

# BIOLOGICAL SYSTEMS ENGINEERING

For the undergraduate curriculum in biological systems engineering leading to the degree bachelor of science. The Biological Systems Engineering program is accredited by the Engineering Accreditation Commission of ABET, <http://www.abet.org/>.

Biological Systems Engineering integrates life sciences with engineering to solve problems related to, or using, biological systems. These biological systems may include microbes, plants, animals, humans and/or ecosystems. Biological systems engineers have a worldview shaped by an understanding of fundamental principles of engineering and life-sciences. They use their understanding of engineering to analyze organisms or ecosystems, and their knowledge of biological systems to inspire and inform their designs. They approach engineering design from a biological systems perspective, appreciating the complexity of biological systems and developing solutions that accommodate and anticipate the adaptability of biological systems.

**Goal:** To educate students to solve problems related to biorenewables production and processing, water quality, environmental impacts of the bioeconomy, food processing, and biosensors, and in so doing to prepare students for professional practice and post-graduate educational opportunities.

**Program Educational Objectives:** Three to five years after graduation, our graduates will be using the knowledge, skills, and abilities from their biological systems engineering degree to improve the human condition through successful careers in a wide variety of fields. They will be effective leaders, collaborators, and innovators who address environmental, social, technical, and business challenges. They will be engaged in life-long learning and professional development through self-study, continuing education, or graduate/professional school.

Well-qualified juniors and seniors in biological systems engineering who are interested in graduate study may apply for concurrent enrollment in the Graduate College to simultaneously pursue a bachelor of science degree in biological systems engineering and a master of science degree in agricultural engineering. Under concurrent enrollment, students are eligible for assistantships and simultaneously take undergraduate and graduate courses.

A concurrent bachelor of science and master of business administration program is also offered by the department.

The department also offers a bachelor of science curriculum in agricultural engineering. See College of Engineering (<http://catalog.iastate.edu/previouscatalogs/2020-2021/collegeofengineering/>). Additionally, the department offers bachelor of science curricula in

agricultural systems technology and in industrial technology. See College of Agriculture and Life Sciences (<http://catalog.iastate.edu/previouscatalogs/2020-2021/collegeofagricultureandlifesciences/>).

The department also participates in interdepartmental majors in environmental science, sustainable agriculture, biorenewable resources and technology, human computer interaction, and toxicology (see Index (<http://catalog.iastate.edu/previouscatalogs/2020-2021/azindex/>)).

## Curriculum in Biological Systems Engineering

Administered by the Department of Agricultural and Biosystems Engineering.

Leading to the degree bachelor of science.

### Total credits required:

**128.0 cr Biorenewable Resources Option**

**127.0 cr Bioenvironmental Engineering Option**

**128.0 cr Food Engineering Option**

**128.0 cr Open Option.**

**Any transfer credit courses applied to the degree program require a grade of C or better (but will not be calculated into the ISU cumulative GPA, Basic Program GPA or Core GPA). See also Basic Program and Special Programs. International Perspectives: 3 cr.<sup>1</sup>**

**U.S. Diversity: 3 cr.<sup>1</sup>**

### Communication Proficiency/Library requirement:

ENGL 150	Critical Thinking and Communication (Must have a C or better in this course)	3
ENGL 250	Written, Oral, Visual, and Electronic Composition (Must have a C or better in this course)	3
LIB 160	Information Literacy	1
Communication Elective: One of the following (Must have a C or better in this course)		3
AGEDS 311	Presentation and Sales Strategies for Agricultural Audiences	
ENGL 309	Proposal and Report Writing	
ENGL 314	Technical Communication	
MKT 450	Advanced Professional Selling	
SP CM 212	Fundamentals of Public Speaking	
SP CM 312	Business and Professional Speaking	

### Social Sciences and Humanities: 12 cr. <sup>1,2</sup>

3 credits from international perspectives-university approved list	3
3 credits from U.S. diversity-university approved list	3
6 credits from Social Sciences and Humanities courses-department approved list	6

**Total Credits** 12

### Basic Program: 24 cr.

A minimum GPA of 2.00 required for this set of courses (please note that transfer course grades will not be calculated into the Basic Program

GPA). See Requirement for Entry into Professional Program in College of Engineering Overview section. Within the Biological Systems Engineering Basic Program, students are required to complete CHEM 167 and CHEM 167L or the sequence of CHEM 177, CHEM 177L, and CHEM 178. This is a departmental requirement within the College of Engineering Basic Program requirements. The CHEM 178 course will show as completing the chemistry portion of the Basic Program and the credits will be applied towards a student's classification.

A B E 160	Systematic Problem Solving and Computer Programming <sup>3</sup>	3
CHEM 167	General Chemistry for Engineering Students or CHEM 177 and CHEM 178	4
ENGL 150	Critical Thinking and Communication (Must have a C or better in this course)	3
ENGR 101	Engineering Orientation	R
LIB 160	Information Literacy	1
MATH 165	Calculus I	4
MATH 166	Calculus II	4
PHYS 221	Introduction to Classical Physics I	5
<b>Total Credits</b>		<b>24</b>

**Biological, Math and Physical Science: 23 cr.**

BIOL 212	Principles of Biology II	3
CHEM 167L	Laboratory in General Chemistry for Engineering or CHEM 177L Laboratory in General Chemistry I	1
Chemistry Sequence I (select from list of lecture with corresponding lab)		4
CHEM 231	Elementary Organic Chemistry	
CHEM 231L	Laboratory in Elementary Organic Chemistry	
CHEM 331	Organic Chemistry I	
CHEM 331L	Laboratory in Organic Chemistry I	
MATH 267	Elementary Differential Equations and Laplace Transforms	4
MICRO 302	Biology of Microorganisms	3
MICRO 302L	Microbiology Laboratory	1
STAT 305	Engineering Statistics (Chemistry Sequence I)	3
Chemistry Sequence II (select from list of lecture with corresponding lab)		4
CHEM 211	Quantitative and Environmental Analysis	
CHEM 211L	Quantitative and Environmental Analysis Laboratory	
CHEM 332	Organic Chemistry II	
CHEM 332L	Laboratory in Organic Chemistry II	
FS HN 311	Food Chemistry	

FS HN 311L	Food Chemistry Laboratory	
<b>Total Credits</b>		<b>23</b>

**Biological Systems Engineering Core: 45 cr.**

(A minimum GPA of 2.00 required for this set of courses, including any transfer courses; please note that transfer course grades will not be calculated into the Core GPA).

A B E 216	Fundamentals of Agricultural and Biosystems Engineering	3
A B E 218	Project Management & Design in Agricultural and Biosystems Engineering	2
A B E 273	CAD for Process Facilities and Land Use Planning	1
A B E 316	Applied Numerical Methods for Agricultural and Biosystems Engineering	3
A B E 363	Agri-Industrial Applications of Electric Power and Electronics	4
A B E 380	Principles of Biological Systems Engineering	3
A B E 404	Instrumentation for Agricultural and Biosystems Engineering	3
A B E 415	Agricultural & Biosystems Engineering Design I	2
A B E 416	Agricultural & Biosystems Engineering Design II	2
A B E 451	Food and Bioprocess Engineering	3
A B E 480	Engineering Analysis of Biological Systems	3
C E 274	Engineering Statics	3
E M 324	Mechanics of Materials	3
E M 327	Mechanics of Materials Laboratory	1
E M 378	Mechanics of Fluids	3
I E 305	Engineering Economic Analysis	3
M E 231	Engineering Thermodynamics I	3
<b>Total Credits</b>		<b>45</b>

**Other Remaining Courses: 11 cr.**

A B E 110	Experiencing Agricultural and Biosystems Engineering	1
A B E 170	Engineering Graphics and Introductory Design	3
A B E 201	Preparing for Workplace Seminar	1
ENGL 250	Written, Oral, Visual, and Electronic Composition (Must have a C or better in this course)	3
Communication Elective: One of the following (Must have a C or better in this course)		3
AGEDS 311	Presentation and Sales Strategies for Agricultural Audiences	
ENGL 309	Proposal and Report Writing	
ENGL 314	Technical Communication	
MKT 450	Advanced Professional Selling	

SP CM 212	Fundamentals of Public Speaking	
SP CM 312	Business and Professional Speaking	
<b>Total Credits</b>		<b>11</b>

Complete remaining courses from one of the following options:

**Biorenewable Resources Engineering Option: 13 cr.**

A B E 325	Biorenewable Systems	3
A B E 469	Engineering for Grain Storage, Preservation, Handling, and Processing Systems	3
M E 436	Heat Transfer	4
Biorenewable Elective (select 3cr from the following):		3
SCM 301	Supply Chain Management	
FS HN 471	Food Processing	
<b>Total Credits</b>		<b>13</b>

**Bioenvironmental Engineering Option: 12 cr.**

A B E 431	Design and Evaluation of Soil and Water Conservation Systems	3
C E 326	Principles of Environmental Engineering	3
C E 372	Engineering Hydrology and Hydraulics	3
Bioenvironmental Elective <sup>2</sup>		3
<b>Total Credits</b>		<b>12</b>

**Food Engineering Option: 13 cr.**

A B E 469	Engineering for Grain Storage, Preservation, Handling, and Processing Systems	3
FS HN 420	Food Microbiology	3
M E 436	Heat Transfer	4
Food Elective (select 3 cr from the following):		3
FS HN 471	Food Processing	
SCM 301	Supply Chain Management	
<b>Total Credits</b>		<b>13</b>

**Open Option: 13 cr.**

M E 436	Heat Transfer	4
Sequence I, II & III Elective <sup>2</sup>		9
<b>Total Credits</b>		<b>13</b>

**Co-op/Internships (Optional)**

1. These university requirements will add to the minimum credits of the program unless the university-approved courses are also approved by the department to meet other course requirements within the degree program.

U.S. Diversity, International Perspectives and Social Science/ Humanities courses may not be taken Pass/Not Pass.

2. Choose from department approved list. (<http://www.abe.iastate.edu/undergraduate-students/biological-systems-engineering/bse-curricula/>)
3. See Basic Program for Professional Engineering Curricula for accepted substitutions for curriculum designated courses in the Basic Program.

See also: A 4-year plan of study grid showing course template by semester for Biological Systems Engineering. (<http://catalog.iastate.edu/previouscatalogs/2020-2021/collegeofengineering/biologicalsystemsengeering/#fouryearplanstext>)

Biological Systems Engineering, B.S. - bioenvironmental engr option

**First Year**

Fall	Credits Spring	Credits
ENGR 101	R A B E 110	1
A B E 170	3 A B E 160	3
CHEM 167	4 MATH 166	4
CHEM 167L	1 PHYS 221	5
MATH 165	4 ENGL 250	3
ENGL 150	3	
LIB 160	1	
<b>16</b>		<b>16</b>

**Second Year**

Fall	Credits Spring	Credits
A B E 216	3 A B E 218	2
C E 274	3 A B E 201	1
BIOL 212	3 A B E 273	1
Chemistry Sequence I with Lab	4 M E 231	3
US Diversity Elective	3 MATH 267	4
	Chemistry Sequence II with Lab	4
<b>16</b>		<b>15</b>

**Third Year**

Fall	Credits Spring	Credits
A B E 316	3 A B E 363	4
E M 378	3 A B E 380	3
MICRO 302	3 C E 372	3
MICRO 302L	1 E M 324	3
STAT 305	3 I E 305	3
Communication Elective	3	
<b>16</b>		<b>16</b>

Fourth Year		
Fall	Credits Spring	Credits
A B E 415	2 A B E 416	2
A B E 404	3 A B E 451	3
A B E 431	3 C E 326	3
A B E 480	3 E M 327	1
Social Science or Humanities Elective	3 Bioenvironmental Elective	3
International Perspectives Elective	3 Social Science or Humanities Elective	3
<b>17</b>		<b>15</b>

Biological Systems Engineering, B.S. - biorenewable resources engr option

First Year		
Fall	Credits Spring	Credits
ENGR 101	R A B E 110	1
A B E 170	3 A B E 160	3
CHEM 167	4 MATH 166	4
CHEM 167L	1 PHYS 221	5
MATH 165	4 ENGL 250	3
ENGL 150	3	
LIB 160	1	
<b>16</b>		<b>16</b>

Second Year		
Fall	Credits Spring	Credits
A B E 216	3 A B E 218	2
C E 274	3 A B E 201	1
BIOL 212	3 A B E 273	1
Chemistry Sequence I with Lab	4 M E 231	3
US Diversity Elective	3 MATH 267	4
	Chemistry Sequence II with Lab	4
<b>16</b>		<b>15</b>

Third Year		
Fall	Credits Spring	Credits
A B E 316	3 A B E 363	4
A B E 325	3 A B E 380	3
E M 378	3 E M 324	3
MICRO 302	3 I E 305	3
MICRO 302L	1 Communication Elective	3

STAT 305	3	
<b>16</b>		<b>16</b>

Fourth Year		
Fall	Credits Spring	Credits
A B E 415	2 A B E 416	2
A B E 404	3 A B E 451	3
A B E 480	3 A B E 469	3
Biorenewable Elective	3 E M 327	1
Social Science or Humanities Elective	3 M E 436	4
International Perspectives Elective	3 Social Science or Humanities Elective	3
<b>17</b>		<b>16</b>

Biological Systems Engineering, B.S. - Open Option

First Year		
Fall	Credits Spring	Credits
ENGR 101	R A B E 110	1
A B E 170	3 A B E 160	3
CHEM 167	4 MATH 166	4
CHEM 167L	1 PHYS 221	5
MATH 165	4 ENGL 250	3
ENGL 150	3	
LIB 160	1	
<b>16</b>		<b>16</b>

Second Year		
Fall	Credits Spring	Credits
A B E 216	3 A B E 218	2
C E 274	3 A B E 201	1
BIOL 212	3 A B E 273	1
Chemistry Sequence I with lab	4 M E 231	3
US Diversity Elective	3 MATH 267	4
	Chemistry Sequence II with Lab	4
<b>16</b>		<b>15</b>

Third Year		
Fall	Credits Spring	Credits
A B E 316	3 A B E 363	4
E M 378	3 A B E 380	3
MICRO 302	3 E M 324	3
MICRO 302L	1 I E 305	3
STAT 305	3 Sequence I Elective	3

Communication Elective	3	
	<b>16</b>	<b>16</b>

**Fourth Year**

Fall	Credits Spring	Credits
A B E 415	2 A B E 416	2
A B E 404	3 A B E 451	3
A B E 480	3 E M 327	1
Sequence II Elective	3 M E 436	4
International Perspectives Elective	3 Sequence III Elective	3
Social Science or Humanities Elective	3 Social Science or Humanities Elective	3
	<b>17</b>	<b>16</b>

Communication Elective	3	
	<b>16</b>	<b>16</b>

**Fourth Year**

Fall	Credits Spring	Credits
A B E 415	2 A B E 416	2
A B E 404	3 A B E 451	3
A B E 480	3 E M 327	1
FS HN 420	3 M E 436	4
Food Elective	3 Social Science or Humanities Elective	3
International Perspectives Elective	3 Social Science or Humanities Elective	3
	<b>17</b>	<b>16</b>

Biological Systems Engineering, B.S. Food Engineering Option

**First Year**

Fall	Credits Spring	Credits
ENGR 101	R A B E 110	1
A B E 170	3 A B E 160	3
MATH 165	4 MATH 166	4
CHEM 167	4 PHYS 221	5
CHEM 167L	1 ENGL 250	3
ENGL 150	3	
LIB 160	1	
	<b>16</b>	<b>16</b>

**Second Year**

Fall	Credits Spring	Credits
A B E 216	3 A B E 218	2
C E 274	3 A B E 201	1
BIOL 212	3 A B E 273	1
Chemistry Sequence I with Lab	4 M E 231	3
US Diversity Elective	3 MATH 267	4
	Chemistry Sequence II with Lab	4
	<b>16</b>	<b>15</b>

**Third Year**

Fall	Credits Spring	Credits
A B E 316	3 A B E 363	4
E M 378	3 A B E 380	3
MICRO 302	3 A B E 469	3
MICRO 302L	1 E M 324	3
STAT 305	3 I E 305	3

## Graduate Study

The department offers master of science, master of engineering, and doctor of philosophy degrees with a major in agricultural and biosystems engineering. Within the agricultural and biosystems engineering major the student may specialize in advanced machinery engineering, animal production systems engineering, biological and process engineering, occupational safety engineering, or water and environmental stewardship engineering. Details on current research programs available at <http://www.abe.iastate.edu/>.

For the master of science program, at least 30 credits of acceptable graduate work must be completed with a minimum of 22 credits of course work; corresponding numbers for the master of engineering program are 32 and 27. For the doctor of philosophy degree, at least 72 credits of acceptable graduate work must be completed with a minimum of 42 credits of course work. All Ph.D. students must complete a teaching/extension experience prior to graduation.

The department also offers both master of science and doctor of philosophy degrees in industrial and agricultural technology.

**Courses primarily for undergraduates:**

**A B E 102: Learning Communities**

Cr. 0.5. F.

8 week learning communities course focusing on student success, engineering, and department curriculum. Building community within the ABE Department. Offered on a satisfactory-fail basis only.

**A B E 110: Experiencing Agricultural and Biosystems Engineering**

(0-2) Cr. 1. S.

Laboratory-based, team-oriented experiences in a spectrum of topics common to the practice of agricultural and biosystems engineering.

Report writing, co-ops, internships, careers, registration planning.

**A B E 160: Systematic Problem Solving and Computer Programming**

(2-2) Cr. 3. S.

*Prereq: Credit or enrollment in MATH 143 or MATH 165*

Engineering approach to problem solution and presentation. Introduction to basic principles from dynamics, statics, conservation laws, and basic electricity. Use of spreadsheet programs and computer programming language(s) to solve and present engineering problems. Only one of ENGR 160, A B E 160, AER E 160, C E 160, CH E 160, CPR E 185, EE 185, IE 148, M E 160 and S E 185 may count towards graduation.

**A B E 170: Engineering Graphics and Introductory Design**

(2-2) Cr. 3.

Applications of multi-view drawings and dimensioning. Techniques for visualizing, analyzing, and communicating 3-D geometries. Application of the design process including written and oral reports.

**A B E 201: Preparing for Workplace Seminar**

(Cross-listed with TSM). (1-0) Cr. 1. F.S.

*Prereq: Prereq: Sophomore classification in AE, AST, BSE, or I TEC*

8 week course. Professionalism in the context of the engineering/technical workplace. Development and demonstration of key workplace competencies: teamwork, initiative, communication, and engineering/technical knowledge. Resumes; Cover Letters; Behavioral Based Interviewing; Industry Speakers; Preparation for internships experiences.

**A B E 216: Fundamentals of Agricultural and Biosystems Engineering**

(2-2) Cr. 3. F.

*Prereq: A B E 160 or permission of the instructor*

Application of mathematics and engineering sciences in agricultural and biosystems engineering. Emphasis is on solving engineering problems.

**A B E 218: Project Management & Design in Agricultural and Biosystems Engineering**

(1-2) Cr. 2. S.

*Prereq: A B E 216*

Project management - critical path, Gantt charts, resource allocations, basic project budgeting, and project management software. Engineering design approaches. Open-ended design projects to demonstrate the preceding principles through application of technical concepts taught in prerequisite coursework.

**A B E 271: Engineering Applications of Parametric Solid Modeling**

(1-2) Cr. 1. F.S.

*Prereq: A B E 170 or TSM 116 or equivalent*

8 week-course. Creating, editing, and documenting part and assembly models using Solidworks.

**A B E 272: Parametric Solid Models, Drawings, and Assemblies Using Creo Parametric**

(1-2) Cr. 1. F.S.

*Prereq: A B E 170 or TSM 116 or equivalent*

8 week-course. Applications of Creo Parametric software. Create solid models of parts and assemblies. Utilize the solid models to create design documentation (standard drawing views, dimensions, and notes) and for the geometric analysis of parts and assemblies.

**A B E 273: CAD for Process Facilities and Land Use Planning**

(1-2) Cr. 1. F.S.

*Prereq: ENGR 170 or TSM 116 or equivalent.*

8-week course. Application of 2-D AutoCAD software to create and interpret 2-D drawings and 3-D models of facilities. Topics include geometric construction, design documentation: (using views, dimension, notes), and AutoCAD specific features (i.e. Layers, Blocks, Standards, Styles).

**A B E 316: Applied Numerical Methods for Agricultural and Biosystems Engineering**

(2-2) Cr. 3. F.S.

*Prereq: A B E 160; MATH 266 or MATH 267*

Computer aided solution of agricultural engineering problems by use of numerical techniques and mathematical models. Systems analysis and optimization applicable to agricultural and biological systems.

**A B E 325: Biorenewable Systems**

(Cross-listed with TSM). (3-0) Cr. 3. F.

*Prereq: CHEM 163 or higher; MATH 140 or higher*

Converting biorenewable resources into bioenergy and biobased products. Biorenewable concepts as they relate to drivers of change, feedstock production, processes, products, co-products, economics, and transportation/logistics.

**A B E 340: Functional Analysis of Soil, Crop, and Machine Systems**

(2-2) Cr. 3. F.

*Prereq: A B E 216*

Principles of machine systems operation (tillage, crop establishment, harvesting and crop protection). Principles of soil and crop interactions with machine systems. Experimental and simulation techniques for testing and evaluation of agricultural field machinery for equipment performance, functional analysis and crop production management.

**A B E 342: Agricultural Tractor Power**

(2-3) Cr. 3. S.

*Prereq: Ch E 381 or M E 231*

Thermodynamic principles and construction of tractor engines. Fuels, combustion, and lubrication. Kinematics and dynamics of tractor power applications; drawbar, power take-off and traction mechanisms.

**A B E 363: Agri-Industrial Applications of Electric Power and Electronics**  
(3-2) Cr. 4. F.S.

*Prereq: A B E 216*

Single phase and three phase circuit design. Electrical safety. Electric motors and controls. Programmable logic controllers. Digital logic, instrumentation and sensors.

**A B E 380: Principles of Biological Systems Engineering**

(2-2) Cr. 3. S.

*Prereq: A B E 316*

Engineering analysis of biological systems, through the study of mass, energy, and information transport. Quantification and modeling of biological interactions, biological activities and bioreactor operations. Includes hands-on laboratory experiences on biological materials characterization, unit operation for bioprocesses and fermentation for producing bioproducts.

**A B E 388: Sustainable Engineering and International Development**

(Cross-listed with C E, E E). (2-2) Cr. 3. F.

*Prereq: Junior classification in engineering*

Multi-disciplinary approach to sustainable engineering and international development, sustainable development, appropriate design and engineering, feasibility analysis, international aid, business development, philosophy and politics of technology, and ethics in engineering. Engineering-based projects from problem formulation through implementation. Interactions with partner community organizations or international partners such as nongovernment organizations (NGOs). Course readings, final project/design report. Meets International Perspectives Requirement.

**A B E 396: Summer Internship**

Cr. R. Repeatable. SS.

*Prereq: Permission of department and Engineering Career Services*

Professional work period of at least 10 weeks during the summer. Students must register for this course prior to commencing work. Offered on a satisfactory-fail basis only.

**A B E 398: Cooperative Education**

Cr. R. Repeatable. F.S.

*Prereq: A B E 218 and permission of department and Engineering Career Services*

Professional work period. One semester per academic or calendar year. Students must register for this course before commencing work. Offered on a satisfactory-fail basis only.

**A B E 403: Modeling, Simulation, and Controls for Agricultural and Biological Systems**

(Dual-listed with A B E 503). (2-2) Cr. 3. Alt. S., offered odd-numbered years.

*Prereq: A B E 316, and A B E 363, and MATH 266 or MATH 267*

Modeling dynamic systems with ordinary differential equations. Introduction to state variable methods of system analysis. Analysis of mechanical, electrical, and fluid power systems. Analytical and numerical solutions of differential equations. Introduction to classical control theory. Feedback and stability examined in the s domain. Frequency response as an analytical and experimental tool. MATLAB will be used throughout the course for modeling. Individual and/or group projects required for graduate credit.

**A B E 404: Instrumentation for Agricultural and Biosystems Engineering**

(Dual-listed with A B E 504). (2-2) Cr. 3. F.

*Prereq: A B E 316 and A B E 363*

Interfacing techniques for computer-based data acquisition and control systems. Basic interfacing components including A/D and D/A conversion, signal filtering, multiplexing, and process control. Sensors and theory of operation applied to practical monitoring and control problems. Individual and group projects required for graduate credit.

**A B E 410: Electronic Systems Integration for Agricultural Machinery**

(Dual-listed with A B E 510). Cr. 3. S.

System architecture and design of electronics used in agricultural machinery and production systems. Emphasis on information technology and systems integration for automated agriculture processes. Design of Controller Area Network (CAN BUS) communication systems and discussion of relevant standards (ISO 11783 and SAE J1939). Application of technologies for sensing, distribution control, and automation of agricultural machinery will be emphasized.

**A B E 413: Fluid Power Engineering**

(Cross-listed with M E). (2-2) Cr. 3. F.

*Prereq: Credit or enrollment in E M 378 or M E 335, A B E 216 or M E 270*

Fundamental fluid power principles, symbols and schematics. Hydraulic fluid properties. Function and performance of components such as connections and fittings, filtration, pumps, valves, actuators, hydrostatic transmissions. Hydraulic system dynamics. Modeling and simulation of circuits. Analysis and design of hydraulic systems. Hydrostatic transmission design. Hands-on construction of circuits, measurement of system variables, and electrohydraulic control.

**A B E 415: Agricultural & Biosystems Engineering Design I**

(1-2) Cr. 2. F.S.

*Prereq: A B E 316 (majors only)*

Identification of current design problems in ag & biosystems engineering. Development of alternate solutions using creativity and engineering analysis and synthesis techniques.

**A B E 416: Agricultural & Biosystems Engineering Design II**

(1-2) Cr. 2. F.S.

*Prereq: A B E 415 (majors only)*

Selection of promising solutions to design problems identified in 415 for development by design teams. Presentation of designs through oral and written reports and prototypes.

**A B E 418: Fundamentals of Engineering Review**

(1-0) Cr. 1.

*Prereq: senior classification.*

8 week course. Review of core concepts covered in the Fundamentals of Engineering examination with emphasis on statics, dynamics, fluid mechanics, heat transfer, electric circuits, and engineering economics. Open to all College of Engineering seniors, however focus is on the general exam, not discipline specific exams.

**A B E 424: Air Pollution**

(Dual-listed with A B E 524). (Cross-listed with C E, ENSCI). (1-0) Cr. 1.

*Prereq: Either PHYS 221 or CHEM 178 and either MATH 166 or 3 credits in statistics. Senior classification or above*

1 cr. per module. Module A prereq for all modules; module B prereq for D and E.

**A B E 424A: Air Pollution: Air quality and effects of pollutants**

(Dual-listed with A B E 524A). (Cross-listed with C E, ENSCI). (1-0) Cr. 1.

*Prereq: Either PHYS 221 or CHEM 178 and either MATH 166 or 3 credits in statistics. Senior classification or above*

1 cr. per module. Module A prereq for all modules; module B prereq for D and E.

**A B E 424B: Air Pollution: Climate change and causes**

(Dual-listed with A B E 524B). (Cross-listed with C E, ENSCI). (1-0) Cr. 1.

*Prereq: Either PHYS 221 or CHEM 178 and either MATH 166 or 3 credits in statistics. Senior classification or above*

1 cr. per module. Module A prereq for all modules; module B prereq for D and E.

**A B E 424C: Air Pollution: Transportation Air Quality**

(Dual-listed with A B E 524C). (Cross-listed with C E, ENSCI). (1-0) Cr. 1.

*Prereq: C E 524A; PHYS 221 or CHEM 178; MATH 166 or 3 credits in statistics. Senior classification or above.***A B E 424D: Air Pollution: Off-gas treatment technology**

(Dual-listed with A B E 524D). (Cross-listed with C E, ENSCI). (1-0) Cr. 1.

*Prereq: C E 524A, C E 524B; Either PHYS 221 or CHEM 178 and either MATH 166 or 3 credits in statistics. Senior classification or above***A B E 424E: Air Pollution: Agricultural sources of pollution**

(Dual-listed with A B E 524E). (Cross-listed with C E, ENSCI). (1-0) Cr. 1.

*Prereq: Either PHYS 221 or CHEM 178 and either MATH 166 or 3 credits in statistics. Senior classification or above*

1 cr. per module. Module A prereq for all modules; module B prereq for D and E.

**A B E 431: Design and Evaluation of Soil and Water Conservation Systems**

(Dual-listed with A B E 531). (2-3) Cr. 3. F.

*Prereq: E M 378 or CH E 356*

Hydrology and hydraulics in agricultural and urbanizing watersheds. Design and evaluation of systems for the conservation and quality preservation of soil and water resources. Use and analysis of hydrologic data in engineering design; relationship of topography, soils, crops, climate, and cultural practices in conservation and quality preservation of soil and water for agriculture. Small watershed hydrology, water movement and utilization in the soil-plant-atmosphere system, agricultural water management, best management practices, and agricultural water quality. Graduate students will prepare several research literature reviews on topics covered in the class in addition to the other assignments.

**A B E 432: Nonpoint Source Pollution and Control**

(Dual-listed with A B E 532). (3-0) Cr. 3.

*Prereq: A B E 431 or C E 372*

Characteristics and courses of non-point source (NPS) pollution in agricultural and urban watersheds, computer modeling and NPS pollution for terrestrial and aquatic systems, strategies to control and manage NPS pollution of water bodies, total maximum daily loads (TMDLs) and integrated watershed management. Graduate students are required to review research papers and develop/deliver lecture models on assigned topics.

**A B E 436: Design and Evaluation of Soil and Water Monitoring Systems**

(Dual-listed with A B E 536). (2-3) Cr. 3. Alt. S., offered even-numbered years.

*Prereq: A B E 431*

Development of monitoring systems that support effective planning, performance evaluation, modeling, or environmental impact assessment of soil-, water-, and waste-management systems. Typical soil and water pollutants and physical, chemical, and biological characteristics that affect sample location and timing. Sample collection, documentation, chain-of-custody, and quality assurance procedures. In addition to other assignments, graduate students will prepare several research literature reviews on topics covered in the class and develop monitoring plans.



**A B E 437: Watershed Modeling and Policy**

(Dual-listed with A B E 537). (Cross-listed with ENSCI). (2-2) Cr. 3. Alt. F., offered odd-numbered years.

*Prereq: CE 372 or equivalent*

A project-based course on watershed-scale models for improving water quality. Legislative and judicial basis of the Total Maximum Daily Load (TMDL) program; approaches to TMDL development; principles and techniques for implementation; stakeholder engagement strategies. Hands-on experiences with GIS-interfaced models, data sources, calibration/validation, statistical assessment of model results, and simulation using multiple tools. In addition to other assignments, graduate students will present case studies of TMDLs using different modeling tools.

**A B E 451: Food and Bioprocess Engineering**

(Dual-listed with A B E 551). (3-0) Cr. 3. S.

*Prereq: A B E 216 and credit or enrollment in M E 436 or C H E 357; or F S H N 351 and MATH 266 or MATH 267*

Application of engineering principles and mathematical modeling to the quantitative analysis of transport phenomena in food and bioprocesses. Physical/chemical characteristics of foods and biological materials and systems, flow processes, thermal processes and separation processes.

**A B E 466: Multidisciplinary Engineering Design**

(Cross-listed with A E R E, B M E, C P R E, E E, E N G R, I E, M E, M A T E). (1-4) Cr. 3. Repeatable. F.S.

*Prereq: Student must be within two semesters of graduation; permission of instructor.*

Application of team design concepts to projects of a multidisciplinary nature. Concurrent treatment of design, manufacturing, and life cycle considerations. Application of design tools such as CAD, CAM, and FEM. Design methodologies, project scheduling, cost estimating, quality control, manufacturing processes. Development of a prototype and appropriate documentation in the form of written reports, oral presentations and computer models and engineering drawings.

**A B E 469: Engineering for Grain Storage, Preservation, Handling, and Processing Systems**

(Dual-listed with A B E 569). (2-3) Cr. 3. S.

*Prereq: A B E 216*

Cereal grain and oilseed production, properties, and quality assessment. Design of storage systems, drying systems, material handling, and size reduction systems. Design of cereal grain processing systems, including dry milling, wet milling, flour milling, feed milling, and fermentation facilities.

**A B E 472: Design of Environmental Modification Systems for Animal Housing**

(Dual-listed with A B E 572). (3-0) Cr. 3. Alt. S., offered even-numbered years.

*Prereq: A B E 216, M E 231*

Principles and design of animal environmental control systems. Insulation, heat and mass transfer, fans, ventilation, air distribution, heating and cooling equipment, and controls. Individual and group projects required for graduate credit.

**A B E 475: Design in Animal Production Systems Engineering**

(2-0) Cr. 2. F.S.

*Prereq: A B E 271, A B E 272, or A B E 273; E M 324 and enrollment in APSE option of AE program.*

Application of engineering fundamentals to the independent solution of an animal production systems engineering problem with well defined criteria and constraints in either environmental control, structural design, manure management, or air quality/mitigation.

**A B E 478: Wood Frame Structural Design**

(Dual-listed with A B E 578). (3-0) Cr. 3. Alt. S., offered odd-numbered years.

*Prereq: E M 324*

Design of light-framed wood structures using LRFD and ASD design procedures. Includes analysis of wind, snow, dead, and live loads. Applications include animal housing and machine storage. Fasteners, laminated posts, truss design and use of National Design Specifications.

**A B E 480: Engineering Analysis of Biological Systems**

(Dual-listed with A B E 580). (Cross-listed with ENSCI). (2-2) Cr. 3. F.

*Prereq: A B E 380 or permission of the instructor*

Systems-level quantitative analysis of various biological systems, including applications in foods, feeds, biofuels, bioenergy, and other bio-based systems. Introduction to techno-economic analysis and life-cycle assessment of these systems at multiple production scales. Applying these tools to evaluate and improve cost and sustainability performance. Students enrolled in ABE 580 will be required to conduct additional learning activities.

**A B E 490: A B E Independent Study**

Cr. 1-5. Repeatable.

Independent Study.

**A B E 490A: A B E Independent Study: Animal Production Systems Engineering**

Cr. 1-5. Repeatable.

Independent Study.

**A B E 490B: A B E Independent Study: Biorenewable Resources**

Cr. 1-5. Repeatable. F.S.SS.

Independent study.

**A B E 490E: A B E Independent Study: Environmental Bioprocessing Engineering**

Cr. 1-5. Repeatable. F.S.SS.

Independent study in environmental bioprocessing engineering.

**A B E 490F: A B E Independent Study: Food Engineering**

Cr. 1-5. Repeatable. F.S.SS.

Independent study in food engineering.

**A B E 490G: A B E Independent Study: General Topics in A B E**

Cr. 1-5. Repeatable. F.S.SS.

Independent study in general A B E topics.

**A B E 490H: A B E Independent Study: Honors**

Cr. 1-5. Repeatable.

Guided instructing in agricultural and biosystems engineering for honors students.

**A B E 490L: A B E Independent Study: Land & Water Resources Engineering**

Cr. 1-5. Repeatable.

Guided instruction in land and water resources engineering.

**A B E 490M: A B E Independent Study: Advanced Machinery Systems Engineering**

Cr. 1-5. Repeatable.

Guided instruction in advance machinery systems engineering.

**A B E 495: Agricultural and Biosystems Engineering Department Study Abroad Preparation or Follow-up**

(Cross-listed with TSM). Cr. 1-2. Repeatable. F.S.SS.

*Prereq: Permission of instructor*

Preparation for, or follow-up of, study abroad experience (496). For preparation, course focuses on understanding the tour destination through readings, discussions, and research on topics such as the regional industries, climate, crops, culture, economics, food, geography, government, history, natural resources, and public policies. For follow-up, course focuses on presentations by students, report writing, and reflection. Students enrolled in this course intend to register for 496 the following term or have had taken 496 the previous term.

Meets International Perspectives Requirement.

**A B E 496: Agricultural and Biosystems Engineering Department Study Abroad**

(Cross-listed with TSM). Cr. 1-4. Repeatable. F.S.SS.

*Prereq: Permission of instructor*

Tour and study at international sites relevant to disciplines of industrial technology, biological systems engineering, agricultural systems technology, and agricultural engineering. Location and duration of tours will vary. Trip expenses paid by students. Pre-trip preparation and/or post-trip reflection and reports arranged through 495.

Meets International Perspectives Requirement.

**Courses primarily for graduate students, open to qualified undergraduates:**

**A B E 503: Modeling, Simulation, and Controls for Agricultural and Biological Systems**

(Dual-listed with A B E 403). (2-2) Cr. 3. Alt. S., offered odd-numbered years.

*Prereq: A B E 316, and A B E 363, and MATH 266 or MATH 267*

Modeling dynamic systems with ordinary differential equations.

Introduction to state variable methods of system analysis. Analysis of mechanical, electrical, and fluid power systems. Analytical and numerical solutions of differential equations. Introduction to classical control theory. Feedback and stability examined in the s domain. Frequency response as an analytical and experimental tool. MATLAB will be used throughout the course for modeling. Individual and/or group projects required for graduate credit.

**A B E 504: Instrumentation for Agricultural and Biosystems Engineering**

(Dual-listed with A B E 404). (2-2) Cr. 3. F.

*Prereq: A B E 316 and A B E 363*

Interfacing techniques for computer-based data acquisition and control systems. Basic interfacing components including A/D and D/A conversion, signal filtering, multiplexing, and process control. Sensors and theory of operation applied to practical monitoring and control problems. Individual and group projects required for graduate credit.

**A B E 506: Applied Computational Intelligence**

(2-2) Cr. 3. Alt. F., offered even-numbered years.

*Prereq: A B E 316 or equivalent, MATH 166, STAT 305*

Applications of biologically inspired computational intelligence tools for data mining, system modeling, and optimization for agricultural, biological and other engineered systems. Introduction to Artificial Neural Networks, Support Vector Machines, Fuzzy Logic, Genetic Algorithms, Bayesian and Decision Tree learning. Fundamental Machine Vision techniques will be introduced in the first part of course and be integrated into the lab exercises for learning different computational intelligence techniques. MATLAB will be used throughout the course for algorithm implementation.

**A B E 510: Electronic Systems Integration for Agricultural Machinery**

(Dual-listed with A B E 410). Cr. 3. S.

System architecture and design of electronics used in agricultural machinery and production systems. Emphasis on information technology and systems integration for automated agriculture processes. Design of Controller Area Network (CAN BUS) communication systems and discussion of relevant standards (ISO 11783 and SAE J1939). Application of technologies for sensing, distribution control, and automation of agricultural machinery will be emphasized.

**A B E 511: Bioprocessing and Bioproducts**

(3-0) Cr. 3. F.

*Prereq: A B E 216 or equivalent, MATH 160 or MATH 165, one of CHEM 167 or higher, BIOL 173 or BIOL 211 or higher or BRT 501, senior or graduate classification*

Sustainability, cleaner production. Taxonomy, kinetics, metabolism, aerobic and anaerobic fermentation. Biofuels, bioenergy and coproducts. Mass/energy balances, process integration, pretreatment, separation. Membrane reactors, bioelectrolysis, microbial fuel cells, nanotechnology, genetic engineering, mutagenesis. Term paper for graduate level only.

**A B E 515: Integrated Crop and Livestock Production Systems**

(Cross-listed with AGRON, AN S, SUSAG). (3-0) Cr. 3. Alt. F., offered odd-numbered years.

*Prereq: SUSAG 509*

Methods to maintain productivity and minimize the negative ecological effects of agricultural systems by understanding nutrient cycles, managing manure and crop residue, and utilizing multispecies interactions. Crop and livestock production within landscapes and watersheds is also considered. Course includes a significant field component, with student teams analyzing Iowa farms.

**A B E 524: Air Pollution**

(Dual-listed with A B E 424). (Cross-listed with C E, ENSCI). (1-0) Cr. 1.

*Prereq: Either PHYS 221 or CHEM 178 and either MATH 166 or 3 credits in statistics. Senior classification or above*

1 cr. per module. Module A prereq for all modules; module B prereq for D and E.

**A B E 524A: Air Pollution: Air quality and effects of pollutants**

(Dual-listed with A B E 424A). (Cross-listed with C E, ENSCI). (1-0) Cr. 1.

*Prereq: Either PHYS 221 or CHEM 178 and either MATH 166 or 3 credits in statistics. Senior classification or above*

1 cr. per module. Module A prereq for all modules; module B prereq for D and E.

**A B E 524B: Air Pollution: Climate change and causes**

(Dual-listed with A B E 424B). (Cross-listed with C E, ENSCI). (1-0) Cr. 1.

*Prereq: Either PHYS 221 or CHEM 178 and either MATH 166 or 3 credits in statistics. Senior classification or above*

1 cr. per module. Module A prereq for all modules; module B prereq for D and E.

**A B E 524C: Air Pollution: Transportation Air Quality**

(Dual-listed with A B E 424C). (Cross-listed with C E, ENSCI). (1-0) Cr. 1.

*Prereq: C E 524A; PHYS 221 or CHEM 178; MATH 166 or 3 credits in statistics. Senior classification or above.*

**A B E 524D: Air Pollution: Off-gas treatment technology**

(Dual-listed with A B E 424D). (Cross-listed with C E, ENSCI). (1-0) Cr. 1.

*Prereq: C E 524A, C E 524B; Either PHYS 221 or CHEM 178 and either MATH 166 or 3 credits in statistics. Senior classification or above*

**A B E 524E: Air Pollution: Agricultural sources of pollution**

(Dual-listed with A B E 424E). (Cross-listed with C E, ENSCI). (1-0) Cr. 1.

*Prereq: Either PHYS 221 or CHEM 178 and either MATH 166 or 3 credits in statistics. Senior classification or above*

1 cr. per module. Module A prereq for all modules; module B prereq for D and E.

**A B E 531: Design and Evaluation of Soil and Water Conservation Systems**

(Dual-listed with A B E 431). (Cross-listed with ENSCI). (2-3) Cr. 3. F.

*Prereq: E M 378 or CH E 356*

Hydrology and hydraulics in agricultural and urbanizing watersheds. Design and evaluation of systems for the conservation and quality preservation of soil and water resources. Use and analysis of hydrologic data in engineering design; relationship of topography, soils, crops, climate, and cultural practices in conservation and quality preservation of soil and water for agriculture. Small watershed hydrology, water movement and utilization in the soil-plant-atmosphere system, agricultural water management, best management practices, and agricultural water quality. Graduate students will prepare several research literature reviews on topics covered in the class in addition to the other assignments.

**A B E 532: Nonpoint Source Pollution and Control**

(Dual-listed with A B E 432). (Cross-listed with ENSCI). (3-0) Cr. 3.

*Prereq: A B E 431 or C E 372*

Characteristics and courses of non-point source (NPS) pollution in agricultural and urban watersheds, computer modeling and NPS pollution for terrestrial and aquatic systems, strategies to control and manage NPS pollution of water bodies, total maximum daily loads (TMDLs) and integrated watershed management. Graduate students are required to review research papers and develop/deliver lecture models on assigned topics.

**A B E 533: Erosion and Sediment Transport**

(Cross-listed with ENSCI, NREM). (2-3) Cr. 3. Alt. F., offered even-numbered years.

*Prereq: C E 372 or GEOL/ENSCI/MTEOR 402, MATH 166 or equivalent*

Soil erosion processes, soil loss equations and their application to conservation planning, sediment properties, initiation of sediment motion and over land flow, flow in alluvial channels and theory of sediment transport, channel stability, reservoir sedimentation, wind erosion, BMPs for controlling erosion.

**A B E 536: Design and Evaluation of Soil and Water Monitoring Systems**

(Dual-listed with A B E 436). (Cross-listed with ENSCI). (2-3) Cr. 3. Alt. S., offered even-numbered years.

*Prereq: A B E 431*

Development of monitoring systems that support effective planning, performance evaluation, modeling, or environmental impact assessment of soil-, water-, and waste-management systems. Typical soil and water pollutants and physical, chemical, and biological characteristics that affect sample location and timing. Sample collection, documentation, chain-of-custody, and quality assurance procedures. In addition to other assignments, graduate students will prepare several research literature reviews on topics covered in the class and develop monitoring plans.

**A B E 537: Watershed Modeling and Policy**

(Dual-listed with A B E 437). (Cross-listed with ENSCI). (2-2) Cr. 3. Alt. F., offered odd-numbered years.

*Prereq: CE 372 or equivalent*

A project-based course on watershed-scale models for improving water quality. Legislative and judicial basis of the Total Maximum Daily Load (TMDL) program; approaches to TMDL development; principles and techniques for implementation; stakeholder engagement strategies. Hands-on experiences with GIS-interfaced models, data sources, calibration/validation, statistical assessment of model results, and simulation using multiple tools. In addition to other assignments, graduate students will present case studies of TMDLs using different modeling tools.

**A B E 551: Food and Bioprocess Engineering**

(Dual-listed with A B E 451). (3-0) Cr. 3. S.

*Prereq: A B E 216 and credit or enrollment in M E 436 or C H E 357; or F S H N 351 and MATH 266 or MATH 267*

Application of engineering principles and mathematical modeling to the quantitative analysis of transport phenomena in food and bioprocesses. Physical/chemical characteristics of foods and biological materials and systems, flow processes, thermal processes and separation processes.

**A B E 556: GIS Programming and Automation**

(Dual-listed with A B E 556). (Cross-listed with C R P). (3-0) Cr. 3. F.

*Prereq: C R P 351 or C R P 551 or NREM 345 or NREM 546 or GEOL 552*

Introduction to automated geoprocessing in Geographic Information Systems. Focus on learning scripting language and object-oriented programming, automation of custom-designed geoprocessing scripts, and application toward student research and/or interests.

**A B E 569: Engineering for Grain Storage, Preservation, Handling, and Processing Systems**

(Dual-listed with A B E 469). (2-3) Cr. 3. S.

*Prereq: A B E 216*

Cereal grain and oilseed production, properties, and quality assessment. Design of storage systems, drying systems, material handling, and size reduction systems. Design of cereal grain processing systems, including dry milling, wet milling, flour milling, feed milling, and fermentation facilities.

**A B E 572: Design of Environmental Modification Systems for Animal Housing**

(Dual-listed with A B E 472). (3-0) Cr. 3. Alt. S., offered even-numbered years.

*Prereq: A B E 216, M E 231*

Principles and design of animal environmental control systems. Insulation, heat and mass transfer, fans, ventilation, air distribution, heating and cooling equipment, and controls. Individual and group projects required for graduate credit.

**A B E 578: Wood Frame Structural Design**

(Dual-listed with A B E 478). (3-0) Cr. 3. Alt. S., offered odd-numbered years.

*Prereq: E M 324*

Design of light-framed wood structures using LRFD and ASD design procedures. Includes analysis of wind, snow, dead, and live loads. Applications include animal housing and machine storage. Fasteners, laminated posts, truss design and use of National Design Specifications.

**A B E 580: Engineering Analysis of Biological Systems**

(Dual-listed with A B E 480). (2-2) Cr. 3. F.

*Prereq: A B E 380 or permission of the instructor*

Systems-level quantitative analysis of various biological systems, including applications in foods, feeds, biofuels, bioenergy, and other bio-based systems. Introduction to techno-economic analysis and life-cycle assessment of these systems at multiple production scales. Applying these tools to evaluate and improve cost and sustainability performance. Students enrolled in ABE 580 will be required to conduct additional learning activities.

**A B E 590: Special Topics in Agricultural & Biosystems Engineering**

Cr. 1-3. Repeatable.

Guided instruction and self-study on special topics relevant to agricultural and biosystems engineering.

**Courses for graduate students:****A B E 601: Graduate Seminar**

(Cross-listed with TSM). (1-0) Cr. 1. F.

Keys to starting a successful graduate research project. Effective literature review, formulating research questions, and setting goals. Practicing effectively communicating research and science. Effective strategies for scholarly writing, professional development, responding to feedback, peer-reviewing, successful publishing in journals, and curating scholarly output.

**A B E 610: Foundations of Sustainable Agriculture**

(Cross-listed with AGRON, ANTHR, SOC, SUSAG). (3-0) Cr. 3. F.

*Prereq: Graduate classification, permission of instructor*

Historical, biophysical, socioeconomic, and ethical dimensions of agricultural sustainability. Strategies for evaluating existing and emerging agricultural systems in terms of the core concepts of sustainability and their theoretical contexts.

**A B E 690: Advanced Topics**

Cr. arr. Repeatable.

Advanced topics.

**A B E 694: Teaching Practicum**

(Cross-listed with TSM). Cr. 1-3. F.S.

*Prereq: Graduate classification and permission of instructor*

Graduate student experience in the agricultural and biosystems engineering departmental teaching program.

**A B E 697: Engineering Internship**

Cr. R. Repeatable.

*Prereq: Permission of department chair, graduate classification*

One semester and one summer maximum per academic year professional work period.

**A B E 699: Research**

Cr. arr. Repeatable.

Research.

**A B E 699B: Research: Biosystems Engineering**

Cr. arr. Repeatable.

Guided graduate research in biosystems engineering.

**A B E 699C: Research: Computer Aided Design**

Cr. arr. Repeatable.

Guided graduate research in computer-aided design.

**A B E 699E: Research: Environmental Systems**

Cr. arr. Repeatable.

Guided graduate research in environmental systems.

**A B E 699F: Research: Food Engineering**

Cr. arr. Repeatable.

Guided graduate research in food engineering.

**A B E 699O: Research: Occupational Safety**

Cr. arr. Repeatable.

Guided graduate research in occupational safety.

**A B E 699P: Research: Power and Machinery Engineering**

Cr. arr. Repeatable.

Guided graduate research in power and machinery engineering.

**A B E 699Q: Research: Structures**

Cr. arr. Repeatable.

Guided graduate research in structures.

**A B E 699R: Research: Process Engineering**

Cr. arr. Repeatable.

Guided graduate research in process engineering.

**A B E 699S: Research: Environment and Natural Resources**

Cr. arr. Repeatable.

Guided graduate research in environment and natural resources.

**A B E 699U: Research: Waste Management**

Cr. arr. Repeatable.

Guided graduate research in waste management.