



DEPARTMENT OF  
HIGHER EDUCATION &  
WORKFORCE DEVELOPMENT

## New Program Report

**Date Submitted:**

11/21/2023

**Institution**

Missouri University of Science & Technology

**Site Information**

**Implementation Date:**

8/1/2024 12:00:00 AM

**Added Site(s):**

**Selected Site(s):**

Missouri University of Science & Technology, 206 Parker Hall, Rolla, MO, 65409-0470

**CIP Information**

**CIP Code:**

140501

**CIP Description:**

A program that prepares individuals to apply mathematical and scientific principles to the design, development and operational evaluation of biomedical and health systems and products such as integrated biomedical systems, instrumentation, medical information systems, artificial organs and prostheses, and health management and care delivery systems.

**CIP Program Title:**

Bioengineering and Biomedical Engineering

**Institution Program Title:**

Bioengineering

**Degree Level/Type**

**Degree Level:**

Doctoral Degree (Research PhD)

**Degree Type:**

Doctor of Philosophy (Ph.D.)

**Options Added:**

Collaborative Program:

N

**Mode of Delivery**

Current Mode of Delivery

Classroom

Student Preparation



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Special Admissions Procedure or Student Qualifications required:

The bioengineering PhD program at Missouri S&T targets highly motivated students who have completed a bachelor's or master's degree in chemical engineering, biomedical engineering, biology, chemistry, or a related field. These individuals should have a strong foundation in mathematics, biology, physics, and chemistry, as well as a background in engineering principles to ensure success in the program. Prior research experience is beneficial, but not mandatory.

Applicants may be required to submit a compelling statement of purpose outlining their research interests and goals, along with letters of recommendation from faculty or professionals in the field. The program recognizes the interdisciplinary nature of bioengineering and welcomes well-prepared students from peripheral disciplines. To accommodate diverse academic backgrounds, these students may need to take elective courses to build the necessary foundation for core courses. In rare cases, lower-division leveling courses identified by their advisors might be required, which fall outside the standard program curriculum. This inclusive approach ensures that all admitted students can strengthen their foundational knowledge and excel in the bioengineering PhD program, regardless of their specific academic background.

Specific Population Characteristics to be served:

n/a

### Faculty Characteristics

Special Requirements for Assignment of Teaching for this Degree/Certificate:

Faculty must hold a PhD or terminal degree.

Estimate Percentage of Credit Hours that will be assigned to full time faculty:

90%

Expectations for professional activities, special student contact, teaching/learning innovation:

n/a

### Student Enrollment Projections Year One-Five

<b>Year 1</b>	<b>Full Time: 5</b>	<b>Part Time: 0</b>	
<b>Year 2</b>	<b>Full Time: 10</b>	<b>Part Time: 0</b>	
<b>Year 3</b>	<b>Full Time: 15</b>	<b>Part Time: 0</b>	<b>Number of Graduates:</b> 0
<b>Year 4</b>	<b>Full Time: 20</b>	<b>Part Time: 0</b>	
<b>Year 5</b>	<b>Full Time: 25</b>	<b>Part Time: 0</b>	<b>Number of Graduates:</b> 5

**Percentage Statement:**

n/a

### Program Accreditation

Institutional Plans for Accreditation:

This new bioengineering PhD degree needs no accreditation to function but will be assessed together with other graduate degrees in the chemical engineering graduate program via the Higher Learning Commission.

### Program Structure



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**Total Credits:**

72

**Residency Requirements:**

n/a

**General Education Total Credits:**

42

**Major Requirements Total Credits:**

13

**Course(s) Added**

COURSE NUMBER	CREDITS	COURSE TITLE
xxxxx	3	Drug and Gene Delivery
xxxxx	1	Integrity and Ethics in Bioengineering
xxxxx	3	Lecture Series
xxxxx	3	Biomaterials I
xxxxx	3	Isolation and Purification of Biologicals
xxxxx	3	Biomanufacturing
xxxxx	3	Pharmaceutical Process Engineering

**Free Elective Credits:**

15

**Internship or other Capstone Experience:**

A dissertation is an essential component of earning a bioengineering PhD. To complete the program and obtain the degree, PhD candidates must successfully submit and defend their bioengineering research in the form of a dissertation.

**Assurances**

I certify that the program is clearly within the institution's CBHE-approved mission. The proposed new program must be consistent with the institutional mission, as well as the principal planning priorities of the public institution, as set forth in the public institution's approved plan or plan update.

I certify that the program will be offered within the proposing institution's main campus or CBHE-approved off-site location.

I certify that the program will not unnecessarily duplicate an existing program of another Missouri institution in accordance with 6 CSR 10-4.010, subsection (9)(C) Submission of Academic Information, Data and New Programs.

I certify that the program will build upon existing programs and faculty expertise.

I certify that the program can be launched with minimal expense and falls within the institution's current operating budget.

I certify that the institution has conducted research on the feasibility of the proposal and it is likely the program will be successful. Institutions' decision to implement a program shall be based upon demand and/or need for the program in terms of meeting present and future needs of the locale, state, and nation based upon societal needs, and/or student needs.

Contact Information



## **New Program Report**

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Kent

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## Executive Summary

Bioengineering is one of the fastest-growing sectors of employment and has seen significant increases in R&D investments by governmental agencies, foundations, and industry. The proposed bioengineering PhD program at Missouri S&T aims to provide students with advanced education and research opportunities in the interdisciplinary field of bioengineering. The importance of the bioengineering PhD program extends from the university level to the state and national levels. Establishing a bioengineering PhD program at Missouri S&T will not only enhance the University's research portfolio and academic reputation but will also help in developing the workforce for bioengineering jobs, which contribute greatly to the growth and economic development of Missouri and the nation.

Evidence of employer and student demand for the program is strong. A market and demand analysis performed using Lightcast™ demonstrates the need for a sizable workforce in bioengineering and biomedical engineering at the PhD level nationally and in Missouri. There were 2,202 jobs for bioengineers and biomedical engineers in 2022, with these fields projected to grow by 15.4% over the next decade (2022-2032). Critically, the projected growth for the next 10 years is 11.1% in the states of Missouri and Illinois. In addition, there is high local student demand for a bioengineering PhD program at Missouri S&T. Out of 34 surveyed BS or MS students in our Biology and Chemical Engineering degree programs, 18 expressed interest in pursuing a bioengineering PhD degree if it were available. This was particularly the case among students with a BS in chemical engineering with biochemical engineering emphasis (10 out of 13 respondents) and students pursuing an MS in biological sciences (6 out of 9 respondents). The economic feasibility of the program is supported by the high demand for bioengineers in various industries, such as pharmaceuticals, biotechnology, and medical devices. The growth of these industries in the region and nationally will provide ample job opportunities for graduates with advanced degrees, attracting more students to the program (see letters of support).

Upon completing the bioengineering PhD program at Missouri S&T, graduates will possess a strong foundation in bioengineering principles and advanced research skills. Specifically, students will be expected to demonstrate a comprehensive understanding of core bioengineering concepts. The new bioengineering Ph.D. program is anticipated to enhance our faculty's research opportunities, particularly for NIH-sponsored programs. Given that the NIH's FY23 budget of \$48.9 billion vastly outweighs the NSF's \$10.9 billion, our program will strengthen our competitiveness for these significant resources and foster growth in the critical field of bioengineering research.

In conclusion, the proposed bioengineering PhD program at Missouri S&T is well-positioned to meet the growing demand for advanced education and research in this interdisciplinary field. The program will not only benefit the University by attracting top talent and enhancing its research capabilities but also contribute to the economic growth of the state and nation.

# 1. Introduction

Bioengineering is one of the fastest-growing employment and research sectors in the US. Inspired in part by the recent performance of pharmaceutical and healthcare biotechnology in vaccine development and manufacturing to combat the COVID-19 pandemic, increasing numbers of students have become interested in bioengineering graduate research and career pathways. Bioengineering encompasses several rapidly growing specialty areas, including biochemical engineering, biomedical engineering, and biomolecular engineering. Specific topics within the scope of bioengineering include biomaterials, biomechanics, chemistry, bioinformatics, process engineering, biology, and pharmaceutical sciences.

## Academic Components and Career Paths

Our goal is to leverage the interdisciplinary nature of bioengineering by offering a multidisciplinary PhD program that can span all the relevant aspects of bioengineering, from upstream research to downstream processing and from the characterization of individual biomolecules to the design of an entire process. The intent of the program will be to break new ground to meet current and future bioengineering challenges for the benefit of society.

Graduates of this program could follow a variety of career paths in areas such as biomaterials development, biomanufacturing processes, bioseparation techniques, pharmaceutical process engineering, regenerative medicine, tissue engineering, and medical device design. The increasing demand for bioengineers and biomedical engineers in the United States, particularly in Missouri, underscores the importance and timeliness of this proposed program.

Through this degree, we will develop a workforce for advanced bioengineering jobs that will contribute to the growth and economic development of Missouri and the nation. The PhD in bioengineering will allow us to effectively combine existing expertise in chemical and biochemical engineering with several allied engineering and science departments at Missouri S&T to provide cutting-edge research and educational experiences for our students. The objectives of the proposed PhD program in bioengineering are as follows:

- (1) To grow graduate enrollment at Missouri S&T by offering a new PhD program with new courses and research opportunities that will attract a large and diverse set of students.
- (2) To build a highly skilled workforce in bioengineering to meet the current and emergent needs of industries, regulatory agencies, and NGOs.
- (3) To serve as an integrator and catalyst for faculty members at Missouri S&T to discover new ideas, develop collaborations, and increase scholarly productivity in the critically important bioengineering research domain.
- (4) To build new research and educational collaborations with industry and other external partners, including those within the UM system. This includes supporting existing focus areas at MU such as precision medicine.

## **Evolution of the Program Concept**

The concept of this program has evolved over the years, driven by the success of our biochemical engineering emphasis area within the chemical engineering degree program and the recognition of the growing need for professionals with expertise at the intersection of engineering and medicine. The proposed bioengineering PhD program at Missouri S&T is designed to educate and train students to become leaders in the rapidly growing field of bioengineering, a discipline that combines the principles of engineering, biology, and medicine to develop innovative solutions for complex healthcare problems. This interdisciplinary program aims to develop highly skilled engineers and well-versed researchers, capable of addressing the grand challenges facing the biotechnology and pharmaceutical industries. By preparing students for successful careers in academia, industry, or government, the program will contribute to the advancement of healthcare and the overall quality of life. This interdisciplinary program is designed to allow faculty from across campus to recruit graduate students from other bioengineering or biomedical engineering programs to pursue advanced degrees in a similar discipline and in so doing, to more effectively compete for research support from agencies like the National Institutes of Health (NIH).

## **Integration of Existing Courses**

Existing courses in related areas, such as chemical engineering, materials science and engineering, and biological sciences, will provide a strong foundation for the proposed program. The interdisciplinary nature of the program will allow students to take advantage of the wide range of expertise and resources available at Missouri S&T, fostering a culture of collaboration and innovation that is essential for breakthroughs in bioengineering. In addition, the program will develop several new courses and seminars to address emerging topics and technologies in this field.

## **Program Coordinator**

The individual responsible for the success of the proposed bioengineering PhD program is Dr. Hu Yang, Chair of the Doshi Department of Chemical and Biochemical Engineering (ChBE). He can be reached at [huyang@mst.edu](mailto:huyang@mst.edu) or (573) 341-4854. Dr. Yang will oversee the development and implementation of the program, ensuring its alignment with the University's strategic goals and the needs of students and employers. Dr. Jee-Ching Wang, Associate Chair for Research and Program Coordinator for the chemical engineering graduate program, will serve as Program Coordinator for the proposed new PhD program. He can be reached at [jcwang@mst.edu](mailto:jcwang@mst.edu) or (573) 341-6705. As the program coordinator, he will be responsible for overseeing student recruitment efforts and coordinating graduate studies to ensure a seamless and enriching experience for all students in the program. If the bioengineering PhD program experiences significant growth, we will appoint an additional faculty member to co-coordinate the program to ensure its continued success. The program will be evaluated annually to determine if additional staffing is necessary to support its growth and success.

## 2. University Mission & Program Analysis

### 2.A. Alignment with University Mission & Goals

**Alignment with campus goals.** The mission of Missouri S&T is to integrate education, research, and technology development to create and convey knowledge that serves our state and helps solve the world's great challenges. This mission is clearly captured within the concept of our proposed bioengineering PhD program. Our program will foster the convergence of ideas, expertise, and technologies across disciplines to stimulate innovative solutions to solving the problems facing our society. Missouri S&T's strategic vision is focused on achieving three "North Star" goals by 2030: Attain Carnegie R1 classification, grow enrollment to 12,000 students, including 4000 graduate students, and achieve a top 100 ranking among national doctoral universities. Therefore, our campus is also dedicated to forming new educational programs that are interdisciplinary in education and research to prepare more students for rapidly evolving and cutting-edge fields like those associated with bioengineering. The proposed bioengineering PhD program is an integral part of our vision and strategy. Additionally, the proposed bioengineering PhD program will maximize existing internal strengths to generate new ones, as well as lead to new collaborations both internally and externally.

Missouri S&T is embarking on a bold new undertaking to bring together and advance biologically focused research across our campus. A major focus of this "Bio-X" initiative is to position ourselves as partners in education and research in key areas that will complement ongoing efforts in the UM system such as the precision medicine initiative as well as partnerships with medical schools. Creating a PhD program in bioengineering is an important part of the Bio-X vision.

**Alignment with college goals.** The mission of the College of Engineering and Computing (CEC) is to (i) Provide our students with a transformative education that prepares and inspires them to shape the future, and to (ii) Lead the way in improving our world and in solving grand societal challenges through research and innovation. The overall goal and objectives of the proposed bioengineering PhD program align very well with this mission in that the program will prepare students for transformative careers in bioengineering and foster cutting-edge research which will address grand societal challenges in health and related areas. This program will allow faculty in CEC departments outside of Chemical and Biochemical Engineering to supervise students with interests in bioengineering or biomedical engineering and to more effectively compete for NIH support in related program areas.

**Alignment with departmental goals.** Within the Doshi Department of Chemical and Biochemical Engineering, the biochemical engineering emphasis area was established alongside the traditional chemical engineering degree more than 30 years ago. The goal has always been to grow this biochemical track into independent undergraduate and graduate degree programs. Our proposal for a PhD program in bioengineering will help us to reach this goal. The department is well-prepared to take the next step and create this new degree

program. We also anticipate growth in student enrollment and research productivity through the new PhD program. We anticipate that this program will attract additional NIH funding through its focus on mentorship and research activities. With the increased financial support from NIH, we will be able to offer a greater number of research opportunities to our students. These opportunities will allow students to participate in cutting-edge research under the guidance of seasoned researchers. Moreover, the increased funding will enable us to provide our students with enhanced facilities and resources. This includes access to the most up-to-date research tools, software, and laboratory equipment, further enriching their learning and research experience.

## **2.B. Duplication & Collaboration within Campus, Across System**

There is no similar PhD program at Missouri S&T.

While there are existing programs within the UM System that have some similarity, our proposed PhD program in bioengineering is unique in its distinct focus on the engineering applications of biochemistry, particularly in the areas of biomaterials and biomanufacturing. The University of Missouri-Columbia offers a PhD in biomedical sciences, which primarily delves into medical sciences and examines the relationship between molecular- or cellular-level changes and mammalian physiology. The University of Missouri-Kansas City (UMKC) provides an interdisciplinary PhD in biomedical and health informatics, centered on biomedical information, data, and knowledge for problem-solving and decision-making. In contrast, our bioengineering PhD program emphasizes the practical applications of biochemistry as they relate specifically to engineering themes. These include the development and utilization of biomaterials, biomanufacturing processes, bioseparations, and pharmaceutical process engineering.

The University of Missouri-Columbia (MU) also offers a PhD program in biological engineering, jointly developed by the College of Agriculture, Food and Natural Resources and the College of Engineering. This program's research areas include biological and biomedical imaging, computational approaches for environmental sustainability, neuroengineering, and regenerative medicine. While there are some potential overlaps here, our proposed bioengineering program is primarily focused on biomaterials, biomanufacturing, bioseparations, and pharmaceutical process engineering.

We believe our proposed program will complement other biologically-focused PhD programs at MU and further enhance our ability to connect with biological and medical research on the other three UM campuses. For example, NextGen Precision Health is a systemwide effort led by MU, uniting the UM system's four public research universities with a shared vision to accelerate innovations in precision health to improve health outcomes for Missourians and the world. Our new PhD program will put us in a better position to contribute to NextGen Precision Health initiatives by graduating highly skilled researchers, fostering collaborations among the four campuses, and translating new findings into clinical applications. Our program will provide engineering research that will inform medicine and drug delivery.

The bioengineering PhD program is designed to promote collaborations with existing graduate programs at Missouri S&T and across the UM System. The proposed bioengineering PhD program will bring together faculty from 13 separate academic departments (Biological Sciences, Chemical and Biochemical Engineering, Chemistry, Computer Science, Civil, Architectural and Environmental Engineering, Electrical and Computer Engineering, Engineering Management and Systems Engineering, Materials Science and Engineering, Mathematics & Statistics, Mechanical and Aerospace Engineering, Mining and Explosives Engineering, Nuclear Engineering and Radiation Science, Psychological Science) spanning three colleges at Missouri S&T (the College of Engineering and Computing, the College of Arts, Sciences, and Education, and the Kummer College of Innovation, Entrepreneurship, and Economic Development (see **Appendix 1**).

We have begun discussions about initiating the bioengineering PhD program with college leaders at both MU and UMKC. We have also explored potential collaborations among various faculty members across different campuses. Beyond these individual engagements, we have nurtured broader institutional collaborations within the UM system in this field. Our ongoing collaborations with MU are particularly noteworthy. Specifically, through our cooperation with NextGen Precision Health in the realm of precision health, and the newly established MU Materials Science & Engineering Institute (MUMSEI) in the field of materials science, we have identified biomaterials as a pivotal field of collaboration. In the spring of 2023, we successfully hosted a joint symposium between Missouri S&T and NextGen. The event saw active participation from faculty and graduate students who contributed by delivering talks and presenting posters. Furthermore, MUMSEI and Missouri S&T have established a formal and ongoing line of communication, inviting faculty to offer virtual seminars to unearth new collaborative opportunities. We believe that our joint efforts in this area will lead to significant advancements in bioengineering that can substantially impact the field of precision health.

In addition to these collaborations, Missouri S&T plays an integral role in MU's NIH R25 training grant, "Biomedical Innovation Entrepreneurial Training for Aging (BETA)." This initiative provides an excellent platform for our bioengineering doctoral students to expand their skill set and engage in entrepreneurial activities, further enriching their educational experience.

Moreover, we recently partnered with the University of Missouri–St. Louis (UMSL) on the National Science Foundation proposal entitled "NSF Engines: Type-2: Reshoring API Manufacture through Innovation." In this collaborative venture, Missouri S&T's attention is primarily directed towards innovation and workforce development for downstream pharmaceutical processes and continuous manufacturing processes. These specific areas of focus not only distinguish our bioengineering program but are also essential in facilitating the reshoring of pharmaceutical manufacturing.

No existing programs will be combined, placed on inactive status, or deleted as a result of implementing our proposed bioengineering PhD program.

## **3. Business-Related Criteria & Justification**

### **3.A. Market Analysis**

#### **3.A.1. Rationale & Workforce Demand for the Program**

The growing biotechnology market, valued at around US\$ 417 billion in 2018, is projected to expand to over US\$ 950 billion by 2027, with a compound annual growth rate (CAGR) of more than 9.4% (Global Market Insight). Bioengineering is an interdisciplinary field, so pinpointing an exhaustive list of job titles for graduates encompassing all bioengineering-related jobs is challenging. We employed the Lightcast™ databases to assess workforce demand for bioengineers and biomedical engineers with doctoral degrees.

Although there are many opportunities in our state, we focused our market analysis on a national level due to the rapidly evolving nature and wide geographical distribution of opportunities in bioengineering and biomedical engineering. A national perspective allows us to align our program with broader trends and workforce needs, while preparing our students, who come from diverse backgrounds, for career opportunities in Missouri and elsewhere across the country. This approach helps ensure our program's competitiveness and relevance. The Lightcast™ report supports the need for a sizable workforce in bioengineering at various education levels nationally. Jobs for bioengineers and biomedical engineers in 2022 were projected to grow by 15% over the next decade (2022-2032). The top posted job titles include Engineering Managers, Project Engineers, Directors of Engineering, Chief Engineers, and Biomedical Engineers. In particular, 11.6% of these jobs require doctoral level education. This implies that out of the 18,963 bioengineering and biomedical engineering job openings in 2022, approximately 2,200 required PhD qualifications. However, the number of PhD graduates in this field in 2021 was only 1,117, indicating a significant gap between the supply and demand in the workforce. This shortage underlines the critical need for more graduates with PhD degrees in bioengineering and biomedical engineering to meet the burgeoning industry demand.

This new PhD program will help build strong connections with the pharmaceutical and biotech industries in our region, and could help in attracting more of these companies to our state. The STL 2030 Jobs Plan reveals that St. Louis City's Equitable Economic plan, the St. Louis metro is home to five strong subsectors that have the potential to drive growth. One of them is the biomedical and health service subsector, which consists of local health services, biopharmaceuticals, and medical devices. Biomedical and health service occupations in the region require educational degrees at various levels. This subsector employs over 198,500 people and represents over 10 percent of non-governmental employment in the St. Louis area. Employment in this subsector grew by 4% from 2012-2018, to which rapidly growing industries emerging within the ecosystem, most notably within biopharmaceuticals, contributed actively.

This robust market demand underlines the importance of a bioengineering PhD program to meet Missouri's academic and economic needs. We have received letters of support from



employers, community partners, and other stakeholders, which can be found in **Appendix 2**. Additionally, quotes from the letters emphasize the value of this program and its alignment with key competencies employers are seeking in graduates, further validating the proposed curriculum.

Bipin Doshi, Trustee Missouri S&T, Board Member KI Foundation, Past Chair Beacon Health System Board, South Bend, Indiana states that *“This new degree will develop a workforce for bioengineering jobs that will contribute to the growth and economic development of Missouri and the nation.”* He stresses that *“There is great demand in the Medical and Biomedical field for biomanufacturing, drug delivery, biomaterials, biomedical devices, imaging devices and technology, antiaging science, as well as preventive and regenerative medicines and technology. Early detection of cancer and other chronic diseases and reversing the onset of certain debilitating conditions will significantly improve the chances of successful treatment and recovery”*.

Jason Shenefield, President and CEO, Phelps Health, declares that *“As a leading healthcare provider in the region, we recognize the value and potential of such a program in advancing the field of bioengineering and meeting the growing demand for skilled professionals.”* Furthermore, Phelps Health expresses interest in working with us to *“explore new opportunities for educational initiatives, internships, and research activities through this program”*. He adds that *“such a program will greatly benefit our healthcare system, the university, and the broader community by fostering the growth of biomedical engineering professionals and promoting innovative healthcare solutions.”*

Justin Sperry, Vice President – Transformational Technology and Chesterfield Site Head, Pfizer, states that *“The bioengineering industry has seen rapid growth in recent years, with a rising need for skilled professionals in biomanufacturing and biomaterials. As a global leader in biopharmaceuticals, Pfizer is well aware of the increasing demand for experts who can develop innovative solutions to address complex challenges in the production and distribution of vital therapies. A new bioengineering PhD program at Missouri S&T would contribute significantly to satisfying the increasing demand for skilled talent in the workforce”*. He adds that *“The institution's track record of producing top-quality engineering graduates, combined with the expertise of the Doshi Department of Chemical and Biochemical Engineering, gives us confidence in the program's potential to produce outstanding bioengineering professionals”*.

Mart Berutti, Vice President Sales, Life Sciences of Emerson points out that *“Missouri has several large employers in addition to Emerson that could benefit from the skills of a PhD in Bioengineering. These include development labs like Pfizer in Chesterfield, Contract Development and Manufacturing Organizations like Millipore Sigma and Thermofisher Patheon in St. Louis, as well the many cell and gene therapy startups throughout the state.”* He adds that *“The Life Sciences industry is changing rapidly as the promise of personalized healthcare grows under the development of new cell, gene, and tissue therapies. NGO's like BioSTL and Continuous API are working to support the growth of large and small molecule production as well as emerging therapies in Missouri. The addition of a PhD Bioengineering program would support this initiative.”*

Charles W. Lyon, Senior Vice President and Chief Commercial Officer, FutureFuel Chemical Company, shows strong support for this new program development. FutureFuel Chemical Company is a specialty chemical company with corporate headquarters in St. Louis, MO and a world-class, fully integrated manufacturing facility sitting on 2,200 acres in Batesville, AR (north-central Arkansas, about a 3 hour drive from Rolla). He points out that *“I hope you can recognize how valuable and attractive a Bioengineering PhD program would be to a company like Futurefuel Chemical Company. We have routinely recruited chemical engineering (mechanical and electrical engineering too!) graduates from Missouri S&T, and those that have worked for us have (or had) very challenging work and perform at a very high standard. It would be excellent to also recruit engineers and scientists associated with a new program like this to support our strategy for the pharma industry. Secondly, I see opportunities for FutureFuel and the department to collaborate in joint research projects in areas such as process development and equipment design (ie. flow reactor technology). Finally, much opportunity lies ahead for us to identify additional ways the Bioengineering program could support my company's success, and we, in turn, can support the program and department.”*

Sarah Bock, Director Capital Engineering, Curium, indicates that *“Curium, a leading global manufacturer and distributor of nuclear medicine products, stands to benefit greatly from graduates of the bioengineering doctoral program at Missouri S&T.”* She emphasizes that *“the establishment of a bioengineering PhD program at Missouri S&T will address the increasing demand for bioengineers and biomedical engineers in the St. Louis area and beyond”*.

Ralph Grant, Director of Business Development-Associate, Clark, Richardson and Biskup Consulting Engineers, Inc., substantiates workforce demand and states that *“CRB has numerous associates and senior fellows that currently have PhD's in biochemical engineering and are considered THE subject matter experts when it comes to biochemical processes, including upstream and downstream processing. Our teams were some of the first to develop industrial scale biologics and we are deeply concerned as that workforce continues to age and retire. There is a significant gap in the market for that talent.”* He further confirms that *“We most certainly would consider the right candidates as additional team members to our staff and see a PhD in Bioengineering to be an asset”*.

Fred Kielhorn, CEO, DeNovix Inc. states that *“The creation of a bioengineering PhD program at Missouri S&T would not only cater to the expanding demand for proficient experts in the industry but also enhance the university's stature as a premier institution in the engineering field.”* Furthermore, he is *“dedicated to supporting the new bioengineering PhD program at Missouri S&T in various ways, including providing internships and sharing my industry insights and experiences with students and faculty.”*

Brian K. Donley, P.E., bd Solutions, LLC, also echoed the need for developing a bioengineering PhD program. He says *“In my role as a research and development leader, I recruited and directed numerous chemistry and biological PhDs. As an engineer, I was disappointed in the lack of bioengineering graduate programs and bioengineering researchers. Unlike traditional fields, emerging bio-programs lack the research coupling of pure science and engineering.”* He adds that *“The Chemical and Biological Engineering department's proposal for a Bioengineering PhD program provides a solution to this unmet need. The establishment of this*

*program will expand the graduate opportunities at MS&T, enabling researchers in the bioengineering field to make new discoveries at one of the nation's premiere research institutions."*

Dr. Jorge A. Ochoa, Managing Partner, Principal Engineer, Biomedical Dynamics LLC, states that *"Establishing a graduate program in biomedical engineering at Missouri S&T will provide talented students with the opportunity to engage in cutting-edge research and interdisciplinary collaboration, preparing them to make significant contributions to the healthcare industry. Graduates of the program will be well-equipped to design and develop medical devices, diagnostic tools, and therapeutic techniques that can save lives, reduce pain, and improve patient health outcomes."* He adds that *"this program will bring immense benefits to Missouri S&T and the state of Missouri. The expansion of Missouri S&T's engineering and technology education, research, and innovation capabilities will drive economic growth, job creation, and attract top talent to the region"*.

In addition to the external letters of support, there are two internal letters of support that are from: Dr. Colin Potts, Provost and Executive Vice Chancellor for Academic Affairs, and Dr. David Borrok, Vice Provost and Dean of College of Engineering and Computing.

### **3.A.2. Student Demand for the Program**

According to the National Academy of Engineering, one of 14 grand challenges for Engineering in the 21st century is to Engineer Better Medicine. We are embracing this grand challenge by preparing the engineering workforce of the future at the intersection of engineering and medicine. According to the Lightcast™ reports, in 2021, a total of 1117 doctorate degrees in bioengineering or biomedical engineering were conferred by 118 public and private institutions in the United States. Among these degrees, 672 were awarded by public institutions and 445 by private institutions. An average of 9.5 doctorate degrees were produced by each institution. In 2021, among all doctoral degree programs, the biomedical engineering and bioengineering programs were ranked third in the US for the number of doctoral degrees awarded. The total number of degrees has risen by 9% over the last 5 years, but the growing market in the US is far from saturated with doctorates in this area. The national workforce in these occupations has not been met. In 2022, there were 2202 jobs that required a doctorate degree in bioengineering or biomedical engineering. A job growth of 15% is anticipated for biomedical engineers and bioengineers with a doctoral or professional degree for the next decade (2022-2032).

The chemical engineering BS- and MS-degree programs at Missouri S&T will be a strong source for students for the proposed bioengineering PhD program. Over the last five years (2017-2021), we have graduated on average 99 chemical engineering BS degree students and 11 MS degree students per year. Our department has a history of offering chemical engineering BS degrees with a biochemical engineering emphasis, and there is an existing biomedical engineering (BME) minor administered by the Materials Science and Engineering Department. There is a sustained interest in bioengineering on our campus, with an average of 21 students annually graduating with either a BME minor or biochemical engineering

emphasis or both between 2017 and 2021. Some fraction of our undergraduate and MS students will stay to complete the new PhD degree in bioengineering. We also expect to attract students on our campus from peripheral backgrounds like materials science and engineering, electrical engineering, chemistry, and biological sciences. An important feature of our bioengineering PhD program is that it is designed to accommodate students with a range of academic experience and interests, but with a common goal of exploring the educational and research opportunities that exist at the interface between medicine and engineering.

**Table 1. S&T Student Interest in Bioengineering PhD Program**

<b>Degree Program</b>	<b>No. of Respondents</b>	<b>Interest in Bioengineering PhD</b>	<b>Interest in Bioengineering PhD at S&amp;T</b>
ChE BS	12	4	2
ChE BS with BioChE	13	12	10
Biological Sciences MS	9	6	6
<b>Total</b>	<b>34</b>	<b>22</b>	<b>18</b>

Chemical Engineering (ChE), Biochemical Engineering (BioChE)

We conducted an anonymous survey among students currently enrolled in undergraduate and master's programs in chemical and biochemical engineering and in biological sciences. According to the survey outcomes, students pursuing a BS in chemical engineering without a focus on biochemical engineering show lower interest in the program, with only 2 out of 12 respondents expressing interest in the proposed bioengineering Ph.D., which is understandable as most of them are pretty set on their career path and many have job offers already. Encouragingly, we observe that students pursuing a BS in chemical engineering with biochemical engineering emphasis (BioChE) show the highest interest among the students in the pipeline, with 12 out of 13 respondents expressing interest in bioengineering Ph.D. and 10 out of 13 in a bioengineering Ph.D. program at Missouri S&T. Students pursuing a MS in biological sciences also expressed great interest in the program, with 6 out of 9 respondents expressing interest in bioengineering Ph.D. at Missouri S&T. Overall, there is a high student demand for a bioengineering PhD program at Missouri S&T, particularly among students with a BS in chemical engineering with biochemical engineering emphasis and students with a MS in biological sciences or non-chemical engineering program.

In addition to a pipeline of local students in chemical engineering and biological sciences, our program will be attractive to other undergraduate and MS students in Missouri and the nation. One way to gauge potential interest is to consider the success of similar programs in our region. For example, from 2015 through 2019, the University of Missouri-Columbia averaged enrollments of 186 undergraduate students in their bio-engineering portfolio (biological engineering, biomedical engineering, and bioengineering). This healthy undergraduate enrollment was matched by a healthy enrollment in biomedical engineering PhDs, with average enrollments of 34 students per year over the same timeframe. Washington University in St. Louis in Missouri is another producer of doctoral degrees in biomedical engineering. It awarded 18 doctoral degrees in 2021. Nonetheless, we feel there is still ample room for an additional graduate program within the UM System and in Missouri,

one that is built on our reputation for excellence in engineering education. With the strength of our existing undergraduate degree programs and recruitment of other students nationally and internationally, we anticipate similar or larger enrollments once the program is established.

We anticipate a starting enrollment of five PhD students with an annual growth of about five to seven students such that we reach an enrollment target of 25 within five years. This includes the expectation that students in the program graduate after four years on average. Like our chemical engineering PhD program, we anticipate receiving a large number of applicants. The actual number of applicants accepted into the program will be primarily determined by the available funds available to pay for graduate research assistantships. As the program grows, we anticipate more faculty will be able to advise and fund more bioengineering PhD students. In return, this will foster a more productive research environment that will attract additional funding.

**Table 1a. Student Enrollment Projections** (anticipated total number of students enrolled in the program during the first five fall semesters following implementation.)

<b>Year:</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
<b>Full-time</b>	5	10	15	20	25
<b>Part-time</b>	0	0	0	0	0
<b>Total</b>	5	10	15	20	25

We expect to admit five students per year, including both new and transfer students, during the first four years of the program. Subsequently, the enrollment is projected to increase to eight students in year five. Please note that these projections take into account students who are anticipated to graduate in the spring or summer semesters of year four, thus reflecting the net enrollment figures.

**Table 1b. New Student Enrollment Projections** (anticipated number of students enrolled in the program during the first five fall semesters following implementation that are new to the University.)

<b>Fiscal Year:</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
<b>Full-time</b>	3	8	13	18	23
<b>Part-time</b>					
<b>Total</b>	3	8	13	18	23

We anticipate to accept internal transfer students to this new program and estimate two transfer students per year in years 1-5. Transfer students are recategorized as continuing students in their second year.

**Table 1c. Projected Number of Degrees Awarded**

<b>Year:</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>
<b># of Degrees Awarded</b>	0	0	0	3	5	5	5	5	7	8

We anticipate students to finish their degrees in four or five years and expect some transfer students to graduate sooner.

### **3.B. Financial Projections**

A completed Pro Forma for the financial projections is included as **Appendix 3**. It was reviewed and endorsed by S&T's fiscal officer.

#### **3.B.1. Additional Resources Needed**

The new bioengineering Ph.D. program has been crafted to rely primarily on existing personnel, resources, and infrastructure at Missouri S&T. The host department and college are committed to providing needed support. Existing resources and infrastructure at the institution are sufficient to support the creation of this new program until it grows to capacity. In years 3-5, we anticipate the need for a half-time staff position to coordinate program activities, oversee laboratory operations, and offer crucial support to students in our expanding bioengineering Ph.D. program. Additionally, to enable essential laboratory activities, we foresee a continuous requirement for funding to cover course-related laboratory costs throughout the program's initial five years. Given that we plan to utilize existing resources and faculty, we don't foresee an immediate need for new hires to launch the program. However, to ensure the long-term sustainability of the program, we do anticipate recruiting new faculty members in the fields of bioengineering or biomedical engineering within the next few years. We've incorporated the budget for these faculty hires into a recent degree proposal for a biomedical engineering BS degree program, which includes the appointment of one tenure-track faculty member and one non-tenure track teaching faculty member in the third year. As these positions are also designed to support the proposed bioengineering PhD program, their associated costs are not included here, as they have already been included in the overall budget for the biomedical engineering BS program, thereby ensuring a comprehensive and sustainable financial plan.

#### **3.B.2. Revenue**

We expect that this new PhD program will boost grant productivity and attract major awards from federal funding agencies such as the NIH. Students in the new bioengineering PhD program will be supported primarily with research assistantships derived from this external funding. A small number of students will be supported as graduate teaching assistants (GTAs). Within 5 years, we anticipate having at least 25 full-time students (50% FTE) enrolled in this program with 20 fully funded by external sources, primarily the NIH. The tuition paid by these students represents revenue for the program. The tuition and fees generated by these graduate students will be approximately \$292,257 in year five after reduction of GTA stipends. GTA stipends will be offset by the revenue generated in the preceding years. In addition, we anticipate patent revenue to be generated in the longer term because bioengineering research projects are highly likely to have patentable research outcomes. The Kummer Institute and Office of Research and Innovation at Missouri S&T have

the capacity to help us develop incubators for new ideas, ultimately leading to economic benefit.

We will evaluate the bioengineering PhD program annually, track costs and revenue, and recognize the effort and credit of all participating faculty and their affiliated departments. This way, any adjustments to marketing and recruiting can be made quickly. Such annual analysis will also provide a basis for the allocation of internal resources and for the justification of student support, and additional faculty and staff positions.

**3.B.3. Net Revenue**

Starting from the first year, annual revenue is projected to exceed annual expenses.

**Table 2. Financial Projections for Proposed Program for Years 1 Through 5.**

	Year 1	Year 2	Year 3	Year 4	Year 5
<b>1. Expenses per year</b>					
<b>A. One-time</b>					
<i>New/Renovated Space</i>					
<i>Equipment</i>					
<i>Library</i>					
<i>Consultants</i>					
<i>Other</i>					
<b>Total one-time</b>	0	0	0	0	0
<b>B. Recurring</b>					
<i>Faculty</i>					
<i>Staff</i>			\$20,000	\$20,600	\$21,218
<i>Benefits</i>			\$7,124	\$7,124	\$7,124
<i>Graduate Teaching Assistants</i>	0	\$52,680	\$80,601	\$109,617	\$139,762
<i>Equipment</i>					
<i>Library</i>					
<i>Other (lab needs)</i>	\$10,000	\$10,000	\$20,000	\$20,000	\$20,000
<b>Total recurring</b>	\$10,000	\$10,000	\$47,124	\$47,124	\$47,124
<b>Total expenses (A+B)</b>	\$10,000	\$62,680	\$127,725	\$157,555	\$188,538
<b>2. Revenue per year</b>					
<i>Tuition/Fees</i>	\$67,500	\$137,700	\$210,681	\$286,526	\$365,321
<i>Institutional Resources (Scholarship Allowance)</i>		(\$27,540)	(\$42,136)	(\$57,305)	(\$73,064)
<i>State Aid -- CBHE</i>					
<i>State Aid -- Other</i>					
<b>Total revenue</b>	\$67,500	\$110,160	\$168,545	\$229,221	\$292,257
<b>3. Net revenue (loss) per year</b>	\$57,500	\$47,480	\$40,820	\$71,666	\$103,719
<b>4. Cumulative revenue (loss)</b>	\$57,500	\$104,980	\$145,799	\$217,465	\$321,184

Financial projections for a 50% enrollment scenario have also been developed. In this situation, the program will request additional support from the university and reduce the budget for lab costs, staff and GTAs to reflect the reduced need for the program.

### **3.B.4. Academic and Financial Viability**

The PhD in Bioengineering will leverage existing financial resources to enhance research activities within Missouri S&T. Minimal costs are associated with the program, which will be covered through strategic reallocation of existing resources within Missouri S&T. Consequently, there is no minimum enrollment required for financial viability. With respect to academic viability, we anticipate a minimum enrollment of 10 students to maintain a vibrant and active learning environment.

**Table 3. Enrollment for Academic and Financial Viability**

<b>Viability</b>	<b>Minimum Enrollment</b>
Academic	10
Financial	N/A
Overall	10

## **3.C. Business Plan: Marketing, Student Success, Transition & Exit Strategies**

### **3.C.1. Marketing Plan**

The marketing plan for our new bioengineering PhD program will involve a multi-faceted approach to reach our target audience, promote the program's unique offerings, and attract prospective students. Our marketing efforts will be primarily managed by the University's Marketing and Communications Department, with shared responsibility by the Department Chair of Chemical and Biochemical Engineering and our participating faculty members.

Key components of our marketing plan include:

**Rebranding:** Once the program is approved, the department will pursue authorization to rebrand as the Doshi Department of Chemical and Biomedical Engineering. This new name will underscore the coexistence of two distinct programs within the department. By effectively conveying its updated identity and vision, the department aims to cultivate robust relationships across academia, industry, and the wider community, and to become an obvious destination for students interested in bioengineering PhD careers.

**Digital Marketing:** We will leverage our University's website, social media platforms, and digital media to highlight the program's strengths, share news about research breakthroughs, showcase faculty expertise, and present student success stories. Digital marketing efforts will also include search engine optimization, targeted Google Ads, and social media advertising campaigns.



**Recruitment Events:** Our admissions team will attend regional and national college fairs, graduate school visits, and other targeted recruitment events to raise awareness about the program. We will also host open house events, virtual information sessions, webinars, and develop workshops to provide prospective students and their families with an opportunity to learn more about our program and campus.

**Collaboration with Universities, Research Institutions, and External Partnerships:** We will establish partnerships with universities, research institutions, national organizations, foundations, and community organizations to facilitate joint research projects, conferences, and events to increase program awareness and encourage enrollment. We will also join the campus efforts with the American Institute of Chemical Engineers, Biomedical Engineering Society, International Society of Pharmaceutical Engineers, and other relevant professional societies.

**Alumni Engagement and Industry Partnerships:** We will engage our alumni network and industry partners to serve as ambassadors for the program, share their experiences, and help us connect with prospective students and create opportunities for research collaborations, internships, and job placements for our graduates.

**Press Releases and Announcements:** When the program launches, we will prepare a press release and send out announcements to appropriate professional societies, such as the American Institute of Chemical Engineers, Biomedical Engineering Society, International Society of Pharmaceutical Engineers, American Society for Engineering Education (ASEE), and target corporations through a listserv or other forms of communication.

We will monitor enrollment trends, marketing analytics, and collect feedback from enrolled students to better understand their decision-making process, which will help us refine our marketing efforts. We will evaluate the program annually to track costs and revenue, and make adjustments to marketing and recruiting strategies as needed. By working with the University's marketing team, we don't anticipate additional costs for marketing.

### **3.C.2. Student Success Plan**

The Doshi Department of Chemical and Biochemical Engineering at Missouri S&T is committed to fostering the success of bioengineering PhD students. We have developed a comprehensive student success plan that focuses on supporting and retaining students through graduation. The plan incorporates the following key components:

**Academic Support:** The department will provide academic support services such as tutoring, workshops, and study groups to assist students in mastering challenging course material. We will also provide access to research resources, such as software, laboratory equipment, and facilities, to help students excel in their research endeavors.

**Faculty Mentorship:** Each PhD student will have a faculty mentor/advisor who will guide them through their research and academic journey and provide graduate assistantships. Mentors will offer advice, support, and networking opportunities, as well as regular progress meetings to ensure students stay on track with their research and degree milestones.

**Financial Support:** We will strive to secure funding opportunities for students through research assistantships, teaching assistantships, and fellowships. These opportunities not only help students finance their education but also provide valuable professional experience.

**Professional Development:** The Office of Graduation Education on campus will offer professional development workshops and seminars that focus on skills such as grant writing, research presentation, job searching, and networking. These opportunities will prepare students for successful careers in academia, industry, or government sectors.

**Interdisciplinary Collaboration:** Students will be encouraged to collaborate with researchers from other departments and disciplines within the University. This exposure to diverse perspectives will enrich their research experience and expand their professional network.

**Career Services:** We will work closely with the University's Career Services to provide students with access to job listings, resume workshops, mock interviews, and job fairs. These services will help students successfully transition from the program to rewarding careers in their chosen field.

**Wellness and Mental Health Support:** Recognizing the importance of mental health and well-being, we will provide students with access to counseling services, stress-management workshops, and wellness resources, to help them maintain a healthy work-life balance throughout their PhD journey.

**Peer Support:** The department will facilitate the creation of student-led support groups, where students can share experiences, discuss challenges, and celebrate successes. These groups will foster a sense of community and belonging among students.

**Regular Progress Assessment:** The department will closely monitor student progress through annual evaluations, ensuring they are on track to complete their degree requirements in a timely manner. This feedback will help students identify areas of improvement and address any challenges they may face.

The student success plan is designed to support bioengineering PhD students in achieving their academic and professional goals. The department's track record of student success in other programs, such as our BS, MS and PhD degrees in chemical engineering, demonstrates our commitment to fostering a supportive and enriching learning environment. By implementing this plan, we aim to ensure that our bioengineering PhD students graduate with the skills, knowledge, and experiences necessary to excel in their careers.

### **3.C.3. Transition Plan**

If the department chair who is primarily responsible for the program leaves the institution or assumes other responsibilities, a transition plan will be in place to ensure program continuity and quality. The plan includes the appointment of an interim department chair by the vice-provost and dean of the College of Engineering and Computing. This will be followed by a national search to identify and hire a new department chair. If the program coordinator leaves or assumes other responsibilities, the department chair will appoint a new member of the faculty as the program coordinator.

### **3.C.4. Exit Strategy**

If the program underperforms expectations or fails to meet minimum enrollment criteria for financial viability continuously for several years after the initial period, the following exit strategy will be implemented:

1. A thorough program evaluation will be conducted by the Office of the Provost to identify any areas in need of improvement or adjustment.
2. Marketing and recruitment efforts will be re-assessed and adjusted as needed to attract more students.
3. If the program continues to underperform after implementing these changes, the University will place the program on hiatus to re-evaluate its offerings and strategies.
4. If the program must be discontinued, the department will develop a teach-out plan to ensure that currently enrolled students can complete their degree requirements in a timely manner. This may include offering necessary courses until all enrolled students graduate or assisting students in transferring to comparable programs at other institutions.

## **4. Institutional Capacity**

Missouri S&T has a strong foundation and the necessary resources to support the implementation of the new bioengineering PhD program.

While leveraging existing assets to a maximum extent, this new program does include the development and delivery of several new courses. The Doshi Department of Chemical and Biochemical Engineering (ChBE) currently has 12 tenure track (TT)/non-tenure track (NTT) faculty members, 1 lecturer, adjunct faculty and affiliated faculty. Currently, the department is conducting a national search for a junior faculty position in bioengineering. We anticipate this junior faculty position to be filled by spring 2024. The addition of this new faculty member will be more than sufficient to initiate the PhD program. As the program goes new hires may will be added in the future.

ChBE is housed in Bertelsmeyer Hall, a recently constructed (2017) 68,500-square-foot, three-story building. The department manages state-of-art equipment and laboratories dedicated to chemical and biochemical engineering research and teaching activities. There is enough existing space in Bertelsmeyer Hall to accommodate the faculty, staff, and classes requirements anticipated for the new program. The University also has a Bio-Imaging Facility, a Bioanalytical Laboratory, a Histology Laboratory, and a small animal vivarium, which we will leverage to support the proposed program. Within the College of Engineering and Computing, faculty who will be affiliated with the bioengineering PhD program maintain facilities and equipment dedicated to creating and testing biomaterials (e.g., materials science and engineering), biosensors, signal processing, and imaging (electrical and computer engineering), bioprinting (mechanical engineering), and other engineering specialties.

The Office of Graduate Education at Missouri S&T also offers a comprehensive range of services to support current and prospective graduate students.

## **5. Program Characteristics**

### **5.A. Program Outcomes**

Upon completing the bioengineering PhD program at Missouri S&T, graduates will possess a strong foundation in bioengineering principles and advanced research skills. Specifically, students are expected to demonstrate a comprehensive understanding of core bioengineering concepts, such as biomaterials, drug and gene delivery, tissue engineering, cellular and molecular bioengineering. They will develop expertise in a specialized area of bioengineering through focused research and coursework, exhibit proficiency in utilizing advanced research techniques, state-of-the-art tools, and software relevant to bioengineering. Graduates will also demonstrate the ability to critically analyze, synthesize, and evaluate scientific literature and research findings in bioengineering.

Furthermore, students will exhibit effective written and oral communication skills for disseminating research findings to diverse audiences, including scientific communities, industry professionals, and the public. They will develop skills in interdisciplinary collaboration, working effectively with researchers from various fields to address complex bioengineering problems. Finally, graduates of the program will demonstrate ethical awareness and professional responsibility in conducting bioengineering research and addressing related challenges.

Graduates will be equipped to apply these skills in academic, industrial, or clinical settings. In addition to core bioengineering competencies, graduates of the program will have experience in advanced research methods, interdisciplinary collaboration, and effective communication. These skills will enable them to excel in their chosen careers and contribute significantly to the advancement of the bioengineering field.

## 5.B. Program Design & Content

The proposed bioengineering PhD program will be situated and managed within the Doshi Department of Chemical and Biochemical Engineering at Missouri S&T. The degree program will also involve collaboration among faculty members from 13 distinct academic departments across three colleges at Missouri S&T, including Biological Sciences, Chemical and Biochemical Engineering, Chemistry, Computer Science, Civil, Architectural and Environmental Engineering, Electrical and Computer Engineering, Engineering Management and Systems Engineering, Materials Science and Engineering, Mathematics & Statistics, Mechanical and Aerospace Engineering, Mining and Explosives Engineering, Nuclear Engineering and Radiation Science, and Psychological Science. These departments fall under the College of Engineering and Computing, the College of Arts, Sciences, and Education, and the Kummer College of Innovation, Entrepreneurship, and Economic Development.

To provide all our students with core competencies within the bioengineering PhD program, students will choose three courses from the list of five below. Three of these core courses currently exist and two new courses (labeled BIO ENG 6XXX) will be added.

### **Core Courses (minimum of 9 hrs required):**

1. *BIO ENG 6XXX Biomanufacturing* (LEC 3.0)
2. *BIO ENG 6XXX Pharmaceutical Process Engineering* (LEC 3.0)
3. *CHEM ENG 5250 Isolation and Purification of Biologicals* (LEC 3.0)
4. *CHEM ENG 5001 Drug and Gene Delivery* (LEC 3.0)
5. *MSE 5200 Biomaterials I* (LEC 3.0)

### **Ethics (1 hr required)**

*BIO ENG 5XXX Integrity and Ethics in Bioengineering* (LEC 1.0)

This course presents research and professional ethics, legal and ethical standards, and codes of ethics and integrity relevant to the profession. Students must pass one credit hour course in ethics.

### **CHEM ENG 6015 Lecture Series (minimum of 2 hrs required)**

All students will take two semesters of the CHEM ENG 6015 graduate seminar series. One faculty member in the department will serve as seminar coordinator on a rotating basis. Graduate seminars often include written assignments (reflection reports) about seminar presentations. In the future, we plan to co-list this offering with existing seminar series in Biology, Chemistry, and Materials Science and Engineering to provide additional content options for students.

It is a common practice in academic programs that if a student entering the program has already completed a course or courses considered equivalent to the required core course(s), those core courses can be waived and substituted with elective courses (see below). Decisions regarding course equivalency will be made upon the student's request by the program coordinator, in consultation with the course instructors.

The list of elective courses below is largely based on existing courses from eight supporting departments at Missouri S&T. Those courses are organized into multiple thematic clusters as suggested below. Also, the *Core Courses* not chosen by a student for their 9 hour requirement may be used to satisfy the *Elective Courses* requirement.

### **Elective Courses (minimum of 18 hrs required)**

#### **Biomufacturing and Biochemical Engineering Process Design**

1. *CHEM ENG 4210 Biochemical Reactors (LEC 3.0)*
2. *CHEM ENG 4220 Biochemical Reactor Laboratory (LAB 2.0 and LEC 1.0)*
3. *CHEM ENG 5001 Drug and Gene Delivery (LEC 3.0) (LEC 3.0)*
4. *CHEM ENG 5100 Intermediate Transport Phenomena (LEC 3.0)*
5. *CHEM ENG 5120 Interfacial Phenomena in Chemical Engineering (LEC 3.0)*
6. *CHEM ENG 5150 Intermediate Process Computing (LAB 1.0 and LEC 2.0)*
7. *CHEM ENG 5161 Intermediate Molecular Engineering (LEC 3.0)*
8. *CHEM ENG 5200 Biomaterials I (LEC 3.0)*
9. *CHEM ENG 5210 Intermediate Biochemical Reactors (LEC 3.0)*
10. *CHEM ENG 5211 Intermediate Bioreactor Laboratory (LAB 2.0 and LEC 1.0)*
11. *CHEM ENG 5250 Isolation and Purification of Biologicals (LEC 3.0)*
12. *CHEM ENG 5251 Intermediate Bioseparations Laboratory (LAB 2.0 and LEC 1.0)*
13. *CHEM ENG 5220 Intermediate Engineering Thermodynamics (LEC 3.0)*

#### **Biomaterials and Tissue Engineering**

14. *CHEM ENG 5300 Principles of Engineering Materials (LEC 3.0)*
15. *CHEM ENG 5320 Introduction to Nanomaterials (LEC 3.0)*
16. *CHEM ENG 6150 Molecular Modeling and Simulation (LEC 3.0)*
17. *CHEM ENG 6300 Biomaterials II (LEC 3.0)*
18. *ELEC ENG 5810 Computational Intelligence (LEC 3.0)*
19. *ELEC ENG 6260 Integrated Microsystems Engineering (LAB 1.5 and LEC 1.5)*
20. *MECH ENG 5229 Smart Materials and Sensors (LAB 1.0 and LEC 2.0)*
21. *MS&E 5210 Tissue Engineering (LEC 3.0)*
22. *MS&E 5460 Molecular Engineering of Materials (LEC 3.0)*
23. *MS&E 6210 Advanced Tissue Engineering (LEC 3.0)*
24. *MS&E 6460 Advanced Molecular Engineering of Materials (LEC 3.0)*
25. *ENV ENG 6601 Biological Principles in Environmental Engineering Systems (LAB 1.0 and LEC 2.0)*
26. *ENV ENG 6612 Biological Operations in Environmental Engineering Systems (LEC 3.0)*

### **Data Analysis and Computational Modelling**

- 27. *STAT 5346 Regression Analysis* (LEC 3.0)
- 28. *STAT 6344 Design And Analysis Of Experiments* (LEC 3.0)
- 29. *COMP SCI 5401 Evolutionary Computing* (LEC 3.0)
- 30. *COMP SCI 5700 Bioinformatics* (LEC 3.0)

### **Biochemical Interactions and Applications in Medicine and Nanotechnology**

- 31. *CHEM 5001 Medicinal Chemistry* (LEC 3.0)
- 32. *CHEM 5610 Biochemistry* (LEC 3.0)
- 33. *CHEM 5620 Biochemical Metabolism* (LEC 3.0)
- 34. *CHEM 5630 Biochemical Nanotechnology* (LEC 3.0)
- 35. *BIO SCI 5533 Pharmacology* (LEC 3.0)
- 36. *BIO SCI 6413 Molecular Cell Biology* (LEC 3.0)
- 37. *BIO SCI 6523 Advanced Biomolecules* (LEC 3.0)
- 38. *BIO SCI 6666 Advanced Nanotechnology in Biomedicine* (LEC 3.0)

Students are required to select at least six courses (equivalent to 18 hours) from a mixture of both existing and newly introduced courses that are listed under the thematic clusters. In addition, students can choose any additional Core Course once they have met the category's minimum requirement of 9 credit hours. To ensure a comprehensive understanding of the themes, students are required, through advising, to engage with at least two different thematic areas. This is a requirement designed to provide structure and enhance interdisciplinary learning. While engagement with three themes is highly recommended, a minimum of two themes is mandatory.

Students, with the guidance of their advisors and committees, will devise an acceptable pathway that aligns with their research interests and, in some cases, helps prepare them for the required core courses. The CHEM ENG 4210 and 5250 courses are particularly beneficial for students entering the program without a robust background in chemical or biochemical engineering, as these courses aim to augment their foundational knowledge.

As the bioengineering PhD program evolves and expands, additional courses will be developed and added to the above list. Choices of the above courses can effectively form a specific bioengineering thematic area within the PhD program and could also earn the student a graduate certificate in designated concentration areas when such options are made available in the future. Faculty members from the participating departments will be allowed to directly advise bioengineering PhD students. More faculty members are expected to be added to the list (**Appendix 1**) as the bioengineering PhD program expands and more bioengineering-related faculty members are hired.

The proposed Ph.D. program in bioengineering will admit highly qualified students with relevant engineering and science backgrounds but the primary recruiting target will be those with BS or MS degrees in chemical engineering, biochemical engineering, biomedical engineering, biomolecular engineering, or biological engineering, as they will be able to take all the core courses directly. As explained above, well-prepared students from related

disciplines may need to take some elective courses to prepare for the core courses and in rare cases may need lower division leveling courses identified by their advisors.

## 5.C. Program Structure

Students who enter the program directly with a BS degree will need to complete a minimum of 72 credit hours beyond their BS degree, which includes a minimum of 30 credit hours of 4000-, 5000-, and 6000-level lecture courses. A student entering with a MS degree can receive up to 30 credit hours toward their PhD, so that they would need to complete only the remaining 42 credit hours, including a minimum of 12 credit hours of 4000-, 5000-, and 6000-level lecture courses.

In addition, students are required to pass a PhD qualifying exam before their 5<sup>th</sup> semester and a comprehensive PhD exam after completing at least 50% of the required coursework for their PhD degree. When they are ready and have obtained sufficient results from their research, students must complete a written dissertation and successfully defend the dissertation in their final examination (defense).

### 5.C.1. Program Structure Form

1. **Total Credits Required for Graduation:** 72
2. **Residence requirements, if any:** None
3. **General education**
  - a. Total general education credits: None
4. **Major Requirements**
  - a. Total credits specific to degree: 13 (9 hours selected from the 5 core courses; 1 hour Integrity and Ethics in Bioengineering; and 3 hours Lecture Series),

Courses (specific course or distribution area and credit hours):

Course	Hrs	Course	Hrs	Course	Hrs
Biomanufacturing	3	Pharmaceutical Process Engineering	3	Isolation and Purification of Biologicals	3
Drug and Gene Delivery	3	Biomaterials I	3		
Integrity and Ethics in Bioengineering	1				
Lecture Series	3				



## 5. Free elective credits

- a. Total free elective credits: 15

Although there are no completely unrestricted electives, students are able to choose from a list of elective courses to fulfill 15 credit hours of electives.

## 6. Requirement for thesis, internship or other capstone experience:

A dissertation is an essential component of earning a bioengineering PhD. To complete the program and obtain the degree, PhD candidates must successfully submit and defend their bioengineering research in the form of a dissertation.

## 7. Any unique features such as interdepartmental cooperation:

Courses that are required for the program will be instructed by faculty members from Chemical and Biochemical Engineering, and Materials Science and Engineering. For elective courses, students may choose from a range of degree programs, such as those offered by Biological Sciences, Chemical and Biochemical Engineering, Chemistry, Computer Science, Electrical Engineering, Environmental Engineering, Mathematics, and Materials Science and Engineering.

### 5.D. Program Goals and Assessment

The bioengineering PhD program at Missouri S&T is committed to ensuring that students achieve the Graduate Learning Outcomes (GLOs) in knowledge, communication, integrity and ethics, scholarship independence, and critical thinking.

**Knowledge:** Students will demonstrate mastery of the contemporary state of knowledge within their discipline through original and substantial contributions.

**Communication:** Students will demonstrate mastery in communication (oral and written) in the standards of published work in their discipline.

**Integrity and Ethics:** Students will demonstrate the highest standards of professional behavior, integrity, and ethical conduct.

**Scholarship Independence:** Students will demonstrate the ability to independently identify, explain, and develop scholarship including a clear plan for addressing open research questions in their field.

**Critical Thinking:** Students will demonstrate the independent, self-directed, ability to evaluate arguments, assess assumptions about information and data, and synthesize knowledge.

To achieve this, the program will develop and implement a comprehensive assessment plan that evaluates students' progress in these areas. This assessment plan includes mapping course learning outcomes to departmental and campus learning outcomes, selecting appropriate assessment tools linked to specific activities or courses, and specifying the frequency of measurements for each tool. A well-defined plan for reviewing and using assessment data will be established, including setting clear criteria for meeting learning outcomes, such as requiring a certain percentage of students to achieve a specific score or level. This comprehensive approach will ensure the program's effectiveness in fostering student success and achieving its goals.

To ensure the success of the program, specific goals for student retention and graduation rates will be set based on historical data, benchmarking with peer institutions, and ongoing program improvements. These rates will be monitored and reported regularly. We anticipate 85% retention and graduation rates or higher. Furthermore, we aim for a 100% placement rate. Graduates will secure positions such as postdoctoral fellowships, or roles in academia, industry, healthcare, or government.

Additionally, the program will describe other measures of success, such as external research funding, faculty and student awards, industry partnerships, or alumni achievements. These measures will be assessed regularly to ensure that the program is achieving its goals and contributing to the advancement of the bioengineering field.

## **5.E. Student Preparation**

The bioengineering PhD program at Missouri S&T targets highly motivated students who have completed a bachelor's or master's degree in chemical engineering, biomedical engineering, biology, chemistry, or a related field. These individuals should have a strong foundation in mathematics, biology, physics, and chemistry, as well as a background in engineering principles to ensure success in the program. Prior research experience is beneficial, but not mandatory.

Applicants may be required to submit a compelling statement of purpose outlining their research interests and goals, along with letters of recommendation from faculty or professionals in the field. The program recognizes the interdisciplinary nature of bioengineering and welcomes well-prepared students from peripheral disciplines. To accommodate diverse academic backgrounds, these students may need to take elective courses to build the necessary foundation for core courses. In rare cases, lower-division leveling courses identified by their advisors might be required, which fall outside the standard program curriculum. This inclusive approach ensures that all admitted students can strengthen their foundational knowledge and excel in the bioengineering PhD program, regardless of their specific academic background.

## 5.F. Faculty and Administration

Dr. Hu Yang, department chair, will be the primary point person for the program, while Dr. Jee-Ching Wang, associate chair for research and graduate coordinator, will serve as program coordinator for this new program and help track activities, students, and advising for the proposed bioengineering PhD program.

This program requires interdepartmental cooperation. A key component of the proposed PhD program is to welcome researchers, students, and ideas from all relevant backgrounds. Participating faculty members (**Appendix 1**) will offer courses listed in the curriculum or mentor students enrolled in the program. Students in the program will have the opportunity to work across disciplines and develop their own individualized plans of study. Similar opportunities are also available to participating faculty on both the research and education fronts. While the proposed curriculum includes the important element of flexibility, it also includes a powerful set of core courses, including offerings in biomanufacturing and biomaterials, which are existing strengths at Missouri S&T.

All participating faculty have relevant qualifications and experience in the field of bioengineering or related areas. PhD advisors are required to hold doctoral faculty status, and committee members must have graduate faculty status.

The curriculum will be evaluated annually using a steering committee of representatives from participating departments, together with the Chair and Graduate Coordinator of the host department. The committee will be charged with meeting annually to discuss and possibly revise curricular requirements in addition to discussing the need for adjusting research priorities, admission criteria, student-advisor assignments, and so on. The chair of the supervisory committee will be the program coordinator of the bioengineering PhD program.

## 5.G. Alumni and Employer Survey

We are committed to continuously gathering feedback from both alumni and employers to evaluate and improve the quality of this new program. Surveys and communication channels are utilized to collect relevant information, ensuring that the program meets the expectations and requirements of both alumni and employers. The following methods and schedules are used for collecting feedback from these key stakeholders:

### **Alumni Survey:**

Method: Online questionnaires and mailed surveys are sent to alumni who graduated three to five years prior. The survey focuses on evaluating their satisfaction with the program and the extent to which it prepared them for their careers.

Schedule: Alumni surveys are conducted biennially, allowing for a comprehensive and up-to-date understanding of alumni perspectives.

Expected/desired satisfaction rates: The department aims to achieve a satisfaction rate of at least 80% among respondents, with the goal of continuously improving the program based on alumni feedback.

### **Employer Survey:**

Method: Online questionnaires and surveys are distributed to employers of the program's graduates. The surveys seek to evaluate the preparedness and performance of alumni in their respective workplaces, as well as solicit suggestions for program improvements.

Schedule: Employer surveys are conducted every three years, allowing sufficient time to gather meaningful feedback while keeping the information current.

Expected/desired satisfaction rates: The department aims to achieve a satisfaction rate of at least 85% among employer respondents, using their input to adapt the program to better meet industry needs and expectations.

In addition to the scheduled surveys, the department encourages ongoing communication with alumni and employers through various channels, including departmental events, Industrial Advisory Council meetings, and direct communication with alumni and employers at on-campus career fairs. This continuous feedback loop helps to ensure that the program stays relevant and aligned with the needs of both alumni and employers.

## **5.H. Program Accreditation**

This new bioengineering PhD degree needs no accreditation to function but will be assessed together with other graduate degrees in the chemical engineering graduate program via the Higher Learning Commission.

## **6. Appendices**

- Appendix 1: List of Participating Faculty Members (page 30)
- Appendix 2: Letters of Support (page 31)
- Appendix 3: New Program Pro Forma\_ Bioengineering PhD (page 50)
- Appendix 4: Response to External Reviews (page 51)