

Chemical Engineering at...

Montana State University

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The chemical engineering program at Montana State University is located on the main campus in Bozeman, Montana. Located 90 miles from Yellowstone National Park, 50 miles from Big Sky ski resort, and just 20 miles from Bridger Bowl ski resort, Bozeman is frequently recognized as one of the best towns in the United States for outdoor activities and livability. In 2012, for example, it was ranked fourth by *National Geographic* magazine in their list of the World's Best Ski Towns (just behind Zermatt, Switzerland, and ahead of Chamonix, France). While the skiing and outdoor recreation in Bozeman are outstanding, greatness is also found in the chemical engineering students at Montana State University.

The chemical engineering program is part of the Department of Chemical and Biological Engineering. The department currently has two undergraduate degree programs: chemical engineering and biological engineering. The biological engineering program was initiated in 2006 and currently has about 150 majors. The chemical engineering program is significantly older, and currently has about 400 majors.

HISTORY

The chemical engineering program was originally established at the Montana State College of Agriculture & Mechanical Arts (now Montana State University, MSU) in 1925 by William Cobleigh. The program grew out of an option that was established in the chemistry department in 1919. In 1930, Cobleigh became dean of the Department of Engineering, and the chemical engineering program was moved to engineering. Two additional faculty were added to teach chemical engineering, and the program operated until 1942 when it went dormant for World War II.

The department was reactivated by Lloyd Berg in 1946, and he was immediately joined by Al Saner. The program grew rapidly and became the first ECPD accredited chemical engineering department in the Rocky Mountain region in 1948. The faculty also grew rapidly over the next two decades,

adding five more faculty to the original two. The size of the department in terms of students and faculty stayed remarkably stable for 60 years between 1946 and 2006. The faculty numbers fluctuated between six and eight individuals, and the student numbers fluctuated between 150 and 300, with an average of about 200 majors at any moment in time.

In 1956 the Department of Chemical Engineering awarded the first earned Ph.D. degree in the state of Montana, and the department continued to lead the state in earned Ph.D. degree production for the next two decades. In the late 1950s, student enrollment in chemical engineering began to decline, so the department initiated a scholarship program for incoming freshman to attract more students. The scholarships were primarily sponsored by companies that would eventually hire the graduates of the program, and the scholarship covered approximately 20% of the tuition cost for the first year. Berg travelled extensively around the state of Montana encouraging high school students to apply for the scholarships. He made a special effort to reach out to female students around the state, and he was able to successfully recruit a number of women who became outstanding engineers in the field of chemical engineering. In 1970, the first woman graduated from the Department of Chemical Engineering at Montana State University and accepted a position with Union Carbide, one of the companies that sponsored scholarships for incoming freshmen. Throughout the remainder of the 1970s, the number of women graduating from the chemical engineering program continued to increase, including five female graduates in 1971, and Montana State University set national records for the numbers of women receiving chemical engineering degrees throughout the 1970s, due in large part to Berg's outreach efforts.

The research programs within the department had a strong industrial focus prior to the 1990s. Major research areas included diesel fuel desulfurization, coal liquefaction, azeotropic



Montana State University is featured in the foreground with Bozeman and the Bridger mountain range shown above. Circled in the lower center are the two buildings that contain the Chemical and Biological Engineering department.

distillation, membrane separations, and rheology and mixing. One notable exception to the industrial focus and a precursor of the current biological engineering research focus was blood rheology work by Giles Cokelet for the NIH.

Lloyd Berg remained the department head for 33 years (1946–1979), and continued on as a faculty member until his death in 2000. Even into the late 1990s, he continued to teach his favorite Chemical Process Industries course. He was awarded more than 250 patents, mainly in the field of extractive and azeotropic distillation.

In 1982, John T. Sears became the department head and helped to recruit the next wave of faculty members into the department in the 1980s, including John Mandell, Max Diebert, Dan Shaeffer, Ron Larsen, and Phil Stewart, who are all still affiliated with the department. Sears retired in 2002, and Ron Larsen became the department head.

The start of this century and the transition to Larsen as department head mark the beginning of a comprehensive transition and a renewed scientific research focus for the chemical engineering program at Montana State University. Most of the faculty who were in the department in the late 1990s retired in the early part of this century. Other faculty members moved to new universities or were promoted within MSU, including Phil Stewart who was promoted to director of the Center for Biofilm Engineering in 2005. As a result of these changes, most of the current faculty within the department joined MSU during the current century. Another major transition was the expansion of and name change from the Department of Chemical Engineering to the Department of Chemical and Biological Engineering. This transition primarily occurred in 2005-2006, and has been an important part of the department's significant growth.

In 2011, Larsen was promoted to associate provost at MSU, and in 2012, Jeff Heys was appointed as interim department head and later in 2014, as department head.

RECENT GROWTH

In the past 10 years, the chemical engineering program at Montana State has grown from less than 200 majors to approximately 400. Over the same time period, the biological engineering program has grown from inception to more than 150 majors. The overall result is a near tripling of the number of students in the department. In response to the growth in the number of majors, the department has grown from seven faculty to 16 faculty (15 tenure track and one full-time non-tenure-track faculty) in the past 10 years. The current faculty as well as their research interests are described in the next section.

To accommodate the student growth, the department's undergraduate teaching lab has been enhanced and extensively reorganized. Smaller, more modular experiments on gas and vapor diffusion, thermodynamic cycles (*i.e.*, refrigeration), tube-and-shell heat exchangers, fermentation, moving-reaction fronts (*i.e.*, cooking potatoes), chromatography, and enzyme kinetics have all been added. New lab benches and moveable lab tables have also been added to enhance the flexibility and modularity of the lab.

RESEARCH AREAS

Research within the Department of Chemical and Biological Engineering is focused in a number of different areas. One of the largest areas of research, biofilms and microbial engineering, is a result of the department's close ties with the Center for Biofilm Engineering (CBE). The CBE was established in 1990 as an NSF Engineering Research Center, and the center has continued to be a research leader in biofilms for more than 25 years as well as a poster child for the successful transition from NSF-funded research center to self-sustainability. Many of the faculty in the department conduct at least some research that is connected to the CBE.

Dr. Phil Stewart joined MSU in 1991 and he served as the director of the CBE from 2005 to 2015. His research examines



A number of the faculty wait in line for the tram at Big Sky ski resort.

fundamental processes in biofilm control with antimicrobial agents, transport phenomena in biofilms, biofilm modeling, and biofilm detachment.

Dr. Brent Peyton moved to MSU from Washington State University in 2005 and he conducts fundamental and applied research in the areas of extremophilic bioprocessing, *in situ* biocatalyzed heavy metal transformations (Se, Cr, U), and growth of algae and fungi for biodiesel production in natural and engineered biological systems. Dr. Peyton also directs the Thermal Biology Institute at MSU.

Dr. Ross Carlson has been a faculty member at MSU since 2005 and directs the Biochemical Engineering Laboratory, which utilizes metabolic network analysis and elementary flux mode analysis to study the properties of microbial reaction networks. The goal in many cases is to apply an understanding of specific biochemistries to control the conversion of inexpensive or undesirable compounds into more valuable or more desirable products. Applications of this work include efficient nutrient recycling and bioremediation of contaminated sites, optimization of biofuels and biomaterials from renewable resources, and improved prevention and treatment strategies for medical infections.

Dr. Robin Gerlach's research activities have revolved around the beneficial use of microorganisms with an emphasis on attached microbes and microbial biofilms. Dr. Gerlach has had a particular focus on microbially induced calcium carbonate

mineral precipitation for environmental benefit. He has also studied microbes in the unique thermal environment that is Yellowstone National Park. Dr. Gerlach is the director of the Environmental and Biofilm Mass Spectrometry Facility at MSU, and he became a faculty member in 2006.

Dr. Abigail Richards became a faculty member in 2007 and conducts research on biofilm growth in extreme environments and exploring ways that microbes might be used to clean contaminated soils. She has a particular focus on the isolation and characterization of iron-chelating molecules, called siderophores, that are secreted by bacteria inhabiting environments of high salinity and pH. Dr. Richards also conducts pedagogical research on student retention, especially the retention of female students.

Dr. Christine Foreman joined the Department of Chemical and Biological Engineering in 2013, and her research is on the organization of microbial communities in relation to their physical environment and the processing of nutrients and organic matter with a particular focus on life in cold environments. Ecological, biochemical, and molecular biology approaches are combined to investigate processes carried out by bacteria in permanently ice-covered lakes, glaciers, and streams. Dr. Foreman also serves as associate dean for Student Success for the College of Engineering.

Dr. Jim Wilking moved from Harvard to MSU in 2013 and conducts research on soft materials and complex fluids.



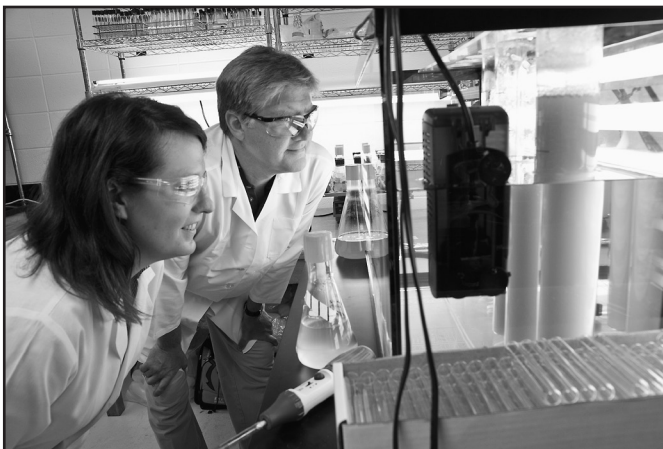
Dr. Paul Gannon (left) and Jude Eziashi handling a sample in the High Temperature Materials Lab.

His research examines the physical and material properties of microbial biofilms, colloidal and nanomaterials synthesis with specific applications in pharmaceutical formulations, and the mechanics of soft materials. The experimental tools for this research include micromechanics, microfluidics, small angle neutron scattering, microscopy, and optical trapping. Dr. Wilking was awarded the NSF CAREER award in 2015.

The department has a growing research focus on microfluidics. This research is supported by the Montana Microfabrication Facility at MSU. Dr. Stephanie McCalla joined MSU in 2014 and utilizes microfluids as a platform for disease diagnosis, RNA/DNA/protein separation, detection and quantification of biomolecules, and to study mass transport in living systems. Dr. McCalla recently earned a Rising Star award, which recognizes promising early-career investigators from the five-state WWAMI (Washington, Wyoming, Alaska, Montana, and Idaho) region, from the Institute of Translational Health.

Dr. Connie Chang moved to MSU from Harvard in 2013 and uses drop-based microfluidics for high-throughput assaying and sensing in biological applications such as viruses, biofilms, and single cell genomics. Her lab also uses microfluidic methods for generating novel colloidal biomaterials. Dr. Chang began her faculty appointment in the fall of 2015.

Material science research has an extensive history in the department and was initiated in the 1980s by Dr. John Mandel, a leading expert in composite materials for wind turbine blades, and Dr. Max Diebert, an expert on fuel cells. Today, Dr. Paul Gannon's research focuses on material science and engineering for advanced energy technologies. Dr. Gannon has directed the High Temperature Materials Lab since 2008 with projects on high temperature corrosion in turbine engines, polysilicon reactors, and stainless steel interconnects for solid oxide fuel cells. To prevent or minimize corrosion in



Dr. Brent Peyton (right) and Karen Moll examine algae growing under controlled conditions in the algal biofuels lab.

these applications, coatings are deposited via physical vapor deposition and electroplating.

Dr. Ryan Anderson joined MSU in 2013 and his research is in heat transfer and fluid flow for applications in clean energy. These interests include fuel cells, flow in porous media, multiphase flow, reacting systems, and uses of various heat transfer fluids. In particular, Dr. Anderson is working to design better PEM fuel cells with improved water management that could lead to significant performance improvements and cost reductions.

In 2001, Dr. Joseph Seymour became a faculty member in the Department of Chemical and Biological Engineering, and he created a new research program in magnetic resonance imaging (MRI). The MRI Laboratory is co-directed by Dr. Seymour and Dr. Sarah Codd of the Department of Mechanical Engineering. Dr. Seymour's research is focused on the use of MRI methods to study fundamental transport phenomena and material characterization. In particular, the lab uses pulsed gradient spin echo techniques to measure velocity and effective diffusion, *e.g.*, hydrodynamic dispersion.

Dr. Jennifer Brown was appointed as a faculty member in 2009 and she uses MRI to study complex fluid dynamics in conjunction with rheometric fluid characterization. Rheometers that can measure both shear stress under controlled shear rate and shear rate under controlled shear stress conditions are used by Dr. Brown to study gels and complex fluids. Dr. Brown's research has helped to advance the development and application of RheoNMR, which allows rheology measurements to be made using the MRI spectrometer

A new research emphasis on the synthesis of platform chemicals, specialty chemicals, and biofuels from lignocellulosic biomass using novel catalytic and separation processes is currently being established by Dr. Stephanie Wettstein, who joined MSU in 2012. The overall goal is to increase the sustainability of biofuels and chemicals produced from lignocellulosic



Miguel Strunk, a student in both the chemical engineering and biological engineering programs, teaches middle school students about science through the making of ice cream with liquid nitrogen.

biomass by improving processing methods, increasing reaction rates, and increasing the yields of biomass carbon that is converted into biofuels and chemicals. This research develops novel, high-yield biomass deconstruction methods, improved biomass conversion processes to increase catalyst stability, and separation methods using zeolite membranes.

Finally, Dr. Jeff Heys currently directs the Computational Biofluids Lab, which was established in 2008, at MSU. The lab's research involves the application of fundamental conservation laws to improve the understanding of transport in biological systems, usually in diseased or pathological systems. The lab has a particular focus on experimental data assimilation, higher-order finite element methods, and algebraic multigrid solvers.

The current faculty have received a number of awards at the university, national, and international level. A few highlights from the past few years include: Dr. Paul Gannon received the 2013 J. Bruce Wagner, Jr. Young Investigator Award from the Electrochemical Society High Temperature Materials Division, Dr. Brent Peyton received the 2014 Vice President for Research's Meritorious Technology/Science Award, Dr. Robin Gerlach won the 2013 Cox Family Awards

for Creative Scholarship and Teaching, Dr. Abigail Richards received the Outstanding Advisor Award from the Tau Beta Pi engineering honor society, and Dr. Joseph Seymour (2012) and Dr. Paul Gannon (2015) received the Lloyd Berg Faculty Mentorship Award.

OUTSTANDING UNDERGRADUATE STUDENTS

Montana State University is unique in that it is the only institution in the nation classified by the Carnegie Foundation as: (1) very high research activity, (2) significant commitment to community engagement, and (3) very high undergraduate enrollment. MSU's commitment to both research excellence and undergraduate studies creates opportunities for undergraduates in chemical engineering to perform cutting edge research that is frequently published in peer-reviewed journals. These unique opportunities have helped enable a number of recent students to receive major national and international awards. Hilary Fabich received MSU's first Gates Cambridge Scholarship in 2012. In 2013, Joe Thiel was selected as a Rhodes Scholar to Oxford University and Bryan Vadheim was MSU's first Marshall Scholar and is currently studying at the London School of Economics. Seven students (Trevor Zuroff,



Student McLain Leonard works on a trayed distillation column in the teaching lab.



The Engineering and Physical Sciences building (foreground) is home to the Center for Biofilm Engineering and some chemical and biological engineering faculty. Cobleigh Hall (taller building in the background) is home for the main Department of Chemical and Biological Engineering office and most faculty.

Chandra Macaully, Nicole Schonenbach, Kathryn Morrissey, Hilary Fabich, Elizabeth Aisenbrey, and Alissa Bleem) have been awarded NSF Graduate Research Fellowships since 2010. Finally, a number of students have been awarded Goldwater Scholarships including Alissa Bleem and Matt Sherick in 2013, Katherine Kent and McLain Leonard in 2014, and Riley Shearer in 2015.

The undergraduate students in chemical engineering at MSU receive an education that is focused on the application of the fundamental conservation principles to engineered processes (Table 1). The goal is to educate engineers that are able to tackle a wide range of problems because the undergraduate students are employed in a diverse range of industries.

Graduates are employed in traditional industries such as refining, agrichemicals, water treatment, and energy, but they are also frequently employed in semiconductor manufacturing, environmental engineering, advanced material processing, pharmaceuticals, and other non-traditional areas. A fraction of the Bachelor degree graduates matriculate into graduate programs in the United States and around the world each year.

The undergraduate curriculum includes a two-semester senior design sequence where the first semester is focused on

the design of a medium-to-large scale process, and the second semester includes detailed economic and safety analysis of the process with some redesign being a likely consequence of the analysis. The senior design projects are unique for each group during a given year, and the groups are often mentored by a retired chemical engineer living in the Bozeman area. Another feature of the undergraduate curriculum is a full-year lab experience course that includes an experimental design teaching component and a wide array of possible experiments.

TABLE 1
Chemical engineering curriculum with general education requirements omitted

Freshman Year Fall		Freshman Year Spring	
ECHM 100	Intro to ChE	EGEN 102	Intro to Eng Computer Apps
CHMY 141	Chemistry I	CHMY 143	Chemistry II
M 171	Calculus I	M 172	Calculus II
US 101	University Seminar	WRIT 101	College Writing
Sophomore Year Fall		Sophomore Year Spring	
ECHM 201	Elementary Principles ChE	ECHM 321	Fluid Mechanics
CHMY 211	Organic Chemistry	EMAT 251	Material Science
M 273	Multi Variable Calculus	M 274	Differential Equations
PHSX 220	Physics I	PHSX 222	Physics II
Junior Year Fall		Junior Year Spring	
ECHM 322	Heat Transfer	ECHM 323	Mass Transfer
BCH 380	Biochemistry	EBIO 493	Bioprocess Engineering
ECHM 307	Thermodynamics I	ECHM 328	Reactor Design
EGEN 350	Data Analysis	EGEN 310	Multidisc. Design
			Technical Elective
Senior Year Fall		Senior Year Spring	
ECHM 411	ChE Design I	ECHM 412	ChE Design II
ECHM 442	ChE Lab I	ECHM 443	ChE Lab II
ECHM 407	Thermodynamics II	ECHM 451	Process Control
ECHM 424	Transport Analysis	CHMY 373	Phys. Chemistry
	Technical Electives		Technical Elective



Dr. Joseph Seymour (right) and Matt Sherick adjust a sample in the magnetic resonance lab.

The number of experiments available in the undergraduate teaching laboratory has grown in recent years to accommodate the larger classes. New experiments on CSTR reactor design, tube-and-shell heat exchangers, liquid and vapor diffusion, refrigeration (thermodynamic) cycles, and chromatography have all been added in the past three years. Finally, the curriculum includes two semesters of chemical engineering specific thermodynamics to reflect the program's emphasis on the fundamental principles behind process design.

GRADUATE PROGRAMS

The department currently offers a number of graduate degrees including Masters of Engineering degrees in chemical engineering and bioengineering, Masters of Science degrees in chemical engineering and environmental engineering, and a Ph.D. in engineering with an option in either chemical engineering or environmental engineering. Over the past six years, the department has graduated an average of four M.S. and three Ph.D. students per year, and has an average graduate enrollment of 25-35 students. Ph.D. students average three publications from their graduate research in top-tier journals. Most of the graduate students are in one of the chemical engineering options. Our goal is to double the size of the graduate program over the next 10 years.

THE FUTURE: NORM ASBJORNSON INNOVATION CENTER

While the Department of Chemical and Biological Engineering has seen the largest percentage growth in students over the past 10 years (approximately 200% growth) in MSU's College of Engineering, the college as a whole has grown more than 50% from 2,000 students to more than 3,300 students. In response to this growth, Norm Asbjornson, a 1960 MSU mechanical engineering graduate, committed to give the university \$50 million towards the construction of the Norm Asbjornson Innovation Center (NAIC). The building will include innovative laboratories and classroom facilities that will enable collaborative hands-on learning and leadership.

The College of Engineering at MSU is currently housed in three buildings: Roberts Hall, Cobleigh Hall, and the Engineering and Physical Sciences building. The chemical engineering program, including many faculty offices, main department office, student computer lab, and some research labs, are all located in Cobleigh Hall. The Norm Asbjornson Innovation Center will serve as the fourth building for engineering at MSU, and it will also house the College of Engineering dean's office. The gift was originally announced in March of 2014, and the planning and design of the building are already well underway. The NAIC building will also serve as the centerpiece of the next phase of MSU's campus expansion to the south. Groundbreaking on the initial project elements began in the fall of 2015.

The Department of Chemical and Biological Engineering has undergone a significant transformation during the past 10 years, and we foresee continued changes over the next decade as new buildings are constructed, the graduate programs continue to expand and improve, and we continue to strive to provide outstanding educational opportunities for all students. Throughout these changes, our mission will continue to be excellence in learning, discovery, and engagement to meet the land grant mission of accessibility and value at Montana State University. □