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AGRICULTURAL AND BIOMEDICAL ENGINEERING: SCOPE AND OPPORTUNITIES

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Abstract

Biological and agricultural engineering (BAE) is the application of engineering principles to any process associated with producing agriculturally based goods and management of our natural resources. BA engineers devise practical, efficient solutions for producing, storing, transporting, processing, and packaging agricultural products; solve problems related to systems, processes, and machines that interact with humans, plants, animals, microorganisms, and biological materials. BAE embraces a variety of specialty areas: Biological Engineering, Natural Resources, Power Systems & Machinery Design, Structures & Environment, Food and Bioprocess Engineers, Information & Electrical Technologies, Forest Engineering, Energy, Aquacultural Engineering, Nursery & Greenhouse Engineering, and Safety and Health. BA engineers understand the interrelationships between technology and living systems, have available a wide variety of employment options. Biomedical engineering (BME) is a discipline that advances knowledge in engineering, biology and medicine, and improves human health through cross-disciplinary activities that integrate the engineering sciences with the biomedical sciences and clinical practice. Biomedical Engineers apply electrical, mechanical, chemical, optical and engineering mechanics principles to understand, modify, or control biologic (i.e., human and animal) systems, as well as design and manufacture products that can monitor physiologic functions and assist in the diagnosis and treatment of patients. When biomedical engineers work within a hospital or clinic, they are more properly called clinical engineers. Some of the well established specialty areas within the field of BME are: bioinstrumentation; biomaterials; biomechanics; cellular, tissue and genetic engineering; clinical engineering; medical imaging; orthopedic surgery; rehabilitation engineering; and systems physiology. Current status and job opportunities for BME and BAE are discussed.

Key words

Biological engineering, agricultural engineering, biomedical engineering, American Society of Agricultural and Biological Engineering, Biomedical Engineering Society.

1. Agricultural and Biological Engineering

1.1 Introduction

Biological and Agricultural Engineering involves finding solutions for life on a small planet. In the early twentieth century, even in industrialized countries, production of the world's food supply required the labor of at least half the population. Today, thanks in large part to advancements made by biological and agricultural engineers; developed countries can accomplish this using only a slim 2% of their populations. And engineering efforts have not been limited to food production: fiber, timber, and energy products, for example, as well as the technologies, equipment, and precious natural resources required to produce them, have all benefited from the talents and vision of these devoted individuals. Now, new challenges present themselves. As world population swells, more food, energy, and goods are required. But our limited natural resources demand that we produce more with less, that higher productivity does not degrade our environment, and that we search for new ways to use agricultural products, byproducts, and wastes. Biological and agricultural engineers are responding with viable, environmentally sustainable solutions, the success of which is expanding career opportunities in such related biological fields as medicine, pharmacy, and bioinstrumentation.

Just what is Biological and Agricultural Engineering? Biological and agricultural engineers ensure that we have the necessities of life: safe and plentiful food to eat, pure water to drink, clean fuel and energy sources, and a safe, healthy environment in which to live. More specifically, biological and agricultural engineering (BAE) is the application of engineering principles to any process associated with producing agriculturally based goods and management of our natural resources.

What do Biological and agricultural engineers devise? They devise practical, efficient solutions for producing, storing, transporting, processing, and packaging agricultural products; Solve problems related to systems, processes, and machines that interact with humans, plants, animals, microorganisms, and biological materials; Develop solutions for responsible, alternative uses of agricultural products, byproducts and wastes and of our natural resources - soil, water, air, and energy; And they do all this with a constant eye toward improved protection of people, animals, and the environment.

1.2 Why Biological and Agricultural Engineering?

For the student who enjoys science and mathematics, biological and agricultural engineering offers a unique opportunity to combine those scholarly interests with the challenge of providing food and other goods for a growing world population while protecting our natural resources. BAE academic programs offer a unique and valuable educational experience. While other engineering students may study a single discipline, BAE programs traditionally include coursework in a variety of engineering disciplines, complemented by classes in biological and agricultural sciences. When they reach their advanced-level courses, BAE students then tend to choose a specialty area according to their individual interests - for example, environmental systems, food production, biological resources or ecological systems, and power and machinery systems. Regardless of the specialty, BAE students enjoy a distinct advantage when it comes time to enter the workforce. Their well-rounded engineering experiences enable them to function exceptionally well on the multidisciplinary teams in today's workforce. And only biological and agricultural engineers have the training and experience to understand the interrelationships between technology and living systems - talents needed to succeed in engineering positions today and in the future.

1.3 Specialty Areas

Biological and agricultural engineering embraces a variety of specialty areas. As new technology and information emerge, specialty areas are created, and many overlap with one or more other areas. Here are descriptions of some of the exciting specialties one could choose to focus on as a student in biological and agricultural engineering. See figures 1 and 2.

Biological Engineering: One of the most rapidly growing of the BAE specialties, biological engineering applies engineering practice to problems and opportunities presented by living things and the natural environment.

Figure 1: Specialty areas in Agricultural and Biological Engineering.

Biological engineers are involved in a variety of exciting interests that continue to emerge as our understanding of science and nature grows. Areas of interest range from environmental protection and remediation, to food and feed production, to medicine and plant-based pharmaceuticals and packaging materials. Some biological engineers design medical implants and other devices, or bioinstrumentation and imaging products. Others develop strategies for natural pest control and treatment of hazardous wastes, for composting, and for enzyme processing of biomass, food, feed, and wastes.

Natural Resources: Our environment is fragile. The 1930s Dust Bowl and climatic events like the El Nino phenomenon remind us that our soil and water are vulnerable to degradation by both natural and man-made forces. BAEs with environmental expertise work to better understand the complex mechanics of these resources, so that they can be used efficiently and without degradation. These engineers determine crop water requirements and design irrigation systems. They are experts in agricultural hydrology principles, such as controlling drainage, and they implement ways to control soil erosion and study the environmental effects of sediment on stream quality. Natural resources engineers design, build, operate and maintain water control structures for reservoirs, floodways and channels. They also work on water treatment systems, wetlands protection, and other water issues.

Power Systems & Machinery Design: BAEs in this specialty focus on designing advanced equipment, making it more efficient and less demanding of our natural resources. They develop equipment for food processing, highly precise crop spraying, agricultural commodity and waste transport, and turf and landscape maintenance, as well as equipment for such specialized tasks as removing seaweed from beaches. This is in addition to the tractors, tillage equipment, irrigation equipment, and harvest equipment that have done so much to reduce the drudgery of farming. Their work remains challenging as technology advances, production practices change and equipment manufacturers expand globally.

Structures & Environment: BAEs understand the importance of creating and maintaining a healthy environment for growing agricultural commodities and for the laborers who produce them. They also understand that our natural resources must not be diminished, in quality or availability, by agricultural operations. Toward these ends, BAEs with expertise in structures and environment design animal housing, storage structures, and greenhouses, with ventilation systems, temperature and humidity controls, and structural strength appropriate for their climate and purpose. They also devise better practices and systems for storing, recovering, reusing, and transporting waste products.

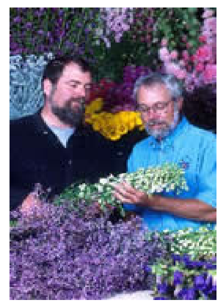
Food and Bioprocess Engineers: Food, fiber, and timber are only the beginning of a long list of products that benefit from efficient use of our natural resources.

Engineering for life with a higher purpose that makes a difference.

Limited natural resources.

Energy

Biological Engineering



NURSERY

Power and Machinary
Safety and Health

Food and bioprocess engineers

Figure 2: Specialty areas in Agricultural and Biological Engineering.

The list is growing - it includes biomass fuels, biodegradable packaging materials, and nutraceuticals, pharmaceutical and other products - and is limited only by the creative vision of food and bioprocess engineers. These engineers understand microbiological processes and use this expertise to develop useful products, to treat municipal, industrial and agricultural wastes, and to improve food safety. They are experts in pasteurization, sterilization, and irradiation, and in the packaging, transportation and storage of perishable products. Food and process engineers combine design expertise with manufacturing methods to develop economical and responsible processing solutions for industry. And food and process engineers look for ways to reduce waste by devising alternatives for treatment, disposal and utilization.

Information & Electrical Technologies engineering is one of the most versatile of the BAE specialty areas, because it is applied to virtually all the others, from machinery design to soil testing to food quality and safety control. Geographic information systems, global positioning systems, machine instrumentation and controls, electromagnetics, and -"bioinfomatics"- biorobotics, machine vision, sensors, spectroscopy - these are some of the exciting information and electrical technologies being used today and being developed for the future.

Forest Engineering: BAE's apply engineering to solve natural resource and environment problems in forest production systems and related manufacturing industries. Engineering skills and expertise are needed to address problems related to equipment design and manufacturing, forest access systems design and construction; machine-soil interaction and erosion control; forest operations analysis and improvement; decision modeling; and wood product design and manufacturing. Forest engineers are involved in a full range of activities in natural resource management and forest production systems.

Energy: Our high standard of living and comfort could not be maintained without energy to power the machines, devices, and systems in our homes and workplaces. But many energy sources are nonrenewable and create undesirable byproducts. Biological and agricultural engineers are at the forefront of the effort to identify and develop viable energy sources - biomass, methane, and vegetable oil, to name a few - and to make these and other systems cleaner and more efficient. These specialists also develop energy conservation strategies to reduce costs and protect the environment, and they design traditional and alternative energy systems to meet the needs of agricultural operations.

Aquacultural Engineering is increasing as natural fish supplies are threatened. Biological and agricultural engineers help design farm systems for raising fish and shellfish, as well as ornamental and bait fish. They specialize in water quality, biotechnology, machinery, natural resources, feeding and ventilation systems, and sanitation. They seek ways to reduce pollution from aquacultural discharges, to reduce excess water use, and to improve farm systems. They also work with aquatic animal harvesting, sorting, and processing.

Nursery & Greenhouse Engineering: In many ways, nursery and greenhouse operations are microcosms of large-scale production agriculture, with many similar needs - irrigation, mechanization, disease and pest control, and nutrient application. However, other engineering needs also present themselves in nursery and greenhouse operations: equipment for transplantation; control systems for temperature, humidity, and ventilation; and plant biology issues, such as hydroponics, tissue culture, and seedling propagation methods. And sometimes the challenges are extraterrestrial: BAEs at NASA are designing greenhouse systems to support a manned expedition to Mars!

Safety and Health: Farming is one of the few industries in which entire families - who often share the work and live on the premises - are vested and are at risk for injuries, illness, and death. Biological and agricultural engineers analyze health and injury data, the use and possible misuse of machines, and equipment compliance with standards and regulation. They constantly look for ways in which the safety of equipment, materials and agricultural practices can be improved and for ways in which safety and health issues can be communicated to the public.

1.4 Preparing for a Career in Biological and Agricultural Engineering

As with any engineering discipline, student needs to take as many math and science courses as one can while in high school, but one should be sure to include life sciences. Every engineer must be able to communicate effectively, and that includes speaking, listening, and the art of persuasion. One will find that university BAE programs have many names, such as biological systems engineering, bioresource engineering, environmental engineering, forest engineering, or food and process engineering. Whatever the title, the typical curriculum begins with courses in writing, social sciences, and economics, along with mathematics (calculus and statistics), chemistry, physics, and biology. Student gains a fundamental knowledge of the life sciences and how biological systems interact with their environment. One also takes engineering courses, such as thermodynamics, mechanics, instrumentation and controls, electronics and electrical circuits, and engineering design. Then student adds courses related to particular interests, perhaps including mechanization, soil and water resource management, food and process engineering, industrial microbiology, biological engineering or pest management. As seniors, engineering students team up to design, build, and test new processes or products.

1.5 Who Employs Biological and Agricultural Engineers?

Biological and agricultural engineers understand the interrelationships between technology and living systems, and have available a wide variety of employment options. Below is an example of the diversity of employers who hire BAE graduates.

3M
Abbott Labs
AGCO
Anheuser Busch
Archer Daniels
Midland
BASF
Briggs & Stratton
Campbell's Soup
Caterpillar

CH2M Hill
Case Corp
Dole
Dow Chemical
Exxon Mobil
Florida Light & Power
Ford Motor Co
General Mills
Grinnell Mutual

Reinsurance COHJ
Heinz
John Deere
Kraft
Lockheed Martin
M & M Mars
Monsanto
Morton Buildings
NASA
New Holland

Ralston Purina
Sunkist
US Department of Agriculture
US Department of Energy
US Environmental Protection Agency

1,6 Father of Agricultural Engineering in U.S.A.

The American Society of Agricultural Engineers [ASABE] was founded December 27, 1907, at the University of Wisconsin. One hundred years ago, the first agricultural engineering department in the world was created at Iowa State by J. Brownlee Davidson, a tall man from rural Nebraska with an affable smile and a dynamic vision. First President of ASABE J.B. Davidson is sometimes referred to in the U.S. as the "Father of Agricultural Engineering." Iowa State's Ag Engineering dept. may be the oldest program of its kind in the US. JB Davidson saw clearly the need to educate student engineers to prepare them to apply Engineering Technology to the solution of agricultural problems.

DB Davidson [Photo courtesy of Iowa State University Library]

During the first 100 years the ASABE has broadened the scope of the founder to expand its role beyond farm production to other components of the supply and delivery processes. The rivers of change that redirected ASABE for the first 100 years will continue to provide the opportunity for BAE to not only maintain but improve its effectiveness in the delivery of a world class quality level of education of the students.

2. Biomedical Engineering

Dr Richard Schoephoerster, Chairman of Biomedical Engineering Department at FIU indicates that the bridge is one of the oldest and most common artifacts for evidence of engineering at its finest. A well-designed bridge provides the foundation and structural integrity for the transport of objects from one location to the next across otherwise impassable terrain. In a similar fashion, Biomedical Engineering serves as a metaphorical "bridge" between engineering and medicine by providing the foundation and structural integrity for the passage of engineering knowledge to the medical field. **Biomedical engineering** is a discipline that advances knowledge in engineering, biology and medicine, and improves human health through cross-disciplinary activities that integrate the engineering sciences with the biomedical sciences and clinical practice. It includes: 1. The acquisition of new knowledge and understanding of living systems through the innovative and substantive application of experimental and analytical techniques based on the engineering sciences. 2. The development of new devices, algorithms, processes and systems that advance biology and medicine and improve medical practice and health care delivery. As used by the Whitaker foundation, the term "biomedical engineering research" is thus defined in a broad sense: It includes not only the relevant applications of engineering to medicine but also to the basic life sciences. Biomedical Engineering ranges from theoretical, non experimental understandings to state of art applications. It encompasses research, development, implementation and operation. Biomedical engineers can provide the tools and techniques to make the health care system more effective and efficient.

2.1 What Biomedical Engineers do?

They apply electrical, mechanical, chemical, optical and engineering mechanics principles to understand, modify, or control biologic (i.e., human and animal) systems, as well as design and manufacture products that can monitor physiologic functions and assist in the diagnosis and treatment of patients. When biomedical engineers work within a hospital or clinic, they are more properly called clinical engineers. The field of biomedical engineering includes many new careers areas as follows:

- Biofluid Mechanics & Computational Fluid Dynamics.
- Application of engineering system analysis (physiologic modeling, simulation and control) to living systems.

- Detection, measurement, and monitoring of physiologic signals (biosensors and biomedical instrumentation).
- Diagnostic interpretation via signal – processing techniques of bioelectric data.
- Therapeutic and rehabilitation procedures and devices: Rehabilitation Eng.
- Devices for replacement or augmentation of bodily functions: artificial organs.
- Computer analysis of patient related data and clinical decision making: Bioinformatics and artificial intelligence.
- Medical imaging: Graphic display of anatomic detail or physiologic function.
- The creation of new biologic products: Biotechnology and tissue engineering.
- Biomaterial engineering.
- Biomechanics of human body.
- Design of telemetry systems for patient monitoring.
- Computer modeling of the biofluid systems of human body.
- Expert systems for biodiagnostics.
- Sports engineering
- Biosafety engineering.
- Biothemodynamics and biomass transport phenomena.

2.2 What are some of the specialty areas?

In this field there is continual change and creation of new areas due to rapid advancement in technology; however, some of the well established specialty areas within the field of biomedical engineering are: bioinstrumentation; biomaterials; biomechanics; cellular, tissue and genetic engineering; clinical engineering; medical imaging; orthopedic surgery; rehabilitation engineering; and systems physiology.

Bioinstrumentation is the application of electronics and measurement techniques to develop devices used in diagnosis and treatment of disease. Computers are an essential part of bioinstrumentation, from the microprocessor in a single-purpose instrument used to do a variety of small tasks to the microcomputer needed to process the large amount of information in a medical imaging system.

Biomaterials include both living tissue and artificial materials used for implantation. Understanding the properties and behavior of living material is vital in the design of implant materials. The selection of an appropriate material to place in the human body may be one of the most difficult tasks faced by the biomedical engineer. Certain metal alloys, ceramics, polymers, and composites have been used as implantable materials. Biomaterials must be nontoxic, non-carcinogenic, chemically inert, stable, and mechanically strong enough to withstand the repeated forces of a lifetime. Newer biomaterials even incorporate living cells in order to provide a true biological and mechanical match for the living tissue.

Biomechanics applies classical mechanics (statics, dynamics, fluids, solids, thermodynamics, and continuum mechanics) to biological or medical problems. It includes the study of motion, material deformation, flow within the body and in devices, and transport of chemical constituents across biological and synthetic media and membranes. Progress in biomechanics has led to the development of the artificial heart and heart valves, artificial joint replacements, as well as a better understanding of the function of the heart and lung, blood vessels and capillaries, and bone, cartilage, intervertebral discs, ligaments and tendons of the musculoskeletal systems.

Cellular, Tissue and Genetic Engineering involves more recent attempts to attack biomedical problems at the microscopic level. These areas utilize the anatomy, biochemistry and mechanics of cellular and sub-cellular structures in order to understand disease processes and to be able to intervene at very specific sites. With these capabilities, miniature devices deliver compounds that can stimulate or inhibit cellular processes at precise target locations to promote healing or inhibit disease formation and progression.

Clinical Engineering is the application of technology to health care in hospitals. The clinical engineer is a member of the health care team along with physicians, nurses and other hospital staff. Clinical engineers are responsible for developing and maintaining computer databases of medical instrumentation and equipment records and for the purchase and use of sophisticated medical instruments. They may also work with physicians to adapt instrumentation to the specific needs of the physician and the hospital. This often involves the interface of instruments with computer systems and customized software for instrument control and data acquisition and analysis. Clinical engineers are involved with the application of the latest technology to health care.

Medical Imaging combines knowledge of a unique physical phenomenon (sound, radiation, magnetism, etc.) with high speed electronic data processing, analysis and display to generate an image. Often, these images can be obtained with minimal or completely noninvasive procedures, making them less painful and more readily repeatable than invasive techniques.

Orthopedic Bioengineering is the specialty where methods of engineering and computational mechanics have been applied for the understanding of the function of bones, joints and muscles, and for the design of artificial joint replacements. Orthopedic bioengineers analyze the friction, lubrication and wear characteristics of natural and artificial joints; they perform stress analysis of the musculoskeletal system; and they develop artificial biomaterials (biologic and synthetic) for replacement of bones, cartilages, ligaments, tendons, meniscus and intervertebral discs. They often perform gait and motion analyses for sports performance and patient outcome following surgical procedures. Orthopedic bioengineers also pursue fundamental studies on cellular function, and mechanic-signal transduction.

Rehabilitation Engineering is a growing specialty area of biomedical engineering. Rehabilitation engineers enhance the capabilities and improve the quality of life for individuals with physical and cognitive impairments. They are involved in prosthetics, the development of home, workplace and transportation modifications and the design of assistive technology that enhance seating and positioning, mobility, and communication. Rehabilitation engineers are also developing hardware and software computer adaptations and cognitive aids to assist people with cognitive difficulties.

Systems Physiology is the term used to describe that aspect of biomedical engineering in which engineering strategies, techniques and tools are used to gain a comprehensive and integrated understanding of the function of living organisms ranging from bacteria to humans. Computer modeling is used in the analysis of experimental data and in formulating mathematical descriptions of physiological events. In research, predictor models are used in designing new experiments to refine our knowledge. Living systems have highly regulated feedback control systems that can be examined with state-of-the-art techniques. Examples are the biochemistry of metabolism and the control of limb movements.

These specialty areas frequently depend on each other. Often, the biomedical engineer who works in an applied field will use knowledge gathered by biomedical engineers working in other areas. For example, the design of an artificial hip is greatly aided by studies on anatomy, bone biomechanics, gait analysis, and biomaterial compatibility. The forces that are applied to the hip can be considered in the design and material selection for the prosthesis. Similarly, the design of systems to electrically stimulate paralyzed muscle to move in a controlled way uses knowledge of the behavior of the human musculoskeletal system. The selection of appropriate materials used in these devices falls within the realm of the biomaterials engineer. **Specific activities** by biomedical engineers may include a wide range of activities such as: Artificial organs (hearing aids, cardiac pacemakers, artificial kidneys and hearts, blood oxygenators, synthetic blood vessels, joints, arms, and legs); Automated patient monitoring (during surgery or in intensive care; healthy persons in unusual environments, such as astronauts in space or underwater divers at great depth); Blood chemistry sensors (potassium, sodium, O2, CO2, and pH); Advanced therapeutic and surgical devices (laser system for eye surgery, automated delivery of insulin, etc.); Application of expert systems and artificial intelligence to clinical decision making (computer-based systems for diagnosing diseases); Design of optimal clinical laboratories (computerized analyzer for blood samples, cardiac catheterization laboratory, etc.); Medical imaging systems (ultrasound, computer assisted tomography, magnetic resonance imaging, positron emission tomography, etc.); Computer modeling of physiologic systems (blood pressure control, renal function, visual and auditory nervous circuits, etc.); Biomaterials design (mechanical, transport and biocompatibility properties of implantable artificial materials); Biomechanics of injury and wound healing (gait analysis, application of growth factors, etc.); and Sports medicine (rehabilitation, external support devices, etc.). List of **Academic Programs in Biomedical Engineering** is available on the Internet at: www.bmenet.org; bmes.org;

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4. Authorization and Disclaimer

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