CHEMICAL AND BIOLOGICAL ENGINEERING

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT
Evolving History
Chemical and Biological Engineering program expands, better preparing students to solve future global concerns

From a school founded in 1874 on mineral extraction, Colorado School of Mines has evolved into a unique institution of higher education focused on engineering and applied science in many disciplines. For over 60 years, our department has pursued education and basic/applied research aimed at global problems. Its new name—the Chemical and Biological Engineering Department—reflects its evolving curriculum, program size and expanding expertise, as well as the doubling of both student enrollment and research volume in the past decade. With more than 700 students and approximately $8 million in annual research awards, Mines’ Chemical and Biological Engineering Department is a dynamic and exciting environment for both research and teaching.
EXPANDING ENROLLMENT AND RESEARCH

KEVIN CASH, assistant professor, specializes in development of biomedical sensors. Current medical diagnostics suffer from one key problem, the need for a blood sample from a patient. His research is focused on eliminating this shortcoming by shifting the design of sensors: rather than bringing a blood sample to a sensor, bring sensors to the blood itself. He is developing nanoparticle-based sensors that are able to profile in vivo metabolic concentrations with something current technologies can’t do: continuous monitoring. This is an important advance as it yields significantly more information than a single time point measurement.

MELISSA KREBS, assistant professor, specializes in tissue engineering. The field of tissue engineering seeks to regenerate diseased or damaged tissues by providing the necessary physical, biochemical, and cellular cues that promote tissue regeneration. Her research is focused on the development of biopolymer systems that will allow the study of cells’ interactions with their microenvironment that can be used for both tissue regeneration and therapeutics. In addition, she is also engineering biopolymer systems for controlled delivery of therapeutic molecules for the treatment of cancer.

NANETTE BOYLE, assistant professor, and Coors Developmental Chair specializes in metabolic engineering. Rising carbon dioxide levels in the atmosphere coupled to variable and uncertain petroleum supplies has led a push to develop sustainable sources of biofuels and other petroleum replacement products. Current industrial production of biofuels, such as ethanol, competes with our food supply for resources. In order to minimize the effect of biofuel production on our food and feed supply, the next generation biofuels will have to be produced directly from carbon dioxide or waste materials. Dr. Boyle’s research is focused on designing cyanobacteria and algae to convert sunlight and carbon dioxide directly to fuels and feedstock chemicals. In order to achieve this, her group uses systems and synthetic biology techniques coupled with metabolic modeling to understand biological processes and re-design them to meet our needs.

MOISES CARREON, associate professor, 2013 recipient of the Presidential Early Career Award for Scientists and Engineers (PECASE) and Coors Developmental Chair specializes in the rational design of advanced functional porous materials at different length scales, including zeolites, mixed metal oxides and metal organic frameworks for applications in molecular gas separations, heterogeneous catalysis, and gas storage. Applications include carbon dioxide capture in natural gas and flue gas treatment, catalytic conversion of carbon dioxide into useful chemicals such as cyclic carbonates and carbamates, natural gas storage employing smart-nanovalve adsorbent composites, and catalytic transformations on biofuels with improved cold flow properties.

FOCUSING ON APPLIED SCIENCE

With 90 percent of its students majoring in engineering, Mines focuses on applied science with the aim of bringing technological advances to the marketplace. As a relatively small engineering school, Mines provides a rigorous educational experience where faculty and top-notch students work together on meaningful research with far-reaching societal applications.

Departmental research areas include hydrates, renewable energy, soft materials, biomedical devices, simulation and modeling, thin-film materials and pedagogy. Its facilities are among the nation’s best, with high quality laboratories for undergraduate and graduate research, powerful on-campus computational facilities and specialized labs. This brochure highlights select areas from the department’s broad catalog of research with more information online at http://chemeng.mines.edu.
Chemical and Biological Engineering

Undergraduate Program

Offering two undergraduate degrees

The Chemical and Biological Engineering Department offers two undergraduate degrees: Bachelor of Science in Chemical Engineering and Bachelor of Science in Chemical and Biochemical Engineering. A student with the latter degree is a Chemical Engineer with their technical electives focused on bio-processing technologies.

Chemical Engineering is a broad field encompassing everything from design to large scale manufacturing of a wide variety of products through chemical and biochemical processes. These products include pharmaceuticals, pulp and paper, petrochemicals, fine chemicals, specialty chemicals, microelectronic devices, polymers, and products used in food processing and in biotechnology. Our alumni are employed in diverse fields including traditional and alternative/renewable energy, manufacturing, health care, biotechnology and business services.

Our chemical engineering curriculum builds upon the fundamentals of biology, chemistry, mathematics, and physics. In this, undergraduate students complete a program of study that includes rigorous instruction in fluid mechanics, heat and mass transport, thermodynamics, reaction kinetics, and chemical process dynamics and control. In addition, our curriculum also includes elements that clearly set us apart from other programs; for example and taught in a new and unique student-centered environment, Studio Biology introduces active learning to instruction of biology at the freshman level. This unique course minimizes lecture and maximizes student involvement in the learning process with the design and performance of experiments exploring biological systems. Our emphasis on active learning is also demonstrated within the unit operations laboratory sequence taken in the summer as a six-week intensive “field session”. Here, the fundamentals of heat, mass, and momentum transport and applied thermodynamics are reviewed in a practical, applications-oriented, hands-on setting. Field session greatly hones students’ teamwork, leadership, critical thinking, and oral and written technical communications skills.

This curriculum is delivered within facilities that are among the best in the nation. Our modern in-house computer network supports over 70 workstations with specialized software for modeling chemical engineering systems. Our honors undergraduate research program provides our undergraduates with the opportunity to work together with graduate students, postdocs, and/or faculty on cutting edge chemical and/or biochemical engineering research. Undergraduate chemical engineering students in this program at CSM have presented at national conferences and have won national competitions and awards based on research conducted while pursuing their baccalaureate degree. CSM also has a very active American Institute of Chemical Engineers (AIChE) student chapter. The student leadership organize “Lunch and Learn” events with industry leaders, host social events throughout the year, organize a rotational dinner for members and recruiters before our Fall Career Fair, and participate in the ChemE car competition at the National AIChE meeting.

With placement outcomes within 3 months of graduation exceeding 80% for the last 5 years and average starting salaries over $69,000, our graduates continue to be in high demand for industry, government, military and graduate school positions across the country.
From its inception in 1952, the Department of Chemical and Biological Engineering (CBE) has focused on education and basic and applied research aimed at problems of national interest. The graduate and research program in Chemical Engineering at CSM is extremely diverse and features programs in renewable energy, materials science, transport processes, theoretical and applied thermodynamics, computational methods and atomistic simulation.

At Mines, we believe that an important component of the graduate program is the personal relationship that develops between the faculty and students pursuing advanced degrees, hence we strive to maintain a high quality research and graduate education program. The department currently has a staff of 18 tenure track faculty and a total enrollment of approximately 90 full-time graduate students. This student to faculty ratio facilitates the development of strong mentoring relationships that is one of the strengths of our department.

The CBE Department at CSM has within its faculty 7 NSF CAREER and 1 PECASE award winner and is recognized as a world leader in alternative energy and advanced materials. Chemical and Biological Engineering receives $7-8 million dollars in research funding each year.

We offer two degrees; a Masters of Science in Chemical Engineering (non-thesis or thesis) and Doctor of Philosophy in Chemical Engineering. Our PhD students are paid a generous stipend with fully paid fees, tuition and health insurance. It typically takes 4-5 years to complete a PhD, 2-3 years for a MS with thesis and 1 year for a non-thesis MS.

The on-line application for graduate school at the Colorado School of Mines can be found here http://www.mines.edu/graduate_admissions. CBE only has Fall admission. We require a statement of purpose, resume, undergraduate transcripts, GRE scores, and 3 letters of recommendation. International students must also submit TOEFL (Test of English as a Foreign Language) scores. December 15th is the deadline for priority funding consideration (for the next Fall) and application review begins shortly after the deadline. Accepted students have until April 15th to enroll at the Colorado School of Mines.

In their first semester new chemical engineering PhD students take CBEN509 Advanced Thermodynamics, CBEN516 Transport Phenomena, CBEN518 Advanced Kinetics, and CBEN568 Introduction to Chemical Engineering Research and Teaching. During this semester, each PhD student is a teaching assistant for a course taught by CBE. Students are required to interview with 3 members of faculty to discuss research opportunities. Before the spring semester starts, new PhD students take the qualifying exam, which is half weighed to the GPA from the core chemical engineering classes and half weighted to the oral qualifying exam. Students choose a chemical engineering review paper from a selection chosen by the faculty. The new PhD students write a one-page research proposal, give a 20-minute presentation that ties the review paper back to core chemical engineering principles, followed by 20 minutes of questions and answers. Students are then placed into research groups based on several factors.
CONVENTIONAL ENERGY CONVERSION AND STORAGE

FOCUS ON HYDRATES

J. DOUGLAS WAY
Extending Resources
Understanding hydrate formation could lead to better methods of storing and producing energy

With funding from the National Science Foundation, scientists in Colorado School of Mines’ Hydrate Center began working on a Deepwater Oil & Gas Well Blowout Prototype Simulator following the 2010 rupture at BP’s Deepwater Horizon oil rig. E. Dendy Sloan, Carolyn Koh and Amadeu Sum will use a U.S. Department of Energy device that was designed to study carbon dioxide, as well as a high-pressure instrument being constructed at Mines, to enable long timescale blowout and hydrate studies.

Profs. Way and Wolden have discovered a new class of low cost materials, Mo2C coated BCC metals, for high temperature hydrogen selective membranes that require no platinum group metals. This innovation builds on Prof. Way’s prior research on the use of Pd and Pd alloy membranes for energy conversion, hydrogen separation/purification, and membrane reactors, which combine both reaction and separation functions. Of particular interest is the application of high-temperature hydrogen permeable membranes in pre-combustion carbon capture schemes, where the products of the water gas shift reaction, CO2 and H2, are separated at high temperature by a membrane device.

CONVENTIONAL ENERGY HIGHLIGHTS
• Prof. Doug Way is developing high-temperature hydrogen separation membranes that could change the way power is generated by gasifying rather than burning carbon sources for fuel.
• Prof. Way’s research is supported by grants and contracts from the U.S. Department of Energy, U.S. Defense Department, Chevron, the World Gold Council, the CO2 Capture Project, the Pall Corporation and Praxair at more than $1 million per year.
• Associate Prof. Matthew Liberatore leads a multi-department team studying heavy crude oils supported by $1.9 million from the Department of Energy and industrial partners.

THE CENTER FOR HYDRATE RESEARCH
• This is the world’s largest and foremost center dedicated to understanding hydrates in flow assurance, science and nature.
• Research began in 1975. Today it includes 30 student and faculty researchers supported by more than $1.6 million in annual funding.
• The center is supported by an industrial consortium of 11 energy companies, the DeepStar Energy Consortium, Mines’ Renewable Energy Materials Research Science and Engineering Center, federal agencies, including the National Science Foundation, the U.S. Department of Energy and nonprofit organizations.

SAMPLE PUBLICATIONS


BIOLOGICAL ENGINEERING

FOCUS ON

BLOOD

KEITH NEEVES
Diagnosing Disease
Biological engineering leads to new cardiovascular diagnostics

Blood has the seemingly impossible task of flowing freely nearly all the time, but then quickly clotting when necessary to stop bleeding. Assistant Prof. Keith Neeves specializes in cardiovascular engineering and the development of biomedical microdevices. Prof. Neeves’ research group has developed microfluidic models of vascular injury, which are undergoing testing at the Rocky Mountain Hemophilia and Thrombophilia Center at CU-Denver. Prof. Neeves calls the research “game changing” and notes that the State of Colorado has provided a grant to accelerate the commercialization of this technology.

With nine faculty involved in research and teaching, bio-related research at Mines goes significantly beyond biomedical applications and extends to efforts in conversion of biomass to biofuels as well as the use of biologically-derived materials as sustainable systems. For example, Prof. John Dorgan is investigating ecobionanocomposites, a new class of green materials, and is working to maximize the renewable content of next-generation plastics. With Mines located only a few miles from the National Renewable Energy Laboratory, these efforts involve active and significant collaboration with other world-class researchers.

FACULTY

Nanette Boyle, Assistant Professor, Metabolic Engineering, Systems and Synthetic Biology, Biofuels

Annette Bunge, Professor Emeritus, Dermal Transport

Kevin Cash, Assistant Professor, Implantable Nanosensors, Biofilms

John Dorgan, Professor, Polymeric Materials from Biorenewable Resources, Biofuels Separation

Melissa Krebs, Assistant Professor, Biomaterials, Tissue Engineering, Drug Delivery

David W.M. Marr, Department Head and Professor, Microfluidics, Biomedical Microdevices

C. Mark Maupin, Assistant Professor, Separation and Sequestration, Enzyme and Channel Simulations, Biofuels

Keith Neeves, Associate Professor, Cardiovascular Engineering, Microfluidics

Cynthia Norrgran, Teaching Associate Professor, Biology, Biophysics, Neurosurgery, Astronomy

Paul Ogg, Teaching Associate Professor, Cell Biology, Virology, Genetics

John Persichetti, Teaching Associate Professor, Process Simulation, Design

Amadeu K. Sum, Associate Professor, Clathrate Hydrates, Biological, Biomolecular Systems, Simulations

BIOFUEL BIOLOGICAL BIOMASS BIOMEDICAL CONVENTIONAL ENERGY ELECTRONIC FUEL CELLS HYDRATES NANO TECHNOLOGY NEW MATERIALS PEDAGOGY POLYMERS RENEWABLE ENERGY SOFT MATERIALS SIMULATIONS SOLAR TEACHING

SAMPLE PUBLICATIONS


HIGH-TEMPERATURE POLYMER MEMBRANES
Fuel cells generate electricity caused by the electrochemical reaction when oxygen and hydrogen combine to form water. Proton exchange membrane (PEM) fuel cells are already finding applications in off-grid, quiet power and niche markets and are anticipated to gain wider acceptance in the marketplace. PEM fuel cells have the highest energy density and fastest start-up time (under a second), making them good choices for vehicles, portable power and backup power. Associate Prof. Andrew Herring believes the next big things on the alternative energy horizon are the direct conversion of sunlight to fuels and alkaline exchange membrane fuel cells, which could revolutionize the portable electronics market by deploying cheaper catalysts to oxidize liquid fuels.

KINETIC CHARACTERIZATION
Prof. Anthony Dean is focused on the quantitative kinetic characterization of reaction networks in high-temperature solid oxide fuel cells, ignition kinetics, catalytic reforming kinetics of fossil and renewable fuels, and the production of fuels and power from the thermochemical conversion of biomass. The Office of Naval Research, the Department of Energy and the National Renewable Energy Laboratory provide funding for Dean’s research.

BIOMASS CONVERSION
Colorado School of Mines is one of the few research universities with a comprehensive portfolio of research projects that are attempting to convert real biomass feedstocks to practical fuels, including a project that uses wastewater to make fish food and another that uses algae to find viable ways to produce biodiesel.

FACULTY
Moises Carreon, Associate Professor, Separation Processes, Catalysis
Anthony M. Dean, Vice President for Research and Technology Transfer, Kinetics, Combustion, Biomass Conversion
Andrew M. Herring, Associate Professor, Catalysis, Membranes
Carolyn Koh, Professor, Clathrate Hydrates, Neutron Diffraction
Matthew Liberatore, Associate Professor, Complex Fluid Rheology
C. Mark Maupin, Assistant Professor, Separation and Sequestration, Enzyme and Channel Simulations, Biofuels
J. Douglas Way, Professor, Membranes, Separation Processes

SAMPLE PUBLICATIONS

POLYMERIC AND SOFT MATERIALS

FOCUS ON MATERIALS

DAVID MARR
NING WU
Self Assembly
Creating polymeric and soft materials that work better, are more environmentally responsible and more cost-effective

Ning Wu, an assistant professor focusing on complex fluids and biomimetic materials, is working with materials that could lead to more efficient photovoltaics, photonic crystals, multi-functional and environmentally adaptive nanomotors, as well as biomedical diagnostic and therapeutic systems. Using applied fields and colloidal systems, he creates micro- and nano-structures that mimic nature. These structures boast features attractive to food, pharmaceutical and cosmetics industries, such as being biodegradable, environment-responsive and more effective in lower amounts.

David Marr, department head and professor, has worked with optical force fields similar to the tractor beams in “Star Trek” to create microdevices, such as pumps, mixers and valves the size of a human red blood cell. Using this approach, Marr also has created optical stretchers for individual cell mechanical property measurement. Whether for research or for biomedical analysis, there is a need for simplified devices that retain complex functionality.

David Wu, a professor who works in simulation and complex materials, develops theory and computer simulation to understand the underlying design principles relating molecular architecture to the chemical and physical properties of polymeric materials. One application for his research is structural modifications to make water-absorbent plastics. His study of kinetics has yielded fundamental information for understanding natural viruses and the principles of self-assembly that can be applied to man-made structures.

FACULTY
John Dorgan, Professor, Polymeric Materials from Biorenewable Resources, Biofuels Separation
Andrew M. Herring, Associate Professor, Catalysis, Membranes
Matthew Liberatore, Associate Professor, Complex Fluid Rheology
David W.M. Marr, Department Head and Professor, Microfluids, Biomedical Microdevices
Amadeu K. Sum, Associate Professor, Clathrate Hydrates, Biological, Biomolecular Systems, Simulations
David T. W. Wu, Professor, Simulation, Complex Materials
Ning Wu, Assistant Professor, Complex Fluids, Biomimetic Materials

BIOFUEL BIOLOGICAL BIOMASS BIOMEDICAL CONVENTIONAL ENERGY ELECTRONIC FUEL CELLS HYDRATES NANOTECHNOLOGY NEW MATERIALS PEDAGOGY POLYMERS RENEWABLE ENERGY SOFT MATERIALS SIMULATIONS SOLAR TEACHING

SAMPLE PUBLICATIONS

SOLAR AND ELECTRONIC MATERIALS

FOCUS ON SUSTAINABILITY

COLIN WOLDEN

SUMIT AGARWAL
Solar Energy Conversion
Harnessing the power of the sun using electronic materials and nanotechnology to meet the terawatt challenge

The terawatt (TW) challenge describes the goal of providing 30 TW of carbon-neutral power by 2050, the amount required to both sustain population growth and stabilize atmospheric CO₂ levels. Weaver Distinguished Prof. Colin Wolden is working to meet this challenge as site director for the Center for Revolutionary Solar Photoconversion.

Wolden and numerous department faculty work in solar and electronic materials. A few of their projects include research in solar photovoltaics, solar fuels and energy efficient electronics. Solar photovoltaic developments include using nanostructures to enhance light harvesting, quantum dot-based solar cells and the use of chalcogen-containing plasmas to develop low-cost, thin-film photovoltaics.

In the area of solar fuels, efforts are under way to increase solar fuel efficiency by employing abundantly available photocatalysts. The new catalysts are being developed to produce solar fuels, such as hydrogen and methanol.

To meet the future energy demands, it will be imperative to reduce waste. Today, windows account for 30 percent of heating and cooling costs in typical buildings. Wolden is collaborating with the National Renewable Energy Laboratory to develop economical routes to manufacture electrochromic “smart” windows, which automatically modulate their transparency for energy efficient buildings.

FACULTY
Sumit Agarwal, Associate Professor, Nanostructured Materials
Andrew M. Herring, Associate Professor, Catalysis, Membranes
Matthew Liberatore, Associate Professor, Complex Fluid Rheology
Rachel Morrish, Teaching Associate Professor, Environmentally Sustainable Processing
Colin Wolden, Professor, Electronic Materials Processing
Ning Wu, Assistant Professor, Soft Materials

BIOFUEL  BIOLOGICAL  BIOMASS  BIOMEDICAL  CONVENTIONAL ENERGY ELECTRONIC FUEL CELLS  HYDRATES  NANOTECHNOLOGY  NEW MATERIALS  PEDAGOGY  POLYMERS RENEWABLE ENERGY  SOFT MATERIALS  SIMULATIONS  SOLAR  TEACHING

SAMPLE PUBLICATIONS

Studio Biology
Using the latest technology as an aid both in and out of the classroom

Taught in a new and unique environment, Studio Biology introduces active learning to the instruction of biology at the freshman level. Studio Biology has little lecture, the students design and perform experiments to explore biological systems. Built upon the success of Studio Physics, the studio approach has been proven highly successful in promoting analytical thinking, improved conceptual understanding as well as improved learning outcomes and increased student satisfaction. Profs. Judy Schoonmaker and Josh Ramey are teaching at the interface between biology and engineering, which will help students see applications of biological concepts in real world examples.

TEACHING HIGHLIGHTS
• Online homework has improved final course grades in the Material and Energy Balance course over the last two years.
• Prof. Matthew Liberatore was awarded the Alfred E. Jenni Faculty Fellowship in 2011 in part for his reputation among students for his dedication and concern for their learning.
• Prof. Liberatore was awarded the 2013 Raymond W. Fahien Award from the ASEE for contributions to ChemE education.
• Prof. Ronald Miller has won 14 teaching awards, including the Lifetime Achievement in Chemical Engineering Pedagogical Scholarship from the American Society for Engineering Education in 2011.
• Prof. Miller is developing graphics-based interactive software to measure students’ intellectual development using expert system and neural network technologies.
• Funded by the National Science Foundation, Teaching Associate Prof. Tracy Gardner is improving student learning through in-class use of tablets and other freeform input devices.

FACULTY
James F. Ely, University Professor Emeritus, Molecular Simulation, Thermophysics
Tracy Gardner, Assistant Department Head and Teaching Associate Professor, Pedagogical Methods
Hugh King, Teaching Professor, Biology, Math, Computer Science
Matthew Liberatore, Associate Professor, Complex Fluid Rheology
Ronald L. Miller, Professor, Pedagogical Methods
C. Josh Ramey, Teaching Assistant Professor, Biology
Judy Schoonmaker, Teaching Associate Professor, Biology
E. Dendy Sloan, University Professor Emeritus, Natural Gas Hydrates, Pedagogical Methods
Charles Vestal, Teaching Associate Professor, Computational Methods, Thermodynamics

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SAMPLE PUBLICATIONS

MINES NUMBERS

1
Mines' ranking according to college.usatoday.com, “25 colleges where graduates make the highest starting salaries.”

1
Mines’ ranking in engineering schools (out of 281) in the country by College Factual, featured in The Denver Post and USA TODAY

7
Mines’ ranking in “Top early-career salaries for bachelor’s degrees” by PayScale, featured in The Wall Street Journal

38
Mines’ ranking in in 2014 Top Public Schools by U.S. News and World Report, 88 in National Universities

3.8
Mines’ undergraduate applicants’ average GPA

44
Research centers on campus

91, 94, 97
Percentages of bachelor’s, master’s and PhD graduates placed upon graduation in 2013-14

1,355
Mines’ incoming undergraduate average SAT scores

5,873
Student body, undergraduates and graduates

ENGINEERING THE WAY
Mines, a public research university devoted to engineering and applied science, has the highest admission standards of any public university in Colorado and among the highest of any public university in the nation. Since its founding in 1874, Mines has distinguished itself by developing educational and research programs that address the world’s critical needs for energy, materials, water and the responsible stewardship of the earth.

GOTHAM
Mines’ official typeface is Gotham, which was designed in 2000 by New York-based Hoefler & Frere-Jones for GQ magazine. Frere-Jones reportedly used the mathematical reasoning of a draftsperson to allow the letters to escape the grid wherever necessary in this geometric class of sans serif fonts.