic and volatile acids	

procedures. Table 5 shows a comprehensive list of possibilities for value-added utilization of waste products. Furthermore, material properties are critical to the design and operation of equipment and facilities and also to the optimization of specific processes and systems.

Table 5: Potential processing and utilization options for waste products (Rosentrater, 2005)

Unit operations	Value-added utilization
Physical processes	**Feed uses**
Blending	As-Is
Blocking/cubing	Blending
Compaction/densification	Component utilization
Compression molding	Use subsequent to further
Dehydration	processing
Dewatering/centrifugation	**Food uses**
Drying	As-Is
Extrusion	Blending
Blown film	Component utilization
Compounding	Use subsequent to further
Profile	processing
Sheet	Bleaching
Gasification	Deodorizing
Injection molding	Flavor analyses
Pelleting	Nutritional supplementation
Physical separation/screening/sieving	Texture analyses
Pyrolysis	Toxicity analyses
Size reduction/grinding/milling	**Industrial uses**
Vacuum thermoforming	As-Is
Chemical processes	Blending
Chemical hydrolysis	Component utilization
Distillation	Use subsequent to further
Fractionation	Processing
Pyrolysis	Briquettes
Solvent extraction	Degrable plastic composite filler
Species-Selective binding and removal	Bioenergy
Biological processes	Resin/binder/adhesive
Aerobic digestion	Soil amendment
Algae feedstock	Wood replacer/substitute
Anaerobic digestion	OSB
Bioreactors	Paper
Activated sludge	Paperboard
Cascading	Particleboard
Fixed-Film	
Photo	
Composting	
Enzymatic hydrolysis	
Fermentation	
Microbial feedstock	

RESULTS AND DISCUSSION

Incorporation into curricula: Many opportunities currently exist to infuse engineering and technology curricula with green and sustainable concepts; the benefits are not only in terms of curricular augmentation alone but they also provide a chance for faculty to develop updated, new or innovative teaching materials. It is true that 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 with all of the concomitant topics that this would entail.

But this approach is not what the researchers are proposing in this study. With all other programmatic requirements currently in place, few academic programs are able to accommodate the addition of yet another course. Therefore, it is beneficial to examine other mechanisms for incorporating the three concepts promoted in this study, either as individual topics, components or units that can be used as specific learning modules into pre-existing coursework. Many unique approaches have been found to be quite successful for augmenting engineering and technology instruction by inserting additional materials into mainstream coursework (Dyrud, 1998).

For example, addressing engineering ethics is a prime case in point of how specific topics can be infused into curricula without adding additional courses. Some avenues that have been shown to work well to achieve this include integrating focused components (theory as well as case study analyses) into specific technical courses (Alenskis, 1997; Case, 1998; Krishnamurthi, 1998; Whiting *et al.*, 1998; Arnaldo, 1999), examining issues during problem solving in specific technical courses (Rabins *et al.*, 1996) issues and topics for review during capstone experiences (Soudek, 1996; Pappas and Lesko, 2001), specific components in coursework dedicated to professionalism (Bhatt, 1993; Fulle and Richardson, 2004), topical seminars (Alford and Ward, 1999) as well as integration throughout the entire curriculum (Davis, 1992; Leone and Isaacs, 2001; Marshall and Marshall, 2003). In fact, the authors feel that it would probably be most appropriate to infuse these three topics (raw materials, efficiencies and waste products) using a variety of the aforementioned techniques in many courses that engineering and technology students take. They are germane to almost every subject that is offered in most technical fields. Ultimately, the successful inclusion of these concepts in educational settings will be dependent upon individual faculty interest, motivation and implementation and will thus be heavily influenced by the creativity and approach of the individual instructor.

Resources for educators: Information regarding green and sustainable engineering is quite dispersed; no single comprehensive literature source exists that can adequately cover the topics that have been discussed in this study. So for instructors, who are interested in incorporating individual, specific topics or modules based on the ideas discussed in this study as well as those who may design and implement entire courses devoted to green and sustainable engineering topics, supporting teaching materials will be critical to the success of these endeavors. Therefore, a listing of some recent text books has been compiled and Table 6 and 7

Table. 6: A few green and sustainable resources for educators-books

Researchers	Years	Titles
D.T. Allen, D.R. Shonnard	2001	Green Engineering: Environmentally Conscious Design of Chemical Processes
American Society of Civil Engineers	2004	Sustainable Engineering Practice: An Introduction
Association of Manufacturing Excellence	2007	Green Manufacturing: Case Studies in Leadership and Improvement
P.F. Barlett, G.W. Chase	2004	Sustainability on Campus
D. Brissaud, S. Tichkiewitch, P. Zwolinski	2006	Innovation in Life Cycle Engineering and Sustainable Development
L.M. Camarinha-Matos	1997	Re-engineering for Sustainable Industrial Production
N.P. Cheremisinoff, A. Bendavid-Val	2001	Green Profits: The Manager's Handbook for ISO 14001 and Pollution Prevention
P.B. Corcoran, A.E.J. Wals	2004	Higher Education and the Challenge of Sustainability
S.H. Creighton	1998	Greening the Ivory Tower: Improving the Environmental Track Record of Universities, Colleges and Other Institutions
M. Doble, A. Kumar	2007	Green Chemistry and Engineering
D. Esty, A. Winston	2009	Green to Gold: How Smart Companies Use Environmental Strategy to Innovate, Create Value, and Build Competitive Advantage
P.J. Gordon	2001	Lean and Green: Profit for Your Workplace and the Environment
S.M. Gupta, A.J.D. Lambert	2007	Environment Conscious Manufacturing
J. Heartfield	2008	Green Capitalism: Manufacturing Scarcity in an Age of Abundance
J. Keniry	1995	Ecodemia: Campus Environmental Stewardship at the Turn of the 21st Century
M. Kutz	2007	Environmentally Conscious Mechanical Design
M. Kutz	2007	Environmentally Conscious Manufacturing
A.J.D. Lambert, S.M. Gupta	2004	Disassembly Modeling for Assembly, Maintenance, Reuse and Recycling
M. Lancaster	2002	Green Chemistry
R.L Lankey, P.T. Anastas	2002	Advancing Sustainability through Green Chemistry and Engineering
L.H. Litten	2007	Advancing Sustainability in Higher Education: New Directions for Institutional Research
A.B. Llewellyn, J.P. Hendrix, K.C. Golden,	2008	Green Jobs: A Guide to Eco-Friendly Employment
W. McDonough	2002	Cradle to Cradle: Remaking the Way We Make Things
K.K. Pochampally, N. Satish, S.M. Gupta	2008	Strategic Planning Models for Reverse and Closed-Loop Supply Chains
S.G. Shina	2008	Green Electronics Design and Manufacturing
E.A. Stevens	2001	Green Plastics: An Introduction to the New Science of Biodegradable Plastics
S. Takata, Y. Umeda	2007	Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses: Proceedings of the 14th CIRP Conference on Life Cycle Engineering
D. Talaba, T. Roche	2005	Product Engineering: Eco-Design, Technologies and Green Energy
M. Townsend	1998	Making Things Greener: Motivations and Influences in the Greening of Manufacturing
C. Uhl	2003	Developing Ecological Consciousness: Paths to a Sustainable Future
D.A. Vallero, C. Brasier	2008	Sustainable Design: The Science of Sustainability and Green Engineering
R. Wool, X.S. Sun	2005	Bio-Based Polymers and Composites

Table 7: A few green and sustainable resources for educators-websites

Titles	URL
A Guide to Sustainable E-waste Management	www.ewasteguide.info
American Institute of Architects	http://info.aia.org/walkthewalk/
ASHRAE Sustainability Resources	www.engineeringforsustainability.org/index.htm
Association for the Advancement of Sustainability in Higher Education	www.aashe.org/resources/engineeringcenters.php
Building Green	www.buildinggreen.com/
Campaign Earth!	www.campaignearth.org
Department of Environmental Protection	State web sites (e.g., www.ct.gov for the State of Connecticut)
Design for the Environment	www.epa.gov/dfe/
Engineering Library Resources in Sustainable Engineering	www.libraries.uc.edu/libraries/engr/resources/sustain.html
Environmental Education Resource for Teachers	www.eelink.net
European Environmental Agency	www.eea.europa.eu/
Federal Emergency Management Agency	www.fema.gov
Green Builder	www.greenbuilder.com/
Green Building and Sustainability News	www.csemag.com/channel/Green_Buildings.php
Green Design	http://greendesign.net/
Green Energy Ohio	www.greenenergyohio.org/page.cfm?pageId=3
Green Engineering Research Guide	www.libraries.psu.edu/psul/researchguides/enginist/green.html
Green Technology Magazine	www.green-technology.org/green_technology_magazine/index.html
ISO 14000 Essentials	www.iso.org/iso/iso_14000_essentials
Leiden University	http://cml.leiden.edu/research/industrialecology/
Medical Design Magazine	http://medicaldesign.com/green/
National Geographic Environment News	www.news.nationalgeographic.com/news/environment.html
National Instruments Technical Library	http://zone.ni.com/devzone/cda/tut/p/id/6522
National Recycling Coalition	www.nrc-recycle.org
National Safety Council	www.nsc.org
New York Times Environmental News	www.environment.about.com/
Online Environmental Community	www.envirolink.org
Rocky Mountain Institute	www.rmi.org/
Pollution Prevention (P2)	www.epa.gov/p2/
Scorecard	www.scorecard.org
Society of Environmental Toxicology and Chemistry	http://www.setac.org/
Sustainable Buildings Industry Council	www.sbicouncil.org/
The Environment Directory	www.webdirectory.com
Univ. California – Berkley Publications	http://cgdm.berkeley.edu/cgdmPubYear.html
U.S. Environmental Protection Agency	www.epa.gov
U.S. Green Building Council	www.usgbc.org/
UNESCO- Education for Sustainable Development	www.unesco.org/education/desd/
World Environmental Organization	www.world.org
Yale Office of Sustainability	www.yale.edu/sustainability/

Table 8: A few green and sustainable resources for educators-journals

Titles	URL
Clean Technologies and Environmental Policy	www.springer.com/10098
Compost Science and Utilization	www.jgpress.com/compostscience/index.html
ecoTECTURE: The Online Journal of Ecological Design	www.ecotecture.com
Electronic Green Journal	http://repositories.cdlib.org/uclalib/egj/
Environmental Science and Technology	http://pubs.acs.org/journals/esthag/index.html
International Journal of Environment and Waste Management	https://www.inderscience.com/browse/index.php?journalID=75
International Journal of Environmentally Conscious Design and Manufacturing	www.ijecdm.com/
International Journal of Green Nanotechnology: Materials Science and Engineering	http://www.tandf.co.uk/journals/titles/19430841.asp
International Journal of Sustainability in Higher Education	http://www.emeraldinsight.com/Insight/viewContainer.do? containerType = Journal and containerId=11316
Journal of Cleaner Production	www.sciencedirect.com/science/journal/09596526
Journal of Engineering and Applied Sciences	http://www.arpnjournals.com/jeas/index.htm
Journal of Environmental Engineering	www.geopages.co.uk/toolbox/journals/eej.html
Journal of Industrial Ecology	http://www3.interscience.wiley.com/journal/118902538/home?CR ETRY = 1and SRETRY = 0
Journal of Material Cycles and Waste Management	www.springerlink.com/content/110360/
Journal of Solid Waste Technology and Management	http://www2.widener.edu/~sxw0004/solid_waste.html
Journal of the Air and Waste Management Association	http://secure.awma.org/journal/
Open Waste Management Journal	www.bentham.org/open/towmj/index.htm
Resources, Conservation and Recycling	www.sciencedirect.com/science/journal/03613658
The International Journal of Life Cycle Assessment	www.scientificjournals.com/sj/lca/startseite
Waste Management	www.sciencedirect.com/science/journal/0956053X
Waste Management and Research	http://wmr.sagepub.com

show several relevant web-based resources (though this list is far from complete-the researchers recommend that the interested reader conduct their own Internet search as well). Table 8 shows a list of relevant peer-reviewed journals that publish research studys focused on green and sustainable topics. These references will not be discussed further in this study. The interested reader is referred to them for more specific information.

CONCLUSION

Diminishing natural resources and increasing amounts of waste have been growing concerns of governments, institutions and citizens for the last several decades. In order devise and deploy environmentally-benign solutions for business and manufacturing operations, sustainability issues need to be a part of the every engineering decision. This includes each step from the design phase until the product reaches to its end-of-life. It continues even after that as efforts to recapture and reuse the material's value may take place. In addition, not only manufacturing operations but also service businesses can be structured and operate in an environmentally-friendly manner, reorganizing material and information flow and embedding environmental rules and regulations into the work environment. These objectives can only be achieved effectively if the potential work force is trained accordingly. In this regard, this study has presented an outline summarizing three important topics that can easily be embedded into existing engineering and technology curricula without major changes. These include raw materials, efficiencies and waste products. Some helpful literature and internet resources have also been provided for the use of educators. Hopefully, the discussions provided herein are helpful toward improving the green and sustainable education of future engineers and technologists.

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