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Feeding the World: the Role of Bioprocess Engineering in Ensuring Sustainable Agriculture for Future Generations

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ABSTRACT: Bioprocess engineering, also biochemical engineering, is a specialization of chemical engineering or biological engineering. It deals with the design and development of equipment and processes for the manufacturing of products such as agriculture, food, feed, pharmaceuticals, nutraceuticals, chemicals, and polymers and paper from biological materials & treatment of waste water. Bioprocess engineering is a conglomerate of mathematics, biology and industrial design, and consists of various spectrums like the design and study of bioreactors (operational mode, instrumentation, and physical layout) to the creation of kinetic models. It also deals with studying various biotechnological processes used in industries for large scale production of biological product for optimization of yield in the end product and the quality of end product. Bioprocess engineering may include the work of mechanical, electrical, and industrial engineers to apply principles of their disciplines to processes based on using living cells or sub component of such cells

KEYWORDS: biochemical, development, agriculture, sustainable, feeding, future, yield, quality, equipments, polymers, paper

I. INTRODUCTION

The focus of the Bioprocess Engineering option is to produce engineers that seamlessly combine engineering and natural sciences to designing and developing systems, processes and equipment that convert biological and agricultural materials to value-added products such as food, nutraceuticals, polymers and pharmaceuticals. For hundreds of years, humans have made use of the chemical reactions of biological organisms in order to create goods. In the mid-1800s, Louis Pasteur was one of the first people to look into the role of these organisms when he researched fermentation.¹ His work also contributed to the use of pasteurization, which is still used to this day. By the early 1900s, the use of microorganisms had expanded, and was used to make industrial products. Up to this point, biochemical engineering hadn't developed as a field yet. It wasn't until 1928 when Alexander Fleming discovered penicillin that the field of biochemical engineering was established. After this discovery, samples were gathered from around the world in order to continue research into the characteristics of microbes from places such as soils, gardens, forests, rivers, and streams.² Today, biochemical engineers can be found working in a variety of industries, from food to pharmaceuticals. This is due to the increasing need for efficiency and production which requires knowledge of how biological systems and chemical reactions interact with each other and how they can be used to meet these needs.³

Bioprocess engineers provide a bridge between the research lab and the economic, large-scale implementation of technologies used to convert these biological materials to value-added products. Bioprocess engineering is concerned with translating biological science into biologically based manufacturing. To be prepared for the biological manufacturing systems of the future, it is important to identify the fields of science and technology that have reached or will soon reach early prototypes and to begin to develop engineering systems to deal with them. The lead time in development of any new technology is long. Biological science is so prolific that any present list of future developments of technology must be incomplete. It is, however, straightforward to identify subjects in which new engineering techniques must be developed now, if the technologies are to be available when they are needed in large-scale manufacturing 5–15 years from now.⁴



Bioreactor

Bioprocess engineering in agriculture and the food industry involves the application of biocatalysts (living cells or their components) to produce useful and value-added products, and it offers opportunities to design and produce new or improved agricultural and food products and their manufacturing processes.⁵ This will likely have a great impact on the U.S. food-processing industry, which has estimated annual sales of \$255 billion. In our increasingly health-conscious society, genetically engineered microorganisms and specialty enzymes will find increased use in improving the nutritional, flavoring, and storage characteristics and safety of food products. Products under development range from genetically improved strains of freeze-resistant yeast used in frozen bakery products to phage-resistant dairy (yogurt) starter cultures. Chymosin, a product of recombinant *E. coli*, is already used in the milk-clotting step of cheese manufacture, and a recombinant maltogenic amylase is being used as an antistaling agent. Enzyme-based immunoassays could develop into a widely used method for detecting pesticides in foods at parts-per-billion concentrations. Challenges that must be addressed include the economics of production and regulatory issues⁶

The most important applications of bioprocess-engineering research and development related to agriculture and food involve production of agricultural chemicals for control of animal and plant diseases, growth-stimulating agents for improved yield, and biological insecticides and herbicides; increasing bioprocess efficiencies for fermented foods, natural food additives, food enzymes as processing aids, and separation and purification of the products; use of plant-cell culture systems to produce secondary metabolites or chemical substances of economic importance; and efficient use of renewable biomass resources for production of liquid fuel and chemical feedstocks and efficient treatment and management of agricultural wastes and wastes from food-processing industries.⁷

Professionals in this role emphasise the study of cellular processes. They apply engineering principles to design devices, systems and products that benefit various industries. For example, these professionals often work with pharmacists and biochemists to design medicines that limit side effects and improve health outcomes for patients. They may also work in industries like agriculture, where they may design hybrid plants or create chemical treatments to protect crops from insects and animals. In other cases, they may work for manufacturing facilities to improve the safety of their processes.⁸



Kisan drones

A biochemical engineer understands how chemical processes support and affect biological functions. These professionals study the chemical makeup of living things and how introducing other chemicals to biological processes can influence them. For example, many biochemical engineers work in the pharmaceutical industry. They apply their knowledge of how chemical processes affect the body, and they develop new medications to improve those processes. Others may work in environmental sciences.⁹ They may assess the risk of chemical pollutants or create processes that reduce waste and improve the health of the environment. Chemical engineers focus their work on areas similar to biochemical engineers. Unlike biochemical engineers, these professionals may also work with synthetic chemicals to create sustainable and synthetic fuels, industrial lubricants or textile components. Many engineers in chemistry applications work in the manufacturing sector, where they oversee chemical processes during operations. Biotechnical engineers may take on many of the same studies and applications as bioprocess engineers, where they combine life science and technology to design and create both industrial and consumer products. They may also have knowledge of computer science and information technology. For example, a biotechnical engineer may create computer systems, software or technology devices that assist biological researchers. They combine their knowledge of bioprocess research with computer science to create technology that assists in the research and engineering processes. Agricultural engineers use bioprocesses in support of developing efficient means of farming, harvesting and processing food crops.¹⁰ Engineers in agriculture often work with commercial farmers, biologists and botanists to research viable methods for genetically enhancing crops, maintaining soil health and protecting ecological diversity during farming practices. An agricultural engineer also oversees the design and development of equipment that is safer and less impactful on the environment during agricultural operations. Environmental engineers use engineering principles to improve the health of the environment. They study the environment to identify problems like pollution and erosion. Based on their findings, they engineer solutions that solve or reduce these problems. For example, an environmental engineer may create biodegradable packaging to reduce how much waste single-use convenience products create.¹¹

II. DISCUSSION

Bioproducts engineering or bioprocess engineering refers to engineering of bio-products from renewable bioresources. This pertains to the design and development of processes and technologies for the sustainable manufacture of bioproducts (materials, chemicals and energy) from renewable biological resources.



Food processing

Bioproducts engineers harness the molecular building blocks of renewable resources to design, develop and manufacture environmentally friendly industrial and consumer products. From biofuels, renewable energy, and bioplastics to paper products and "green" building materials such as bio-based composites,¹² Bioproducts engineers are developing sustainable solutions to meet the world's growing materials and energy demand. Conventional bioproducts and emerging bioproducts are two broad categories used to categorize bioproducts. Examples of conventional bio-based products include building materials, pulp and paper, and forest products. Examples of emerging bioproducts or biobased products include biofuels, bioenergy, starch-based and cellulose-based ethanol, bio-based adhesives, biochemicals, biodegradable plastics, etc.^{[1][2]} Bioproducts Engineers play a major role in the design and development of "green" products including biofuels, bioenergy, biodegradable plastics, biocomposites, building materials, paper and chemicals.¹³ Bioproducts engineers also develop energy efficient, environmentally friendly manufacturing processes for these products as well as effective end-use applications. Bioproducts engineers play a critical role in a sustainable 21st century bio-economy by using renewable resources to design, develop, and manufacture the products we use every day. The career outlook for bioproducts engineers is very bright with employment opportunities in a broad range of industries, including pulp and paper, alternative energy, renewable plastics, and other fiber, forest products, building materials and chemical-based industries.¹⁴

Commonly referred to as bioprocess engineering, bioprocess engineering is a specialization of biotechnology, biological engineering, chemical engineering or of agricultural engineering. It deals with the design and development of equipment and processes for the manufacturing of products such as food, feed, pharmaceuticals, nutraceuticals, chemicals, and polymers and paper from biological materials. Bioprocess engineering is a conglomerate of mathematics, biology and industrial design, and consists of various spectrums like designing of fermentors, study of fermentors (mode of operations etc.).¹⁴ It also deals with studying various biotechnological processes used in industries for large scale production of biological product for optimization of yield in the end product and the quality of end product. Bio process engineering may include the work of mechanical, electrical and industrial engineers to apply principles of their disciplines to processes based on using living cells or sub component of such cells.^[3]

Many industries rely on the work of bioprocess engineers. Here are some industries in which bioprocess engineering has applications:

Pharmaceuticals

Engineers in pharmaceutical research and development study and test chemical and biological processes to help create medicines that are safe to use. They may aid in a laboratory to study various compounds to develop vaccines, medical therapies, alternative disease treatments and even veterinary medicines. Bioprocess engineers in the pharmaceutical industry may also work with medical researchers and professionals to develop more effective diagnostic methods.¹⁵



Biomedicine

Bioprocess engineers often work in biomedicine, in which they may create medical devices or applications. For example, a bioprocess engineer may develop a synthetic material that doctors can use to 3D print organs for transplants. These engineers may also develop medical imaging equipment, life support devices and devices that make it easier to administer medications. Often, engineers who work in biomedicine work with a team that includes doctors, medical researchers and biochemists.

Agriculture and food science

Agricultural applications that rely on bioprocess engineering include food production and commercial farming. In food production, bioprocesses help maintain and add nutrients to foods, initiate fermentation and create products that are safe for consumption. Commercial farming necessitates bioprocessing for creating drought- and disease-resistant crops, maximising nutrient content and creating more efficient pest management.¹⁶

With bioprocess engineering, many agricultural applications continue to advance with alternative food sources and more environmentally sustainable methods of planting, harvesting and processing crops. This can improve the quality of foods, the sustainability of farming practices and increase global access to food. By making food more nutritious and more abundant while maintaining the sustainability of the environment, bioprocess engineers ensure that more people can access the food they need.

Conservation

Bioprocess engineers can improve conservation efforts. For example, their knowledge of the environment and biological systems can help them create natural control methods that improve environmental sustainability. A bioprocess engineer may introduce a type of microorganism into an environment to filter pollutants and enrich the soil in the area. Some engineers in this field may work as consultants. In a consultation role, they meet with industrial developers and offer solutions to reduce the impact of construction and development efforts on the local environment.¹⁷

III. RESULTS

Food and bioprocess engineers develop and manage equipment and systems that process and distribute food and other biologically based materials. They are required by the food industry to help develop processes that add value to food products. These processing technologies are designed to improve the storage life and marketability of food products, reduce their transportation costs, handle processing wastes, and develop alternative uses for biological materials. (For example, newspaper and soy flour are used to make the construction material, Environ™, and corn stalks can be used to make chemical absorbent pads.) The food industry makes up one of the largest segments of our nation's economy and continues to enjoy steady growth due to the ever-changing needs of consumers and increased awareness of nutritional and environmental issues. Food and bioprocess engineers play a vital role in meeting this need. From potato chips to microwavable entrees, food and bioprocess engineers continue to develop processes to convert raw materials from the farm to food products for the dining room table.¹⁸

The field of Agricultural & Bio-Processing (ABPRO) covers the gamut of handling and storage of crops in fresh form from farm to market, to processing of agricultural materials into food, feed products, and industrial products. Loss reduction, quality retention, improved efficiency, and cost effectiveness of the various postharvest and processing operations are prime considerations in development of technologies for ABPRO. Coursework covers heat, mass, and momentum transfer, crop processing operations, physical properties of agricultural materials, and refrigeration systems. Students are also encouraged to enroll in elective courses in other colleges of UPLB to broaden their perspective and increase their understanding of biosystems. These electives generally include courses in animal science, postharvest horticulture, agricultural economics, and food science.¹⁹

Postharvest Engineering – high-value commercial crops include fresh fruits, vegetables, and cutflowers. Due to their inherent perishability, a significant fraction of the volume produced yearly is lost due to improper handling, inappropriate packaging, and inadequate storage and transport facilities. More distant production areas, greater need for food safety, and stricter quality requirements all pose an increasing challenge to agricultural and biosystems engineers. This area of specialization of Agricultural Engineering is involved in the sorting and grading, packaging, temperature



management, transport, and short-term storage of high-value crops. Development of equipment, facilities, and protocols to reduce losses, extend shelf life, and maintain quality of perishable crops in fresh form are the main objectives of this field of specialization.²⁰

Crop Processing – involves the transformation of raw agricultural materials into intermediate or finished products such as animal feed, crude oil extracts for biofuel production, industrial fibers. This field of specialization involves the determination of physical properties of raw materials, development of size reduction and extraction equipment and processes, evaluation of processed products, and drying and dehydration methods. Special emphasis is placed on drying and milling of Philippine crops such as rice and corn.

Food Engineering – is the integration of the fields of engineering, chemistry, and microbiology for developing solutions to processing of food materials into finished products with added value and a stable shelf life. This field of specialization involves the development of new food products, pharmaceuticals, food processing machinery, packaging materials and edible coatings, processing protocols, and treatments for processing plant waste.²¹

Energy Engineering – involved in biomass and other alternative energy resource development (calculation of energy potentials, policy formulation, status of the industry), biofuels potential and sustainability, energy conservation and efficiency measures, and theory and design of combustion systems for agricultural commodities.

Thermal Processing – principles and application of psychrometry in postharvest engineering and crop processing applications, design of refrigerated storage systems, and thermodynamic analysis of postharvest and thermal systems.²²

Applications in Biotechnology

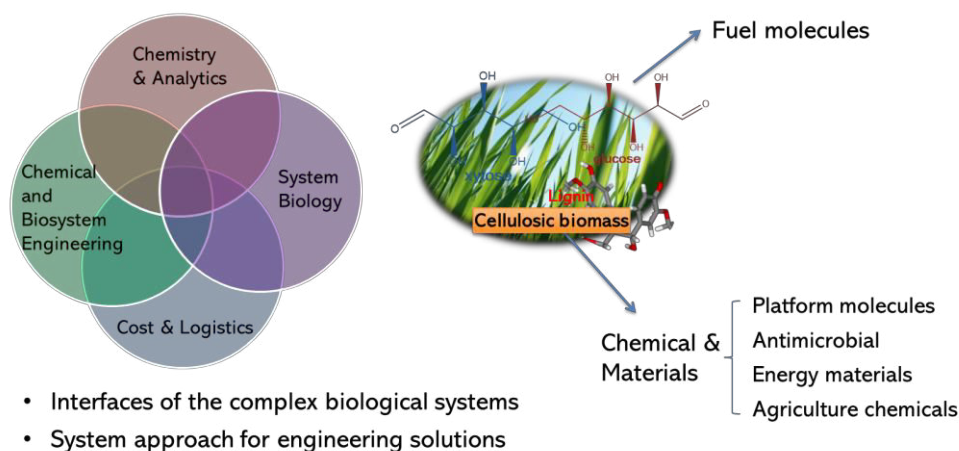
Biotechnology and biochemical engineering are closely related to each other as biochemical engineering can be considered a sub-branch of biotechnology. One of the primary focuses of biotechnology is in the medical field, where biochemical engineers work to design pharmaceuticals, artificial organs, biomedical devices, chemical sensors, and drug delivery systems. Biochemical engineers use their knowledge of chemical processes in biological systems in order to create tangible products that improve people's health. Specific areas of studies include metabolic, enzyme, and tissue engineering. The study of cell cultures is widely used in biochemical engineering and biotechnology due to its many applications in developing natural fuels, improving the efficiency in producing drugs and pharmaceutical processes, and also creating cures for disease.²³

Applications in food industry

Biochemical engineers primarily focus on designing systems that will improve the production, processing, packaging, storage, and distribution of food.^[1] Some commonly processed foods include wheat, fruits, and milk which undergo processes such as milling, dehydration, and pasteurization in order to become products that can be sold. There are three levels of food processing: primary, secondary, and tertiary. Primary food processing involves turning agricultural products into other products that can be turned into food, secondary food processing is the making of food from readily available ingredients, and tertiary food processing is commercial production of ready-to eat or heat-and-serve foods. Drying, pickling, salting, and fermenting foods were some of the oldest food processing techniques used to preserve food by preventing yeasts, molds, and bacteria to cause spoiling.^[5] Methods for preserving food have evolved to meet current standards of food safety but still use the same processes as the past. Biochemical engineers also work to improve the nutritional value of food products, such as in golden rice, which was developed to prevent vitamin A deficiency in certain areas where this was an issue. Efforts to advance preserving technologies can also ensure lasting retention of nutrients as foods are stored. Packaging plays a key role in preserving as well as ensuring the safety of the food by protecting the product from contamination, physical damage, and tampering.^[5] Packaging can also make it easier to transport and serve food. A common job for biochemical engineers working in the food industry is to design ways to perform all these processes on a large scale in order to meet the demands of the population. Responsibilities for this career path include designing and performing experiments, optimizing processes, consulting with groups to develop new technologies, and preparing project plans for equipment and facilities.^[5]

IV. IMPLICATIONS

Shifting society's dependence on petroleum-based fuels and chemicals to biomass derived products is important not only to reduce our carbon footprint but also to increase the robustness of our energy security and economic stability.²⁴ There are emerging needs to address some of the societal and sustainability challenges in the food, energy, and water (FEW) nexus. The research areas we are working on under bioprocess engineering are well suited to meet the FEW demands. Aligned with these research priorities, our overarching research goal is to understand and develop novel bioprocesses and models to produce biofuels, bioproducts, and renewable materials by exploring the interface between chemistry, engineering, and system biology.



1) Molecular dynamics-guided enzyme engineering for biocatalysis in novel solvent systems

Great opportunities have emerged for using ionic liquid or deep eutectic solvent as solvent, reaction medium and catalyst to enable cost effective and efficient bioprocessing technologies for broad applications. The superior and tunable properties of these novel solvents make them suitable for processing many recalcitrant natural and synthetic polymers. We explore catalysis and biocatalysis routes in these novel solvent systems for potential applications related to plastic upcycling, compounds extraction, CO₂ capture, bioremediation, and cellulose/lignin derived chemicals and materials. Data-driven enzyme engineering approaches (including bioprospecting, molecular dynamic simulation of enzyme-solvent interactions, rational design of enzymes, and surface charge engineering) are being explored in our lab.²⁵

2) Lignin valorization for chemicals and advanced materials

Lignin is the second most abundant biopolymer in nature. However, in current bio-refinery concept, lignin is commonly burned for generating steam and electricity. Converting lignin waste streams to high value-added chemicals will greatly enhance the economic viability and success of a biorefinery. Collaborating with plant scientists, we study the impact of lignin modification (transgenic plants) on lignin extraction and optimize a process for generating a range of low molecule weight phenolics highly amenable to catalytic conversion to fuels and chemicals. We also investigate lignin derived nano-composite materials for novel applications in catalysis, antimicrobial, and energy storage.²⁶

3) Biomass feedstock logistics and modeling

Significant knowledge gaps exist in understanding and mitigating the variabilities in biomass feedstocks such as composition, structure, chemistry, and inorganics and their impact on biological and thermochemical conversion.²⁹ Systems based research is needed to correlate biomass chemical characteristics (using advanced analytical tools) to the performance of conversion process and feedstock supply systems. Our group is developing novel predictive models connecting the chemical and physical characterization of biomass-derived feedstocks with efficiencies in biomass conversions. Such models will be integrated and used to develop TEA/LCA guided feedstock preprocessing/variation mitigation strategies.²⁸

4) Nanotechnology and fermentation for food and agricultural applications

The three elements of food-energy-water nexus are interconnected and tied to sustainable agriculture. Overuse and overreliance on synthetic agrochemicals and fertilizers are threatening the environment, the ecosystem, and the



sustainability of agriculture. A transition from synthetic to biobased products is a long-term challenge. New bioprocesses are being developed in our lab to convert agricultural wastes to bioproducts for agricultural applications. To achieve that, we investigate interactions between biomass-derived chemicals and nanoparticles and the microbiome in food and agricultural systems and based on the mechanistic understanding of their interactions to formulate novel products such as antimicrobials, biofertilizer, biocontrol agent and crop yield enhancers.²⁷

V. CONCLUSIONS

Food, Agriculture and bioprocess engineers are responsible for performing various duties in the areas of food and biomanufacturing industries that produce food products (packaged foods, beverages, dairy foods, etc.), ingredients, biofuels, biopolymers and chemicals. These areas include:

- Process and product development
- Process improvements
- Design and implementation of new equipment and systems
- Procession operation, control, testing and troubleshooting
- Equipment layout
- Packaging design and applications
- Safety and quality monitoring
- Technical support for clients and employers during implementation phase³⁰

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