The Importance of Emerging Biobased Industries to Engineering and Technology

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Abstract

Our society has developed an insatiable demand for energy and material goods. Historically, these needs have been met primarily by fossil fuels and other non-renewable raw materials. As environmental concerns grow, however, renewable resources are gaining increased attention. This paper examines the emergence and importance that biobased industries are increasingly beginning to play. A biobased enterprise, similar in concept to a traditional refinery or factory, utilizes conversion technologies to produce various products. These operations are rapidly increasing both in number as well as in capacity throughout this country, and are poised to add significantly to the nation's energy and material supplies in coming years. Therefore, to adequately prepare engineering and technology graduates for the emerging opportunities in these areas, it is vital for them to understand this developing industrial segment and its fundamental concepts. Toward these ends, this paper will discuss several essential topics, including traditional and biobased chemicals, energy, fuels, and manufactured products; similarities between traditional and biobased industries; technical tools essential for success; relevance to engineering and technology education; and curriculum modification and incorporation techniques that can be used to achieve these efforts. The trends discussed here and their implications are critical for educators, because in coming years these industries will increasingly be used to simultaneously meet the needs of our society as well as that of environmental stewardship.

Keywords

Biochemicals, Bioenergy, Biofuels, Biomass, Bioprocessing, Biopower, Bioproducts, Biorefining, Curriculum Development

Introduction

The U.S. has enormous economic strength, with a total GDP of $12.4 trillion, and exports of more than $927 billion worth of goods each year [1]. Much of this strength is reflected in the manufacturing sector, which traditionally has been a benchmark for gauging the health of the country's economy. Figure 1 illustrates historic trends for the value of all U.S. manufacturing shipments. The U.S. chemical industry, which is vitally linked to manufacturing, is currently a $550 billion industry itself, and constitutes approximately 2% of the entire U.S. GDP. This sector includes product categories such as industrial chemicals, life science chemicals, specialty chemicals, consumer products, and fertilizers [2].

From the inception of this country, engineering and associated technology disciplines have been cornerstones upon which the U.S. has flourished. As our nation has evolved, it has witnessed substantial population growth contemporaneous with economic expansion. With this growth over the years, coupled with increasing industrialization, population, and consumption, several critical challenges have arisen. These include pollution, environmental degradation, raw material depletion, increasing dependence on foreign supplies of nonrenewable resources, and national security concerns, to name a few.

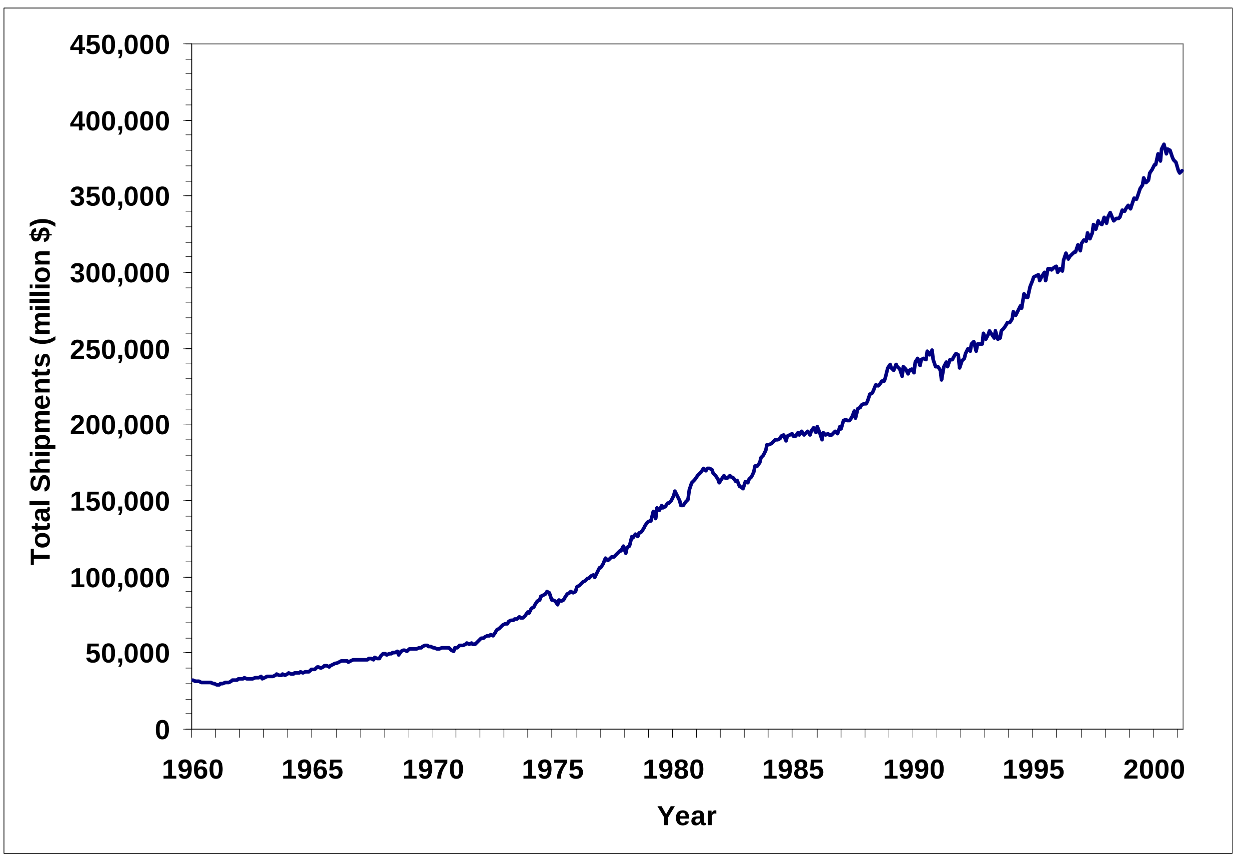

Figure 1. Trends in U.S. manufacturing shipments [adapted from 3].

At this point in time, the U.S. is heavily dependent upon imports to supply many raw materials and energy sources. For example, the quantity of oil imported into the U.S. for transportation fuels has been steadily increasing during the last 20 years (Figure 2). In fact, it currently imports more than 60% of its yearly petroleum requirements.

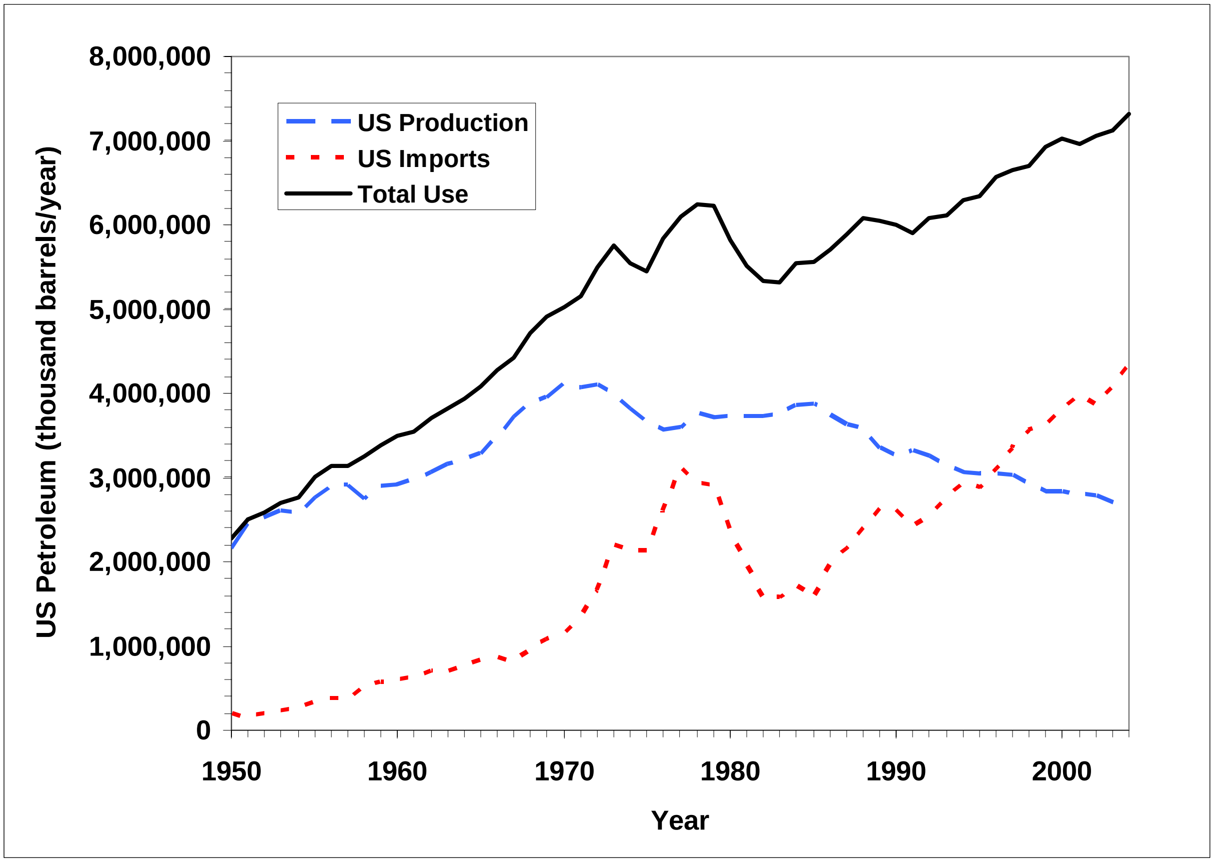

Figure 2. Trends in U.S. oil supply and demand [adapted from 4].

Another critical challenge is overall national energy consumption. Figure 3 depicts the history of U.S. energy in terms of total energy used, as well as the energy consumed from the primary fossil fuel and nuclear power sectors. Other than two slight declines (in the mid-1970s and the early 1980s) in response to energy crises, energy consumption has progressively increased. This is due to many factors, some of which include the advent of the micro computer, the information and technology revolution, the ubiquitous SUV, as well as increasing productivity in the industrial sector, not to mention population growth itself. Consequently, the consumption of all fossil fuels has also been increasing over time in order to meet this increasing demand. Petroleum has historically been the single greatest energy source in the U.S., so its consumption (as shown in Figure 2) closely parallels that of total energy consumption, at least up until the mid-1980s. After that point, the rate of increase for total energy has been greater than that provided by petroleum alone, as evidenced by the consumption curves. Nuclear, coal, and natural gas are increasingly being used to help meet this increasing demand. The hurricanes of 2005 that devastated the Gulf Coast clearly illustrated to many how volatile the energy markets currently are [5].

Petroleum-based hydrocarbons are a key to our society and to our highly successful mass-production systems for the manufacture of products, chemicals, energy, and transportation fuels.

Much of these hydrocarbon molecules are contained in crude oil. There is currently, however, much debate regarding the future of the world's supply of oil [6, 7].

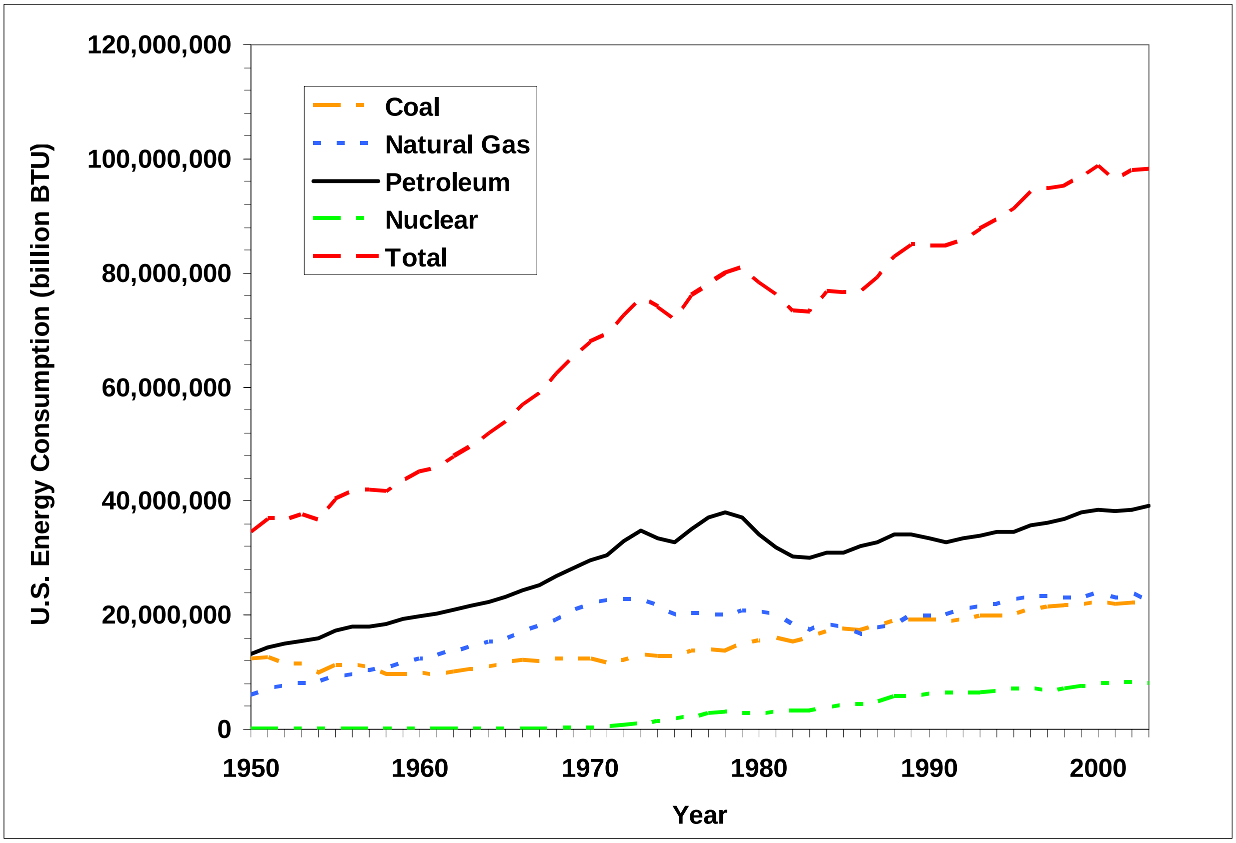

Figure 3. Trends in U.S. energy consumption [adapted from 4].

Our nation, and in fact the entire world, are on the cusp of very real changes. Tremendous advances in science and engineering over the last several decades, especially biochemical and fermentation technologies, have substantially enhanced the ability to utilize renewable, biological materials. Additionally, advances in agricultural practices, production capabilities, and economics have added to this potential [8]. Biomass conversion technologies are now practical and affordable for a variety of biobased products, and they offer many opportunities to augment traditional nonrenewable resources. Indeed, the U.S. has abundant renewable biomass resources that can be used to help meet many of our needs.

Unfortunately, there are very limited collegiate engineering and technology courses devoted to biobased processes or products. Therefore, the objective of this paper is to introduce engineering and technology educators to this emerging area so that existing curricula can be augmented, and this void can be filled. Toward that end, several essential topics will be discussed, including national biomass resources, biobased industries (including bioenergy, biofuels, and bioproducts), advantages of biobased products, governmental policies, engineering and technology education, technical tools, literature resources for educators, and curriculum incorporation strategies. It is not intended to be a comprehensive literature review; instead, its aim is to introduce educators to this topic, and provide a basis for further inquiry.

National Biomass Resources

Tremendous quantities of biomass are produced on our planet [9]. Considering forest biomass only, approximately 4.2 x 10^{11} tonnes are produced worldwide [10]. Further, it is estimated that if all available biomass was fully utilized, the global potential for production of biomass-based energy could reach up to 1135 EJ/y during the next 50 years [11]. In the U.S. alone, considering all biomass sources, between 423 million and 3.2 trillion dry tonnes are produced each year (Figure 4) [12, 13]. If all of this were converted to bioenergy, it has the potential to produce up to 60 trillion GJ [12]. Out of this potential domestic supply, however, only approximately 190 millions tons are currently utilized [14].

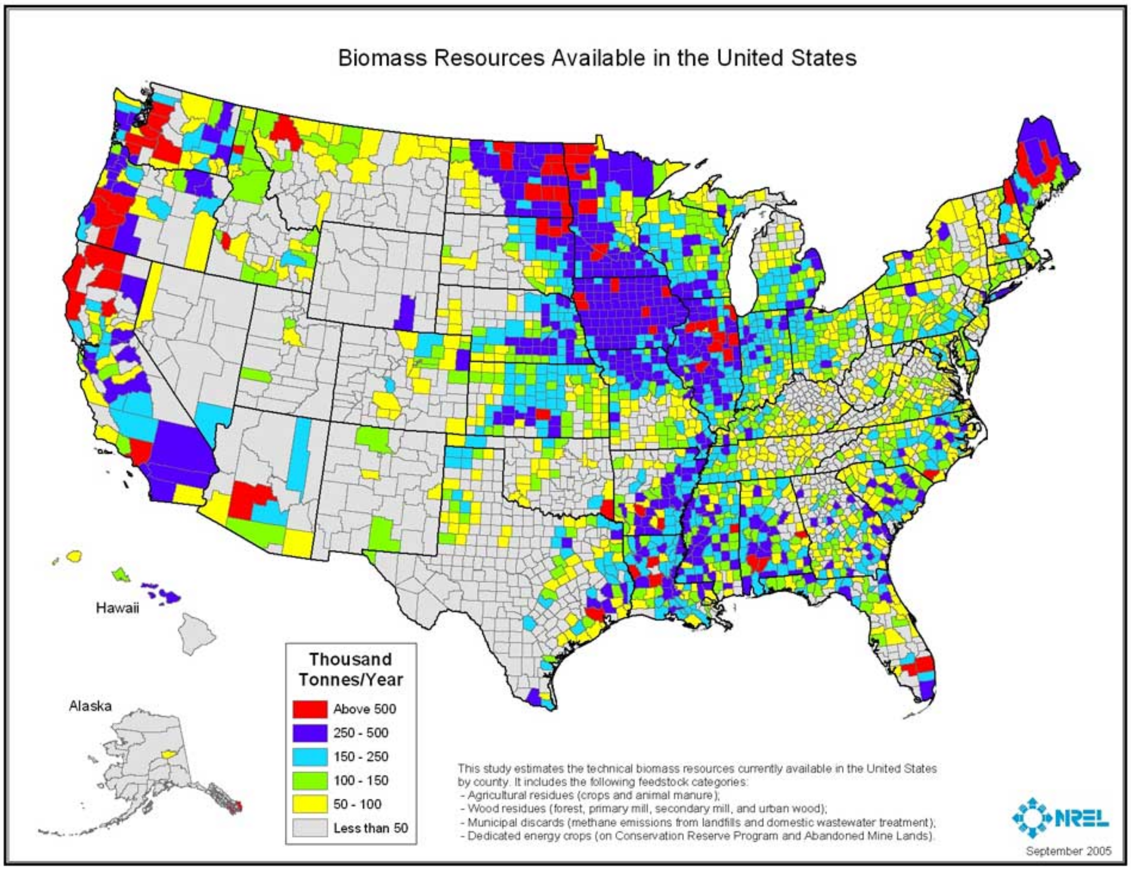

Figure 4. Total estimated biomass resources in the U.S. [from 13].

Potential biomass sources include crops dedicated to the production of biochemicals, biofuels, bioproducts, bioenergy, or intermediates. These are known as primary biomass. Potential sources also include secondary biomass, which include agricultural harvest residues, such as stover, stalks, leaves, cobs, etc., which are left in fields after crops are harvested; forestry residues; and food and organic processing byproduct/waste streams. Tertiary biomass includes municipal solid waste (i.e., MSW), especially the paper, food, and other organic waste constituents within the MSW; and animal manure.

Primary biomass encompasses an array of crops grown specifically to be used for energy, fuel, or chemical production, as opposed to foods or feeds. Herbaceous crops, such as sugarcane, Napier grass, sorghum, reed canary grass, fescue, and switchgrass, can be harvested annually, and can yield up to 55 Mg/ha/yr. Short-rotation woody crops, such as poplar, maple, sycamore, and alder, can generally be harvested in 10 years or less, and can yield up to 43 Mg/ha/yr [12, 15, 16]. Granted, biomass yields will vary tremendously depending on the specific crop that is cultivated, the geographic location, and growing conditions for a given growing season. More information can be found in [12, 17].

Utilizing biomass to displace petroleum feedstocks to produce chemicals, energy, fuels, and products is attractive. They are domestic, abundant, renewable, and sustainable raw material sources that are low-cost and currently much underutilized. Due to the heterogeneous nature (physically and chemically) of the various biomass sources, as well as the logistically dispersed and disparate supply, though, many challenges must be overcome in order to effectively utilize these materials for industrial production. In addition to the technical issues associated with the conversion processes themselves, the major infrastructural issues include harvesting, transportation, and storage of the materials until needed for processing. To address these, several federal research programs within both the Department of Energy (www.doe.gov) and the Department of Agriculture (www.usda.gov), are currently underway. More information regarding these initiatives can be found at the respective websites, as well as in [14, 18].

Emerging Biobased Industries

When processing biological materials, two of the main targets in these raw product streams are the carbohydrates and the oils, because these contain the components that can be converted into a range of valuable biobased products, process intermediates, or even foods and feeds. The following discussions will attempt to briefly capture some of the main concepts of using biological materials in manufacturing, but will not be completely exhaustive. More comprehensive treatments can be found in [12, 19-25], to which the reader is referred for more information.

Manufacturing industries that utilize biological materials are poised to contribute substantially to the supply of energy, transportation fuels, industrial chemicals, and manufactured products in coming years. Prominent topics currently include fuel ethanol, biodiesel, novel processing and conversion technologies, including enzymatic, microbial, and thermochemical conversion processes, lignocellulose (e.g., corn stover, switchgrass, and woody crop) production, biomass transportation, storage, and processing, and even hydrogen production from biomass. Some of these topics will be discussed more thoroughly below. For additional information, the reader is referred to the websites and other references provided, where extensive information can be found.

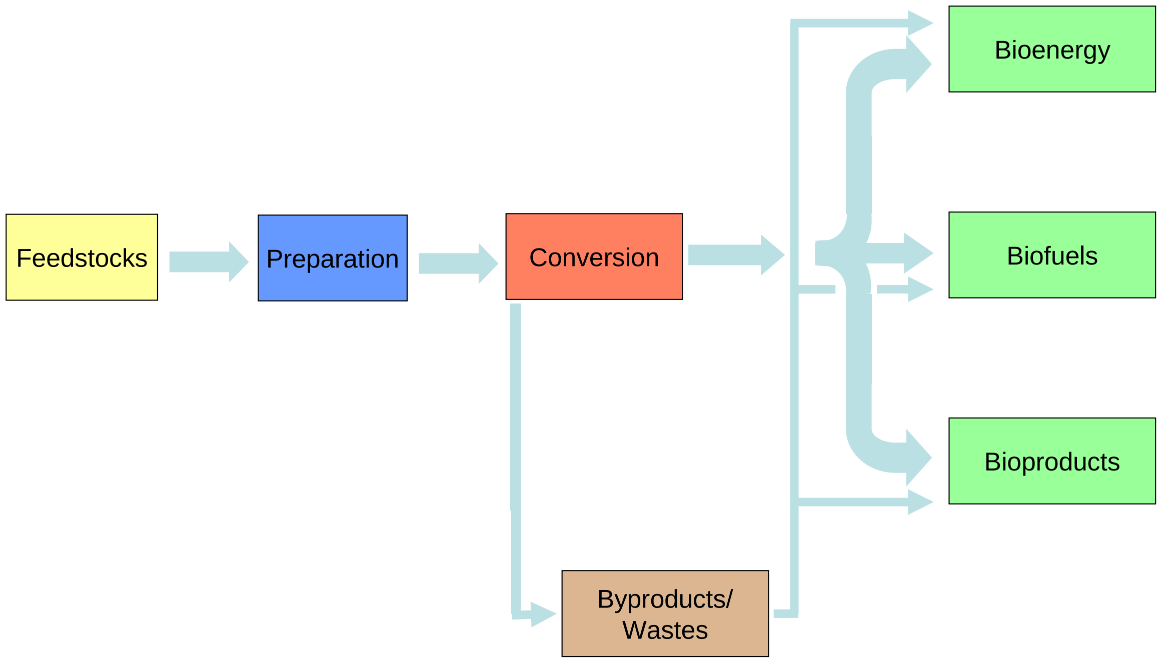

Figure 5. Major processing steps associated with biomass conversion.

In general, biomass streams cannot be utilized directly as bioenergy, biofuels, biochemicals, or bioproducts; they typically must undergo some type of conversion process in order to improve the often relatively poor characteristics vis-à-vis energy, fuel, or material precursors. These obstacles can include: 1) nonhomogeneity in size as well as composition; 2) low to modest thermal content; 3) moderate to high moisture content; and 4) low bulk density (which can lead to material handling and storage challenges). Conversion of biomass is typically accomplished via several sequential steps (Figure 5), including material preparation (e.g., drying and grinding), pre-treatment and hydrolysis, fermentation, and distillation, or it can be accomplished via thermochemical means. Pre-treatment processes, such as acid, enzymatic, or steam hydrolysis, are used to liberate sugars from the lignocellulose matrix, and thus make the biomass suitable for subsequent fermentation.

Fermentation is a process where microorganisms digest the carbohydrates, especially sugars and starches, and produce various end products, depending on the specific organisms, biomass source, and operational conditions used. Potential fermentation products include ethanol, lactic acid, and succinic acid. Distillation is then used to remove various water-soluble compounds. More information regarding industrial fermentation of biomass can be found in [26-29].

Thermochemical conversion, on the other hand, can include pyrolysis, where the biomass is heated in the absence of oxygen to produce a bio-oil, residual solids (known as char), and gases (such as methane, carbon monoxide, and carbon dioxide), or liquefaction, where the biomass is converted at moderate temperatures and pressures into a liquid state. The end products produced via thermochemical conversion contain high concentrations of organic compounds, and thus are useful as concentrated precursors for further utilization. More information regarding thermochemical conversion of biomass can be found in [30-36].

Converted biomass can then be transformed into bioenergy, primarily in the form of heat or electric power by stationary generation. In primary and secondary biomass, it is often only the residual lignin and cellulose components are used to produce bioenergy, because the other constituents of these materials are typically utilized for other higher-value uses, such as biofuels and bioproducts. Combustion and gasification are the primary techniques that are commonly used to generate bioenergy from these materials. Combustion, which is the conversion of biomass into heat, can be accomplished in a variety of combustors, furnaces, and boilers. More information regarding combustion of biomass can be found in [37-39]. Gasification, which is the conversion of biomass into flammable synthetic gas (known as syngas) using an atmosphere deficient in oxygen, can be accomplished in gasifiers, of which there are several types. More information regarding gasification can be found in [40-43]. Tertiary biomass, on the other hand, is generally converted to bioenergy using anaerobic digestion, which is the decomposition and conversion of biomass using microbes into flammable methane gas. It can be accomplished in a variety of digesters. More information regarding anaerobic digestion can be found in [44-51]. The gas produced by gasifiers and anaerobic digesters can then be combusted and used to drive electricity generation turbines.

As a high-value utilization option, converted biomass can be processed into liquid fuels for automobiles. Biofuels, which are renewable sources of energy, can help meet increasing energy needs, and are produced from various primary and secondary biomass sources including switchgrass, canary grass, residue straw, corn stover, perennial grasses and legumes, and other agricultural and biological materials. At the moment, however, the most heavily utilized is corn grain, because corn starch can be easily hydrolyzed and fermented into ethanol on an industrial scale. Industrial ethanol production from corn is readily accomplished at a relatively low cost vis-à-vis other biomass sources. In coming years, however, due to rapid technological advances, the hydrolysis and conversion of these other lignocellulosic materials is expected to become cost-competitive as this industry matures [52]. More information regarding the production of bioethanol can be found in [53-56]. Currently, bioethanol is the biofuel with greatest use in the U.S., but biodiesel is also poised to significantly contribute to the nation's energy supply in coming years. Biodiesel is produced by converting triglycerides into methyl or ethyl esters via chemical modification. Soybean, sunflower, safflower, cottonseed, and other oil seed crops are targeted for production of commercial biodiesel. More information regarding the manufacture of biodiesel can be found in [57-59].

Converted biomass can also be manufactured into many different industrial products, such as biobased chemicals and biopolymers, both of which are currently prime utilization avenues. These include finished products as well as intermediates which are precursors for further manufacture. At the moment, several important chemicals are currently manufactured from various biomass sources, including citric acid, polylactic acid (PLA), furfural, gluconic acid, lactic acid, mannitol, sorbitol, and xylitol. Moreover, several additional chemicals should be commercially-viable in the near future, including acetic acid, hydroxyacetaldehyde, levoglucosan, levulinic acid, and polyhydroxybutyrate. More information regarding the production of these biochemicals can be found in [12, 48, 60-63]. The conversion of biological materials, especially fibers, into various products has been successfully advanced and highly utilized over the years in the pulp, paper, and textile industries. Fibers are, however, increasingly being used to develop novel biopolymers, biocomposites, and plastic reinforcements. Traditional plastics manufacturing operations, such as compression and injection molding, as well as extrusion processing, have been shown to be quite successful in developing these products. More information regarding production of these types of biomaterials can be found in [64-66].

Advantages of Biobased Products

For both the nation as well as the individual consumer, biologically-based materials and products have many potential benefits, some of which include [8, 67]:

- The supplies of raw materials for energy, fuels, chemicals, and manufactured products are renewable, sustainable, and domestically produced.
- Innovative manufacturing processes are required to produce novel finished products.
- Economic growth potential, especially for rural areas of the country, as underutilized biomass materials, and land areas to produce them, become used to their potential.
- Environmental protection, including a decrease in pollutants from petrochemical processing, increased utilization of carbon-fixing biomass, which will help reduce overall greenhouse gas emissions, and increased utilization of biodegradable products.
- Meeting the nation's energy and material needs has become a matter of national security.

Biomass will play an increasing role in meeting the nation's material and energy needs, and these potential benefits can be realized if the research, development, and commercialization of these products can be accomplished economically. A key to providing momentum to the growth of the biobased industrial sector is government policies that favor and support their development.

Governmental Policies

Federal and state governments play a crucial role in helping to promote biobased products, and thus are vital to the growth of these industries. A few key initiatives will be briefly discussed below. Through these policy initiatives, the federal government can provide aid to these fledgling industries by providing tax credits and incentives. Examples include provisions for electricity generation from biomass and other renewable sources, as well as the manufacture of transportation fuels such as ethanol, methanol, and biodiesel. Additionally, the federal government is a prime source of funding for many research, development, and demonstration projects, especially through the Departments of Energy and Agriculture.

The Agricultural Risk Protection Act of 2000 (PL 106-224) established the Biomass R&D Act of 2000 [68], which created the Biomass Research and Development Board Technical Advisory Committee, in order to investigate the utilization of biological sources for the production of energy and material products. According to this committee, "By 2030, a well-established, economically viable, bioenergy and biobased products industry will create new economic opportunities for rural America, protect and enhance our environment, strengthen U.S. energy independence, provide economic security, and deliver improved products to consumers" [67]. This vision articulates aggressive goals of utilizing biomass to produce 5% of the nation's electric power, 20% of the transportation fuels, and 25% of all chemicals by 2030.

The Farm Security and Rural Investment Act of 2002 (PL 107-171) [69], also known as the "Farm Bill", established funding programs for biomass (Section 9008), bioenergy (Section 9010), biodiesel (Section 9004), and fuel ethanol (Section 9010). Additionally, under Section 9002, it directed the USDA to develop and implement procurement requirements that prefer biobased to traditional products. Known as the Federal Biobased Products Preferred Procurement Program [70], all government agencies will be required to purchase and use biobased products when they are available and meet performance specifications. Accordingly, a biobased product has been defined as a product that is "a commercial or industrial product (other than food or feed) that is composed, in whole or in significant part, of biological products or renewable domestic agricultural materials (including plant, animal, and marine materials) or forestry materials." Product categories can include adhesives, coatings, composites, fibers, fuels, inks, landscaping materials, lubricants, packaging, paints, paper, plastics, solvents, and sorbents, to name a few [71].

The latest federal policy, which has been widely publicized in the news, is the Energy Security Act of 2005 (PL 109-58) [72]. Known as the "Energy Bill", it articulates a comprehensive national energy strategy, and encourages increased efficiency and conservation, updating the nation's energy infrastructure, and the use of renewable sources of energy, including biodiesel and fuel ethanol. In fact, it establishes the Renewable Fuels Standard, which mandates the use of 7.5 billion gallons of ethanol in the nation's gasoline supply by 2012. It also provides for research and development programs focused on the production of fuel ethanol from lignocellulosic materials.

On the state level, several states have legally mandated Renewable Portfolio Standards, which require that a percentage of all electricity produced within that specific state is generated from renewable sources, including biomass. Sixteen states currently have these standards in place [73]: Arizona, California, Colorado, Connecticut, Iowa, Maine, Maryland, Massachusetts, Nevada, New Jersey, New Mexico, New York, Pennsylvania, Rhode Island, Texas, and Wisconsin. Illinois, Minnesota, and Hawaii also have voluntary programs, which are not legal mandates.

As biobased energy and products continue to gain prevalence, there will be a growing need for trained personnel to design and operate facilities to produce these biologically-based products, design the products themselves, and ensure their quality during manufacture. Engineering and technology educators currently have an exciting opportunity to expand their mission to address biological processing and manufacturing, and to contribute to this coming wave of change in the industry.

Engineering and Technology Education

Biologically-derived energy, fuels, chemicals, and products are poised to be key contributors to the U.S. economy in coming years. It is thus essential that engineering and technology graduates are cognizant of these as we enter the 21^{st} Century. As noted in [8], there is currently a large void vis-à-vis biorenewable curricula in U.S. colleges and universities; the need to increase educational efforts in these areas is underscored by the lack of programs at the secondary, post-secondary, institutional, and national levels. As a case in point, during the last ten years at the national American Society for Engineering Education conferences (http://www.asee.org), no papers were presented that discussed bioproducts; two covered bioenergy, six focused on biofuels, three discussed biomass, four covered bioprocesses, and 10 focused on biochemicals: 25 total papers (out of thousands presented) in 10 years! Clearly there are many untapped opportunities to improve the educational experiences of engineering and technology students in this area.

Although many differences do exist, such as unit operations and equipment used, plant layout and design, sanitation guidelines, and even the underlying science, there are many similarities between traditional and biobased manufacturing operations. Job categories involved in both of these types of industries require advanced technical training that is received via post-secondary education. Some of these include engineering and design, production and operations, research and development, quality management and improvement, information technology, marketing and sales, management, human resources, and even workplace safety and health. Thus, biobased industries are very germane to the engineering and technology disciplines. Biobased operations require skill sets similar to traditional manufacturing settings, but also have a need for knowledge in biological sciences, which can vary according to the specific product(s) produced at a given facility (i.e., bioenergy, biofuels, biochemicals, or bioproducts). For example, equipment, processes, and unit operations must be designed; these systems must be optimized, modeled, and simulated; and their economics must be analyzed. Furthermore, facilities to house and service these processes, as well as human-machine interfaces, must be designed and constructed. Thus, the fields of engineering and technology are fundamental to the successful design and deployment of these operations. To date, specific engineering areas that have been most involved with these types of industries include Agricultural, Biological, Biochemical, Bioprocess, and Chemical Engineering. Even so, other disciplines will also be vital to these ventures as their number, size, and scope increase over time. These include Industrial, Manufacturing, Mechanical, and Structural. In reality, all branches of engineering and technology will be required if these emerging industries are to succeed.

Essential Technical Tools

Biobased industries are highly process oriented. Therefore, a number of quality tools that are utilized to analyze traditionally manufactured products and related processes are directly relevant to biobased manufacturing. These tools include Pareto charts, flowcharts, and histograms, which are used to help in problem identification, and are equally valid in both scenarios. Skills in the application of causal identification tools and procedures, such as the cause-and-effect diagram, root cause analysis, stratification, and correlation analysis can be seamlessly transferred as well. Arguably, the most important quality tool that would apply to biobased manufacturing would be statistical process control charts based on the methods advocated by Shewhart [74, 75], which have found universal appeal in traditional manufacturing globally. Due to the inherent nature of the presence of a number of simultaneously acting variables, and possible varied levels of each, within biobased manufacturing scenarios, quality techniques such as the design of experiments and Taguchi studies [76] become highly relevant for process innovation and improvement. Knowledge in these and other basic quality principles is a prerequisite in most engineering and technology degree programs, so extending these concepts to include biobased manufacturing scenarios and case studies can be accomplished with relative ease.

Business concepts, including project planning, scheduling, management, and control are indispensable in the operation of successful bioindustries, as are budgets, scopes of work, and contracts. The concepts of supply chain management, including site location, plant layout, inventory control, transportation, logistics, and information systems will play a significant role in the growth and sustainability of biobased products in society. There is a wide array of specific management tools in planning, scheduling, and control that have been in use in industry for decades, and new tools appear frequently. Use of these tools is just as important for biobased manufacturing. Because these industries are only now emerging, much documentation of successful experiences in the literature remains to be forthcoming.

Problem-solving tools are always an important part of the engineering and technology education, and biobased industries lend themselves to the application of traditional problem solving models that have been successfully used in engineering and technology for years. The typical six-step iterative approach to problem solving (i.e., problem definition, generation of ideas, refinement of ideas, analysis, decision, and implementation) need not be underestimated just because the context has changed from non-renewable to renewable forms. The time honored principle of the plan-do-check-act methodology to attack problems and promote continuous improvement of processes remains valid in the new materials era as well.

Literature Resources for Educators

Information regarding current and promising biobased products and processes is quite dispersed; no single comprehensive literature source exists. This is unfortunate for educators. For those instructors who are interested in incorporating learning modules into existing engineering or technology coursework at appropriate locations during the semester, as well as those who may design and implement entire courses devoted to the aforementioned topics, supporting teaching materials will be critical to these endeavors. Therefore, several recent textbooks and key online publications have been compiled and are provided below in Table 1.

Curriculum Strategies

Over the years engineering and technology programs have primarily focused on traditional industrial materials and manufacturing processes. Even though technological innovation has been constantly advancing, the U.S. manufacturing industry base has suffered substantially in recent years due to changes in international trade policies. Biobased manufacturing offers one potential route to alleviate some of these pressures in the global marketplace, in addition to the potential to help meet increasing national energy and material needs. But, up to this point in time, biobased manufacturing has been largely ignored by most educational programs. In fact, only a few studies have examined their potential to augment existing curricula [77-80], and even these have been very limited in scope; none of these have been comprehensive in nature. In this emerging arena, many opportunities currently exist to infuse undergraduate curricula with cutting-edge science, not only in terms of curricular augmentation, but also as a chance for faculty to develop truly innovative teaching materials.

Table 1. Essential biobased industry resources for educators.

Books

Brown, R.C. 2003. Biorenewable Resources – Engineering New Products from Agriculture. Blackwell Publishing Co. New York, NY.

Dokon, L. E. 2001. The Alcohol Fuel Handbook. Infinity Publishing.

Klass, D.L. 1998. Biomass for Renewable Energy, Fuels, and Chemicals. Academy Press. New York, NY.

Pahl, G. 2005. Biodiesel: Growing a New Energy Economy. Chelsea Green Publishing Company.

Sorensen, B. 2004. Renewable Energy. Academic Press.

Wyman, C. 1996. Handbook on Bioethanol: Production and Utilization. Taylor & Francis.

Websites & Online Publications

Biobased Industrial Products: Research and Commercialization Priorities. 2000. Commission on Life Sciences. http://books.nap.edu/books/0309053927/html/1.html

Bioenergy Terminology – Factsheet No. atlas_006. 2005. Zimmermann, L. and I. Nuberg. http://www.brs.gov.au/bioenergy_atlas/factsheets/Atlas_006.pdf#search='Bioenergy%20 Terminology

Biomass as a Renewable Energy Source. 2004. Royal Commission on Environmental Pollution. www.rcep.org.uk/bioreport.htm

Biomass Program. 2006. U.S. Department of Energy. http://www.eere.energy.gov/biomass/

Biomass Program: Biomass Publications. 2005. US Department of Energy. http://www.eere.energy.gov/biomass/publications.html#feed

Biomass Program: Feedstock Composition Glossary. 2005. US Department of Energy. http://www.eere.energy.gov/biomass/feedstock_glossary.html

Biomass Research. What is a Biorefinery? National Renewable Energy Laboratory. www.nrel.gov/biomass/biorefinery.html

Chemicals Industry of the Future. 2005. US Department of Energy. http://www.eere.energy.gov/industry/chemicals/index.html

Chemical Industry Vision 2020. 2006. http://www.chemicalvision2020.org/

CoProducts and Near CoProducts of Fuel Ethanol Fermentation from Grain. 1996. Tibelius, C. http://res2.agr.ca/publications/cfar/index_e.htm

Feed Co-Products of the Dry Corn Milling Process. 2006. Weigel, J., D. Loy. and L. Kilmer. http://www.iowacorn.org/forms/drymillbook.pdf

Industrial Bioproducts: Today and Tomorrow. 2003. Energetics Incorporated / US Department of Energy. www.bioproducts-bioenergy.gov/pdfs/BioProductsOpportunitiesReportFinal.pdf

Outlook for Biomass Ethanol Production and Demand. 2000. DiPardo, J. http://www.eia.doe.gov/oiaf/renewable.html

The Biomass Economy. 2002. National Renewable Energy Laboratory. www.nrel.gov/docs/gen/fy04/36369.pdf

Top Value Added Chemicals from Biomass. 2004. Werpy, T. and G. Peterson, eds. US Department of Energy. http://www.nrel.gov/docs/fy04osti/35523.pdf

Roadmap for Agricultural Biomass Feedstock Supply in the United States. 2003. US Department of Energy. http://www1.eere.energy.gov/biomass/publications.html

Vision for Bioenergy & Biobased Products in the United States. 2002. Biomass Technical Advisory Committee. www.bioproducts-bioenergy.gov/pdfs/BioVision_03_Web.pdf

To adequately cover the extensive range of topics relevant to biobased industries, the authors recommend a full-semester stand-alone course dedicated to the processing of biological materials. Ideally, this would be implemented in a lecture/lab format, so that the various learning styles of both engineering and/or technology students alike can be addressed. Core topics for such a course could include the various processes for converting biomass into biobased energy, chemicals, transportation fuels, and manufactured products, with an emphasis on product design considerations and required unit operations; economic analysis of the bioprocesses; and environmental impacts of these operations. In conjunction with the other topics discussed in this paper, these could be readily converted into an appropriate course syllabus. Moreover, not only should students be exposed to the theoretical and technical details of this industry, they should also have hands-on, applied experiences to have a meaningful education in these biological areas – disciplines in which most students will have little prior experience. Thus laboratory exercises will be keys to the success of such a curriculum effort. Design and implementation of these warrant follow-up articles to discuss them thoroughly.

Because few, if any, engineering and technology students have a bioprocessing background, additional supporting coursework could include biology, inorganic chemistry, organic chemistry, biochemistry, biotechnology, plant science, and industrial microbiology. Perhaps these could, in fact, lead to a minor in bioprocessing, which is an area that has been traditionally limited to only agricultural and chemical engineering programs.

Understandably, not all academic programs will be able to accommodate the addition of another course with all other programmatic requirements currently in place. Therefore, it is beneficial to examine other mechanisms for incorporating bioprocessing instruction, either as individual topics, components, or units that can be used as specific learning modules, into existing coursework. Many approaches have been found to be quite successful vis-à-vis augmenting engineering and technology instruction by inserting additional materials into mainstream instruction. Some avenues that have been shown to work well include integrating focused components (theory as well as case study analyses) into specific technical courses, examining issues during technical problem solving in specific core courses, issues and topics for review during capstone experiences, specific components in coursework dedicated to professionalism, topical seminars, and integration throughout the entire curriculum. Ultimately, the successful inclusion of biological concepts in undergraduate engineering and technology education will depend upon individual faculty interest and motivation, and thus will be heavily influenced by the creativity of the instructor.

Conclusions

It is becoming apparent that our society's need for petroleum-based energy and material products is reaching a point that is no longer sustainable. Biorenewable resources and their utilization for electric power, transportation fuels, chemicals, and products are not only technically feasible, but also economical. Thus emerging biobased industries are a very relevant topic today, and will become even more so as we move into the 21st Century and continue to tax the Earth's finite resources. Unfortunately, these topics are not well covered in collegiate programs throughout the nation. This paper has been intended to help address this gap. Essential concepts have been discussed, as have the relevance to engineering and technology education, and curriculum infusion techniques. Although it is not completely comprehensive in nature, many references have been included, so educators should find this a useful resource base from which to work.

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