

*Colorado
School of Mines*

*2011–2012
Graduate Bulletin*

To Mines Graduate Students:

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Published by

Colorado School of Mines, Golden, CO 80401

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Academic Calendar

Fall Semester 2011

Confirmation deadline	Aug. 22, Monday
Faculty Conference	Aug. 22, Monday
Classes start (1)	Aug. 23, Tuesday
Graduate Students—last day to register without late fee	Aug. 26, Friday
Labor Day (Classes held)	Sept. 5, Monday
Last day to register, add or drop courses without a “W” (Census Day)	Sept. 7, Wednesday
Fall Break	Oct. 17 & 18, Monday & Tuesday
Midterm grades due	Oct. 17, Monday
Last day to withdraw from a course—Continuing students	Nov. 15, Tuesday
Priority Registration Spring Semester	Nov. 14-18, Monday–Friday
Non-class day prior to Thanksgiving Break	Nov. 23, Wednesday
Thanksgiving Break	Nov. 24–Nov. 25, Thursday–Friday
Last day to withdraw from a course—New students in 1st or 2nd semester at CSM	Dec. 2, Friday
Last day to completely withdraw from CSM	Dec. 8, Thursday
Classes end	Dec. 8, Thursday
Dead Week	Dec. 5-Dec. 9, Monday-Friday
Dead Day	Dec. 9, Friday
Final exams	Dec. 10, 12-15, Saturday, Monday–Thursday
Semester ends	Dec. 16, Friday
Midyear Degree Convocation	Dec. 16, Friday
Final grades due	Dec. 19, Monday
Winter Recess	Dec. 19–Jan. 10, Saturday–Tuesday

Spring Semester 2012

Confirmation deadline	Jan. 10, Tuesday
Classes start (1)	Jan. 11, Wednesday
Grad Students—last day to register without late fee	Jan. 13, Friday
Last day to register, add or drop courses without a “W” (Census Day)	Jan. 26, Thursday
Non-class day - Presidents’ Day	Feb. 20, Monday
Midterms grades due	March 5, Monday
Spring Break	March 12-16, Monday-Friday
Last day to withdraw from a course—Continuing students	April 10, Tuesday
E-Days	March 29 - March 31, Thursday–Saturday
Priority Registration, Summer and Fall Terms	April 9-13, Monday–Friday
Last day to withdraw from a course—New students in 1st or 2nd semester at CSM	April 27, Friday
Last day to completely withdraw from CSM	May 3, Thursday
Classes end	May 3, Thursday
Dead Week	April 30-May 4, Monday-Friday
Dead Day	May 4, Friday
Final exams	May 5, 7-10 Saturday, Monday–Thursday
Semester ends	May 11, Friday
Commencement	May 11, Friday
Final grades due	May 14, Monday

Summer Sessions 2012

Summer I - First Day of Class (1)	May 14, Monday
Summer I (Census Day)	May 18, Friday
Memorial Day (Holiday—No classes held)	May 28, Monday
Last day to withdraw from Summer I Term (all students)	June 8, Friday
Summer I ends	June 22, Friday
Summer I grades due	June 25, Monday
Summer II First Day of Class (1)	June 25, Monday
Independence Day (Holiday—No classes held)	July 4, Wednesday
Summer II Census Day	June 29, Friday
Last day to withdraw from Summer II Term (all students)	July 20, Friday
Summer II ends (2)	Aug. 3, Friday
Summer II grades due	Aug. 6, Monday

(1) Petition for changes in tuition classification due in the Registrar’s office for this term.

(2) PHGN courses end two weeks later on Friday, August 17th.

University Administration / Useful Contacts

Office of Graduate Studies

Mailing address

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Golden, CO 80401-1887

Telephone

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International Student Advisor

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Registrar

303-273-3200

Graduate Student Association

Daniel Baker

303 273-2101

President

Academic Departments & Divisions

The address for all CSM academic departments
and divisions is

1500 Illinois Street

Golden, Colorado 80401-1887

World Wide Web address: <http://www.mines.edu/>

Academic department and division telephone numbers are

Chemical and Biological Engineering

..... 303 273-3720

Chemistry and Geochemistry

..... 303 273-3610

Economics and Business

..... 303 273-3482

Engineering

..... 303 273-3650

Environmental Science and Engineering

..... 303 273-3427

Geology and Geological Engineering

..... 303 273-3800

Geophysics

..... 303 273-3450

Liberal Arts and International Studies

..... 303 273-3750

Materials Science

..... 303 273-3660

Mathematical and Computer Sciences

..... 303 273-3860

Metallurgical and Materials Engineering

..... 303 273-3770

Mining Engineering

..... 303 273-3701

Nuclear Engineering

..... 303-273-3618

Petroleum Engineering

..... 303 273-3740

Physics

..... 303 273-3830

General Information

Mission and Goals

Colorado School of Mines is a public research university devoted to engineering and applied science related to resources. It is one of the leading institutions in the world in these areas. It has the highest admission standards of any university in Colorado and among the highest of any public university in the U.S. Mines has dedicated itself to responsible stewardship of the earth and its resources. It is one of a very few institutions in the world having broad expertise in resource exploration, extraction, production and utilization that can be brought to bear on the world's pressing resource-related environmental problems. As such, it occupies a unique position among the world's institutions of higher education.

The school's role and mission has remained constant and is written in the Colorado statutes as: *The Colorado School of Mines shall be a specialized baccalaureate and graduate research institution with high admission standards. The Colorado School of Mines shall have a unique mission in energy, mineral, and materials science and engineering and associated engineering and science fields. The school shall be the primary institution of higher education offering energy, mineral and materials science and mineral engineering degrees at both the graduate and undergraduate levels. (Colorado revised Statutes, Section 23-41-105)*

Throughout the school's history, the translation of its mission into educational programs has been influenced by the needs of society. Those needs are now focused more clearly than ever before. We believe that the world faces a crisis in balancing resource availability with environmental protection and that Mines and its programs are central to the solution to that crisis. Therefore the school's mission is elaborated upon as follows:

Colorado School of Mines is dedicated to educating students and professionals in the applied sciences, engineering, and associated fields related to

- ◆ *the discovery and recovery of the Earth's resources,*
- ◆ *their conversion to materials and energy,*
- ◆ *their utilization in advanced processes and products, and*
- ◆ *the economic and social systems necessary to ensure their prudent and provident use in a sustainable global society.*

This mission will be achieved by the creation, integration, and exchange of knowledge in engineering, the natural sciences, the social sciences, the humanities, business and their union to create processes and products to enhance the quality of life of the world's inhabitants.

The Colorado School of Mines is consequently committed to serving the people of Colorado, the nation, and the global community by promoting stewardship of the Earth upon which all life and development depend. (Colorado School of Mines Board of Trustees, 2000)

Institutional Values and Principles

Graduate Education

The Colorado School of Mines is dedicated to serving the people of Colorado, the nation and the global community by providing high quality educational and research experiences to students in science, engineering and related areas that support the institutional mission. Recognizing the importance of responsible earth stewardship, Mines places particular emphasis on those fields related to the discovery, production and utilization of resources needed to improve the quality of life of the world's inhabitants and to sustain the earth system upon which all life and development depend. To this end, Mines is devoted to creating a learning community that provides students with perspectives informed by the humanities and social sciences, perspectives that also enhance students' understanding of themselves and their role in contemporary society. Mines therefore seeks to instill in all graduate students a broad class of developmental and educational attributes:

- ◆ An in-depth knowledge in an area of specialization, enhanced by hands-on experiential learning, and breadth in allied fields, including:
 1. the background and skills to be able to recognize, define and solve problems by applying sound scientific and engineering principles, and
 2. for thesis-based students, experience in conducting original scientific research and engineering design at the forefront of their particular area of specialization.
- ◆ The ability to function effectively in an information-based economy and society, including:
 1. written, oral and graphical communications skills that enable effective transmission of concepts and ideas as well as technical information, and
 2. expertise in finding, retrieving, evaluating, storing and disseminating information in ways that enhance their leadership role in society and their profession.
- ◆ Preparation for leadership in a team-based milieu, including:
 1. the flexibility to adjust to an ever-changing professional environment and to appreciate diverse approaches to understanding and solving professional and societal problems,
 2. the creativity, resourcefulness, receptivity and breadth of interests to think critically about a wide range of cross-disciplinary issues,
 3. a strong work ethic that inspires commitment and loyalty on the part of colleagues,
 4. interpersonal skills and attitudes which promote cooperation and enable leadership, and
 5. acceptance of responsibility for their own growth through life-long learning.

- ◆ The capability of adapting to, appreciating and working effectively in an international environment, including:
 1. being able to succeed in an increasingly interdependent world where borders between cultures and economies are becoming less distinct, and
 2. appreciating the traditions and languages of other cultures, as well as valuing and supporting diversity in their own society.
- ◆ High standards of integrity expressed through ethical behavior and acceptance of the obligation to enhance their profession and society through service and leadership.

Professional Education

A central purpose of a university is the widespread and open distribution of the special knowledge created by, and reposing in, the expertise of the faculty. At Mines, that special knowledge falls into several broad categories:

- ◆ A mature body of knowledge, in areas of historic leadership, which is of great value to professionals in those fields throughout the world.
- ◆ Creative advances in emerging fields of science and engineering, developed in Mines' leading-edge research laboratories, which can contribute to the economic and physical well-being of people in Colorado and the nation.
- ◆ Expertise in problem-solving methodologies, including engineering design and structured decision-making, which is of growing importance in all technical-social-political realms as our global society becomes increasingly complex and interdependent.
- ◆ Leadership in the development of innovative educational tools and techniques which can help people—young and old—to be better prepared to succeed in advanced education, productive careers, and satisfying personal lives.

Additional outreach responsibilities are imposed by the special role and nature of Mines:

- ◆ Mines is committed to inculcating in its traditional residential undergraduate and graduate students an appreciation for and commitment to life-long learning and inquiry. This imposes on Mines a responsibility to create and support Professional Outreach programs that will expose students to self-directed learning experiences while still in residence, and provide opportunities for continued intellectual growth after they graduate.
- ◆ The State requires all public colleges and universities in Colorado, in concert, to provide appropriate educational opportunities in rural areas which are under-served by traditional residential institutions.

In addition to these philosophical goals, Professional Outreach can make an important pragmatic contribution to the university by:

- ◆ Developing and sustaining programs which address the lifelong education needs of individuals in professions associated with science, mathematics, engineering, and technology.
- ◆ Recruiting high-quality students for the traditional residential programs
- ◆ Spreading and enhancing the reputation of Mines throughout the world
- ◆ Generating revenues that help support the residential and research missions of the university

Research

The creation and dissemination of new knowledge are primary responsibilities of all members of the university community. Public institutions have an additional responsibility to use that knowledge to contribute to the economic growth and public welfare of the society from which they receive their charter and support. As a public institution of higher education, a fundamental responsibility of Mines is to provide an environment that enables contribution to the public good by encouraging creative research and ensuring the free exchange of ideas, information, and results. To this end, the institution acknowledges the following responsibilities:

- ◆ To insure that these activities are conducted in an environment of minimum influence and bias, it is essential that Mines protect the academic freedom of all members of its community.
- ◆ To provide the mechanisms for creation and dissemination of knowledge, the institution recognizes that access to information and information technology (e.g. library, computing and internet resources) are part of the basic infrastructure support to which every member of the community is entitled.
- ◆ To promote the utilization and application of knowledge, it is incumbent upon Mines to define and protect the intellectual-property rights and responsibilities of faculty members, students, as well as the institution.

The following principles derive from these values and responsibilities:

- ◆ The institution exists to bring faculty and students together to form a community of scholars.
- ◆ Faculty members have unique relationship with the institution because of their special responsibility to create and disseminate knowledge independent of oversight or direction from the institution.
- ◆ Students have a dual role as creators and recipients of knowledge.
- ◆ The institution and the faculty share responsibility for facilitating the advancement of students in their chosen discipline.

- ◆ The institution and the faculty are mutually dependent upon each other, and share the responsibility for the reputation of both the university and the individual.
- ◆ Although research objectives should be informed by the institution's responsibility (as a public institution) to contribute to economic growth and societal well-being, research priorities must be driven by academic needs relating to the creation, development and dissemination of knowledge.
- ◆ Research policies and practices must conform to the state non-competition law which requires that all research projects have an educational component through the involvement of students and/or post-doctoral fellows.
- ◆ Both the creator and the institution have interest in, and a responsibility to promote, the dissemination and utilization of new knowledge for public good through publication and commercialization.
- ◆ Although commercialization is not a primary responsibility of the university community, it is a common result of technology transfer. The creator and the institution may each have an interest in the commercialization of intellectual property and should share in the potential benefits and risks based on their contributions.

Intellectual Property

The creation and dissemination of knowledge are primary responsibilities of all members of the university community. As an institution of higher education, a fundamental mission of Mines is to provide an environment that motivates the faculty and promotes the creation, dissemination, and application of knowledge through the timely and free exchange of ideas, information, and research results for the public good. To insure that these activities are conducted in an environment of minimum influence and bias, so as to benefit society and the people of Colorado, it is essential that Mines protect the academic freedom of all members of its community. It is incumbent upon Mines to help promote the utilization and application of knowledge by defining and protecting the rights and responsibilities of faculty members, students and the institution, with respect to intellectual property which may be created while an individual is employed as a faculty member or enrolled as a student. The following principles, derived from these responsibilities and values, govern the development and implementation of Mines' Intellectual Property Policies.

- ◆ The institution exists to bring faculty and students together to form a community of scholars.
- ◆ Faculty members have a unique relationship with the institution because faculty create and disseminate knowledge independent of oversight or direction from the institution.
- ◆ Faculty activities must be driven by academic needs relating to the creation and dissemination of knowledge rather than commercial opportunities.
- ◆ The institution and the faculty share responsibility for facilitating the advancement of students in their chosen discipline. Students are the independent creators of the expression of ideas in their theses, but may have a dual role as both an independent creator of an expression of ideas and as directed employees.
- ◆ The institution and the faculty are mutually dependent upon each other, and share the responsibility for the reputation of both the university and the individual.
- ◆ Both the creator and the institution have an interest in, and a responsibility to promote, the dissemination and utilization of knowledge for the public good.
- ◆ Although commercialization is not a primary responsibility of the university community, it is sometimes the result of technology transfer.
- ◆ The creator and the institution should share in the potential benefits and risks in proportion to their contributions and/or agreed assumption of benefits and risks.
- ◆ All members of the Mines community will demonstrate the highest level of integrity in their activities associated with intellectual property.

History of Colorado School of Mines

In 1865, only six years after gold and silver were discovered in the Colorado Territory, the fledgling mining industry was in trouble. The nuggets had been picked out of streams and the rich veins had been worked, and new methods of exploration, mining, and recovery were needed.

Early pioneers like W.A.H. Loveland, E.L. Berthoud, Arthur Lakes, George West and Episcopal Bishop George M. Randall proposed a school of mines. In 1874 the Territorial Legislature appropriated \$5,000 and commissioned Loveland and a Board of Trustees to found the Territorial School of Mines in or near Golden. Governor Routt signed the Bill on February 9, 1874, and when Colorado became a state in 1876, the Colorado School of Mines was constitutionally established. The first diploma was awarded in 1883.

As Mines grew, its mission expanded from the rather narrow initial focus on nonfuel minerals to programs in petroleum production and refining as well. Recently it has added programs in materials science and engineering, energy and environmental engineering, and a broad range of other engineering and applied science disciplines. Mines sees its mission as education and research in engineering and applied science with a special focus on the earth science disciplines in the context of responsible stewardship of the earth and its resources.

Mines long has had an international reputation. Students have come from nearly every nation, and alumni can be found in every corner of the globe.

Location

Golden, Colorado, has always been the home of Mines. Located in the foothills of the Rocky Mountains 20 minutes west of Denver, this community of 15,000 also serves as home to the Coors Brewing Company, the National Renewable Energy Laboratory, and a major U.S. Geological Survey facility that also contains the National Earthquake Center. The seat of government for Jefferson County, Golden once served as the territorial capital of Colorado. Skiing is an hour away to the west.

Administration

By State statute, the school is managed by a seven-member board of trustees appointed by the governor, and the student and faculty bodies elect one nonvoting board member each. The school is supported financially by student tuition and fees and by the State through annual appropriations. These funds are augmented by government and privately sponsored research, and private gift support from alumni, corporations, foundations and other friends.

Colorado School of Mines Non-Discrimination Statement

In compliance with federal law, including the provisions of Titles VI and VII of the Civil Rights Act of 1964, Title IX of the Education Amendment of 1972, Sections 503 and 504 of the Rehabilitation Act of 1973, the Americans with Disabilities Act (ADA) of 1990, the ADA Amendments Act of 2008, Executive Order 11246, the Uniformed Services Employment and Reemployment Rights Act, as amended, the Genetic Information Nondiscrimination Act of 2008, and Board of Trustees Policy 10.6, the Colorado School of Mines does not discriminate against individuals on the basis of age, sex, sexual orientation, gender identity, gender expression, race, religion, ethnicity, national origin, disability, military service, or genetic information in its administration of educational policies, programs, or activities; admissions policies; scholarship and loan programs; athletic or other school-administered programs; or employment.

Inquiries, concerns, or complaints should be directed by subject content as follows:

The Employment-related EEO and discrimination contact is Mike Dougherty, Associate Vice President for Human Resources, Guggenheim Hall, Room 110, Golden, Colorado 80401 (Telephone: 303.273.3250). The ADA Coordinator and the Section 504 Coordinator for employment is Ann Hix, Benefits Manager, Human Resources, Guggenheim Hall, Room 110, Golden, Colorado 80401 (Telephone: 303.273.3250). The ADA Coordinator and the Section 504 Coordinator for students and academic educational programs is Ron Brummett, Director of Career Planning & Placement / Student Development Services, 1600 Maple Street, Suite 8, Golden, Colorado 80401 (Telephone: 303.273.3297). The Title IX Coordinator is Maureen Durkin, Director of Policy and Planning, Guggenheim Hall, Room 212A, Golden, Colorado 80401 (Telephone: 303.384.2236). The ADA Facilities Access Coordinator is Gary Bowersock, Director of Facilities Management, 1318 Maple Street, Golden, Colorado 80401 (Telephone: 303.273.3330).

The Graduate School

Unique Programs

Because of its special focus, Colorado School of Mines has unique programs in many fields. For example, Mines is the only institution in the world that offers doctoral programs in all five of the major earth science disciplines: Geology and Geological Engineering, Geophysics, Geochemistry, Mining Engineering, and Petroleum Engineering. It also has one of the few Metallurgical and Materials Engineering programs in the country that still focuses on the complete materials cycle from mineral processing to finished advanced materials.

In addition to the traditional programs defining the institutional focus, Mines is pioneering both undergraduate and graduate interdisciplinary programs. The School understands that solutions to the complex problems involving global processes and quality of life issues require cooperation among scientists, engineers, economists, and the humanities.

Mines offers interdisciplinary programs in areas such as materials science, environmental science and engineering, management and public policy, hydrology, and geochemistry. These programs make interdisciplinary connections between traditional fields of engineering, physical science and social science, emphasizing a broad exposure to fundamental principles while cross-linking information from traditional disciplines to create the insight needed for breakthroughs in the solution of modern problems.

When the need arises, Mines also offers interdisciplinary, non-thesis Professional Master degrees to meet the career needs of working professionals in Mines' focus areas.

Coordinated by the several departments involved, these interdisciplinary programs contribute to Mines' leadership role in addressing the problems and developing solutions that will enhance the quality of life for all of earth's inhabitants in the next century.

Graduate Degrees Offered

Mines offers professional masters, master of science (M.S.), master of engineering (M.E.) and doctor of philosophy (Ph.D.) degrees in the disciplines listed in the chart at right.

In addition to masters and Ph.D. degrees, departments and divisions can also offer graduate certificates. Graduate certificates are designed to have selective focus, short time to completion and consist of course work only.

Accreditation

Mines is accredited through the doctoral degree by the Higher Learning Commission (HLC) of the North Central Association, 230 South LaSalle Street, Suite 7-500, Chicago, Illinois 60604-1413 – telephone (312) 263-0456.

The Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology, 111 Market Place, Suite 1050, Baltimore, MD 21202-4012 - telephone (410) 347-7700, accredits undergraduate degree programs in chemical engineering, engineering, engineering physics, geological

engineering, geophysical engineering, metallurgical and materials engineering, mining engineering and petroleum engineering. The American Chemical Society has approved the degree program in the Department of Chemistry and Geochemistry.

Degree Programs	Prof.	M.S.	M.E.	Ph.D.
Applied Physics		■		■
Chemical Engineering		■		■
Chemistry		■		
Applied Chemistry				■
Engineering		■		■
Engineering & Technology Management		■		
Environmental Geochemistry	■			
Environmental Science & Engineering		■		■
Geochemistry		■		■
Geological Engineering		■	■	■
Geology		■		■
Geophysical Engineering		■		■
Geophysics		■		■
Hydrology		■		■
International Political Economy & Resources		□		
Materials Science		■		■
Mathematical & Computer Science		■		■
Metallurgical & Materials Engineering		■	■	■
Mineral & Energy Economics		■		■
Mineral Exploration & Mining Geosciences	■			
Mining & Earth Systems Engineering		■	■	■
Nuclear Engineering		■		■
Operations Research with Engineering				■
Petroleum Engineering		■	■	■
Petroleum Reservoir Systems	■			

□ Master of International Political Economy of Resources

Admission to the Graduate School

Admission Requirements

The Graduate School of Colorado School of Mines is open to graduates from four-year programs at recognized colleges or universities. Admission to all graduate programs is competitive, based on an evaluation of prior academic performance, test scores and references. The academic background of each applicant is evaluated according to the requirements of each department outlined later in this section of the Bulletin.

To be a candidate for a graduate degree, students must have completed an appropriate undergraduate degree program. Colorado School of Mines undergraduate students in the Combined Degree Program may, however, work toward completion of graduate degree requirements prior to completing undergraduate degree requirements. See the Combined Undergraduate/Graduate Degree section of the Graduate Bulletin for details of this program.

Categories of Admission

There are four categories of admission to graduate studies at Colorado School of Mines: regular, provisional, graduate nondegree and foreign exchange.

Regular Degree Students

Applicants who meet all the necessary qualifications as determined by the program to which they have applied are admitted as regular graduate students.

Provisional Degree Students

Applicants who are not qualified to enter the regular degree program directly may be admitted as provisional degree students for a trial period not longer than 12 months. During this period students must demonstrate their ability to work for an advanced degree as specified by the admitting degree program. After the first semester, the student may request that the department review his or her progress and make a decision concerning full degree status. With department approval, the credits earned under the provisional status can be applied towards the advanced degree.

Nondegree Students

Practicing professionals may wish to update their professional knowledge or broaden their areas of competence without committing themselves to a degree program. They may enroll for regular courses as nondegree students. Inquiries and applications should be made to the Graduate Office, CSM, Golden, CO 80401-0028. Phone: 303-273-3247; FAX 303-273-3244. A person admitted as a nondegree student who subsequently decides to pursue a regular degree program must apply and gain admission to the Graduate School. All credits earned as a nondegree student may be transferred into the regular degree program if the student's graduate committee and department head approve.

Foreign Exchange Students

Graduate level students living outside of the U.S. may wish to take courses at Colorado School of Mines as exchange students. They may enroll for regular courses as for-

eign exchange students. Inquiries and applications should be made to the Office of International Programs, CSM, Golden, CO 80401-0028. Phone: 303-384-2121. A person admitted as a foreign exchange student who subsequently decides to pursue a regular degree program must apply and gain admission to the Graduate School. All credits earned as a foreign exchange student may be transferred into the regular degree program if the student's graduate committee and department head approve.

Combined Undergraduate/Graduate Programs

Several degree programs offer Mines undergraduate students the opportunity to begin work on a Graduate Degree while completing the requirements of their Bachelor Degree. These programs can give students a head start on graduate education. An overview of these combined programs and description of the admission process and requirements are found in the Graduate Degrees and Requirements section of this Bulletin.

Admission Procedure

Applying for Admission

Apply electronically for admission on the World Wide Web. Our Web address is

http://www.mines.edu/graduate_admissions

Follow the procedure outlined below.

1. Application: Go to the online application form at <http://www.mines.edu/gradschoolapp/onlineapp.html>. You may download a paper copy of the application from our website or contact 303-273-3247 or grad-school@Mines.edu to have one sent my mail. Students wishing to apply for graduate school should submit completed applications by the following dates:

for Fall admission*

January 15 - Priority consideration for financial support

May 1 - International student deadline

July 1 - Domestic student deadline

for Spring Admission*

October 1

*Some programs have different application deadlines. Please refer to http://www.mines.edu/Deadlines_GS for current deadline information for specific programs.

Students wishing to submit applications beyond the final deadline should make a request to the individual academic department.

2. Transcripts: Send to the Graduate School one official transcript from each school previously attended. The transcripts should be sent directly by the institution attended. International students' transcripts must be in English or have an official English translation attached.

3. Letters of Recommendation: Three (3) letters of recommendation are required. Individuals who know your personal qualities and scholastic or professional abilities can use the online application system to submit letters of recommendation on your behalf. Letters can also be mailed directly to the Graduate Office.

4. Graduate Record Examination: Most departments require the General test of the Graduate Record Examination for applicants seeking admission to their programs. Refer to the section Graduate Degree Programs and Courses by Department or the Graduate School application packet to find out if you must take the GRE examination. For information about the test, write to Graduate Record Examinations, Educational Testing Service, PO Box 6000, Princeton, NJ 08541-6000 (Telephone 609-771-7670), or visit online at www.gre.org.

5. English Language Requirements: Applicants whose native language is not English must prove proficiency. Language examination results must be sent to the Graduate School as part of the admission process. The institution has minimum English proficiency requirements - learn more at: http://www.mines.edu/Intl_GS.

English proficiency may be proven by achieving one of the following:

- a) A TOEFL (Test of English as a Foreign Language) minimum score of 550 on the paper-based test, or a computer-based score of 213, or a score of 79 on the internet Based TOEFL (iBT).
- b) At IELTS (International English Language Testing System) Score of 6.5, with no band below a 6.0.
- c) A PTE A (Pearson test of English) score of 70 or higher.
- d) Independent evaluation and approval by the admission-granting department.

6. Additional instructions for admission to graduate school specific to individual departments are contained in the application for admission.

Financial Assistance

To apply for Mines financial assistance, check the box in the Financial Information section of the online graduate application or complete the Financial Assistance section on the paper application.

Application Review Process

When application materials are received by the Graduate School, they are processed and sent to the desired degree program for review. The review is conducted according to the process developed and approved by the faculty of that degree program. The degree program transmits its decision to the Dean of the Graduate School, who then notifies the applicant. The decision of the degree program is final and may not be appealed.

Health Record and Additional Steps

When students first enroll at Mines, they must complete the student health record form which is sent to them when they are accepted for enrollment. Students must submit the student health record, including health history, medical examination, and record of immunization, in order to complete registration.

Questions can be addressed to the Coulter Student Health Center, 1225 17th Street, Golden, CO 80401-1869. The Health Center telephone numbers are 303-273-3381 and 303-279-3155.

International Students

Qualifying international students (see Admission Requirements above) apply for graduate study by following steps one through six listed above.

Summer Courses For New Students

New graduate students entering during the fall semester will be expected to pay full student fees for any courses taken in the summer sessions prior to the fall term of entry.

Student Life at CSM

Housing

Mines Park

The Mines Park apartment complex is located west of the 6th Avenue and 19th Street intersection on 55 acres owned by CSM. The complex houses upper class students, graduate students, families, and some freshmen. Residents must be full-time students.

Units are complete with refrigerators, stoves, dishwashers, cable television wired and wireless internet connections, and an optional campus phone line for an additional fee. There are two community centers which contain the laundry facilities, recreational/study space, and a convenience store.

2011-2012 rates are as follows:

Family Housing

1 bedroom	\$750/mo
2 bedroom	\$866/mo

Apartment Housing

1 bedroom	\$750/mo
2 bedroom	\$1,016/mo
3 bedroom	\$1,359/mo

Tenant pays gas and electric utilities. A Mines Park parking pass is included.

For a Mines Park application, please contact the housing office at (303) 273-3350 or visit the Student Life office in the Ben Parker Student Center, Room 218.

Student Services

Ben H. Parker Student Center

The Ben H. Parker Student Center contains the offices for the Vice President of Student Life and Dean of Students, Associate Dean of Students, Housing, Student Activities and Greek Life, Student Government (ASCMS), Admissions and Financial Aid, Cashier, Student Development and Academic Services, Services for Students with Disabilities, International Student Services, Career Services, Registrar, Blaster Card, Conferences Services, and student organizations. The Student Center also contains the student dining hall (known as the Slate Café), food court, bookstore, student lounges, meeting rooms, and banquet facilities.

Student Recreation Center

Completed in May 2007, the 108,000 square foot Student Recreation Center, located at the corner of 16th and Maple Streets in the heart of campus, provides a wide array of facilities and programs designed to meet students' recreational and leisure needs while providing for a healthy lifestyle. The Center contains a state-of-the-art climbing wall, an eight-lane, 25 meter swimming and diving pool, a cardiovascular and weight room, two multi-purpose rooms designed and equipped for aerobics, dance, martial arts programs and other similar activities, a competition gymnasium containing three full-size basketball courts as well as seating for 2500 people, a separate recreation gymnasium designed specifically for a wide variety of recreational programs, extensive locker room and shower facilities, and a large lounge intended for relaxing, playing games or watching televi-

sion. In addition to housing the Outdoor Recreation Program as well as the Intramurals and Club Sports Programs, the Center serves as the competition venue for the Intercollegiate Men and Women's Basketball Programs, the Intercollegiate Volleyball Program and the Men and Women's Intercollegiate Swimming and Diving Program.

Office for Student Development and Academic Services

The Student Development and Academic Services Office (SDAS), located in the Student Center, serves as the personal, academic and career counseling center for all students enrolled in four credit hours or more or any student that has paid the Student Services Fee. Through its various services, the center acts as a comprehensive resource for the personal growth and life skills development of our students. SDAS houses a library of over 200 books and other materials for checkout, and is home to Mine's Engineers Choosing Health Options (ECHO) program, promoting wise and healthy decision making regarding students' use of alcohol and other drugs. Please visit <http://counseling.mines.edu> for more information.

Counseling: Experienced, professional counselors offer assistance in a variety of areas. Personal counseling for stress management, relationship issues, wellness education and/or improved self image are a few of the areas often requested. Assertiveness, stress management, time management, gender issues, the MBTI, and career assessments are also popular interactive presentations. SDAS works closely with other student life departments to address other issues.

Academic Services: The staff conducts workshops in areas of interest to college students, such as time management, learning skills, test taking, preparing for finals and college adjustment. One-on-one academic counseling with assessment of individual learning skills is also available. Additional learning resources are provided on the department website. Please visit <http://academicservices.mines.edu> for more information about tutoring programs, and academic counseling.

Tutoring and Academic Excellence Workshops: Graduate students are welcome to avail themselves of free walk-in tutoring and/or weekly workshops in introductory calculus, chemistry, and physics.

Disability Services: This office serves students with documented disabilities who are seeking academic accommodations or adjustments. Disability Services coordinates CSM's efforts to comply with the broad mandates of Section 504 of the Rehabilitation Act of 1973 and the Americans with Disabilities Act Amendments Act of 2008 (ADAAA). Further information, application and documentation guidelines can be found on the Disability Services website <http://disabilities.mines.edu>.

International Student Services

International student advising and international student services are the responsibility of International Student and Scholar Services, located in the Student Center. The International Student and Scholar Services Office coordinates the Friendship Family Program. Orientation programs for new international students are held at the beginning of each semester. Visas and work permits are processed through the International Student Advisor at the International Student and Scholar Services Office.

For more information, call the International Student and Scholar Services office at 303-273-3210 or FAX 303-273-3099.

Identification Cards (BLASTER CARD)

Blaster Cards are made in the Student Activities Office in the Parker Student Center, and all new students must have a card made as soon as possible after they enroll. Each semester the Student Activities Office issues RTD Bus Pass stickers for student ID's. Students can replace lost, stolen, or damaged Blaster Cards for a small fee.

The Blaster Card can be used as a debit card to make purchases at all campus food service facilities, to check material out of the CSM Library, to make purchases at the campus residence halls, and may be required to attend various CSM campus activities.

Please visit the website at <http://www.is.mines.edu/BlasterCard> for more information.

Student Health Center

The Student Health Center, located at 17th and Elm, provides primary health care to CSM students and their spouses. Students pay a Student Health Services fee each semester which entitles them to unlimited visits with a healthcare provider as well as certain prescriptions and over-the-counter medications. Spouses of enrolled students may also pay the fee and receive services except for dental services. The health center provides wellness education, immunizations, allergy shots, flu shots, nutrition counseling and information regarding a wide range of health concerns. Staff members are available to provide health-promotion events for students groups and residence hall programming.

The Student Health Center is open Monday through Friday 8 A.M.-12 P.M. and 1-4:45 P.M. It is staffed by Nurse Practitioners and RN's throughout the day. A physician is on campus several days per week from 3-4:45 pm during the academic year, and is on call when the Health Center is closed.

Dental services are provided to students at the Student Health Center. Services are provided by a dentist, dental hygienist, and dental assistant, and are available by appointment 3 days per week during the academic year and with limited hours during the summer. Services include x-rays, cleanings, fillings, and simple extractions. Referrals to local specialists are made if necessary.

To be eligible for care at the Health Center, students must be enrolled in four or more credit-hours and have paid the Health Services fee. Supervised by the Director of Student Services. Phone: (303) 273-3381; FAX: (303) 279-3155.

Mandatory Health Insurance

Mines requires that all degree-seeking students who are U. S. Citizens or permanent residents, and all international students regardless of degree-seeking status have health insurance that meets or exceeds Mines coverage requirements. Please see <http://healthcenter.mines.edu/Insurance-Information> for current information. Enrollment in the Student Health Benefit Plan is automatic, and each student's account will be charged the Student Health Benefit Plan premium unless a waiver is completed. Domestic students must complete an online enrollment/waiver prior to Census Date. International students must complete a paper waiver and submit it to the International Student and Scholar Services Office prior to Census Date each academic year.

Immunizations

Documentation confirming proof of immunity to measles, mumps, rubella (MMR's) is required of all students enrolled in four credit hours or more or any student that has paid the Student Health Services fee. A health history form will be sent to students after they are accepted for admission and have stated their intent to enroll. It must be returned to the Student Health Center prior to arriving on campus

Proof of immunity consists of an official Certificate of Immunization signed by a physician, nurse, or public health official which documents two doses of each (measles, mumps, and rubella). The Certificate must specify the type of vaccine and the dates (month, day, and year) of administration or written evidence of laboratory tests showing immunity to measles, mumps, and rubella. Failure to meet the immunization requirement will result in a hold on students' registration until this information is received by the Student Health Center.

The completed health history form is confidential and will be a student's medical record while at Mines. This record will be kept in the Student Health Center. The record will not be released unless the student signs a written release.

Motor Vehicle Parking

All motor vehicles on campus must be registered with the campus Facilities Management Division of Parking Services, 1318 Maple Street, and must display a CSM parking permit. Vehicles must be registered at the beginning of each semester or upon bringing your vehicle on campus, and updated whenever you change your address.

Public Safety

The Colorado School of Mines Department of Public Safety is a full service, community oriented law enforcement agency, providing 24/7 service to the campus. It is the mission of the Colorado School of Mines Police Department to make the Mines campus the safest campus in Colorado.

The department is responsible for providing services such as:

- ◆ Proactive patrol of the campus and its facilities;
- ◆ Investigation and reporting of crimes and incidents;
- ◆ Motor vehicle traffic and parking enforcement;
- ◆ Crime and security awareness programs;
- ◆ Alcohol / Drug abuse awareness / education;
- ◆ Self defense classes;
- ◆ Consultation with campus departments for safety and security matters;
- ◆ Additional services to the campus community such as: vehicle unlocks and jumpstarts, community safe walks (escorts), authorized after-hours building and office access, and assistance in any medical, fire, or other emergency situation.

The police officers employed by the Department of Public Safety are fully trained police officers in accordance with the Peace Officer Standards and Training (P.O.S.T.) Board and the Colorado Revised Statute.

Career Center

The CSM Career Center mission is to assist students in developing, evaluating, and/or implementing career, education, and employment decisions and plans. Career development is integral to the success of CSM graduates and to the mission of CSM. All Colorado School of Mines graduates will be able to acquire the necessary job search and professional development skills to enable them to successfully take personal responsibility for the management of their own careers. Services are provided to all students and for all recent graduates, up to 24 months after graduation. Students must adhere to the ethical and professional business and job searching practices as stated in the Career Center Student Policy, which can be found in its entirety on the Student's Homepage of Digger-Net.

In order to accomplish our mission, we provide a comprehensive array of career services:

Career Advice and Counseling

- ◆ Resources to help choose a major;
- ◆ Individual resume and cover letter critiques;
- ◆ Individual job search advice; and
- ◆ Practice video-taped interviews.

Career Planning Services

- ◆ Online resources for exploring careers and employers at <http://careers.mines.edu>;
- ◆ "Career Digger" online - short bios describe what recent grads are doing on their jobs;

- ◆ "Career Manual" online - resume writing, resume and cover letter examples, and job search tips;
- ◆ Job Search Workshops - successful company research, interviewing, business etiquette, networking skills;
- ◆ Salary and overall outcomes information;
- ◆ Company contact information;
- ◆ Grad school information; and
- ◆ Career resource library.

Job Resources

- ◆ Career Day (Fall and Spring);
- ◆ Online summer, part-time, and full-time entry-level job postings at <http://diggernet.net>;
- ◆ Virtual Career Fairs and special recruiting events;
- ◆ On-campus interviewing - industry and government representatives visit the campus to interview students and explain employment opportunities;
- ◆ General employment board;
- ◆ Resume referrals;
- ◆ Employer searching resource; and
- ◆ Continued services up to 24 months after graduation.

Oredigger Student Newspaper

The Oredigger student newspaper, published on a regular basis during the school year, contains news, features, sports, letters, and editorials of interest to students, faculty, and the Golden community.

Veterans' Benefits

The Registrar's Office offers veterans counseling services for students attending the School and using educational benefits from the Veterans Administration.

Military Science Army ROTC (AROTC)

The Military Science Program at the Colorado School of Mines (CSM) is offered in conjunction with the University of Colorado at Boulder (CU-B). The Department of Military Science offers programs leading to an officer's commission in the active Army, Army Reserve, or National Guard in conjunction with an undergraduate or graduate degree. Military Science courses are designed to supplement a regular degree program by offering practical leadership and management experience. Students attend classes at the Colorado School of Mines in Golden.

Two-Year Program

The two-year program consists of the advanced course, preceded by attending the Leaders Training Course (a four-week summer ROTC basic course at Fort Knox, Kentucky). Veterans or Active Army Reserve/Army National Guard Soldiers, are eligible to enroll in the advanced course without attending the Leaders Training Course. Inquiries on advanced placement should be directed to the Department of Military Science. Advanced course students must obtain permission to enroll from the Professor of Military Science (PMS) at 303-492-6495.

Registration and AROTC Course Credit

Army ROTC serves as elective credit in most departments. Elective course credit toward your degree for AROTC classes will be determined by your individual academic advisor. AROTC classes begin with the MSGN prefix.

For more information about the Army ROTC program and scholarships, contact the CU-Boulder Army ROTC Enrollment and Scholarship Officer at 303-492-3549 or 303-492-6495. You can also go to <http://www.colorado.edu/AROTC>. For information specifically about Army ROTC at CSM, call 303-273-3398 or 303-273-3380.

Student Activities

Student government committees, professional societies, living group organizations, special events, honor societies, and interest group organizations add a balance to the CSM community and offer participants the chance to develop leadership and management skills. The Student Activities office can give you an up-to-date list of recognized campus organizations and more information about them.

Student Government

The Associated Students of the Colorado School of Mines (ASCSM) works to advance the interest and promote the welfare of CSM and of all students, and to foster and maintain harmony among those connected with or interested in the school, including students, alumni, faculty, trustees, and friends.

Through funds collected as student fees, ASCSM strives to ensure a full social and academic life for all students with its organization, publications, and social events.

The Graduate Student Association was formed in 1991 and is recognized by CSM and the National Association of Graduate-Professional Students (NSGPS). GSA's primary goal is to improve the quality of a graduate education, offer academic support for graduate students, and provide social interaction.

GSA takes an active role in university affairs and promotes the rights and responsibilities of graduate students. GSA also serves to develop university responsibility to non-academic concerns of graduate students. GSA is funded through and works with Associated Students of the Colorado School of Mines and is presently represented on the Faculty Senate Graduate Council and Associated Students of CSM. Phone: 303-273-3094.

The Mines Activity Council (MAC) serves the ASCSM as the campus special events board. Most student events on campus are planned by the MAC committees. Committees are the Friday Afternoon Club (FAC) committee, which brings comedians and other performers to campus on most Fridays in the academic year; the Special Events committee, which coordinates events like Discount Sport Nights at professional sporting events and one-time specialty entertainment; Movies Committee; the E-Days committee; and the Homecoming committee.

Special Events

Research Fair: GSA presently sponsors a graduate research fair each Spring semester. The fair is designed to give graduate students the opportunity to make formal research presentations in a professional conference setting. At the conclusion of the event, cash prizes are awarded to graduate students whose presentations exhibit outstanding contributions to their areas of study.

International Day is planned and conducted by the International Student Organization. It includes exhibits and programs designed to further the cause of understanding among the countries of the world. The international dinner, including entertainment and samples of foods from countries all over the world, is one of the top campus social events of the year.

Winter Carnival, sponsored by Blue Key, is an all-school ski day held each year at one of the nearby ski slopes.

Homecoming weekend is one of the high points of the entire year's activities. Events include a football rally and game, campus decorations, election of Homecoming queen and beast, parade, burro race, and other contests.

Engineer Days are held each spring. The three-day affair is organized entirely by students. Contests are held in drilling, hand-spiking, mucking, oil-field olympics, and softball, to name a few. Additional events include a fireworks display, an E-Day concert, and the traditional orecart pull.

GSA Fall and Spring Blowout: GSA sponsors parties twice a year for graduate students. Held in the late spring and early fall at local parks, they let graduate students take a break from studying.

Honor Societies

Honor societies recognize the outstanding achievements of their members in scholarship, leadership, and service. Each of the CSM honor societies recognizes different achievements by our students.

Interest Organizations

Interest organizations meet the special and unique needs of the CSM student body by providing specific co-curricular activities.

International & Minority Organizations

International and minority organizations provide the opportunity to experience different cultures while at Mines and help the students from those cultures adjust to Mines campus life.

Professional Societies

Professional societies are generally student chapters of the national professional societies. As student chapters, the professional societies offer a chance for additional professional development outside the classroom through guest speakers, trips, and interactive discussions about the current activities in the profession. Many of the organizations also offer internships, fellowships, and scholarships.

Recreational Organizations

Recreational organizations give students with similar recreational interests the chance to participate as a group in the activities. Most of the recreational organizations compete on both the local and regional levels at tournaments during the school year.

Please visit the Student Activities Office or <http://student-activities.mines.edu/> for a complete list of currently active student organizations.

Facilities and Academic Support

Arthur Lakes Library

JOANNE V. LERUD-HECK, Librarian and Library Director

LISA G. DUNN, Librarian

LAURA A. GUY, Librarian

LISA S. NICKUM, Associate Librarian

CHRISTOPHER THIRY, Associate Librarian

HEATHER L. WHITEHEAD, Associate Librarian

PATRICIA E. ANDERSEN, Assistant Librarian

CHRISTINE BAKER, Assistant Librarian

PAMELA M. BLOME, Assistant Librarian

LIA VELLA, Assistant Librarian

JULIE CARMEN, Research Librarian

Arthur Lakes Library is a regional information center for engineering, energy, minerals, materials, and associated engineering and science fields. The Library supports university education and research programs and is committed to meeting the information needs of the Mines community and all library users.

The Library has over 140,000 visitors a year and is a campus center for learning, study and research. Facilities include meeting space, a campus computer lab, and individual and group study space. We host many cultural events during the year, including concerts and art shows.

The librarians provide personalized help and instruction, and assist with research. The Library's collections include more than 500,000 books; thousands of print and electronic journals; hundreds of databases; one of the largest map collections in the West; an archive on Colorado School of Mines and western mining history; and several special collections. The Library is a selective U.S. and Colorado state depository with over 600,000 government publications.

The Library Catalog provides access to Library collections and your user account. Our databases allow users to find publications for classroom assignments, research or personal interest. Students and faculty can use most of the Library's electronic databases and publications from any computer on the campus network, including those in networked Mines residential facilities. Dial-up and Internet access are available out of network.

Arthur Lakes Library is a member of the Colorado Alliance. Students and faculty can use their library cards at other Alliance libraries, or can order materials directly using Prospector, our regional catalog. Materials can also be requested from anywhere in the world through interlibrary loan.

Computing, Communications, & Information Technologies (CCIT)

DEREK WILSON, CIO

PHIL ROMIG, III, CISO & Director, Computing & Networking Infrastructure

GINA BOICE, Director, Customer Services & Support

TIM KAISER, Director, High Performance and Research Computing

DAVID LEE, Director, Enterprise Systems

GEORGE FUNKEY, Director, Policy, Planning, & Integration Services

Campus Computing, Communications, & Information Technologies (CCIT) provides computing and networking services to meet the instructional, research, administrative, and networking infrastructure needs of the campus. CCIT manages and operates campus networks along with central academic and administrative computing systems, telecommunication systems, a high performance computing cluster for the energy sciences (see <http://geco.mines.edu>), and computer classrooms and workrooms in several locations on campus. CCIT's customer services and support group also provides direct support for most electronic classrooms, departmental laboratories and desktops throughout the campus.

Central computing accounts and services are available to registered students and current faculty and staff members. Information about hours, services, and the activation of new accounts is available on the web site at <http://ccit.mines.edu/>, directly from the Help Desk in the Computer Commons (in CTLM 156), or by calling (303) 273-3431.

Workrooms in several locations on campus contain networked PCs and workstations. Printers, scanners, digitizers, and other specialized resources are available for use in some of the locations.

In addition to central server and facilities operations, services supported for the campus community include e-mail, wired and wireless network operation and support, access to the commodity Internet, Internet 2, and National Lambda Rail, network security, volume and site licensing of software, on-line training modules, videoconferencing, student registration, billing, and other administrative applications, campus web sites and central systems administration and support. CCIT also manages and supports the central learning management system (Blackboard), printing, short-term equipment loan, and room scheduling for some general computer teaching classrooms.

All major campus buildings are connected to the computing network operated by CCIT and most areas of the campus are covered by the wireless network. All residence halls and the Mines Park housing complex are wired for network access and some fraternity and sorority houses are also directly connected to the network.

All users of Colorado School of Mines computing and networking resources are expected to comply with all policies related to the use of these resources. Policies are available via the web pages at <http://ccit.mines.edu>.

Copy Center

Located on the first floor of Guggenheim Hall, the Copy Center offers on-line binding, printed tabs, transparencies and halftones. Printing can be done on 8 1/2"x 11", 11"x14" and 11"x17" paper sizes from odd-sized originals. Some of the other services offered are GBC and Velo Binding, folding, sorting and machine collating, reduction and enlargement, two sided copying, and color copying. We have a variety of paper colors, special resume paper and CSM wa-

termark for thesis copying. These services are available to students, faculty, and staff. The Copy Center campus extension is 3202.

CSM Alumni Association

The Colorado School of Mines Alumni Association (CSMAA), established in 1895, serves the Colorado School of Mines and more than 23,000 proud members of the powerful and successful alumni community. While all alumni are included in the reach of the CSMAA, it is a membership-based, independent organization reliant upon membership funds for much of its budget. Other sources of funding include the School, Foundation, merchandise sales and revenue-sharing partnerships. For example, CSMAA administers the Colorado School of Mines license plate program for cars registered in Colorado.

General services and programs include:

- Mines magazine, a quarterly publication covering campus and alumni news;
- An online directory of all Mines alumni for networking purposes;
- Online job listings for alumni two years out of school;
- Access to the alumni network on LinkedIn;*
- Section activities that provide social and networking connections to the campus and Mines alumni around the world;
- Alumni gatherings (meetings, reunions, golf tournaments, educational programs and other special events) on and off campus;
- Alumni recognition awards;
- On-campus CSM library privileges for Colorado residents;

Benefits for current Colorado School of Mines students include:

- Legacy Grants for children or grandchildren of alumni when parent or grandparent has been a consistent member of CSMAA for previous five years;
- The Student Financial Assistance Program;
- Celebration of Alumni banquet for graduating students;
- The CSMAA Mentorship program, pairing students with alumni for professional development;*
- Invitations to social and networking events, i.e. Dinner and Dialogue, Leadership Development events, Holiday Party, sporting events
- Access to the alumni network on LinkedIn;*
- Access to the CSMAA social networking website, www.minesonline.net;
- Early notice, information and reminders about alumni-based scholarships;
- Exclusive opportunities to enter drawings for a CSMAA book scholarship;*
- CSM Bookstore discounts (excluding textbooks and Apple products);*
- Renter's insurance discount from Liberty Mutual;

- "Blaster Pack" – Mines marbles, an "M"-ulator t-shirt, membership card and more;*

Students can join the CSMAA at the student membership ("M"-ulator) level for exclusive benefits marked with an asterisk. For further information, call 303-273-3295, Fax 303-273-3583, e-mail csmmaa@mines.edu, or write Mines Alumni Association, Coolbaugh House, P.O. Box 1410, Golden, CO 80402-1410.

Environmental Health and Safety

The Environmental Health and Safety (EHS) Department is located in Chauvenet Hall room 194. The Department provides a variety of services to students, staff and faculty members. Functions of the Department include: hazardous waste collection and disposal; chemical procurement and distribution; chemical spill response; assessment of air and water quality; fire safety; laboratory safety; industrial hygiene; radiation safety; biosafety; and recycling. Staff is available to consult on issues such as chemical exposure control, hazard identification, safety systems design, personal protective equipment, or regulatory compliance. Stop by our office or call 303 273-3316. The EHS telephone is monitored nights and weekends to respond to spills and environmental emergencies.

Green Center

Completed in 1971, the Cecil H. and Ida Green Graduate and Professional Center is named in honor of Dr. and Mrs. Green, major contributors to the funding of the building.

Bunker Memorial Auditorium, which seats 1,386, has a large stage that may be used for lectures, concerts, drama productions, or for any occasion when a large attendance is expected.

Friedhoff Hall contains a dance floor and an informal stage. Approximately 600 persons can be accommodated at tables for banquets or dinners. Auditorium seating can be arranged for up to 450 people.

Petroleum Hall and Metals Hall are lecture rooms seating 123 and 310, respectively. Each room has audio visual equipment. In addition, the Green Center houses the Department of Geophysics.

For more information visit www.greencenter.mines.edu.

LAIS Writing Center

Located on the third floor of Stratton Hall (phone: 303-273-3085), the LAIS Writing Center is a teaching facility providing all CSM students, faculty, and staff with an opportunity to enhance their writing abilities. The LAIS Writing Center faculty are experienced technical and professional writing instructors who are prepared to assist writers with everything from course assignments to theses and dissertations, to scholarship and job applications. This service is free to CSM students, faculty, and staff and entails one-to-one tutoring and online resources (at <http://www.mines.edu/academic/lais/wc/>).

Off-Campus Study

A student must enroll in an official CSM course for any period of off-campus, course-related study, whether U.S. or foreign, including faculty-led short courses, study abroad, or any off-campus trip sponsored by CSM or led by a CSM faculty member. The registration must occur in the same term that the off-campus study takes place. In addition, the student must complete the necessary release, waiver, and emergency contact forms, transfer credit pre-approvals, and FERPA release, and provide adequate proof of current health insurance prior to departure. For additional information concerning study abroad requirements, contact the Office of International Programs at (303) 384-2121; for other information, contact the Registrar's Office.

Office of International Programs

The Office of International Programs (OIP) fosters and facilitates international education, research and outreach at CSM. OIP is administered by the Office of Academic Affairs.

OIP is located in 1706 Illinois Street. For more specific information about study abroad and other international programs, contact OIP at 384-2121 or visit the OIP web page (<http://OIP.mines.edu>).

The office works with the departments and divisions of the School to: (1) help develop and facilitate study abroad opportunities for CSM undergraduate and graduate students and serve as an informational and advising resource for them; (2) assist in attracting new international students to CSM; (3) serve as an information resource for faculty and scholars of the CSM community, promoting faculty exchanges and the pursuit of collaborative international research activities; (4) foster international outreach and technology transfer programs; (5) facilitate arrangements for official international visitors to CSM; and (6) in general, help promote the internationalization of CSM's curricular programs and activities.

Graduate students may apply for participation in dual degree programs offered by CSM and its partners. Generally these programs require the preparation and defense of one jointly supervised thesis project and the completion of degree requirements at each participating university (<http://OIP.mines.edu/studentabroad/schol.html>).

Office of Technology Transfer

The purpose of the Office of Technology Transfer (OTT) is to reward innovation and entrepreneurial activity by students, faculty and staff, recognize the value, preserve ownership of CSM's intellectual property, and contribute to local and national the economic growth. OTT reports directly to the Vice President of Research and Technology Transfer and works closely with the school's offices of Legal Services and Research Administration to coordinate activities. With support from its external Advisory Board, OTT strives to:

- (1) Initiate and stimulate entrepreneurship and development of mechanisms for effective investment of CSM's intellectual capital;
- (2) Secure CSM's intellectual properties generated by faculty, students, and staff;
- (3) Contribute to the economic growth of the community, state, and nation through facilitating technology transfer to the commercial sector;
- (4) Retain and motivate faculty by rewarding entrepreneurship;
- (5) Utilize OTT opportunities to advance high-quality faculty and students;
- (6) Provide a return on investment on CSM inventions which is used to expand the school's research and education missions.

Public Relations

For information about the school's publications guidelines, including the use of Mines logos, and for media-related requests, contact Karen Gilbert, Public Relations Director, at 303-273-3541 or kgilbert@mines.edu.

Registrar

LARA MEDLEY, Registrar
DAHL GRAYCKOWSKI, Associate Registrar for Systems
DIANA ANGLIN, Associate Registrar for Operations
TABATHA GRAYCKOWSKI, Assistant Registrar for Graduation
MARGARET KENNEY, Reporting Specialist
NOLAN OLTJENBRUNS, Registration Specialist
JUDY WESTLEY, Records Specialist

The Office of the Registrar supports the academic mission of the Colorado School of Mines by providing service to our current and former students, faculty, staff, and administration. These services include maintaining and protecting the integrity and security of the official academic record, registration, degree verification, scheduling and reporting. Our office routinely reviews policy, makes recommendations for change, and coordinates the implementation of approved policy revisions.

The Office of the Registrar seeks to fulfill this mission through a commitment to high quality service provided in a professional, efficient and courteous manner. Our specific services include but are not limited to:

- Enrollment and degree verifications
- Transcripts
- Degree auditing and diplomas (undergraduate)
- Transfer credit entry and verification
- Veteran's Administration Certifying Official services
- Registration setup and execution
- Course and room scheduling
- Academic and enrollment reporting
- Residency for current students
- Grade collection, reporting and changes

Management of the Registrar's Office adheres to the guidelines on professional practices and ethical standards developed by the American Association of Collegiate Registrars and Admissions Officers (AACRAO). Our office also complies with the Family Educational Rights and Privacy Act of 1974 (FERPA), Colorado Department of Higher Education rules and policies, and the Colorado School of Mines policies on confidentiality and directory information.

The Registrar's Office is located in the Student Center, Room 31. Hours of operation are Monday/Tuesday/Thursday/Friday, 9am-5pm; Wednesday 10am-5pm. The office phone number is (303) 273-3200. The fax number is (303) 384-2253. Lara Medley represents Colorado School of Mines as the Registrar. She is normally available on a walk-in basis (when not in meetings) if a student or other client has an issue that needs special attention. Appointments are also welcomed.

Research Administration

The Office of Research Administration (ORA), under the Vice President for Finance and Administration, provides administrative support in proposal preparation and contract and grant administration, which includes negotiation, account set-up, and close out of expired agreements. Information on any of these areas of research and specific forms can be accessed on our web site at www.is.mines.edu/ora.

Office of Strategic Enterprises

NIGEL MIDDLETON, Senior Vice President

The mission of the Office of Strategic Enterprises (OSE) is to bring Mines' educational and intellectual resources to the world and enable professionals, corporate entities, and universities from around the globe to interact with Mines. The goal is a distinctive "anywhere, anytime" approach to learning in a fast-paced, changing world. Initiatives include executive and corporate training, non-degree courses, and summer intensives. Professionals needing continuing education can find short-term and part-time offerings, targeted training, off-campus programs and certificate courses. OSE also reaches out to prospective universities on different continents to initiate partnerships that could benefit from Mines' academic capabilities in resource or energy development. Advancing Mines' global mission in other countries, OSE increases opportunities for international researchers to study at Mines, and for Mines researchers to work at international facilities. The Office of Special Programs and Continuing Education (SPACE) reports to OSE and administers most of the programmatic offerings. For further information about OSE, visit inside.mines.edu/Educational_Outreach.

Special Programs and Continuing Education (SPACE)

The SPACE Office administers short courses, special programs, and professional outreach programs to practicing engineers and other working professionals. Short courses, offered both on the CSM campus and throughout the US, provide concentrated instruction in specialized areas and are taught by faculty members, adjuncts, and other experienced professionals. The Office offers a broad array of programming for K-12 teachers and students through its Teacher Enhancement Program, and the Denver Earth Science Project. The Office also coordinates educational programs for international corporations and governments through the International Institute for Professional Advancement and hosts the educational portion of the Mine Safety and Health Training Program. A separate bulletin lists the educational programs offered by the SPACE Office, CSM, 1600 Jackson Street, Suite 160A Golden, CO 80401. Phone: 303 279-5563; FAX 303 277-8683; email space@mines.edu; website www.mines.edu/Educational_Outreach.

Telecommunications

The Telecommunications Office is located in the CTLM building 2nd floor east end room 256 and provides telephone services to the campus. The office is open 8:00am to 4:00pm Monday through Friday, and can be reached by calling (303) 273-3355 or via the web at <http://inside.mines.edu/Telecommunications>.

Courtesy phones are provided on each floor of the traditional residence halls and Weaver Towers as well as school owned fraternities and sororities. In-room phones are available to students living in Mines Park for \$18.50 per month. Students wishing to take advantage of in-room phones in Mines Park should contact the Telecommunications Office to arrange for service. Telephone sets are not provided by the Telecommunications Office.

Students may make long distance calls from any CSM provided phone by using a third party calling card. Access to third party carriers is available through toll-free (800, 888, 877, 866 and 855) numbers provided by the third party carrier along with the appropriate instructions.

Women in Science, Engineering and Mathematics (WISEM) Program

The mission of WISEM is to enhance opportunities for women in science and engineering careers, to increase retention of women at CSM, and to promote equity and diversity in higher education. The office sponsors programs and services for the CSM community regarding gender and equity issues. For further information, contact: Debra K. Lasich, Executive Director of Women in Science, Engineering and Mathematics, Colorado School of Mines, 1710 Illinois Street, Golden, CO 80401-1869. Phone (303) 273-3097; email dla-sich@mines.edu; website <http://wisem.mines.edu/>.

Registration and Tuition Classification

General Registration Requirements

The normal full load for graduate students is 9 credit hours per term. Special cases outlined below include first-year international students who must receive special instruction to improve their language skills, and students who have completed their credit-hour requirements and are working full time on their thesis.

Full-time graduate students may register for an overload of up to 6 credit hours (up to 15 credit hours total) per term at no increase in tuition. Subject to written approval by their advisor and department head or division director, students may register for more than 15 credit hours per term by paying additional tuition at the regular part-time rate for all hours over 15. The maximum number of credits for which a student can register during the summer is 12.

Except for students meeting any of the following conditions, students may register at less than the required full-time registration.

- ◆ International students subject to immigration requirements. This applies to international students holding J-1 and F-1 visas.
- ◆ Students receiving financial assistance in the form of graduate teaching assistantships, research assistantships, fellowships or hourly contracts.
- ◆ Students enrolled in academic programs that require full-time registration. Refer to the degree program sections of this bulletin to see if this applies to a particular program.

Students for whom any one of these conditions apply must register at the appropriate full-time credit hour requirement.

To remain active in their degree program, students must register continuously each fall and spring semester. If not required to register full-time, part-time students may register for any number of credit hours less than the full-time credit hour load.

Summer registration is not required to maintain an active program. Students who continue to work on their degree program and utilize Mines facilities during the summer, however, must register. Students registered during the summer are assessed regular tuition and fees.

New graduate students entering during the fall semester will be expected to pay full student fees for any courses taken in the summer sessions prior to the fall term of entry.

Research Registration

In addition to completing prescribed course work and defending a thesis, students in thesis-based degree programs must complete a research experience under the direct supervision of their faculty advisor. Master students must complete a minimum of 6 hours of research credit, and doctoral students must complete a minimum of 24 hours of research credit at Mines. While completing this experience, students

register for research credit under course numbers 705 (M.S.) or 706 (Ph.D.) as appropriate. Faculty assign grades indicating satisfactory or unsatisfactory progress based on their evaluation of the student's work. Students registered for research during the summer semester and working on campus must pay regular tuition and thesis research fees for summer semester.

Eligibility for Reduced Registration

Students enrolled in thesis-based degree programs who have completed a minimum number of course and research credit hours in their degree programs are eligible to continue to pursue their graduate program as full-time students at a reduced registration level. In order to be considered for this reduced, full-time registration category, students must satisfy the following requirements:

1. For M.S. students, completion of 36 hours of eligible course, research and transfer credits combined
2. For Ph.D. students, completion of 72 hours of eligible course, research, and transfer credits combined
3. For all students, an approved Admission to Candidacy form must be on file in the Graduate Office within the first week of the semester you are applying for reduced thesis registration.
4. Candidates may not count more than 12 credit hours per semester in determining eligibility for reduced, full-time registration.

Students who are eligible for reduced, full-time registration are considered full time if they register for 4 credit hours of research under course numbers 705 (M.S.) or 706 (Ph.D.) as appropriate.

Graduation Requirements

To graduate, students must be registered during the term in which they complete their program. In enforcing this registration requirement, the Graduate School allows students to complete their checkout requirements past the end of the semester. Late checkout is accepted by the Graduate School through the last day of registration in the term immediately following the semester in which a student has completed his or her academic degree requirements; the Spring for Fall completion, the Summer I for Spring completion, and Fall for Summer II completion. Students not meeting this checkout deadline are required to register for an additional semester before the Graduate School will process their checkout request. For additional information, refer to http://inside.mines.edu/admiss/grad/graduation_rqmts.htm.

Full-time Status - Required Course Load

To be deemed full-time during the fall and spring semesters, students must register for at least 9 credit hours. However, international students need only register for 6 credit hours during their first year, if they are required to take special lan-

guage instruction or are accepted in Provisional Status. In the event a thesis-based student has completed his or her required course work and research credits and is eligible for reduced, full-time registration, the student will be deemed full-time if he or she is registered for at least 4 credit hours of research credit.

To be deemed full-time during the summer semester, students must register for a minimum of 3 credit hours.

Late Registration Fee

Students must complete their registration by the date specified in the Academic Calendar. Students who fail to complete their registration during this time will be assessed a \$100 late registration fee and will not receive any tuition fellowships for which they might otherwise be eligible.

Leave of Absence

Leaves of absence are granted only when unanticipated circumstances make it temporarily impossible for students to continue to work toward a degree. Leave of absence requests for the current semester must be received by the Dean of Graduate Studies prior to the last day of classes. Leave of absence requests for prior semesters will not be considered.

Any request for a leave of absence must have the prior approval of the student's faculty advisor, the department head or division or program director and the Dean of Graduate Studies. The request for a leave of absence must be in writing and must include (1) the reasons why the student must interrupt his or her studies and (2) a plan (including a timeline and deadlines) for resuming and completing the work toward the degree in a timely fashion.

Students on leaves of absence remain in good standing even though they are not registered for any course or research credits.

Thesis-based students will not have access to Mines resources while on a leave of absence. This includes, but is not limited to, office space, computational facilities, library and faculty.

Students who fail to register and who are not on approved leaves of absence have their degree programs terminated. Students who wish to return to graduate school after an unauthorized leave of absence must apply for readmission and pay a \$200 readmission fee.

The financial impact of requesting a leave of absence for the current semester is covered in the section on "Payments and Refunds" on page 37.

Parental Leave

Graduate students in thesis-based degree programs, who have full-time student status, may be eligible to request up to eight (8) weeks of parental leave. The Parental Leave Policy is designed to assist students who are primary child-care providers immediately following the birth or adoption of a child. The Policy is designed to make it possible for students

to maintain full-time status in research-based degree programs while taking a leave from that program to care for their new child, and facilitate planning for continuance of their degree program.

Nothing in the Parental Leave policy can, or is intended to replace communication and cooperation between the student and his or her advisor, and the good-faith efforts of both to accommodate the birth or adoption of a child within the confines and expectations of participating in a research-active graduate degree program. It is the intent of this Policy to reinforce the importance of this cooperation, and to provide a framework of support and guidance.

Eligibility

In order to be eligible for Parental Leave, a graduate student must:

- ◆ be the primary child care provider;
- ◆ have been a full-time graduate student in his/her degree program during at least the two (2), prior consecutive semesters;
- ◆ be enrolled in a thesis-based degree program (i.e., Doctoral or thesis-based Masters);
- ◆ be in good academic standing as defined in the Unsatisfactory Academic Performance section of this Bulletin;
- ◆ provide a letter from a physician or other health care professional stating the anticipated due date of the child, or provide appropriate documentation specifying an expected date of adoption of the child;
- ◆ notify advisor of intent to apply for Parental Leave at least four (4) months prior to the anticipated due date or adoption date; and
- ◆ at least two (2) months prior to the expected leave date complete, and have approved, the Request for Parental Leave Form that includes an academic Program Plan for program continuance.

Exceptions and Limitations

This Policy has been explicitly constructed with the following limitations:

- ◆ part-time and non-thesis students are not eligible for Parental Leave. These students may, however, apply for a Leave of Absence through the regular procedure defined above;
- ◆ if both parents are Mines graduate students who would otherwise qualify for leave under this Policy, each is entitled to a Parental Leave period immediately following the birth or adoption of a child during which he or she is the primary care provider, but the leaves may not be taken simultaneously; and
- ◆ leaves extending beyond eight (8) weeks are not covered by this Policy. The regular Leave of Absence policy defined in the Graduate Bulletin applies to these cases.

Benefits

Under this Policy students will receive the following benefits and protections:

- ◆ a one-semester extension of all academic requirements (e.g., qualifying examinations, time to degree limitations, etc.);
- ◆ maintenance of full-time status in degree program while on Parental Leave;
- ◆ documentation of an academic plan that specifies both how a student will continue work toward his or her degree prior to the leave period and how a student will reintegrate into a degree program after returning from leave; and
- ◆ continuance of assistantship support during the semester in which the leave is taken.

Planning and Approval

It is the student's responsibility to initiate discussions with his/her advisor(s) at least four (4) months prior to the anticipated birth or adoption. This notice provides the lead time necessary to rearrange teaching duties (for those students supported by teaching assistantships), to adjust laboratory and research responsibilities and schedules, to identify and develop plans for addressing any new health and safety issues, and to develop an academic Program Plan that promotes seamless reintegration back into a degree program.

While faculty will make every reasonable effort to meet the needs of students requesting Parental Leave, students must recognize that faculty are ultimately responsible for ensuring the rigor of academic degree programs and may have a direct requirement to meet specific milestones defined in externally funded research contracts. Within this context, faculty may need to reassess and reassign specific work assignments, modify laboratory schedules, etc. Without good communication, such efforts may lead to significant misunderstandings between faculty and students. As such, there must be good-faith, and open communication by each party to meet the needs and expectations of each during this potentially stressful period.

The results of these discussions are to be formalized into an academic Program Plan that is agreed to by both the student and the advisor(s). This Plan, to be accepted, must also receive approval by the appropriate Department Head, Division or Program Director and the Graduate Dean. Approval of the Dean should be sought by submitting to the Office of Graduate Studies a formal Parental Leave request, with all necessary signatures along with the following documentation;

- ◆ letter from a physician or other health care professional stating the anticipated due date of the child or other appropriate documentation specifying an expected date of adoption of the child; and

- ◆ the advisor(s) and Department Head, Division or Program Director approved academic Program Plan.

These materials should be delivered to the Office of Graduate Studies no less than two (2) months prior to the anticipated date of leave.

If a student and faculty member can not reach agreement on a Program Plan, they should consult with the appropriate Department Head, Division or Program Director to help mediate and resolve the outstanding issues. As appropriate, the Department Head, Division or Program Director may request the Dean of Graduate Studies and the Director of the Women in Science, Engineering and Mathematics program provide additional assistance in finalizing the Program Plan.

Graduate Students with Appointments as Graduate Research and Teaching Assistants

A graduate student who is eligible for Parental Leave and has a continuing appointment as a research or teaching assistant is eligible for continued stipend and tuition support during the semester(s) in which the leave is taken. For consideration of this support, however, the timing of a leave with continued stipend and tuition support must be consistent with the academic unit's prior funding commitment to the student. No financial support will be provided during Leave in a semester in which the student would have otherwise not been funded.

Tuition and Fee Reimbursement: If the assistantship, either teaching or research, would have normally paid a student's tuition and mandatory fees, it will continue to do so for the semester(s) in which the Leave is taken. Costs for tuition will be shared proportionally between the normal source of funding for the research or teaching assistantship and the Office of Graduate Studies.

Stipend Support: Stipends associated with the assistantship will be provided at their full rate for that portion of the semester(s) during which the student is not on Parental Leave. No stipend support need be provided during the time period over which the Parental Leave is taken. The student may, however, choose to have the stipend he or she would receive during the semester(s) in which the Leave is taken delivered in equal increments over the entire semester(s).

While on Leave, students may elect to continue to work in some modified capacity and Faculty, Departments and Programs may elect to provide additional stipend support in recognition of these efforts. Students, however, are under no obligation to do so, and if they choose to not work during their Leave period this will not be held against them when they return from Leave. Upon return, students on Research Assistantships are expected to continue their normal research activities as defined in their Academic Plans. Students on Teaching Assistantships will be directed by the Department, Division or Program as to specific activities in which they will engage upon return from Parental Leave.

Registration

Students on Parental Leave should register at the full-time level for research credit hours under the direction of their Thesis Advisor. The advisor will evaluate student progress toward degree for the semester in which Parental Leave is taken only on those activities undertaken by the student while he or she is not on Leave.

Reciprocal Registration

Under the Exchange Agreement Between the State Supported Institutions in Northern Colorado, Mines graduate students who are paying full-time tuition may take courses at Colorado State University, University of Northern Colorado, and University of Colorado (Boulder, Denver, Colorado Springs, and the Health Sciences Center) at no charge by completing the request form and meeting the required conditions on registration and tuition, course load, and course and space availability. Request forms are available from the Registrar's office.

Courses completed under the reciprocal agreement may be applied to a student's degree program. These are, however, applied as transfer credit into the degree program. In doing so, they are subject to all the limitations, approvals and requirements of any regularly transferred course.

In-State Tuition Classification Status

General Information

The State of Colorado partially subsidizes the cost of tuition for all students whose domicile, or permanent legal residence, is in Colorado. Each Mines student is classified as either an "in-state resident" or a "non-resident" at the time of matriculation. These classifications, which are governed by Colorado law, are based upon information furnished by each student on his or her application for admission to Mines. A student who willfully furnishes incorrect information to Mines to evade payment of non-resident tuition shall be subject to serious disciplinary action.

It is in the interest of each graduate student who is a U.S. citizen and who is supported on an assistantship or fellowship to become a legal resident of Colorado at the earliest opportunity. Typically, tuition at the non-resident rate will be paid by Mines for these students during their first year of study only. After the first year of study, these students may be responsible for paying the difference between resident and non-resident tuition.

Requirements for Establishing In-State Residency

The specific requirements for establishing residency for tuition classification purposes are prescribed by state law (Colorado Revised Statutes, Title 23, Article 7). Because Colorado residency status is governed solely by Colorado law, the fact that a student might not qualify for in-state status in any other state does not guarantee in-state status in Colorado. The tuition classification statute places the burden of proof on the student to provide clear and convincing evidence of eligibility.

In-state or resident status generally requires domicile in Colorado for the year immediately preceding the beginning of the semester in which in-state status is sought. "Domicile" is "a person's true, fixed and permanent home and place of habitation." An unemancipated minor is eligible for in-state status if at least one parent (or his or her court-appointed guardian) has been domiciled in Colorado for at least one year. If neither of the student's parents are domiciliaries of Colorado, the student must be a qualified person to begin the one-year domiciliary period. A "qualified person" is someone who is at least twenty-two years old, married, or emancipated. A student may prove emancipation if: (1) the student's parents have entirely surrendered the right to the student's custody and earnings; (2) the student's parents are no longer under any duty to financially support the student; and (3) the student's parents have made no provision for the continuing support of the student.

To begin the one-year domiciliary period, a qualified person must be living in Colorado with the present intention to reside permanently in Colorado. Although none of the following indicia are determinative, voter registration, driver's license, vehicle registration, state income tax filings, real property interests, and permanent employment (or acceptance of future employment) in Colorado will be considered in determining whether a student has the requisite intention to permanently reside in Colorado. Once a student's legal residence has been permanently established in Colorado, he or she may continue to be classified as a resident student so long as such residence is maintained, even though circumstances may require extended temporary absences from Colorado.

For more information about the requirements for establishing in-state residency, please contact the Registrar's Office.

Petitioning for In-State Tuition Classification

A continuing, non-resident student who believes that he or she has become eligible for in-state resident tuition due to events that have occurred subsequent to his or her initial enrollment may file a *Petition for In-State Tuition Classification* with the Registrar's Office. This petition is due in the Registrar's Office no later than the first day of the semester for which the student is requesting in-state resident status. Upon receipt of the petition, the Registrar will initially decide whether the student should be granted in-state residency status. The Registrar's decision may be appealed by petition to the Tuition Classification Review Committee. For more information about this process, please contact the Registrar's Office.

In-State Tuition Classification for WICHE Program Participants

WICHE, the Western Interstate Commission for Higher Education, promotes the sharing of higher education resources among the participating western states. Under this program, residents of Alaska, Arizona, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming who are enrolled in qualifying graduate programs may be eligible for in-state tuition classification. Current qualifying programs include:

- Applied Chemistry (Ph.D.)
- Chemistry (M.S.)
- Engineering Systems (M.S. and Ph.D.)
- Environmental Science & Engineering (M.S. and Ph.D.)
- Geochemistry (M.S. and Ph.D.)
- Geological Engineering (M.S., M.E., and Ph.D.)
- Hydrology (M.S. and Ph.D.)
- Mineral Economics (M.S. and Ph.D.)
- Mining and Earth Systems Engineering (M.S. and Ph.D.)
- Petroleum Engineering (M.S. and Ph.D.)

Contact the Office of Graduate Studies for more information about WICHE.

Dropping and Adding Courses

Students may drop or add courses through web registration without paying a fee during the first 11 school days of a regular semester, the first four school days of a six-week field course, or the first six school days of an eight-week summer term.

After the 11th day of classes through the 12th week, continuing students may drop any course for any reason with a grade of “W”. Graduate students in their first or second semesters at Mines have through the 14th week of that semester to drop a course. A student must process a drop-add form and pay a \$5.00 fee for any change in class schedule after the first 11 days of class, except in cases of withdrawal from school. Forms are available in the Registrar’s Office.

After the 12th (or 14th) week, no drops are permitted except in case of withdrawal from school or for extenuating circumstances. To request consideration of extenuating circumstances, a student must submit a written request to the Graduate Dean, which includes the following:

1. A list of the courses from which they wish to withdraw. This must include all courses for which they are registered.
2. Documentation of the problem which is the basis for the request.
3. If the problem involves a medical condition, the documentation must be signed by a licensed medical doctor or a representative of the Mines Counseling Office.
4. Signatures indicating approval by the student’s advisor and department head or division director.

A student who is allowed to withdraw from courses under this policy will receive a grade of “W” for each course and will be placed on automatic leave of absence. In order to resume their graduate program, they must submit a written application that includes documentation that the problems which caused the withdrawal have been corrected. The student will be reinstated to active status upon approval of their application by their advisor and their department head or division director.

The financial impact of a withdrawal is covered in the section on “Payments and Refunds.”

Auditing Courses

As part of the maximum of 15 semester hours of graduate work, students may enroll for no credit (NC) in a course with the permission of the instructor. Tuition charges are the same for no credit as for credit enrollment.

Students must enroll for no credit before census day, the last day of registration. The form to enroll for a course for no credit is available in the Registrar’s Office. NC designation is awarded only if all conditions stipulated by course instructors are met.

Mines requires that all U.S. students who are being supported by the institution register full time, and federal financial aid regulations prohibit us from counting NC registration in determining financial aid eligibility. In addition, the INS requires that international students register full time, and recent anti-terrorism proposals discourage us from counting NC registration toward that requirement. Furthermore, there are no consistent standards for expectations of students who register for NC in a course. Therefore, in order to treat all Mines students consistently, NC registration will not count toward the minimum number of hours for which students are required to register. This includes the minimum continuous registration requirement of part-time students and the 3-, or 9-hour requirement for students who must register full time.

The reduced registration policy is based on the principle that the minimum degree requirement (36 or 72 hours) would include only the credits applied toward that degree. Deficiency and extra courses are above and beyond that minimum. NC courses fall into the latter category and may not be applied toward the degree. Therefore, NC registration will not count toward the number of hours required to be eligible for reduced thesis registration.

NC registration may involve additional effort on the part of faculty to give and/or grade assignments or exams, so it is the institution’s policy to charge tuition for NC courses. Therefore, NC registration will count toward the maximum number of credits for which a graduate student may be allowed to register. This includes a tuition surcharge for credits taken over 15.

Off-Campus Study

A student must enroll in an official Mines course for any period of off-campus, course-related study, whether U.S. or foreign, including faculty-led short courses, study abroad, or any off-campus trip sponsored by Mines or led by a Mines faculty member. The registration must occur in the same term that the off-campus study takes place. In addition, the student must complete the necessary release, waiver, and emergency contact forms, transfer credit pre-approvals, and FERPA release, and provide adequate proof of current health insurance prior to departure. For additional information concerning study abroad requirements, contact the Office of International Programs at (303) 384-2121; for other information, contact the Registrar's Office.

General Regulations

Graduate School Bulletin

It is the responsibility of the graduate student to become informed and to observe all regulations and procedures required by the program the student is pursuing. Ignorance of a rule does not constitute a basis for waiving that rule. The current Graduate Bulletin when a graduate student first enrolls, gives the academic requirements the student must meet to graduate. However, with department consent, a student can change to the requirements in a later catalog published while the student is enrolled in the graduate school. Changes to administrative policies and procedures become effective for all students as soon as the campus community is notified of the changes.

The Graduate Bulletin is available to students in both print and electronic forms. Print bulletins are updated annually. Electronic versions of the Graduate Bulletin may be updated more frequently to reflect changes approved by the campus community. As such, students are encouraged to refer to the most recently available electronic version of the Graduate Bulletin. This version is available at the CSM website. The electronic version of the Graduate Bulletin is considered the official version of this document. In case of disagreement between the electronic and print versions, the electronic version takes precedence.

Curriculum Changes

The Mines Board of Trustees reserves the right to change any course of study or any part of the curriculum to respond to educational and scientific developments. No statement in this Bulletin or in the registration of any student shall be considered as a contract between Colorado School of Mines and the student.

General Policies of Student Conduct

In addition to the student conduct policies described in detail in this section of the Graduate Bulletin, the Colorado School of Mines has a number of policies which govern student behavior on campus. Following is a list of those important policies with a brief definition or description of each. Copies of the complete text describing each policy are available at the following website: http://inside.mines.edu/student_policies.

Campus Security

This policy is intended to improve security and reduce crime on campus. It includes the publishing of campus crime statistics and procedures for reporting crimes.

Alcohol Use

This policy conforms to state and local laws on alcohol use, distribution, and consumption. The text restates the legal drinking age, designates campus locations for consuming alcoholic beverages, explains procedures for planning student events at which alcohol is served, and gives the penalties for violating the policy.

Drug Use

Recognizing the threat to health and welfare from the use of illegal drugs, this policy requires Mines students to obey all Colorado and Federal laws concerning the manufacture, possession, sale, and use of drugs.

Drug Free Schools & Communities Act

This policy informs Mines students of community standards and potential consequences (the legal sanctions) for using alcohol or drugs illegally.

Firearms, Explosives, and Other Weapons

Covered in this policy are the general ban on campus of firearms, explosives, and other weapons, exceptions to the ban, and the firearm storage procedures.

Distribution of Literature

Given in this policy are the restrictions on distributing (including the selling of) literature, newspapers, and magazines on school property; the limit on distributing advertising or commercial material (for example, handbills); the requirements for soliciting and vending on school property; and the right to picket or demonstrate on campus.

Academic Integrity

The Colorado School of Mines affirms the principle that all individuals associated with the Mines academic community have a responsibility for establishing, maintaining and fostering an understanding and appreciation for academic integrity. In broad terms, this implies protecting the environment of mutual trust within which scholarly exchange occurs, supporting the ability of the faculty to fairly and effectively evaluate every student's academic achievements, and giving credence to the university's educational mission, its scholarly objectives and the substance of the degrees it awards. The protection of academic integrity requires there to be clear and consistent standards, as well as confrontation and sanctions when individuals violate those standards. The Colorado School of Mines desires an environment free of any and all forms of academic misconduct and expects students to act with integrity at all times.

Student Honor Code

The Colorado School of Mines students also feel strongly about academic integrity. The students independently wrote and approved an Honor Code promoting high academic standards and zero tolerance of academic misconduct.

Preamble: The students of Colorado School of Mines (Mines) have adopted the following Student Honor Code (Code) in order to establish a high standard of student behavior at Mines. The Code may only be amended through a student referendum supported by a majority vote of the Mines student body. Mines students shall be involved in the enforcement of the Code through their participation in the Student Judicial Panel.

Code: Mines students believe it is our responsibility to promote and maintain high ethical standards in order to en-

sure our safety, welfare, and enjoyment of a successful learning environment. Each of us, under this Code, shall assume responsibility for our behavior in the area of academic integrity. As a Mines student, I am expected to adhere to the highest standards of academic excellence and personal integrity regarding my schoolwork, exams, academic projects, and research endeavors. I will act honestly, responsibly, and above all, with honor and integrity in all aspects of my academic endeavors at Mines. I will not misrepresent the work of others as my own, nor will I give or receive unauthorized assistance in the performance of academic coursework. I will conduct myself in an ethical manner in my use of the library, computing center, and all other school facilities and resources. By practicing these principles, I will strive to uphold the principles of integrity and academic excellence at Mines. I will not participate in or tolerate any form of discrimination or mistreatment of another individual.

Policy on Violation of Student Academic Misconduct

Academic misconduct is the intentional act of fraud, in which an individual seeks to claim credit for the work and efforts of another without authorization, or uses unauthorized materials or fabricated information in any academic exercise. Student Academic Misconduct arises when a student violates the principle of academic integrity. Such behavior erodes mutual trust, distorts the fair evaluation of academic achievements, violates the ethical code of behavior upon which education and scholarship rest, and undermines the credibility of the university. Because of the serious institutional and individual ramifications, student misconduct arising from violations of academic integrity is not tolerated at Mines. If a student is found to have engaged in such misconduct, sanctions such as change of a grade, loss of institutional privileges, or academic suspension or dismissal may be imposed. As a guide, some of the more common forms of academic misconduct are noted below as a. This list is not intended to be all inclusive, but rather to be illustrative of practices the Mines faculty have deemed inappropriate:

1. Dishonest Conduct - general conduct unbecoming a scholar. Examples include issuing misleading statements; withholding pertinent information; not fulfilling, in a timely fashion, previously agreed to projects or activities; and verifying as true, things that are known to the student not to be true or verifiable.
2. Plagiarism - presenting the work of another as one's own. This is usually accomplished through the failure to acknowledge the borrowing of ideas, data, or the words of others. Examples include submitting as one's own work the work of another student, a ghost writer, or a commercial writing service; quoting, either directly or paraphrased, a source without appropriate acknowledgment; and using figures, charts, graphs or

facts without appropriate acknowledgment. Inadvertent or unintentional misuse or appropriation of another's work is nevertheless plagiarism.

3. Falsification/Fabrication – inventing or altering information. Examples include inventing or manipulating data or research procedures to report, suggest, or imply that particular results were achieved from procedures when such procedures were not actually undertaken or when such results were not actually supported by the pertinent data; false citation of source materials; reporting false information about practical, laboratory, or clinical experiences; submitting false excuses for absence, tardiness, or missed deadlines; and, altering previously submitted examinations.
4. Tampering - interfering with, forging, altering or attempting to alter university records, grades, assignments, or other documents without authorization. Examples include using a computer or a false-written document to change a recorded grade; altering, deleting, or manufacturing any academic record; and, gaining unauthorized access to a university record by any means.
5. Cheating – using or attempting to use unauthorized materials or aid with the intent of demonstrating academic performance through fraudulent means. Examples include copying from another student's paper or receiving unauthorized assistance on a homework assignment, quiz, test or examination; using books, notes or other devices such as calculators, PDAs and cell phones, unless explicitly authorized; acquiring without authorization a copy of the examination before the scheduled examination; and copying reports, laboratory work or computer files from other students. Authorized materials are those generally regarded as being appropriate in an academic setting, unless specific exceptions have been articulated by the instructor.
6. Impeding - negatively impacting the ability of other students to successfully complete course or degree requirements. Examples include removing pages from books and removing materials that are placed on reserve in the Library for general use; failing to provide team members necessary materials or assistance; and, knowingly disseminating false information about the nature of a test or examination.
7. Sharing work – giving or attempting to give unauthorized materials or aid to another student. Examples include allowing another student to copy your work; giving unauthorized assistance on a homework assignment, quiz, test or examination; providing, without authorization, copies of examinations before the scheduled examination; posting work on a website for others to see; and sharing reports, laboratory work or computer files with other students.

Procedures for Addressing Student Academic Misconduct

Faculty members and thesis committees have discretion to address and resolve misconduct matters in a manner that is commensurate with the infraction and consistent with the values of the Institution. This includes imposition of appropriate academic sanctions for students involved in academic misconduct. However, there needs to be a certain amount of consistency when handling such issues, so if a member of the Mines community has grounds for suspecting that a student or students have engaged in academic misconduct, they have an obligation to act on this suspicion in an appropriate fashion. The following procedure will be followed:

1. The faculty member or thesis committee informs the student(s) of the allegations and charge of academic misconduct within 10 business days. This involves both verbal and written communication to the student(s). A conversation regarding the incident should take place between the faculty member/thesis committee and student. This conversation allows faculty members to get the student's perspective prior to making an official decision. It also allows faculty members to educate the student on inappropriate behavior.
2. In the case of an allegation of academic misconduct associated with regular coursework, if after talking with the student, the faculty member feels the student is responsible for misconduct the faculty member should:
 - a. Assign a grade of "F" in the course to the student(s) that committed academic misconduct. A faculty member may impose a lesser penalty if the circumstances warrant, however, the typical sanction is a grade of "F".
 - b. Contact the Associate Dean of Students and his/her Department Head/Division Director to officially report the violation in writing within 5 business days of the charge of academic misconduct. The Associate Dean of Students will communicate the final resolution in writing to the student, the faculty member, the Office of Graduate Studies and the student's advisor. The Associate Dean of Students will also keep official records on all students with academic misconduct violations.
3. In the case of an allegation of academic misconduct associated with activities not a part of regular coursework (e.g., an allegation of cheating on a comprehensive examination), if after talking with the student, faculty member(s) feel the student is responsible for misconduct the faculty should:
 - a. Assign an outcome to the activity that constitutes failure. If appropriate, the student's advisor may also assign a grade of "PRU" for research credits in which the student is enrolled. Regular institutional procedures resulting from either of these outcomes are then fol-

lowed. Faculty members may impose a lesser penalty if the circumstances warrant, however, the typical sanction is failure.

- b. Contact the Associate Dean of Students, Graduate Dean and the student's Department Head/Division Director to officially report the violation in writing within 5 business days of the charge of misconduct. The Associate Dean of Students will communicate the final resolution in writing to the student, the faculty member, the Office of Graduate Studies and the student's advisor. The Associate Dean of Students will also keep official records on all students with academic misconduct violations.
4. In the case of an allegation of academic misconduct associated with research activities, investigation and resolution of the misconduct is governed by the Institution's Research Integrity Policy. The Research Integrity Policy is available as section 10.11 of the Faculty Handbook. If, after talking with the student, the faculty member feels the student is responsible for misconduct of this type, the faculty member should proceed as indicted in the Research Integrity Policy. If appropriate, the student's advisor may also assign a grade of "PRU" for research credits in which the student is enrolled. Regular institutional procedures resulting from this grade assignment are then followed.

Prescribed Disciplinary Action for misconduct associated with regular coursework:

- 1st Offense: - A grade of "F" in the course
- 2nd Offense: - A grade of "F" in the course
- One-year academic suspension
 - Permanent notation of Academic Misconduct on the student's transcript

Students who suspect other students of academic misconduct should report the matter to the appropriate faculty member, the appropriate Department Head/Division/Program Director, the Dean of Graduate Studies, and the Vice President for Student Life or the Associate Dean of Students. The information is then provided to the faculty member concerned.

Appeal Process for Student Academic Misconduct

Students charged with academic misconduct must be afforded a fair opportunity for an appeal. For those alleged to have engaged in research misconduct, the appeal procedure is defined in the Faculty Handbook section 10.11. For all other allegations of academic misconduct and the associated penalties, the student may appeal the decision of the faculty member for one of the following grounds for appeal only:

- ◆ The student believes his/her due process rights were violated as the student was not allowed to present relevant information
- ◆ The student can provide evidence that academic misconduct did not occur and the faculty member abused his/her authority and/or made an arbitrary decision without fully considering the information presented.
- ◆ There is new information to consider that, if true, would be sufficient to alter the faculty member's decision. Such information must not have been known by the student appealing at the time of the original meeting with the faculty member.

To appeal the decision, the student must submit a written request in the form of a letter to the Vice President for Student Life. The letter of appeal should provide a thorough explanation of the following:

1. Under what grounds (see list above) is the appeal being requested?
2. How does the appeal request fit the selected grounds for appeal?
3. What specific aspect of the decision is being appealed?

The letter of appeal must be received by the Vice President for Student Life within 7 business days of the date of the written notice of a violation from the Associate Dean of Students. Once an appeal request is received, the Vice President for Student Life will forward it on to one of the Appeal Review Administrators. The Appeal Review Administrator will review the written request to determine if the acceptable grounds for an appeal are met and if the appeal is timely filed. After review of the request, the Appeal Review Administrator will take one of the following actions:

- a. Deny the appeal. If the appeal is denied, the decision is final and considered binding upon all involved, from which no additional appeals are permitted.
- b. Proceed with the appeal by notifying the student and submitting all the details and the evidence to the Student Appeals Committee for resolution.

If the appeal request is granted, the Student Appeals Committee will review the case within 15 days. Please see the Student Handbook for more information on the Student Appeals Committee. The Student Appeals Committee may do any or all of the following during the review: interview with the faculty member; interview with the student(s); interview any appropriate witnesses; and/or review the student file including any homework, tests, quizzes or other assignments that were involved in the alleged misconduct. At the conclusion of the review, the Student Appeals Committee will make one of the following decisions:

- a. Reverse the decision of the faculty member and withdraw the charge from the student's record.

- b. Affirm the decision of the faculty member and uphold the sanction(s).
- c. Forward the case to the Office of Academic Affairs for further consideration: the Student Appeals Committee believes that additional considerations should be made which could include increasing or decreasing the sanctions imposed or addressing additional issues that arose through the appeal process. Recommendations for appropriate sanctions should be made by the Student Appeals Committee to the Office of Academic Affairs. The additional consideration will be conducted by the Dean of Undergraduate Studies or Dean of Graduate Studies, depending on the academic standing of the student requesting the appeal. The Office of Academic Affairs staff member will make a final decision that will be communicated to the student within 10 business days.

The decision issued by the Student Appeals Committee or the Office of Academic Affairs (in matters that are forwarded for further consideration) is final and shall be considered binding upon all involved, from which no additional appeals are permitted.

Resolution of Conflicting Bulletin Provisions

If a conflict or inconsistency is found to exist between these policies and any other provision of the Mines Graduate Bulletin, the provisions of these policies shall govern the resolution of such conflict or inconsistency.

Unsatisfactory Academic Performance *Unsatisfactory Academic Progress Resulting in Probation or Discretionary Dismissal*

A student's progress toward successful completion of a graduate degree shall be deemed unsatisfactory if any of the following conditions occur:

- ◆ Failure to maintain a cumulative grade point average of 3.0 or greater (see Grading System section);
- ◆ Receipt of an "In-Progress-Unsatisfactory" grade for research; or
- ◆ Receipt of an "Unsatisfactory Progress" recommendation from: (1) the head or director of the student's home department or division, (2) the student's thesis committee, or (3) a departmental committee charged with the responsibility of monitoring the student's progress.

Unsatisfactory academic progress on the part of a graduate student shall be reported to the Dean of Graduate Studies in a timely manner. Students making unsatisfactory progress by any of the measures listed above shall be placed on academic probation upon the first occurrence of such indication. Upon the second occurrence of an unsatisfactory progress indication, the Dean shall notify the student that he or she is subject

to discretionary dismissal according to the procedure outlined below.

In addition, students in thesis-based degree programs who are not admitted to candidacy within the time limits specified in this Bulletin may be subject to immediate mandatory dismissal according to the procedure outlined below. Failure to fulfill this requirement must be reported to the Dean of Graduate Studies in a timely manner by the department head or division/program director.

Probation and Discretionary Dismissal Procedures

If a student is subject to academic probation as a result of an initial indication of unsatisfactory academic progress, the Dean of Graduate Studies shall notify the student of his or her probationary status in a timely manner.

If a student is subject to discretionary dismissal by one of the mechanisms defined above, the Dean shall notify the student and invite him or her to submit a written remedial plan, including performance milestones and deadlines, to correct the deficiencies that caused or contributed to the student's unsatisfactory academic progress. The remedial plan, which must be approved by the student's faculty advisor and the department head, division or program director, shall be submitted to the Dean no later than 15 business days from the date of official notification to the student of the potential discretionary dismissal. If the Dean concludes that the remedial plan is likely to lead to successful completion of all degree requirements within an acceptable time frame, the Dean may halt the discretionary dismissal process and allow the student to continue working toward his or her degree. If the Dean concludes that the remedial plan is inadequate, or that it is unlikely to lead to successful completion of all degree requirements within an acceptable time frame, the Dean shall notify the student of his or her discretionary dismissal and inform the student of his or her right to appeal the dismissal as outlined below.

Unsatisfactory Academic Performance Resulting in Mandatory Dismissal

Unsatisfactory performance as gauged by any of the following measures shall result in immediate, mandatory dismissal of a graduate student: (1) failure to successfully defend the thesis after two attempts; (2) failure to be admitted to candidacy; or (3) failure by a student subject to discretionary dismissal to achieve a performance milestone or meet a deadline contained in his or her remedial plan. The Dean of Graduate Studies shall be notified promptly of any situation that may subject a student to mandatory dismissal. In this event, the Dean shall notify the student of his or her dismissal and inform the student of his or her right to appeal the dismissal as outlined below.

Students who have been notified of mandatory dismissal will be placed in non-degree status. They may request re-admission to either the same or a different degree program by

submitting a full application for admission to the Graduate Office. The application will be reviewed through the normal admission process.

If a student who has been reinstated or readmitted to his or her former degree program and is subsequently found to be making unsatisfactory progress, the student will immediately be subject to mandatory dismissal.

Appeal Procedures

Both mandatory and discretionary dismissals may be appealed by a graduate student pursuant to this procedure. To trigger review hereunder, an appeal must: (1) be in writing; (2) contain a succinct description of the matter being appealed; and (3) be filed with the Office of the Dean of Graduate Studies no later than 20 business days from the date upon which the student received official notification from the Dean regarding his or her dismissal.

Upon receipt of a timely appeal of a discretionary or mandatory dismissal, the Dean shall appoint a review committee composed of three tenured faculty members who are not members of the student's home or minor department or division. The review committee shall review the student's appeal and issue a written recommendation thereon to the Dean within 20 business days. During the course of performing this function, the committee may: (1) interview the student, the student's advisor, and, if appropriate, the student's thesis committee; (2) review all documentation related to the appeal under consideration; (3) secure the assistance of outside expertise, if needed; and (4) obtain any other relevant information necessary to properly consider the appeal.

The authority to render a final decision regarding all graduate student appeals filed hereunder shall rest with the Dean of Graduate Studies.

Exceptions and Appeals

Academic Policies and Requirements

Academic policies and requirements are included in the Bulletin on the authority of the Mines Board of Trustees as delegated to the Faculty Senate. These include matters such as degree requirements, grading systems, thesis and dissertation standards, admission standards and new and modified degree programs, certificates, minors and courses. No Mines administrator, faculty or staff member may change, waive or grant exceptions to such academic policies and requirements without approval of the Graduate Council, the Senate and/or the Board of Trustees as appropriate.

Administrative Policies and Procedures

Administrative Policies and Procedures are included in this Bulletin on the authority of the Mines Board of Trustees as delegated to the appropriate administrative office. These include (but are not limited to) matters such as student record keeping, thesis and dissertation formats and deadlines, registration requirements and procedures, assessment of tuition and fees, and allocation of financial aid. The Dean of Gradu-

ate Studies may waive or grant exceptions to such administrative policies and procedures as warranted by the circumstances of individual cases.

Any graduate student may request a waiver or exception by the following process:

1. Contact the Graduate Office to determine whether a standard form exists. If so, complete the form. If a standard form does not exist, prepare a memo with a statement of the request and a discussion of the reasons why a waiver or exception would be justified.
2. Have the memo or the form approved by the student's advisor and department head or division director, then submit it to the Dean of Graduate Studies.
3. If the request involves academic policies or requirements, the Dean of Graduate Studies will request Graduate Council approval at the Council's next regularly scheduled meeting.
4. The Dean of Graduate Studies will notify the student of the decision. The student may file a written appeal with the Provost within 10 business days of being notified of the decision. The Provost will investigate as appropriate to the issue under consideration and render a decision. The decision of the Provost is final.
5. At the next graduate Council meeting, the Dean will notify the Graduate Council of the request, the decision and the reasons for the decision. If the Graduate Council endorses the decision, then any other student in the same situation having the same justification can expect the same decision.

Public Access to the Graduate Thesis

The award of a thesis-based graduate degree is conditioned on the student's deposit of his or her completed thesis in the Mines library to ensure its availability to the public. Although the student retains the copyright in the thesis, by depositing the thesis with the library, the student assigns a perpetual, non-exclusive, royalty-free license to Mines to permit Mines to copy the thesis and allow the public reasonable access to it.

Under special circumstances, Mines may agree to include proprietary research in a graduate student's thesis. The nature and extent of the proprietary research reported in the thesis must be agreed upon in writing by the principal investigator, student and Dean of Graduate Studies. In some cases, the proprietary nature of the underlying research may require the school to delay public access to the completed thesis for a limited period of time. In no case will public access to the thesis be denied for more than 12 months from the date the Statement of Work Completion form is submitted to the Graduate School.

Making up Undergraduate Deficiencies

If the department or division decides that new students do not have the necessary background to complete an advanced degree, they will be required to enroll in courses for which they will receive no credit toward their graduate degree, or complete supervised readings, or both. Students are notified of their apparent deficiency areas in their acceptance letter from the Graduate School or in their first interview with their department advisor.

Graduate students must attain a B average in deficiency courses, and any student receiving a grade of D in a deficiency course will be required to repeat the course. Grades for these deficiency courses are recorded on the student's transcript, become part of the student's permanent record, and are calculated into the overall GPA. Students whose undergraduate records are deficient should remove all deficiencies as soon as possible after they enroll for graduate studies.

Graduate Students in Undergraduate Courses

Students may apply toward graduate degree requirements a maximum of nine (9) semester hours of department-approved 400-level course work not taken to remove deficiencies upon the recommendation of the graduate committee and the approval of the Graduate Dean.

Students may apply toward graduate degree requirements 300-level courses only in those programs which have been recommended by the department and have been approved by the Graduate Council before the student enrolls in the course. In that case a maximum of nine (9) total hours of 300- and 400-level courses will be accepted for graduate credit.

Independent Study (X99)

For each semester credit hour awarded for independent study a student is expected to invest approximately the same effort that would be required for an equivalently credited traditional course. To register for independent study course, a student should get from the Registrar's Office the form provided for that purpose, have it completed by the instructor involved and appropriate department/division head, and return it to the Registrar's Office.

Course and Research Grades

All candidates for graduate degrees must maintain a cumulative grade point average of at least 3.0 in all courses taken after acceptance into a degree program. This includes both graduate and undergraduate courses. Any grade lower than "C-" is not acceptable for credit toward graduate degree requirements or graduate deficiencies.

For research credits, students receive either an "In Progress-Satisfactory" or an "In Progress-Unsatisfactory" grade based on their faculty advisor's evaluation of their work. Research grades do not enter into the calculation of the student's grade point average.

Students who fail to maintain a grade point average of at least 3.0, or who receive an In Progress-Unsatisfactory research grade are placed on academic probation by the Graduate Dean and may be subject to discretionary dismissal as defined by the Unsatisfactory Academic Performance section of this Bulletin (see page 28).

Grade Appeal Process

Mines faculty have the responsibility, and sole authority for, assigning grades. As instructors, this responsibility includes clearly stating the instructional objectives of a course, defining how grades will be assigned in a way that is consistent with these objectives, and then assigning grades. It is the student's responsibility to understand the grading criteria and then maintain the standards of academic performance established for each course in which he or she is enrolled.

If a student believes he or she has been unfairly graded, the student may appeal the grade to the Faculty Affairs Committee of the Faculty Senate. The Faculty Affairs Committee is the faculty body authorized to review and modify course grades, in appropriate circumstances. Any decision made by the Faculty Affairs Committee is final. In evaluating a grade appeal, the Faculty Affairs Committee will place the burden of proof on the student. For a grade to be revised by the Faculty Affairs Committee, the student must demonstrate that the grading decision was unfair by documenting that one or more of the following conditions applied:

1. The grading decision was based on something other than course performance; unless the grade was a result of penalty for academic dishonesty or the grade was WI (withdrawn involuntarily).
2. The grading decision was based on standards that were unreasonably different from those applied to other students in the same section of that course.
3. The grading decision was based on standards that differed substantially and unreasonably from those previously articulated by the instructor.

To appeal a grade, the student must proceed as follows:

1. The student must prepare a written appeal of the grade received in the course. This appeal must clearly define the basis for the appeal and must present all relevant evidence supporting the student's case.
2. After preparing the written appeal, the student must deliver this appeal to the course instructor and attempt to resolve the issue directly with the instructor. Written grade appeals must be delivered to the instructor no later than 10 business days after the start of the regular (fall or spring) semester immediately following the semester in which the contested grade was received. In the event that the course instructor is unavailable, the course coordinator (first) or the Department Head/Division Director (second) will represent the instructor.

3. If after discussion with the instructor, the student is still dissatisfied, he or she can proceed with the appeal by submitting three copies of the written appeal plus three copies of a summary of the instructor/student meetings held in connection with the previous step to the President of the Faculty Senate. These must be submitted to the President of the Faculty Senate no later than 25 business days after the start of the regular semester immediately following the semester in which the contested grade was received. The President of the Faculty Senate will forward the student's appeal and supporting documents to the Faculty Affairs Committee, the course instructor's Department Head/Division Director, and the instructor.
4. The Faculty Affairs Committee will request a response to the appeal from the instructor and begin an investigation of the student's allegations and basis for appealing the grade. During the course of performing its investigation, the Committee may: 1) interview the student, the student's advisor, the course instructor and other witnesses deemed relevant to the investigation; 2) review all documentation related to the appeal under consideration; 3) secure the assistance of outside expertise, if needed; and 4) obtain any other information deemed necessary to consider and resolve the appeal.

Upon request, the Faculty Affairs Committee may share summaries of testimony and other information examined by the Committee with both the student and the instructor. Certain information, however, may be redacted from materials forwarded to the student and instructor to maintain other students' rights subject to protection under the Family Educational Rights and Privacy Act (FERPA), or other state and federal law.

Based on its investigation, the Faculty Affairs Committee will determine whether the grade should be revised. The decision rendered will be either: 1) the original grading decision is upheld, or 2) sufficient evidence exists to indicate a grade has been assigned unfairly. In this latter case, the Faculty Affairs Committee will assign the student a new grade for the course. The Committee's written decision and supporting documentation will be delivered to the President of the Faculty Senate, the office of the EVPAA, the student, the instructor, and the instructor's Department Head/Division Director no later than 25 business days following the Senate's receipt of the grade appeal. The Faculty Affairs Committee's decision shall constitute the final decision of the grade appeal. There is no further internal appeal available to the parties.

The schedule, but not the process, outlined above may be modified upon mutual agreement of the student, the instructor, and the Faculty Affairs Committee

Graduation

All students expecting to graduate must submit a graduation application to the Office of Graduate Studies.

Graduation application deadlines are scheduled well in advance of the date of Commencement to allow time for ordering diploma covers and for printing graduation invitations and programs. Students who submit applications after the stated deadline cannot be guaranteed a diploma dated for that graduation, and cannot be assured inclusion in the graduation program or ceremony. Graduation applications are accepted only for students who have previously submitted to, and had approved by the Office of Graduate Studies, the appropriate Advisor/Thesis Committee and Admission to Candidacy forms as applicable to the degree sought.

All graduating students must officially check out of their degree program, including paying the mandatory graduation fee. Checkout cards may be obtained from the Graduate Office and must be completed and returned by the established deadline. Students must register for the next term unless the graduation checkout process is completed by the last day of registration for the following semester.

The awarding of a degree is contingent upon the student's successful completion of all program requirements with at least a 3.000 GPA before the date of graduation. Students who fail to graduate at the time originally anticipated must reapply for the next graduation before the appropriate deadline date stated in the Graduate Handbook.

Students who have completed all of their degree requirements before the specific graduation date, but who have not applied for graduation can, if necessary, request a letter from the Graduate Office certifying the completion of their programs. The student should apply for the next graduation, and the diploma will show the date of that graduation.

Graduation exercises are held in December and May. Students eligible to graduate at these times are expected to attend their respective graduation exercises. Students in thesis-based degree programs may not, under any circumstances, attend graduation exercises before completing all degree requirements.

Diplomas, transcripts, and letters of completion will not be released by the School for any student or graduate who has an unsettled obligation of any kind to the School.

Withdrawing from School

To officially withdraw from Mines, a graduate student must communicate directly with the Graduate Dean or process a withdrawal form through the Graduate Office. When the form is completed, the student will receive grades of W in courses in progress. If the student does not officially withdraw the course grades are recorded as F's. Leaving school without having paid tuition and fees will result in the encumbrance of the transcript. Federal aid recipients should

check with the financial aid office to determine what impact a withdrawal may have on current or future aid.

Nondegree Students

A nondegree student is one who has not applied to pursue a degree program at Mines but wishes to take courses regularly offered on campus. Nondegree students register for courses through the Registrar's office after degree students have registered. Such students may take any course for which they have the prerequisites as listed in the Mines Bulletin or have the permission of the instructor. Transcripts or evidence of the prerequisites are required. Nondegree students pay all applicable tuition, but do not pay student fees except for the technology fee.

Veterans' Benefits

Colorado School of Mines is approved by the Colorado State Approving Agency for Veteran Benefits under chapters 30, 31, 32, 35, and 1606. Graduate students must register for and maintain nine hours of graduate work in any semester to be certified as a full-time student for full-time benefits. Any hours taken under the full-time category will decrease the benefits to 3/4 time, 1/2 time, or tuition payment only.

Students receiving benefits must report all changes in hours, addresses, marital status, or dependents to the Veterans' Counseling Office located in the Registrar's Office as soon as possible to avoid overpayment or underpayment. Veterans must see the Veterans' Counselor each semester to be certified for any benefits for which they may be eligible. In order for veterans to continue to receive benefits, they must make satisfactory progress as defined by CSM.

Graduate Grading System

Grades

When a student registers in a graduate (500 and 600 level) course, one of the following grades will appear on the academic record. Grades are based on the level of performance and represent the extent of the student's demonstrated mastery of the material listed in the course outline and achievement of the stated course objectives. These are CSM's grade symbols and their qualitative interpretations:

A	Excellent
A-	
B+	
B	Acceptable for Graduate credit
B-	
C+	
C	May be acceptable for Graduate credit
C-	
D+	
D	Not acceptable for graduate credit
D-	
F	Failed

S Satisfactory	C- or better, used only as a mid-term grade
U	Unsatisfactory below C-, used only as a mid-term grade
INC	Incomplete
PRG	Satisfactory Progress
PRU	Unsatisfactory Progress

Graduate students enrolled in undergraduate-level courses (400-level and below) are graded using the undergraduate grading system. See the Mines Undergraduate Bulletin for a description of this system.

In addition to these performance symbols, the following is a list of additional registration symbols that may appear on a CSM transcript.

WI	Involuntarily Withdrawn
W	Withdrew, No Penalty
T	Transfer Credit
NC	Not for Credit
Z	Grade not yet Submitted

Incomplete Grade

If a graduate student fails to complete a course because of illness or other reasonable excuse, the student receives a grade of Incomplete, a temporary grade which indicates a deficiency in the quantity of work done. A graduate student must remove all Incomplete grades within the first four weeks of the first semester of attendance following that in which the grade was received. If not removed within the four weeks, the Incomplete will become an F.

Satisfactory Progress Grades

A graduate student may receive a grade of Satisfactory Progress, PRG, in either one of two possible situations: 1) as a grade for a course extending more than one semester and 2) as a grade indicating completion of research credit hours.

For students completing independent study or seminar courses extending over multiple semesters, the progress grade has no point value. In such cases, the student receives a grade of PRG, which indicates that the work is not yet completed. For multi-semester independent study courses, upon completion of course requirements, final grades are assigned to all semesters in which the student enrolled in the course, replacing previous PRG grades as appropriate. In seminar courses which may not be repeated for credit, even if continuous enrollment is required by the degree program, the PRG grade remains with a final grade being assigned to last semester of attendance only.

For all multi-semester courses, independent study and seminar, students must register for the same course in each regular (Fall or Spring) semester of attendance until such time as a final grade is assigned."

When applied to research credits, the Satisfactory Progress grade, PRG, also has no point value toward a student's GPA, but indicates satisfactory progress toward completion of the research component of a student's thesis-based degree program. In this situation, a grade of PRU, Unsatisfactory

Progress, may be given, and if given, indicates that a student has not made satisfactory progress toward the research component of a thesis-based degree program. In this case, receipt of a grade of PRU may trigger academic disciplinary proceedings as described in the Unsatisfactory Academic Performance portion of this Bulletin (see page 28).

Unless faculty submit change of grade forms to the Registrar, grades of PRU delivered for unsatisfactory research performance, are not changed to PRG upon the successful completion of a student's degree program.

NC Grade

For special reasons and with the instructor's permission, a student may register in a course for no credit (NC). To have the grade NC appear on the transcript, the student must enroll at registration time as a NC student in the course and comply with all conditions stipulated by the course instructor. If a student registered as NC fails to satisfy all conditions, no record of this registration in the course will be made.

Quality Hours and Quality Points

For graduation a student must successfully complete a certain number of required semester hours and must maintain grades at a satisfactory level. Numerical values assigned to each letter grade are given in the table below.

Grade	Numerical Value
A	4.000
A-	3.700
B+	3.300
B	3.000
B-	2.700
C+	2.300
C	2.000
C-	1.700
D+	1.300
D	1.000
D-	0.700
F	0.000

The number of quality points earned in any course is the number of semester hours assigned to that course multiplied by the numerical value of the grade received. The quality hours earned are the number of semester hours in which grades are awarded. To compute a grade-point average, the number of cumulative quality hours is divided into the cumulative quality points earned. Grades of W, WI, INC, PRG, PRU, or NC are not counted in quality hours.

Semester Hours

The number of times a class meets during a week (for lecture, recitation, or laboratory) determines the number of semester hours assigned to that course. Class sessions are normally 50 minutes long and represent one hour of credit for each hour meeting. Two to four hours of laboratory work per week are equivalent to 1-semester hour of credit. For the average student, each hour of lecture and recitation requires at least two hours of preparation.

Grade-Point Averages

Grade-Point Averages shall be specified, recorded, reported, and used to three figures following the decimal point for any and all purposes to which said averages may apply.

All graduate degree programs require students have a minimum overall grade point average of 3.000 in order to be eligible to receive the degree. All courses (including deficiency courses) taken at the Colorado School of Mines after first enrolling in a graduate degree program are included in the calculation of the overall grade point average for that program. Grades for courses applied to a degree program as transfer credit are not included in any grade point average calculation. Specifics in calculating the overall, and other grade point averages are defined below.

Overall Grade-Point Average

Beginning Fall 2011, all attempts at every CSM course will count in the overall grade point average. No repeat exclusions apply.

The overall grade-point average includes all attempts at courses taken at Colorado School of Mines with the exception of courses which fall under the repeat policy in effect from Fall 2007 through Summer 2010.

If a course completed during the Fall 2007 term through Summer 2010 was a repeat of a course completed in any previous term and the course was not repeatable for credit, the grade and credit hours earned for the most recent occurrence of the course will count toward the student's grade-point average and the student's degree requirements. The most recent course occurrence must be an exact match to the previous course completed (subject and number). The most recent grade is applied to the overall grade-point average even if the previous grade is higher.

Courses from other institutions transferred to Colorado School of Mines are not counted in any grade-point average, and cannot be used under this repeat policy. Only courses originally completed and subsequently repeated at Colorado School of Mines during Fall 2007 through Summer 2010 with the same subject code and number apply to this repeat policy.

All occurrences of every course taken at Colorado School of Mines will appear on the official transcript along with the associated grade.

Courses from other institutions transferred to Colorado School of Mines are not counted in any grade-point average.

Electronic Communications (Email) Policy

BACKGROUND AND PURPOSE

Communication to students at the Colorado School of Mines (Mines) is an important element of the official business of the university. It is vital that Mines have an efficient and workable means of getting important and timely information to students. Examples of communications that require timely distribution include information from Fiscal Services, the Registrar's Office, or other offices on campus that need to deliver official and time-sensitive information to students. (Please note that emergency communications may occur in various forms based on the specific circumstances).

Electronic communication through e-mail and Trailhead Portal announcements provides a rapid, efficient, and effective form of communication. Reliance on electronic communication has become the accepted norm within the Mines community. Additionally, utilizing electronic communications is consistent with encouraging a more environmentally-conscious means of doing business and encouraging continued stewardship of scarce resources. Because of the wide-spread use and acceptance of electronic communication, Mines is adopting the following policy regarding electronic communications with students.

POLICY

It is the policy of the Colorado School of Mines that official university-related communications with students will be sent via Mines' internal e-mail system or via campus or targeted Trailhead announcements. All students will be assigned a Mines e-mail address and are expected to periodically check their Mines assigned e-mail as well as their Trailhead portal page. It is also expected that e-mail sent to students will be read in a timely manner. Communications sent via e-mail to students will be considered to have been received and read by the intended recipients.

PROCEDURES

1. All students will be given an EKey, which is an activation code that offers access to electronic resources at Mines. With their EKey, students must activate their assigned Mines e-mail address.
2. Once their e-mail address is activated, students are expected to check their Mines e-mail inbox on a frequent and consistent basis and have the responsibility to recognize that certain communications from the university may be time-critical. As such, students also are responsible for responding in a timely manner to official communications from the university when a response is requested.
3. The policy does not prevent students from using a personal e-mail address for university-related communications and purposes. If a student chooses to use a personal e-mail address as his or her address of choice for receiving

university-related communications, he or she must forward e-mail from the Mines assigned e-mail address to the personal e-mail address. However, if a student chooses to forward communications to a personal e-mail address, she or he must be aware that Mines personnel may not be able to assist in resolving technical difficulties with personal e-mail accounts. Furthermore, forwarding communications to a personal e-mail address does not absolve a student from the responsibilities associated with communication sent to his or her official Mines e-mail address. Please note: If a student changes his or her official Mines e-mail address to a personal address, it will be changed back to the Mines assigned e-mail address. Students have the option to forward their Mines e-mail to a personal address to avoid this problem. Should a student choose the forwarding option, he or she must ensure that SPAM filters will not block e-mail coming from the mines.edu address.

4. Nothing in these procedures should be construed as prohibiting university -related communications being sent via traditional means. Use of paper-based communication may be necessary under certain circumstances or may be more appropriate to certain circumstances. Examples of such communications could include, but not be limited to disciplinary notices, fiscal services communications, graduation information and so forth.

RESPONSIBLE PARTIES

Questions about this policy may be directed as follows:

Registrar's Office

Phone: 303-273-3200 or

E-mail: registrar@mines.edu

Academic Computing and Networking

Phone: 303-273-3431 or

Complete a request form at the

Mines Help Center (<http://helpdesk.mines.edu/>)

Access to Student Records

Students at the Colorado School of Mines are protected by the Family Educational Rights and Privacy Act of 1974, as amended. This Act was designed to protect the privacy of education records, to establish the right of students to inspect and review their education records, and to provide guidelines for the correction of inaccurate or misleading data through informal and formal hearings. Students also have the right to file complaints with The Family Educational Rights and Privacy Act Office (FERPA) concerning alleged failures by the institution to comply with the Act. Copies of local policy can be found in the Registrar's Office. Contact information for FERPA complaints is

Family Policy Compliance Office

U.S. Department of Education

400 Maryland Avenue, SW

Washington, D. C. 20202-4605

Directory Information. The School maintains lists of information which may be considered directory information as defined by the regulations. This information includes name, current and permanent addresses and phone numbers, date of birth, major field of study, dates of attendance, part or full-time status, degrees awarded, last school attended, participation in officially recognized activities and sports, class, and academic honors. Students who desire that this information not be printed or released must so inform the Registrar before the end of the first two weeks of the fall semester for which the student is registered. Information will be withheld for the entire academic year unless the student changes this request. The student's signature is required to make any changes for the current academic year. The request must be renewed each fall term for the upcoming year. The following student records are maintained by Colorado School of Mines at the various offices listed below:

1. General Records: Registrar and Graduate Dean
2. Transcript of Grades: Registrar
3. Computer Grade Lists: Registrar
4. Encumbrance List: Controller and Registrar
5. Academic Probation/Suspension List: Graduate Dean
6. Advisor File: Academic Advisor
7. Option/Advisor/Enrolled/ Minority/Foreign List: Registrar, Dean of Students, and Graduate Dean
8. Externally Generated SAT/GRE Score Lists: Graduate Dean
9. Financial Aid File: Financial Aid (closed records)
10. Medical History File: School Physician (closed records)

Student Access to Records. The graduate student wishing access to his or her educational records will make a written request to the Graduate Dean. This request will include the student's name, date of request and type of record to be reviewed. It will be the responsibility of the Dean to arrange a mutually satisfactory time for review. This time will be as soon as practical but is not to be later than 30 business days from receipt of the request. The record will be reviewed in the presence of the Dean or designated representative. If the record involves a list including other students, steps will be taken to preclude the viewing of the other student name and information.

Challenge of the Record. If the student wishes to challenge any part of the record, the Dean will be so notified in writing. The Dean may then (1) remove and destroy the disputed document, or (2) inform the student that it is his decision that the document represents a necessary part of the record; and, if the student wishes to appeal, (3) convene a meeting of the student and the document originator (if reasonably available) in the presence of the Executive Vice President for Academic Affairs as mediator, whose decision will be final.

Destruction of Records. Records may be destroyed at any time by the responsible official if not otherwise precluded by law except that no record may be destroyed between the dates of access request and the viewing of the record. If during the viewing of the record any item is in dispute, it may not be destroyed.

Access to Records by Other Parties. Colorado School of Mines will not permit access to student records by persons outside the School except as follows:

1. In the case of open record information as specified in the section under Directory Information.
2. To those people specifically designated by the student. Examples would include request for transcript to be sent to graduate school or prospective employer.
3. Information required by a state or federal agency for the purpose of establishing eligibility for financial aid.
4. Accreditation agencies during their on-campus review.
5. In compliance with a judicial order or lawfully issued subpoena after the student has been notified of the intended compliance.
6. Any institutional information for statistical purposes which is not identifiable with a particular student.
7. In compliance with any applicable statute now in effect or later enacted. Each individual record (general, transcript, advisor, and medical) will include a log of those persons not employed by Colorado School of Mines who have requested or obtained access to the student record and the legitimate interest that the person has in making the request.

The School discloses education records without a student's prior written consent under the FERPA exception for disclosure to school officials with legitimate educational interests. A school official is a person employed by the School in an administrative, supervisory, academic or research, or support staff position (including law enforcement unit personnel and health staff); a person or company with whom the School has contracted as its agent to provide a service instead of using School employees or officials (such as an attorney, auditor, or collection agent); a person serving on the Board of Trustees; or a student serving on an official committee, such as a disciplinary or grievance committee, or assisting another school official in performing his or her tasks.

A school official has a legitimate educational interest if the official needs to review an education record in order to fulfill his or her professional responsibilities for the School.

Posthumous Degree Awards

The faculty may recognize the accomplishments of students who have died while pursuing their educational goals. If it is reasonable to expect that the student would have completed his or her degree requirements, the faculty may award a Baccalaureate or Graduate Degree that is in all ways identical to the degree the student was pursuing. Alternatively, the faculty may award a Posthumous BS, MS, or Ph.D. to commemorate students who distinguished themselves while at Mines by bringing honor to the School and its traditions.

Consideration for either of these degrees begins with a petition to the Faculty Senate from an academic department or degree granting unit. The petition should identify the degree sought. In the event that the degree-granting unit is seeking a conventional degree award, the petition should include evidence of the reasonable expectations that the student would have completed his or her degree requirements. For a Baccalaureate, such evidence could consist of, but is not limited to:

- The student was a senior in the final semester of coursework,
- The student was enrolled in courses that would have completed the degree requirements at the time of death
- The student would have passed the courses with an acceptable grade, and would likely have fulfilled the requirements of the degree.

For a Graduate Degree:

- For graduate degrees not requiring a research product, the student was enrolled in courses that would have completed the degree requirements at the time of death, would have passed the courses with an acceptable grade, and would likely have fulfilled the requirements of the degree.
- For graduate degrees requiring a research product, the student had completed all course and mastery requirements pursuant to the degree and was near completion of the dissertation or thesis, and the student's committee found the work to be substantial and worthy of the degree.

The requirement that there be a reasonable expectation of degree completion should be interpreted liberally and weight should be given to the judgment of the departmental representative(s) supporting the petition.

In the event that the degree being sought is a Posthumous BS, MS, or Ph.D., the petition should include evidence that the student conducted himself or herself in the best tradition of a Mines' graduate and is therefore deserving of that honor.

Tuition, Fees, Financial Assistance

Tuition and fees are established by the Board of Trustees of the Colorado School of Mines following the annual budget process and action by the Colorado General Assembly and Governor.

Graduate Tuition

The official tuition and approved charges for the 2010-2011 academic year will be available prior to the start of the 2010-2011 academic year located at http://www.is.mines.edu/budget/budget_current/tuition_rates.pdf

Fees

The official fees, approved charges, and fee descriptions for the 2009-2010 academic year will be available prior to the start of the 2009-2010 academic year and can be found at: http://www.is.mines.edu/budget/budget_current/fees.pdf

Please note that graduate students who register for undergraduate courses to satisfy deficiencies may be assessed the same fee that an undergraduate student would pay.

Payments and Refunds

Payment Information

A student is expected to complete the registration process, including the payment of tuition and fees, before attending class. Students should mail their payments to: Cashier Colorado School of Mines 1500 Illinois St. Golden, CO 80401-1869 or pay at the Cashier's Office in The Ben Parker Student Center. Please write your student ID on payment.

Late Payment Penalties

A penalty will be assessed against a student if payment is not received in full by the official day of registration. The penalty is described in the schedule of courses for each semester. If payment is not completed by the sixth week of class, the student may be officially withdrawn from classes.

Financial Responsibility

Registration for classes at CSM implies an obligation by the student to meet all related financial responsibilities in a timely manner. Students who do not fulfill their financial obligations according to published deadlines are subject to the following: late payment penalties accrued on any outstanding balance, and the withholding of transcripts. Past due accounts will be turned over to Colorado Central Collection Services in accordance with Colorado law. Collection costs will be added to the student's account, and delinquencies may be reported to national credit bureaus.

Encumbrances

A student will not be permitted to register for future classes, to graduate, or to get an official transcript of his academic record while indebted in any way to CSM.

Refunds

Refunds for tuition and fees are made according to the following policy:

The amount of tuition and fee assessment is based primarily on each student's enrolled courses. In the event a student withdraws from a course or courses, assessments will be adjusted as follows:

- ✓ If the withdrawal is made prior to the end of the add/drop period for the term of enrollment, as determined by the Registrar, tuition and fees will be adjusted to the new course level without penalty.
- ✓ If the withdrawal from a course or courses is made after the add/drop period, and the student does not officially withdraw from school, no adjustment in charges will be made.
- ✓ If the withdrawal from courses is made after the add/drop period, and the student withdraws from school, tuition and fee assessments will be reduced according to the following schedule:
 - ✓ Within the 7 calendar days following the end of the add/drop period, 60 percent reduction in charges.
 - ✓ Within the next following 7 calendar days, a 40 percent reduction in charges.
 - ✓ Within the next following 7 calendar days, a 20 percent reduction in charges.
 - ✓ After that period, no reduction of charges will be made.

The schedule above applies to the Fall and Spring semesters. The time periods for the Summer sessions - Field and Summer - will be adjusted in proportion to the reduced number of days in these semesters.

Room and board refunds are pro-rated to the date of checkout from the Residence Hall. Arrangements must be made with the Housing Office. Student health insurance charges are not refundable. The insurance remains in effect for the entire semester.

PLEASE NOTE: Students receiving federal financial aid under the Title IV programs may have a different refund determined as required by federal law or regulations.

Financial Assistance for Graduate Studies

Graduate study is a considerable investment of time, energy, and money by serious students who expect a substantial return not only in satisfaction but also in future earnings. Applicants are expected to weigh carefully the investment they are willing to make against expected benefits before applying for admission.

Students are also expected to make full use of any resources available, including personal and loan funds, to cover expenses, and the School can offer some students financial aid through graduate research and teaching assistantships and through industry, state, and federal fellowships.

Purpose of Financial Aid

The Graduate School's limited financial aid is used

1. To give equal access to graduate study by assisting students with limited personal resources;
2. To compensate graduate students who teach and do research;
3. To give an incentive to exceptional students who can provide academic leadership for continually improving graduate programs.

Employment Restrictions and Agreements

Students who are employed full time or who are enrolled part time are not eligible for financial aid through the Graduate School.

Students who are awarded assistantships must sign an appointment agreement, which gives the terms of appointment and specifies the amount and type of work required. Graduate assistants who hold regular appointments are expected to devote all of their efforts to their educational program and may not be otherwise employed without the written permission of their supervisor and the Graduate Dean. Students with assistantships during the academic year must be registered as full time. During the summer session they must be registered for a minimum of three credit hours, unless they qualify for the summer research registration exception. Please see http://www.mines.edu/graduate_admissions for details on summer registration exception eligibility.

Aid Application Forms

New students interested in applying for financial aid are encouraged to apply early. Financial aid forms are included in Graduate School application packets and may be filled out and returned with the other application papers.

Graduate Fellowships

The departments and divisions award Colorado Fellowships based on the student's academic performance.

Graduate Student Loans

Need-based federal student loans are available for graduate students who need additional funding beyond their own resources and any assistantships or fellowships they may receive. The Free Application for Federal Student Aid (FAFSA) must be completed to apply for these loan funds. Students must be degree seeking and attending at least part-time (4.5 hrs) per semester to be eligible. Degree seeking students who are approved for reduced registration (4 hrs/semester) are also eligible.

Specific information and procedures for filing the FAFSA can be found on the Financial Aid Office web site at http://financial.mines.edu/Grad_TOC.html. The Financial Aid Office telephone number is 303-273-3220, and the e-mail address is financial@mines.edu.

Satisfactory Academic Progress for Federal Student Loans and Colorado Grad Grant

To maintain eligibility for federal student loans, students are expected to achieve a minimum 3.000 cumulative grade average at the end of each semester. In addition, if students enroll full time (9 credits or more) they must pass at least 9 credits. If enrolled for fewer than 9 credits, students must pass all of the credits for which they are registered. If this is not done, the student will be given a financial aid warning semester, after which the student must return to satisfactory academic standing to maintain eligibility. Satisfactory academic progress is determined after each semester, including summer.

Graduate Degrees and Requirements

Colorado School of Mines offers post-baccalaureate programs leading to the awarding of Graduate Certificates, Professional Masters degrees, thesis and non-thesis Master of Science and Master of Engineering degrees, and Doctor of Philosophy degrees. This section describes these degrees and explains the minimum institutional requirements for each.

Students may apply to, and be admitted in, multiple graduate degrees simultaneously. In this case, a student may use the same graduate course credits to satisfy the degree requirements for each degree. Students enrolled simultaneously in two Masters degree programs may double count up to half of the course credits required for the Masters degree program with the smallest course credit hour requirement toward both degree programs. Students simultaneously enrolled in a Masters degree and Doctoral degree may double count course credits toward each degree without limit. Course credits, however, may never be applied (i.e., double counted in the case of concurrent degree enrollment or used as transfer credit in the case of sequential degree enrollment) toward more than two graduate degrees.

Before the Graduate School will count these credits toward each degree requirement, the student must obtain written permission to do so from each department, division or program granting degree. This permission should be submitted with the student's Admission to Candidacy forms and should clearly indicate that each degree program is aware that credits are being counted toward the requirements of multiple degrees. For thesis-based students this permission should be provided by the student's thesis committee. For non-thesis and certificate programs, permission should be obtained from program coordinators or department/division chairs.

I. Responsible Conduct of Research Requirement

All students supported at any time in their graduate career through the National Science Foundation (NSF), as research assistants, hourly employees or fellowship awardees, must complete training in the responsible conduct of research (RCR). This requirement is in addition to all other institutional and program requirements described below and in the appropriate program sections of this Bulletin.

To satisfy the RCR requirement students must as a minimum complete the one credit hour course; SYGN502, or an equivalent. This may be done at any time prior a student's formal Admission to Candidacy. Equivalent programs may include alternative RCR training options offered by individual degree programs. To apply toward meeting this requirement, these must have been formally approved by the Ethics Across the Curriculum Committee. Refer to the individual program sections of this Bulletin for a description of equivalent means of satisfying the RCR requirement that may exist within individual degree programs.

Students and advisors are required to certify successful completion of the NSF-RCR requirement as part of the Admission to Candidacy process described in the sections below.

II. Professional Programs

A. Graduate Certificate Program

Graduate Certificate Programs at CSM are designed to have selective focus, short time to completion and consist of course work only. For more information about specific professional programs, please refer to the "Graduate Degree Programs and Description of Courses" portion of this Bulletin.

1. Academic Requirements

Each Graduate Certificate requires a minimum of 12 total credit hours. No more than 3 credit hours at the 400 level may be applied toward the minimum credit-hours requirement. All other credits must be at or above the 500 level. Students may not, on an individual basis, request credit hours be transferred from other institutions as part of the Certificate requirements. Some Graduate Certificates, however, may allow the application of specific, pre-approved transfer credits, or credits from other institutions with whom CSM has formal agreements for this purpose toward fulfilling the requirements of the Certificate. All courses applied to a Graduate Certificate are subject to approval by the program offering the certificate.

If a student has earned a Graduate Certificate and subsequently applies, and is accepted into a Master's or PhD program at Mines, credits earned in the Certificate Program may, with the approval of the advanced degree program, be applied to the advanced degree subject to all the applicable restrictions on credit hours that may be applied toward fulfilling the requirements of the advanced degree.

2. Admission to Candidacy

Full-time students must complete the following requirements within the first semester after enrolling into a Graduate Certificate degree program.

- ◆ complete all prerequisites and core curriculum course requirements of their program, and
- ◆ be admitted into full candidacy for the certificate.

A list of prerequisites and core curriculum requirements for Graduate Certificate degrees is published by each program. When a student is admitted with deficiencies, the appropriate department head, division director or program director will provide the student with a written list of courses required to remove these deficiencies. This list will be given to the student no later than one week after the start of classes of his/her first semester in order to allow for adding/dropping courses as necessary.

Upon completion of the above-defined requirements, a student must submit an Admission to Candidacy and a Statement of Work Completion forms documenting satisfactory

completion of the prerequisites and core curriculum requirements. The form must have the written approval of the program offering the Graduate Certificate.

B. Professional Master's Program

CSM awards specialized, career-oriented non-thesis Master degrees with the title of "Professional Master (descriptive title)." These are custom-designed, interdisciplinary degrees, each with a curriculum meeting the career advancement needs of a particular group of professionals in a field that is part of CSM's role and mission. For more information about these programs, please refer to the "Graduate Degree Programs and Description of Courses" portion of this Bulletin.

1. Academic Requirements

Each Professional Master's degree consists of a minimum of 30 total credit hours. Students must complete at least 21 credit hours at CSM in the degree program. The remaining hours may be transferred into the program. Requests for transfer credit must be approved by the faculty according to a process defined by the student's home department or division. Transfer credits must not have been used as credit toward a Bachelor degree. The transfer limit includes CSM distance learning courses. Up to six credit hours of Special Topic or Independent Study may be in the form of project credits done on the job as an employee or as a graduate intern. If project credits are to be used, the project proposal and final report must be approved by a CSM faculty advisor, although direct supervision may be provided by the employer. Students must maintain a cumulative grade point average of 3.0 or better in CSM course work.

2. Admission to Candidacy

Full-time students must complete the following requirements within the first calendar year after enrolling into a Professional Master's degree program.

- ◆ complete all prerequisite and core curriculum course requirements of their program, and
- ◆ be admitted into full candidacy for the degree.

Each program publishes a list of prerequisites and core curriculum requirements for Professional Master's degrees. When a student is admitted with deficiencies, the appropriate department head, division director or program director will provide the student with a written list of courses required to remove these deficiencies. This list will be given to the student no later than one week after the start of classes of his/her first semester in order to allow for adding/dropping courses as necessary.

Upon completion of the above-defined requirements, a student must submit an Admission to Candidacy form documenting satisfactory completion of the prerequisites and core curriculum requirements. The form must have the written approval of the program offering the Professional Master's degree.

III. Master of Science and Engineering Programs

A. General Requirements

Graduate study at CSM can lead to one of a number of thesis and non-thesis based Master's degrees, depending on the interests of the student. All Master's degree programs share the same academic requirements for grades, definition of minor programs, and the need to apply for admission to candidacy.

1. Academic Requirements

A Master's degree at Mines requires a minimum of 30 total credit hours. As part of this 30 hours, departments and divisions are required to include a research or design experience supervised by Mines faculty. For more information about the specific research/design requirements, please refer to the appropriate department/division section of the "Graduate Degree Programs and Description of Courses" portion of this Bulletin.

For non-thesis Master's degrees, students must complete at least 21 credit hours at Mines in the degree program. All other credits may be completed as transfer credits into the degree program. For thesis Master's degrees, no more than 9 credits may transfer. The transfer credit limit includes Mines distance learning courses. Transfer credits must not have been used as credit toward a Bachelor degree. Requests for transfer credit must be approved by the faculty according to the process defined by a student's home department or division. All credits applied toward degree, except transfer credits, must be earned on campus. Students must maintain a cumulative grade point average of 3.0 or better in Mines course work.

2. Minor Programs

Students may choose to have a minor program or programs at the Master's level. A minor program may not be taken in the student's major area of study. A designated minor requires a minimum of 9 semester hours of course work and must be approved by the student's advisor, home department head, and a faculty representative of the minor area of study.

3. Admission to Candidacy

Full-time students must complete the following requirements within one calendar year of enrolling into the Master's degree program.

- ◆ have a thesis committee appointment form on file in the Graduate Office;
- ◆ complete all prerequisite and core curriculum course requirements of their department, division or program; and
- ◆ be admitted into full candidacy for the degree.

Each degree program publishes a list of prerequisite and core curriculum requirements for that degree. If students are

admitted with deficiencies, the appropriate department heads, division directors or program directors will provide the students written lists of courses required to remove the deficiencies. These lists will be given to the students no later than one week after the start of classes of their first semester in order to allow them to add/drop courses as necessary.

Upon completion of the above defined requirements, students must submit an Admission to Candidacy form documenting satisfactory completion of the prerequisite and core curriculum requirements and granting permission to begin Master's level research. The form must have the written approval of all members of the advisor and thesis committee, if appropriate.

B. Non-thesis Option

Non-thesis Master's degrees (both non-thesis Master of Science and Master of Engineering) are offered by a number of departments, divisions and programs. In lieu of preparing a thesis, non-thesis master's program students are required to complete a research or design experience taken as a special problem or as an independent study course. See the department/division section of the "Graduate Degree Programs and Description of Courses" portion of this Bulletin for more information. Although non-thesis master's students are not assigned a Thesis Committee, students in this program do select a faculty advisor, subject to the approval of the student's home department.

C. Thesis Option

Thesis-based Master of Science degrees require completion of a satisfactory thesis and successful oral defense of this thesis. Academic credit toward completion of the thesis must include successful completion of no fewer than 6 credit hours of masters-level research credit. The thesis is expected to report on original research that results in new knowledge and/or techniques or on creative engineering design that applies state-of-the-art knowledge and techniques to solve an important problem. In either case, the thesis should be an exemplary product that meets the rigorous scholarship standards of the Colorado School of Mines. The student's faculty advisor and the Master's Thesis Committee must approve the program of study and the topic for the thesis. The format of the thesis must comply with the appropriate guidelines promulgated by the Graduate School.

1. Faculty Advisor Appointment

Each thesis-based Master's student must select a faculty advisor to provide advice regarding the student's thesis direction, research and selection of courses by the middle of their second semester at CSM. The faculty advisor will serve as a voting member of the student's Thesis Committee. The student's department head or division director and the Graduate Dean must approve all faculty advisor appointments.

Advisors must be full-time members of the CSM faculty and must hold the rank of professor, associate professor, as-

sistant professor, research professor, associate research professor or assistant research professor. Upon approval by the Graduate Dean, adjunct professors and off-campus representatives may be designated co-advisors. When appropriate and upon approval by the Graduate Dean, faculty members outside the student's home department may serve as the student's faculty co-advisor. In either of these cases, a co-advisor must be selected from the student's home department.

2. Thesis Committee

The Graduate Dean appoints a Thesis Committee whose members have been recommended by the student, the student's faculty advisor, and the student's department head. Students should have a thesis committee appointed by the end of their second semester. This Committee will have a minimum of three voting members, including the student's advisor, who are familiar with the student's area of study. Of these Committee members, two must be from the home department or, in the case of interdisciplinary degree programs, an allied department. Off-campus members can be assigned to the Committee to serve either with full voting status or in a non-voting capacity. Off-campus members with voting status assume all of the responsibilities of on-campus Committee members with respect to attendance of Committee meetings, review of thesis drafts and participation in oral examinations and thesis defense sessions. If a thesis co-advisor is assigned, an additional faculty member from the home or allied department must be added to the committee. Students who choose to have a minor program at the Master's level must select a representative from their minor area of study to serve on the Thesis Committee. Minor representatives must be full-time members of the CSM faculty.

A Thesis Committee Chairperson is designated by the student at the time he/she requests the formation of his/her thesis committee. The chairperson is responsible for leading all meetings of the thesis committee and for directing the student's thesis defense. In selecting a Thesis Committee chairperson, the following guidelines must be met: 1) the chairperson cannot be the student's advisor or co-advisor and 2) the chairperson must be a full-time CSM faculty member.

Shortly after its appointment, the Committee will meet with the student to hear a presentation of the proposed course of study and thesis topic. The Committee and the student must agree on a satisfactory program and the student must obtain the Committee approval of the written thesis proposal at least one semester prior to the thesis defense. The student's faculty advisor assumes the primary responsibility for monitoring the program and directing the thesis work. The award of the thesis-based Master's degree is contingent upon the student's researching and writing a thesis acceptable to the student's faculty advisor and Thesis Committee.

3. Thesis Defense

The student submits an initial draft of his or her thesis to the faculty advisor, who will work with the student on neces-

sary revisions. Upon approval of the student's advisor, the revised thesis is circulated to the Thesis Committee members at least one week prior to the oral defense of the thesis. The oral defense of the thesis is scheduled during the student's final semester of study. Students must be registered to defend. This defense session, which may include an examination of material covered in the student's course work, will be open to the public.

Following the defense, the Thesis Committee will meet privately to vote on whether the student has successfully defended the thesis. Three outcomes are possible: the student may pass the oral defense; the student may fail the defense; or the Committee may vote to adjourn the defense to allow the student more time to address and remove weaknesses or inadequacies in the thesis or underlying research. Two negative votes will constitute a failure regardless of the number of Committee members present at the thesis defense. In the event of either failure or adjournment, the Chair of the Thesis Committee will prepare a written statement indicating the reasons for this action and will distribute copies to the student, the Thesis Committee members, the student's department head and the Graduate Dean. In the case of failure or adjournment, the student may request a re-examination, which must be scheduled no less than one week after the original defense. A second failure to defend the thesis satisfactorily will result in the termination of the student's graduate program.

Upon passing the oral defense of thesis or report, the student must make any corrections in the thesis required by the Thesis Committee. The final, corrected copy and an executed signature page indicating approval by the student's advisor and department head must be submitted to the Office of Graduate Studies for format approval. (Format instructions are available in the Office of Graduate Studies and should be obtained before beginning work on the thesis.)

4. Time Limitations

A candidate for a thesis-based Masters degree must complete all requirements for the degree within five years of the date of admission into the degree program. Time spent on approved leaves of absence is included in the five-year time limit. Candidates not meeting the time limitation will be notified and withdrawn from their degree programs.

Candidates may apply for a one-time extension of this time limitation. This application must be made in writing and approved by the candidate's advisor, thesis committee, department and Dean of Graduate Studies. The application must include specific timelines and milestones for degree completion. If an extension is approved, failure to meet any timeline or milestone will trigger immediate withdrawal from the degree program.

If the Dean of Graduate Studies denies an extension request, the candidate may appeal this decision to the Provost. The appeal must be made in writing, must specifically state how the candidate believes the request submitted to the Dean met the requirements of the policy, and must be received no

later than 10 business days from the date of notification of the Dean's denial of the original request.

If a candidate is withdrawn from a degree program through this process (i.e., either by denial of an extension request or failure to meet a timeline or milestone) and wishes to reenter the degree program, that candidate must formally reapply for readmission. The program has full authority to determine if readmission is to be granted and, if granted to fully re-evaluate the Candidate's work to date and determine its applicability to the new degree program.

IV. Doctor of Philosophy

A. Credits, Hour and Academic Requirements

The Doctor of Philosophy degree requires completion of a minimum of 72 semester hours beyond the Bachelor degree. At least 24 semester hours must be research credits earned under the supervision of a Mines faculty advisor and at least 18 credit hours of course work must be applied to the degree program. Course requirements for each department or division are contained in the "Graduate Degree Programs and Description of Courses" section of this Bulletin.

The degree also requires completion of a satisfactory doctoral thesis and successful oral defense of this thesis. The Doctoral Thesis is expected to report on original research that results in a significant contribution of new knowledge and/or techniques. The student's faculty advisor and the Doctoral Thesis Committee must approve the program of study and the topic for the thesis.

B. Residency Requirements

Doctoral students must complete a residency requirement during the course of their graduate studies. The purpose of this requirement is to:

- ◆ require students to become engaged in extended and focused research activities under the direct supervision of Mines faculty;
- ◆ allow students to become immersed in the culture of an academic environment;
- ◆ allow students to engage in the professional activities associated with their research discipline;
- ◆ ensure students have access to the research tools and expertise needed for their chosen research activity;
- ◆ ensure the conduct of cutting-edge research with the expectation that this research will be completed in a timely fashion so that it is still relevant to the larger research community;
- ◆ provide Mines faculty with the ability to directly evaluate the research and academic credentials of a student and as such protect the integrity of the degree, department and the institution;
- ◆ ensure the research produced by students claiming a Mines degree is actually the product of Mines' intellectual environment; and
- ◆ make it clear that the intellectual property developed while in the degree program is the property of Mines as defined in the Faculty Handbook.

The residency requirement may be met by completing two semesters of full-time registration at Mines. The semesters need not be consecutive. Students may request an exception to the full-time registration requirement from the Dean of Graduate Studies. Requests for exception must be in writing, must clearly address how the student's learning experience has met the goals of the residency requirement, as articulated above, and must be submitted by both the student and the student's thesis advisor and be approved by the student's Department Head/Division Director.

C. Transfer of Credits

Up to 24 semester hours of graduate-level course work may be transferred from other institutions toward the PhD degree subject to the restriction that those courses must not have been used as credit toward a Bachelor degree. Requests for transfer credit must be approved by the faculty according to a process defined by the student's home department or division. Transfer credits are not included in calculating the student's grade point average at CSM.

In lieu of transfer credit for individual courses defined above, students who enter the PhD program with a thesis-based Master's degree from another institution may transfer up to 36 semester hours in recognition of the course work and research completed for that degree. The request must be approved by the faculty according to a process defined by the student's home department or division.

D. Faculty Advisor Appointments

Each doctoral student must select a faculty advisor to advise with respect to the student's thesis direction and research and selection of courses by the middle of their second semester at CSM. The faculty advisor will serve as a voting member of the student's Doctoral Thesis Committee. The student's department head and the Graduate Dean must approve all faculty advisor appointments.

Advisors must be full-time members of the CSM faculty and must hold the rank of professor, associate professor, assistant professor, research professor, associate research professor or assistant research professor. Upon approval by the Graduate Dean, adjunct professors and off-campus representatives may be designated co-advisors. When appropriate and upon approval by the Graduate Dean, faculty members outside the student's home department may serve as the student's faculty co-advisor. In either of these cases, a co-advisor must be selected from the student's home department.

E. Minor Programs

Students may choose a minor program or programs at the PhD level consisting of 12 course credits in the minor program. The student's faculty advisor and Doctoral Thesis Committee, including an appropriate minor committee member as described below, approve the course selection and sequence in the selected minor program. Students may choose to complete multiple minor programs. Each program must

consist of at least 12 credit hours approved by the faculty advisor and Doctoral Thesis Committee, including the appropriate minor committee members.

F. Doctoral Thesis Committees

The Graduate Dean appoints a Doctoral Thesis Committee whose members have been recommended by the student's home department or division. Students should have a thesis committee appointed by the end of their second semester. This Committee must have a minimum of five voting members that fulfill the following criteria:

1. The Committee must include an advisor who is assigned responsibility for directing the research. If two advisors are appointed, they both shall be considered co-advisors and shall be voting members of the Committee.
2. Either the advisor or at least one co-advisor must be a full-time permanent faculty member, as defined above, in the home department, division or program in order to ensure compliance with degree requirements.
3. The Committee must have at least four other voting members in addition to the advisor and co-advisors, and a majority of the voting members (including the advisor or co-advisors) must be full-time permanent CSM faculty members.
4. At least two of the "additional" committee members must be knowledgeable in the technical areas of the thesis, and at least one of them must be a member of the student's home or allied department, division or program.
5. If a minor field is designated, the third "additional" committee member must be an expert in that field. In the case of an interdisciplinary degree, the third committee member must be an expert in one of the fields represented in the research. Minor representatives must be full-time members of the CSM faculty. If multiple minor programs are being pursued, each must have a committee representative as defined above.
6. The fourth "additional" committee member must be from outside the home and allied departments or divisions and the minor field if applicable.
7. If off-campus members are nominated for voting status, the committee request form must include a brief resume of their education and/or experience that demonstrates their competence to judge the quality and validity of the thesis. Such members also must agree to assume the same responsibilities expected of on-campus Committee members including, but not limited to, attendance at Committee meetings, review of thesis proposals and drafts, and participation in oral examinations and defenses.

A Thesis Committee Chairperson is designated by the student at the time he/she requests the formation of his/her the-

sis committee. The chairperson is responsible for leading all meetings of the thesis committee and for directing the student's thesis defense. In selecting a Thesis Committee chairperson, the following guidelines must be met: 1) the chairperson cannot be the student's advisor or co-advisor, 2) the chairperson must be a full-time Mines faculty member, and 3) the chairperson must be from outside the student's home department, division or program and, if possible, should not be a representative of a minor program of study.

Shortly after its appointment, the Doctoral Thesis Committee meets with the student to hear a presentation of the proposed course of study and thesis topic. The Committee and student must agree on a satisfactory program. The student's faculty advisor then assumes the primary responsibility for monitoring the program, directing the thesis work, arranging qualifying examinations, and scheduling the thesis defense.

G. Admission to Candidacy

Full-time students must complete the following requirements within the first two calendar years after enrolling into the PhD program.

- ◆ have a thesis committee appointment form on file in the Graduate Office;
- ◆ complete all prerequisite and core curriculum course requirements of their department, division or program;
- ◆ demonstrate adequate preparation for, and satisfactory ability to conduct, doctoral research; and
- ◆ be admitted into full candidacy for the degree.

Each degree program publishes a list of prerequisite and core curriculum requirements for that degree. If students are admitted with deficiencies, the appropriate department heads, division directors or program directors will provide the students written lists of courses required to remove the deficiencies. These lists will be given to the students no later than one week after the start of classes of their first semester in order to allow them to add/drop courses as necessary. Each program also defines the process for determining whether its students have demonstrated adequate preparation for, and have satisfactory ability to do, high-quality, independent doctoral research in their specialties. These requirements and processes are described under the appropriate program headings in the section of this Bulletin on Graduate Degree Programs and Description of Courses.

Upon completion of these requirements, students must submit an Admission to Candidacy form documenting satisfactory completion of the prerequisite and core curriculum requirements and granting permission to begin doctoral research. The form must have the written approval of all members of the Ph.D. Committee.

H. Thesis Defense

The doctoral thesis must be based on original research of excellent quality in a suitable technical field, and it must exhibit satisfactory literary merit. In addition, the format of

the thesis must comply with guidelines promulgated by the Office of Graduate Studies. (Students should obtain a copy of these guidelines from the Office of Graduate Studies before beginning work on the thesis.)

The thesis topic must be submitted in the form of a written proposal to the student's faculty advisor and the Committee. The Committee must approve the proposal at least one year before the thesis defense.

The student's faculty advisor is responsible for supervising the student's research work and consulting with other Doctoral Thesis Committee members on the progress of the work. The advisor must consult with the Committee on any significant change in the nature of the work. The student submits an initial draft of his or her thesis to the advisor, who will work with the student on necessary revisions. Upon approval of the student's advisor, the revised thesis is distributed to the other members of the Committee at least one week prior to the oral defense of the thesis.

The student must pass an oral defense of his or her thesis during the final semester of studies. Students must be registered to defend. This oral defense may include an examination of material covered in the student's course work. The defense will be open to the public.

Following the defense, the Doctoral Thesis Committee will meet privately to vote on whether the student has successfully defended the thesis. Three outcomes are possible: the student may pass the oral defense; the student may fail the defense; or the Committee may vote to adjourn the defense to allow the student more time to address and remove weaknesses or inadequacies in the thesis or underlying research. Two negative votes will constitute a failure regardless of the number of Committee members present at the thesis defense. In the event of either failure or adjournment, the Chair of the Doctoral Thesis Committee will prepare a written statement indicating the reasons for this action and will distribute copies to the student, the Thesis Committee members, the student's department head and the Graduate Dean. In the case of failure, the student may request a re-examination, which must be scheduled no less than one week after the original defense. A second failure to defend the thesis satisfactorily will result in the termination of the student's graduate program.

Upon passing the oral defense of thesis, the student must make any corrections in the thesis required by the Doctoral Thesis Committee. The final, corrected copy and an executed signature page indicating approval by the student's advisor and department head must be submitted to the Office of Graduate Studies for format approval.

I. Time Limitations

A candidate for a thesis-based Doctoral degree must complete all requirements for the degree within nine years of the date of admission into the degree program. Time spent on approved leaves of absence is included in the nine-year time

limit. Candidates not meeting the time limitation will be notified and withdrawn from their degree programs.

Candidates may apply for a one-time extension of this time limitation. This application must be made in writing and approved by the candidate's advisor, thesis committee, department and Dean of Graduate Studies. The application must include specific timelines and milestones for degree completion. If an extension is approved, failure to meet any timeline or milestone will trigger immediate withdrawal from the degree program.

If the Dean of Graduate Studies denies an extension request, the candidate may appeal this decision to the Provost. The appeal must be made in writing, must specifically state how the candidate believes the request submitted to the Dean met the requirements of the policy, and must be received no later than 10 business days from the date of notification of the Dean's denial of the original request. The Provost's decision is final.

If a candidate is withdrawn from a degree program through this process (i.e., either by denial of an extension request or failure to meet a timeline or milestone) and wishes to reenter the degree program, that candidate must formally reapply for readmission. The program has full authority to determine if readmission is to be granted and, if granted to fully re-evaluate the Candidate's work to date and determine its applicability to the new degree program.

V. Combined Undergraduate/Graduate Degree Programs

A. Overview

Many degree programs offer CSM undergraduate students the opportunity to begin work on a Graduate Certificate, Professional Master's Degree, Master's Degree or Doctoral Degree while completing the requirements for their Bachelor's Degree. These combined Bachelors-Masters/Doctoral programs have been created by Mines faculty in those situations where they have deemed it academically advantageous to treat undergraduate and graduate degree programs as a continuous and integrated process. These are accelerated programs that can be valuable in fields of engineering and applied science where advanced education in technology and/or management provides the opportunity to be on a fast track for advancement to leadership positions. These programs also can be valuable for students who want to get a head start on graduate education.

The combined programs at Mines offer several advantages to students who choose to enroll in them:

1. Students can earn a graduate degree in their undergraduate major or in a field that complements their undergraduate major.
2. Students who plan to go directly into industry leave Mines with additional specialized knowledge and skills which may allow them to enter their career path at a higher level and advance more rapidly. Alternatively, students planning on attending graduate school can get a head start on their graduate education.

3. Students can plan their undergraduate electives to satisfy prerequisites, thus ensuring adequate preparation for their graduate program.
4. Early assignment of graduate advisors permits students to plan optimum course selection and scheduling in order to complete their graduate program quickly.
5. Early acceptance into a Combined Degree Program leading to a Graduate Degree assures students of automatic acceptance into full graduate status if they maintain good standing while in early-acceptance status.
6. In many cases, students will be able to complete both a Bachelor's and a Master's Degrees in five years of total enrollment at Mines.

Certain graduate programs may allow Combined Degree Program students to fulfill part of the requirements of their graduate degree by including up to six hours of specified course credits which also were used in fulfilling the requirements of their undergraduate degree. These courses may only be applied toward fulfilling Doctoral degree or, Master's degree requirements beyond the institutional minimum Master's degree requirement of 30 credit hours. Courses must meet all requirements for graduate credit, but their grades are not included in calculating the graduate GPA. Check the departmental section of the Bulletin to determine which programs provide this opportunity.

B. Admission Process

A student interested in applying into a graduate degree program as a Combined Degree Program student should first contact the department or division hosting the graduate degree program into which he/she wishes to apply. Initial inquiries may be made at any time, but initial contacts made soon after completion of the first semester, Sophomore year are recommended. Following this initial inquiry, departments/divisions will provide initial counseling on degree application procedures, admissions standards and degree completion requirements.

Admission into a graduate degree program as a Combined Degree Program student can occur as early as the first semester, Junior year, and must be granted no later than the end of registration, last semester Senior year. Once admitted into a graduate degree program, students may enroll in 500-level courses and apply these directly to their graduate degree. To apply, students must submit the standard graduate application package for the graduate portion of their Combined Degree Program. Upon admission into a graduate degree program, students are assigned graduate advisors. Prior to registration for the next semester, students and their graduate advisors should meet and plan a strategy for completing both the undergraduate and graduate programs as efficiently as possible. Until their undergraduate degree requirements are completed, students continue to have undergraduate advisors in the home department or division of their Bachelor's Degrees.

C. Requirements

Combined Degree Program students are considered undergraduate students until such time as they complete their

undergraduate degree requirements. Combined Degree Program students who are still considered undergraduates by this definition have all of the privileges and are subject to all expectations of both their undergraduate and graduate programs. These students may enroll in both undergraduate and graduate courses (see section D below), may have access to departmental assistance available through both programs, and may be eligible for undergraduate financial aid as determined by the Office of Financial Aid. Upon completion of their undergraduate degree requirements, a Combined Degree Program student is considered enrolled full-time in his/her graduate program. Once having done so, the student is no longer eligible for undergraduate financial aid, but may now be eligible for graduate financial aid. To complete their graduate degree, each Combined Degree Program student must register as a graduate student for at least one semester.

Once admitted into a graduate program, undergraduate Combined Program students must maintain good standing in the Combined Program by maintaining a minimum semester GPA of 3.0 in all courses taken. Students not meeting this requirement are deemed to be making unsatisfactory academic progress in the Combined Degree Program. Students for whom this is the case are subject to probation and, if occurring over two semesters, subject to discretionary dismissal from the graduate portion of their program as defined in the Unsatisfactory Academic Performance section of this Bulletin.

Upon completion of the undergraduate degree requirements, Combined Degree Program students are subject to all requirements (e.g., course requirements, departmental approval of transfer credits, research credits, minimum GPA, etc.) appropriate to the graduate program in which they are enrolled.

D. Enrolling in Graduate Courses as a Senior in a Combined Program

As described in the Undergraduate Bulletin, seniors may enroll in 500-level courses. In addition, undergraduate seniors who have been granted admission through the Combined Degree Program into thesis-based degree programs (Masters or Doctoral) may, with graduate advisor approval, register for 700-level research credits appropriate to Masters-level degree programs. With this single exception, while a Combined Degree Program student is still completing his/her undergraduate degree, all of the conditions described in the Undergraduate Bulletin for undergraduate enrollment in graduate-level courses apply. 700-level research credits are always applied to a student's graduate degree program.

If an undergraduate Combined Degree Program student would like to enroll in a 500-level course and apply this course directly to his/her graduate degree, he/she must notify the Registrar of the intent to do so at the time of enrollment in the course. The Registrar will forward this information to Financial Aid for appropriate action. Be aware that courses taken as an undergraduate student but applied directly toward a graduate degree are not eligible for undergraduate financial aid or the Colorado Opportunity Fund. If prior consent is not received, all 500-level graduate courses taken as an undergraduate Combined Degree Program student will be applied to the student's undergraduate degree transcript. If these are not used toward an undergraduate degree requirement, they may, with program consent, be applied to a graduate degree program as transfer credit. All regular regulations and limitations regarding the use of transfer credit to a graduate degree program apply to these credits.

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Graduate Degree Programs and Description of Courses

In addition to the general degree requirements described in the previous pages, the following specific department, division, or program requirements must also be met:

Chemical and Biological Engineering

DAVID W. M. MARR, Professor and Department Head

TRACY Q. GARDNER, Teaching Associate Professor and Assistant Department Head

ANTHONY M. DEAN, W. K. Coors Distinguished Professor

JOHN R. DORGAN, Professor

RONALD L. MILLER, Professor

J. DOUGLAS WAY, Professor

COLIN A. WOLDEN, Weaver Distinguished Professor

DAVID T. WU, Professor (also Chemistry)

SUMIT AGARWAL, Associate Professor

ANDREW M. HERRING, Associate Professor

CAROLYN A. KOH, Associate Professor

MATTHEW W. LIBERATORE, Associate Professor

C. MARK MAUPIN, Assistant Professor

KEITH B. NEEVES, Assistant Professor

AMADEAU K. SUM, Assistant Professor

NING WU, Assistant Professor

HUGH KING, Teaching Professor

RACHEL MORRISH, Teaching Associate Professor

CYNTHIA NORRGRAN, Teaching Associate Professor

PAUL D. OGG, Teaching Associate Professor

JOHN M. PERSICHETTI, Teaching Associate Professor

JUDITH N. SCHOONMAKER, Teaching Associate Professor

ANGEL ABBUD-MADRID, Research Associate Professor

HANS HEINRICH-CARSTENSEN, Research Associate Professor

ROBERT M. BALDWIN, Professor Emeritus

ANNETTE L. BUNGE, Professor Emerita

JAMES F. ELY, University Professor Emeritus

JAMES H. GARY, Professor Emeritus

JOHN O. GOLDEN, Professor Emeritus

ARTHUR J. KIDNAY, Professor Emeritus

J. THOMAS MCKINNON, Professor Emeritus

E. DENDY SLOAN, Jr., University Professor Emeritus

VICTOR F. YESAVAGE, Professor Emeritus

Degrees Offered:

Master of Science (Chemical Engineering)

Doctor of Philosophy (Chemical Engineering)

Program Description:

The program of study for an advanced degree in chemical engineering is selected by the student in consultation with his/her advisor and with the approval of the thesis committee. Upon approval of the thesis committee, graduate credit may be earned for selected 400-level courses. All full-time graduate students are required to enroll for colloquium (ChEN605) for each semester that they are in residence at CSM.

Program Requirements:

See Required Curriculum below.

Prerequisites:

The program outlined here assumes that the candidate for an advanced degree has a background in chemistry, mathematics, and physics equivalent to that required for the BS degree in Chemical Engineering at the Colorado School of Mines. Undergraduate course deficiencies must be removed prior to enrollment in graduate coursework.

The essential undergraduate courses include ChEN201, ChEN307, ChEN308, ChEN357, ChEN375, and ChEN418.

Required Curriculum:

Master of Science Program:

Students entering the Master of Science (with thesis) program with an acceptable undergraduate degree in chemical engineering are required to take a minimum of 18 semester hours of coursework. All students must complete the 4 chemical engineering core graduate courses (ChEN509, ChEN516, ChEN518, and ChEN568) and an additional 6 hours of approved electives. In addition, students must take a minimum of 6 research credits, complete, and defend an acceptable Masters dissertation. Between coursework and research credits a student must earn a minimum of 30 total semester hours. Full-time Masters students must enroll in graduate colloquium (ChEN605) each semester that they are in residence.

Students entering the Master of Science (non-thesis) program with an acceptable undergraduate degree in chemical engineering are required to take a minimum of 30 semester hours of coursework. All students must complete 3 chemical engineering core graduate courses (ChEN509, ChEN516, and ChEN518) and at least an additional 15 hours of approved electives. Students may complete an acceptable engineering report for up to 6 hours of academic credit. Full-time Masters students must enroll in graduate colloquium (ChEN605) each semester they are in residence.

CSM undergraduates enrolled in the combined BS/MS degree program must meet the requirements described above for the MS portion of their degree (both thesis and non-thesis). Students accepted into the combined program may take graduate coursework and/or research credits as an undergraduate and have them applied to their MS degree.

Doctor of Philosophy Program:

The course of study for the PhD degree consists of a minimum of 30 semester hours of coursework. All PhD students must complete the 4 core courses (ChEN509, ChEN516, ChEN518, and ChEN568) and an additional 18 hours of approved electives of which at least 6 credit hours are for ChEN 600-level courses. In addition, students must complete and defend an acceptable Doctoral dissertation. Full-time PhD students must enroll in graduate colloquium (ChEN605) each semester they are in residence.

Students in the PhD program are required to pass both a Qualifying Exam and the PhD Proposal Defense. After successful completion of 30 semester hours of coursework and completion of the PhD proposal defense, PhD candidates will be awarded a non-thesis Master of Science Degree. The additional requirements for the PhD program are described below.

PhD Qualifying Examination

The PhD qualifying examination will be offered twice each year, at the start and end of the Spring semester. All students who have entered the PhD program must take the qualifying examination at the first possible opportunity. A student may retake the examination once if he/she fails the first time; however, the examination must be retaken at the next regularly scheduled examination time. Failure of the PhD qualifying examination does not disqualify a student for the MS degree, although failure may affect the student's financial aid status.

The qualifying examination will cover the traditional areas of Chemical Engineering, and will consist of two sections: a written section and an oral section. The written section will contain 6 questions, 3 at the undergraduate level (covering fluid mechanics, heat transfer, and mass transfer/material and energy balances) and 3 at the graduate level (covering applied transport, reaction kinetics, and thermodynamics). The qualifying examination is open-book and students are free to use any reference books or course notes during the written examination. The oral examination will consist of a presentation by the student on a technical paper from the chemical engineering literature. Students will choose a paper in one of 4 areas (thermodynamics, kinetics, transport, and materials) from a list determined by the faculty. The student is required to present an oral critique of the paper of approximately 15-20 minutes followed by questions from the faculty. Papers for the oral examination will be distributed well in advance of the oral portion of the exam so students have sufficient time to prepare their presentations.

PhD Proposal Defense

After passing the Qualifying Exam, all PhD candidates are required to prepare a detailed written proposal on the subject of their PhD research topic. An oral examination consisting of a defense of the thesis proposal must be completed within approximately one year of passing the Qualifying Examination. Written proposals must be submitted to the student's thesis committee no later than one week prior to the scheduled oral examination.

Two negative votes from the doctoral committee members are required for failure of the PhD Proposal Defense. In the case of failure, one re-examination will be allowed upon petition to the Department Head. Failure to complete the PhD Proposal Defense within the allotted time without an approved postponement will result in failure. Under extenuating circumstances a student may postpone the exam with approval

of the Graduate Affairs committee, based on the recommendation of the student's thesis committee. In such cases, a student must submit a written request for postponement that describes the circumstances and proposes a new date. Requests for postponement must be presented to the thesis committee no later than 2 weeks before the end of the semester in which the exam would normally have been taken.

Description of Courses

Senior Year

ChEN402. CHEMICAL ENGINEERING DESIGN (II) (WI)

Advanced computer-aided process simulation and process optimization. Prerequisites: ChEN201, ChEN307, ChEN308, ChEN357, and ChEN375. Corequisites: ChEN418 and ChEN421. 3 hours lecture; 3 semester hours.

ChEN403. PROCESS DYNAMICS AND CONTROL (II)

Mathematical modeling and analysis of transient systems. Applications of control theory to response of dynamic chemical engineering systems and processes. Prerequisites: ChEN201, ChEN307, ChEN308, and ChEN375. 3 hours lecture; 3 semester hours.

ChEN408. NATURAL GAS PROCESSING (II) Application of chemical engineering principles to the processing of natural gas.

Emphasis on using thermodynamics and mass transfer operations to analyze existing plants. Relevant aspects of computer-aided process simulation. Prerequisites: CHGN221, ChEN201, ChEN307, ChEN308, ChEN375, or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN409. PETROLEUM PROCESSES (I) Application of chemical engineering principles to petroleum refining. Thermodynamics and reaction engineering of complex hydrocarbon systems. Relevant aspects of computer-aided process simulation for complex mixtures. Prerequisites: CHGN221, ChEN201, ChEN357, and ChEN375, or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN415/CHGN430/MLGN530. POLYMER SCIENCE AND TECHNOLOGY Chemistry and thermodynamics of polymers and polymer solutions. Reaction engineering of polymerization. Characterization techniques based on solution properties. Materials science of polymers in varying physical states. Processing operations for polymeric materials and use in separations. Prerequisites: CHGN221, MATH225, ChEN 201, ChEN357, or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN416. POLYMER ENGINEERING AND TECHNOLOGY Polymer fluid mechanics, polymer rheological response, and polymer shape forming. Definition and measurement of material properties. Interrelationships between response functions and correlation of data and material response. Theoretical approaches for prediction of polymer properties. Processing operations for polymeric materials; melt and flow instabilities. Prerequisites: ChEN201, ChEN307, and MATH225, or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN418. REACTION ENGINEERING (I) (WI) Applications of the fundamentals of thermodynamics, physical chemistry, and organic chemistry to the engineering of reactive processes. Reac-

tor design; acquisition and analysis of rate data; heterogeneous catalysis. Relevant aspects of computer-aided process simulation. Prerequisites: ChEN201, ChEN307, ChEN308, ChEN357, MATH225, CHGN221 and CHGN351. 3 hours lecture; 3 semester hours.

ChEN420. MATHEMATICAL METHODS IN CHEMICAL ENGINEERING Formulation and solution of chemical engineering problems using numerical solution methods within the Excel and MathCAD environments. Setup and numerical solution of ordinary and partial differential equations for typical chemical engineering systems and transport processes. Prerequisites:

MATH225, DCGN210 (or equivalent), ChEN201, ChEN307, and ChEN357, or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN421/EBGN321. ENGINEERING ECONOMICS Economic analysis of engineering processes and systems. Interest, annuity, present value, depreciation, cost accounting, investment accounting and financing of engineering enterprises along with taxation, market evaluation and break-even analysis. Prerequisite: consent of instructor. 3 hours lecture; 3 semester hours.

ChEN430. TRANSPORT PHENOMENA (I) Theory and chemical engineering applications of momentum, heat, and mass transfer. Set up and solution of problems involving equations of motion and energy. Prerequisites: ChEN201, ChEN307, ChEN308 ChEN357, ChEN375 and MATH225. 3 hours lecture; 3 semester hours.

ChEN435/PHGN435. INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY (II) Application of science and engineering principles to the design, fabrication, and testing of microelectronic devices. Emphasis on specific unit operations and the interrelation among processing steps. Prerequisites: Senior standing in PHGN, ChEN, MTGN, or EGGN, and consent of instructor. Due to lab space the enrollment is limited to 20 students. 1.5 hours lecture, 4 hours lab; 3 semester hours.

ChEN440. MOLECULAR PERSPECTIVES IN CHEMICAL ENGINEERING Applications of statistical and quantum mechanics to understanding and prediction of equilibrium and transport properties and processes. Relations between microscopic properties of materials and systems to macroscopic behavior. Prerequisites: ChEN 201, ChEN307, ChEN308, ChEN357, ChEN375, CHGN351 and 353, CHGN221 and 222, and MATH225, or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN450. HONORS UNDERGRADUATE RESEARCH Scholarly research of an independent nature. Prerequisites: senior standing, consent of instructor and department head. 1 to 3 semester hours.

ChEN451. HONORS UNDERGRADUATE RESEARCH Scholarly research of an independent nature. Prerequisites: senior standing, consent of instructor and department head. 1 to 3 semester hours.

ChEN460. BIOPROCESS ENGINEERING (I) The analysis and design of biochemical unit operations and processes used in conjunction with bioreactors are investigated in this course. Indus-

trial enzyme technologies are developed and explored. A strong focus is on the basic processes for producing bioethanol and biodiesel. Biochemical systems for organic oxidation and fermentation and inorganic oxidation and reduction will be presented. Prerequisites: ChEN201, ChEN357, ChEN375, CHGN428, and CHGN462. 3 hours lecture; 3 semester hours.

ChEN461. BIOCHEMICAL ENGINEERING LABORATORY (I) The measurement, calculation and analysis of processes including separations and reaction equilibria and their application to biochemical engineering. Relevant aspects of computer-aided process simulation. Prerequisites: ChEN201, ChEN357, ChEN375, CHGN428 and CHGN462. Corequisite: ChEN460. 1 credit hour; 3 hours laboratory.

ChEN470/BELS470. INTRODUCTION TO MICROFLUIDICS (I) This course introduces the basic principles and applications of microfluidic systems. Concepts related to microscale fluid mechanics, transport, physics, and biology are presented. To gain familiarity with small-scale systems, students are provided with the opportunity to design, fabricate, and test a simple microfluidic device. Prerequisites: ChEN 201, ChEN307 and DCGN210 (or equivalent) or permission of instructor. 3 semester hours.

ChEN480. NATURAL GAS HYDRATES The purpose of this class is to learn about clathrate hydrates, using two of E.D.

Sloan's books, (1) Clathrate Hydrates of Natural Gases, Third Edition (2008) co-authored by C.A.Koh, and (2) Hydrate Engineering, (2000). Using a basis of these books, and accompanying programs, we have abundant resources to act as professionals who are always learning. 3 hours lecture; 3 semester hours.

ChEN497. SUMMER PROGRAMS

ChEN498. SPECIAL TOPICS IN CHEMICAL ENGINEERING Topical courses in chemical engineering of special interest. Prerequisite: consent of instructor; 1 to 6 semester hours. Repeatable for credit under different titles.

ChEN499. INDEPENDENT STUDY Individual research or special problem projects. Topics, content, and credit hours to be agreed upon by student and supervising faculty member. Prerequisite: consent of instructor and department head, submission of "Independent Study" form to CSM Registrar. 1 to 6 semester hours. Repeatable for credit.

Graduate Courses

The 500-level courses are open to qualified seniors with permission of the department and the Dean of the Graduate School.

The 600-level courses are open only to students enrolled in the Graduate School.

ChEN504. ADVANCED PROCESS ENGINEERING ECONOMICS Advanced engineering economic principles applied to original and alternate investments. Analysis of chemical and petroleum processes relative to marketing and return on investments. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

ChEN505. NUMERICAL METHODS IN CHEMICAL ENGINEERING Engineering applications of numerical methods. Numerical integration, solution of algebraic equations, matrix

algebra, ordinary differential equations, and special emphasis on partial differential equations. Emphasis on application of numerical methods to chemical engineering problems which cannot be solved by analytical methods. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

ChEN507. APPLIED MATHEMATICS IN CHEMICAL ENGINEERING This course stresses the application of mathematics to problems drawn from chemical engineering fundamentals such as material and energy balances, transport phenomena and kinetics. Formulation and solution of ordinary and partial differential equations arising in chemical engineering or related processes or operations are discussed. Mathematical approaches are restricted to analytical solutions or techniques for producing problems amenable to analytical solutions. Prerequisite: Undergraduate differential equations course; undergraduate chemical engineering courses covering reaction kinetics, and heat, mass and momentum transfer. 3 hours lecture-discussion; 3 semester hours.

ChEN509. ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS Extension and amplification of undergraduate chemical engineering thermodynamics. Topics will include the laws of thermodynamics, thermodynamic properties of pure fluids and fluid mixtures, phase equilibria, and chemical reaction equilibria. Prerequisite: ChEN357 or equivalent or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN513. SELECTED TOPICS IN CHEMICAL ENGINEERING Selected topics chosen from special interests of instructor and students. Course may be repeated for credit on different topics. Prerequisite: Consent of instructor. 1 to 3 semester hours lecture/discussion; 1 to 3 semester hours.

ChEN516. TRANSPORT PHENOMENA Principles of momentum, heat, and mass transport with applications to chemical and biological processes. Analytical methods for solving ordinary and partial differential equations in chemical engineering with an emphasis on scaling and approximation techniques including singular and regular perturbation methods. Convective transport in the context of boundary layer theory and development of heat and mass transfer coefficients. Introduction to computational methods for solving coupled transport problems in irregular geometries. Prerequisites: ChEN307 (or equivalent) or consent of instructor. 3 hours lecture-discussion; 3 semester hours.

ChEN518. REACTION KINETICS AND CATALYSIS Homogeneous and heterogeneous rate expressions. Fundamental theories of reaction rates. Analysis of rate data and complex reaction networks. Properties of solid catalysts. Mass and heat transfer with chemical reaction. Heterogeneous non-catalytic reactions. Prerequisite: ChEN418 or equivalent. 3 hours lecture; 3 semester hours.

ChEN524. COMPUTER-AIDED PROCESS SIMULATION Advanced concepts in computer-aided process simulation are covered. Topics include optimization, heat exchanger networks, data regression analysis, and separations systems. Use of industry-standard process simulation software (Aspen Plus) is

stressed. Prerequisite: consent of instructor. 3 hours lecture; 3 semester hours.

ChEN535/PHGN535/MLGN535. INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY (II) Application of science and engineering principles to the design, fabrication, and testing of microelectronic devices. Emphasis on specific unit operations and the interrelation among processing steps. Consent of instructor 1 hour lecture, 4 hours lab; 3 semester hours.

ChEN550. MEMBRANE SEPARATION TECHNOLOGY This course is an introduction to the fabrication, characterization, and application of synthetic membranes for gas and liquid separations. Industrial membrane processes such as reverse osmosis, filtration, pervaporation, and gas separations will be covered as well as new applications from the research literature. The course will include lecture, experimental, and computational (molecular simulation) laboratory components. Prerequisites: ChEN375, ChEN430 or consent of instructor. 3 hours lecture; 3 semester hours.

ChEN555/CHGN555/MLGN555/BELS555. POLYMER AND COMPLEX FLUIDS COLLOQUIUM The Polymer and Complex Fluids Group at the Colorado School of Mines combines expertise in the areas of flow and field based transport, intelligent design and synthesis as well as nanomaterials and nanotechnology. A wide range of research tools employed by the group includes characterization using rheology, scattering, microscopy, microfluidics and separations, synthesis of novel macromolecules as well as theory and simulation involving molecular dynamics and Monte Carlo approaches. The course will provide a mechanism for collaboration between faculty and students in this research area by providing presentations on topics including the expertise of the group and unpublished, ongoing campus research. Prerequisites: consent of instructor. 1 hour lecture; 1 semester hour. Repeatable for credit to a maximum of 3 hours.

ChEN568. INTRODUCTION TO CHEMICAL ENGINEERING RESEARCH Students will be expected to apply chemical engineering principles to critically analyze theoretical and experimental research results in the chemical engineering literature, placing it in the context of the related literature. Skills to be developed and discussed include oral presentations, technical writing, critical reviews, ethics, research documentation (the laboratory notebook), research funding, types of research, developing research, and problem solving. Students will use state-of-the-art tools to explore the literature and develop well-documented research proposals and presentations. Prerequisites: graduate student in Chemical and Biological Engineering in good standing or consent of instructor. 3 semester hours.

ChEN570 INTRODUCTION TO MICROFLUIDICS This course introduces the basic principles and applications of microfluidic systems. Concepts related to microscale fluid mechanics, transport, physics, and biology are presented. To gain familiarity with small-scale systems, students are provided with the opportunity to design, fabricate, and test a simple microflu-

idic device. Students will critically analyze the literature in this emerging field. Prerequisites: ChEN307 or equivalent or consent of instructor. 3 hours lecture, 3 semester hours.

ChEN580 NATURAL GAS HYDRATES The purpose of this class is to learn about clathrate hydrates, using two of the instructor's books, (1) Clathrate Hydrates of Natural Gases, Third Edition (2008) co-authored by C.A.Koh, and (2) Hydrate Engineering, (2000). Using a basis of these books, and accompanying programs, we have abundant resources to act as professionals who are always learning. 3 hours lecture; 3 semester hours.

ChEN584/CHGN584. FUNDAMENTALS OF CATALYSIS The basic principles involved in the preparation, characterization, testing and theory of heterogeneous and homogeneous catalysts are discussed. Topics include chemisorption, adsorption isotherms, diffusion, surface kinetics, promoters, poisons, catalyst theory and design, acid base catalysis and soluble transition metal complexes. Examples of important industrial applications are given. Prerequisite: consent of instructor. 3 hours lecture; 3 semester hours.

ChEN598. SPECIAL TOPICS IN CHEMICAL ENGINEERING Pilot course of special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

ChEN599. INDEPENDENT STUDY Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

ChEN604. TOPICAL RESEARCH SEMINARS Lectures, reports, and discussions on current research in chemical engineering, usually related to the student's thesis topic. Sections are operated independently and are directed toward different research topics. Course may be repeated for credit. Prerequisite: Consent of instructor. 1 hour lecture-discussion; 1 semester hour. Repeatable for credit to a maximum of 3 hours.

ChEN605. COLLOQUIUM Students will attend a series of lectures by speakers from industry, academia, and government. Primary emphasis will be on current research in chemical engineering and related disciplines, with secondary emphasis on ethical, philosophical, and career-related issues of importance to the chemical engineering profession. Prerequisite: Graduate status. 1 hour lecture; 1 semester hour. Repeatable for credit to a maximum of 10 hours.

ChEN608. ADVANCED TOPICS IN FLUID MECHANICS In-depth analysis of selected topics in fluid mechanics with special emphasis on chemical engineering applications. Prerequisite: ChEN508 or consent of instructor. 1 to 3 hours lecture-discussion; 1 to 3 semester hours.

ChEN609/MLGN634. ADVANCED TOPICS IN THERMODYNAMICS Advanced study of thermodynamic theory and application of thermodynamic principles. Possible topics include stability, critical phenomena, chemical thermodynamics, thermodynamics of polymer solutions and thermodynamics of aqueous and ionic solutions. Prerequisite: consent of instructor. 1 to 3 semester hours.

ChEN610. APPLIED STATISTICAL THERMODYNAMICS Principles of relating behavior to microscopic properties. Topics include element of probability, ensemble theory, application to gases and solids, distribution theories of fluids, and transport properties. Prerequisite: consent of instructor. 3 hours lecture; 3 semester hours.

ChEN625/CHGN625/MLGN625. MOLECULAR SIMULATION Principles and practice of modern computer simulation techniques used to understand solids, liquids, and gases. Review of the statistical foundation of thermodynamics followed by in-depth discussion of Monte Carlo and Molecular Dynamics techniques. Discussion of intermolecular potentials, extended ensembles, and mathematical algorithms used in molecular simulations. Prerequisites: ChEN509 or equivalent, ChEN610 or equivalent recommended. 3 hours lecture; 3 semester hours.

ChEN690. SUPERVISED TEACHING OF CHEMICAL ENGINEERING Individual participation in teaching activities. Discussion, problem review and development, guidance of laboratory experiments, course development, supervised practice teaching. Course may be repeated for credit. Prerequisite: Graduate standing, appointment as a graduate student instructor, or consent of instructor. 6 to 10 hours supervised teaching; 2 semester hours.

ChEN698. SPECIAL TOPICS IN CHEMICAL ENGINEERING Pilot course of special topics course. Topics chosen from special interests of instructor(s) and student(s). Prerequisite: consent of instructor. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

ChEN699. INDEPENDENT STUDY Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

ChEN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

ChEN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

Chemistry and Geochemistry

DANIEL M. KNAUSS, Professor and Department Head
MARK E. EBERHART, Professor
KENT J. VOORHEES, Professor
DAVID T. WU, Professor
STEPHEN G. BOYES, Associate Professor
SCOTT W. COWLEY, Associate Professor
JAMES F. RANVILLE, Associate Professor
RYAN RICHARDS, Associate Professor
E. CRAIG SIMMONS, Associate Professor
BETTINA M. VOELKER, Associate Professor
KIM R. WILLIAMS, Associate Professor
MATTHEW C. POSEWITZ, Assistant Professor
YONGAN YANG, Assistant Professor
MARK SEGER, Teaching Associate Professor
ROBERT RACICOT, Teaching Associate Professor
EDWARD A. DEMPSEY, Teaching Assistant Professor
YUAN YANG, Research Assistant Professor
RAMON E. BISQUE, Professor Emeritus
STEPHEN R. DANIEL, Professor Emeritus
DEAN W. DICKERHOOF, Professor Emeritus
KENNETH W. EDWARDS, Professor Emeritus
GEORGE H. KENNEDY, Professor Emeritus
RONALD W. KLUSMAN, Professor Emeritus
DONALD LANGMUIR, Professor Emeritus
GEORGE B. LUCAS, Professor Emeritus
DONALD L. MACALADY, Professor Emeritus
PATRICK MACCARTHY, Emeritus Professor
MICHAEL J. PAVELICH, Professor Emeritus
THOMAS R. WILDEMAN, Professor Emeritus
JOHN T. WILLIAMS, Professor Emeritus
ROBERT D. WITTERS, Professor Emeritus

Degrees Offered:

- Master of Science (Chemistry; thesis and non-thesis option)
- Doctor of Philosophy (Applied Chemistry)
- Master of Science (Geochemistry; thesis)
- Professional Masters in Environmental Geochemistry (non-thesis)
- Doctor of Philosophy (Geochemistry)

All graduate degree programs in the Department of Chemistry & Geochemistry have been admitted to the Western Regional Graduate Program (WICHE). This program allows residents of Alaska, Arizona, California, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming to register at Colorado resident tuition rates.

Program Description:

The Department of Chemistry & Geochemistry offers graduate degrees in chemistry and in geochemistry. This section of the Bulletin only describes the chemistry degrees. For geochemistry degrees, please consult the Geochemistry section of the bulletin.

Prerequisites:

A candidate for an advanced degree in the chemistry program should have completed an undergraduate program in chemistry which is essentially equivalent to that offered by the Department of Chemistry & Geochemistry at the Colorado School of Mines. Undergraduate deficiencies will be determined by faculty in the Department of Chemistry & Geochemistry through interviews and/or placement examinations at the beginning of the student's first semester of graduate work.

Required Curriculum:

Chemistry:

A student in the chemistry program, in consultation with the advisor and thesis committee, selects the program of study. Initially, before a thesis advisor and thesis committee have been chosen, the student is advised by a temporary advisor and by the Graduate Affairs Committee in the Department of Chemistry & Geochemistry. The following four graduate courses are designated as core courses in the Department of Chemistry and Geochemistry: CHGN502 (inorganic), CHGN503 (physical), CHGN505 (organic), and CHGN507 (analytical).

M.S. Degree (chemistry, thesis option): The program of study includes the four core courses: (CHGN502, CHGN503, CHGN505, and CHGN507), the M.S.-level seminar (CHGN560), research, and the preparation and oral defense of an MS thesis based on the student's research. Students must be enrolled in CHGN560 for each Fall and Spring semester that they are in residence at CSM. A minimum of 36 semester hours, including at least 24 semester hours of course work, are required. At least 15 of the required 24 semester hours of course work must be taken in the Department of Chemistry & Geochemistry at CSM. The student's thesis committee makes decisions on transfer credit. Up to 9 semester hours of graduate courses may be transferred from other institutions, provided that those courses have not been used as credit toward a Bachelor degree.

Research-Intensive MS Degree: CSM undergraduates who enter the graduate program through the combined BS/MS program may use this option (thesis-based MS) to acquire a research-intensive MS degree by minimizing the time spent on coursework. This option requires a minimum of 12 hours of coursework up to six hours of which may be double counted from the student's undergraduate studies at CSM (see below).

M.S. Degree (chemistry, non-thesis option): The non-thesis M.S. degree requires 36 semester hours of course credit, composed of 30 semester hours of course work and 6 hours of independent study. The program of study includes the four core courses: (CHGN502, CHGN503, CHGN505, and CHGN507), the M.S.-level seminar (CHGN560), independent study on a topic determined by the student and the student's faculty advisor, and the preparation of a report based

on the student's study topic. Students must be enrolled in CHGN560 for each Fall and Spring semester that they are in residence at CSM. At least 21 of the required 36 semester hours of course work must be taken as a registered master's degree student at CSM. The student's committee makes decisions on courses to be taken, transfer credit, and examines the student's written report. Up to 15 semester hours of graduate courses may be transferred into the degree program, provided that those courses have not been used as credit toward a Bachelor degree.

CSM undergraduates entering a combined B.S./M.S. program in chemistry may double-count six hours from their undergraduate studies toward the M.S. degree. The undergraduate courses that are eligible for dual counting toward the M.S. degree are: CHGN401, CHGN410, CHGN403, CHGN422, CHGN428, CHGN430, CHGN475, and CHGN498 (with approval of faculty advisor and committee). Any 500 level lecture course taken as an undergraduate may also be counted as part of the six hours from the undergraduate program (with approval of faculty advisor and committee).

Ph.D. Degree (Applied Chemistry): The program of study for the Ph.D. degree in Applied Chemistry includes the departmental core courses (CHGN502, CHGN503, CHGN505, and CHGN507), the M.S.-level seminar (CHGN560), the Ph.D.-level seminar (CHGN660), a comprehensive examination, research, and the preparation and oral defense of a Ph.D. thesis based on the student's research. The total hours of course work required for the Ph.D. degree is determined on an individual basis by the student's thesis committee. Up to 24 semester hours of graduate-level course work may be transferred from other institutions toward the Ph.D. degree provided that those courses have not been used by the student toward a Bachelor's degree. The student's thesis committee may set additional course requirements and will make decisions on requests for transfer credit. Ph.D. students may base their CHGN560 seminar on any chemistry-related topic including the proposed thesis research. The CHGN560 seminar requirement must be completed no later than the end of the student's second year of graduate studies at CSM. After completion of the CHGN560 seminar, students must enroll in CHGN660. Students must be enrolled in either CHGN560 or CHGN660 for each Fall and Spring semester that they are in residence at CSM. The CHGN660 seminar must be based on the student's Ph.D. research and must include detailed research findings and interpretation thereof. This CHGN 660 seminar must be presented close to, but before, the student's oral defense of the thesis. The comprehensive examination comprises a written non-thesis proposal wherein the student prepares an original proposal on a chemistry topic distinctly different from the student's principal area of research. The student must orally defend the non-thesis proposal before the thesis committee. The non-thesis proposal requirement must be completed prior to the end of the student's second year of

graduate studies. A student's thesis committee may, at its discretion, require additional components to the comprehensive examination process such as inclusion of cumulative or other examinations.

Geochemistry:

Please see the Geochemistry section of the bulletin for information on Geochemistry degree programs.

Fields of Research:

Analytical and bioanalytical chemistry. Separation and characterization techniques for polymers, biopolymers, nanoparticles and natural colloids. Biodetection of pathogens.

Energy sciences. Alternative fuels. New materials for solar energy conversion.

Environmental chemistry. Detection and fate of anthropogenic contaminants in water, soil, and air. Acid mine drainage. Ecotoxicology. Environmental photochemistry.

Geochemistry and biogeochemistry. Microbial and chemical processes in global climate change, biomineralization, metal cycling, medical and archeological geochemistry, humic substances.

Inorganic Chemistry. Synthesis, characterization, and applications of metal and metal oxide nanoparticles.

Nanoscale materials. Design, synthesis and characterization of new materials for catalysis, energy sciences, spectroscopic applications and drug delivery. Environmental fate of nanoparticles.

Organic Chemistry. Polymer design, synthesis and characterization. Catalysis. Alternative fuels.

Physical and Computational Chemistry. Computational chemistry for polymer design, energy sciences, and materials research. Surface-enhanced Raman spectroscopy. Eberhart, Wu

Polymers. New techniques for controlling polymer architecture and composition. Theory and simulation. Separation and characterization.

Description of Courses

CHGN401. THEORETICAL INORGANIC CHEMISTRY (II)

Periodic properties of the elements. Bonding in ionic and metallic crystals. Acid-base theories. Inorganic stereochemistry. Nonaqueous solvents. Coordination chemistry and ligand field theory. Prerequisite: CHGN341 or consent of instructor. 3 hours lecture; 3 semester hours.

CHGN402. BONDING THEORY AND SYMMETRY (II) Introduction to valence bond and molecular orbital theories, symmetry; introduction to group theory; applications of group theory and symmetry concepts to molecular orbital and ligand field theories. Prerequisite: CHGN401 or consent of instructor. 3 hours lecture; 3 semester hours.

CHGN410/MLGN510. SURFACE CHEMISTRY (II) Introduction to colloid systems, capillarity, surface tension and contact angle, adsorption from solution, micelles and microemulsions,

the solid/gas interface, surface analytical techniques, van der Waal forces, electrical properties and colloid stability, some specific colloid systems (clays, foams and emulsions). Students enrolled for graduate credit in MLGN510 must complete a special project. Prerequisite: DCGN209 or consent of instructor. 3 hours lecture; 3 semester hours.

CHGN422. POLYMER CHEMISTRY LABORATORY (I) Prerequisites: CHGN221. 3 hours lab; 1 hour credit.

CHGN428. INTRODUCTORY BIOCHEMISTRY (II) Introductory study of the major molecules of biochemistry, including amino acids, proteins, enzymes, nucleic acids, lipids, and saccharides- their structure, chemistry, biological function, and biosynthesis. Stresses bioenergetics and the cell as a biological unit of organization. Discussion of classical genetics, molecular genetics, and protein synthesis. Prerequisite: CHGN221 or permission of instructor. 3 hours lecture; 3 semester hours.

CHGN430/MLGN530. INTRODUCTION TO POLYMER SCIENCE (I) An introduction to the chemistry and physics of macromolecules. Topics include the properties and statistics of polymer solutions, measurements of molecular weights, molecular weight distributions, properties of bulk polymers, mechanisms of polymer formation, and properties of thermosets and thermoplastics including elastomers. Prerequisite: CHGN221 or permission of instructor. 3 hour lecture, 3 semester hours.

CHGN475. COMPUTATIONAL CHEMISTRY (II) Prerequisites: CHGN351, CHGN402. 3 hours lecture; 3 credit hours.

CHGN490. SYNTHESIS AND CHARACTERIZATION (S) Advanced methods of organic and inorganic synthesis; high-temperature, high-pressure, inert-atmosphere, vacuum-line, and electrolytic methods. Prerequisites: CHGN323, CHGN341. 6-week summer field session; 6 credit hours.

CHGN495. UNDERGRADUATE RESEARCH (I, II, S) Individual research project under direction of a member of the Departmental faculty. Prerequisites: Completion of chemistry curriculum through the junior year or permission of the department head. 1-6 credit hours.

CHGN497. INTERNSHIP (I, II, S) Individual internship experience with an industrial, academic, or governmental host supervised by a Departmental faculty member. Prerequisites: Completion of chemistry curriculum through the junior year or permission of the department head. 1-6 credit hours.

CHGN498. SPECIAL TOPICS IN CHEMISTRY (I, II) Topics chosen from special interests of instructor and students. Prerequisite: Consent of head of department. 1 to 3 semester hours. Repeatable for credit under different titles.

CHGN499. UNDERGRADUATE RESEARCH (I, II) Individual investigational problems under the direction of members of the chemistry staff. Written report on research required for credit. Prerequisite: Consent of head of department. 1 to 3 semester hours. Repeatable for credit.

Graduate Courses

The following courses are offered at the graduate level. They will be given if sufficient qualified students register. Some 500-level courses are open to qualified seniors with the permission of the department and Dean of the Graduate School. 600-level courses are open only to students enrolled in the Graduate School. Geochemistry courses are listed after Chemistry courses.

Chemistry Courses

CHGN502. ADVANCED INORGANIC CHEMISTRY (II) Detailed examination of topics such as ligand field theory, reaction mechanisms, chemical bonding, and structure of inorganic compounds. Emphasis is placed on the correlations of the chemical reactions of the elements with periodic trends and reactivities. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

CHGN503. ADVANCED PHYSICAL CHEMISTRY I (II) Quantum chemistry of classical systems. Principles of chemical thermodynamics. Statistical mechanics with statistical calculation of thermodynamic properties. Theories of chemical kinetics. Prerequisite: Consent of instructor. 4 hours lecture; 4 semester hours.

CHGN505. ADVANCED ORGANIC CHEMISTRY (I) Detailed discussion of the more important mechanisms of organic reaction. Structural effects and reactivity. The application of reaction mechanisms to synthesis and structure proof. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

CHGN507. ADVANCED ANALYTICAL CHEMISTRY (I) Review of fundamentals of analytical chemistry. Literature of analytical chemistry and statistical treatment of data. Manipulation of real substances; sampling, storage, decomposition or dissolution, and analysis. Detailed treatment of chemical equilibrium as related to precipitation, acid-base, complexation and redox titrations. Potentiometry and UV-visible absorption spectrophotometry. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

CHGN508. ANALYTICAL SPECTROSCOPY (II) Detailed study of classical and modern spectroscopic methods; emphasis on instrumentation and application to analytical chemistry problems. Topics include: UV-visible spectroscopy, infrared spectroscopy, fluorescence and phosphorescence, Raman spectroscopy, arc and spark emission spectroscopy, flame methods, nephelometry and turbidimetry, reflectance methods, Fourier transform methods in spectroscopy, photoacoustic spectroscopy, rapid-scanning spectroscopy. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

CHGN510. CHEMICAL SEPARATIONS (II) Survey of separation methods, thermodynamics of phase equilibria, thermodynamics of liquid-liquid partitioning, various types of chromatography, ion exchange, electrophoresis, zone refining, use of inclusion compounds for separation, application of sepa-

ration technology for determining physical constants, e.g., stability constants of complexes. Prerequisite: CHGN507 or consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

CHGC514. GEOCHEMICAL THERMODYNAMICS AND KINETICS (II) Fundamental principles of classical thermodynamics and kinetics with specific application to the earth sciences. Volume-temperature–pressure relationships for solids, liquids, gases and solutions. Energy and the First Law, Entropy and the Second and Third Laws. Gibbs Free Energy, chemical equilibria and the equilibrium constant. Solutions and activity-composition relationships for solids, fluids and gases. Phase equilibria and the graphical representation of equilibria. Application of the fundamentals of kinetics to geochemical examples. Prerequisite: Introductory chemistry, introductory thermodynamics, mineralogy and petrology, or consent of the instructor. 3 hours lecture, 3 semester hours. Offered in alternate years.

CHGN515/MLGN503. CHEMICAL BONDING IN MATERIALS (I) Introduction to chemical bonding theories and calculations and their applications to solids of interest to materials science. The relationship between a material's properties and the bonding of its atoms will be examined for a variety of materials. Includes an introduction to organic polymers. Computer programs will be used for calculating bonding parameters. Prerequisite: Consent of department. 3 hours lecture; 3 semester hours.

CHGN523/MLGN509. SOLID STATE CHEMISTRY (I) Dependence of properties of solids on chemical bonding and structure; principles of crystal growth, crystal imperfections, reactions and diffusion in solids, and the theory of conductors and semiconductors. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

CHGN536/MLGN536. ADVANCED POLYMER SYNTHESIS (II) An advanced course in the synthesis of macromolecules. Various methods of polymerization will be discussed with an emphasis on the specifics concerning the syntheses of different classes of organic and inorganic polymers. Prerequisite: CHGN430, ChEN415, MLGN530 or consent of instructor. 3 hours lecture, 3 semester hours

CHGN560. GRADUATE SEMINAR, M.S. (I, II) Required for all candidates for the M.S. and Ph.D. degrees in chemistry and geochemistry. M.S. students must register for the course during each semester of residency. Ph.D. students must register each semester until a grade is received satisfying the prerequisites for CHGN660. Presentation of a graded non-thesis seminar and attendance at all departmental seminars are required. Prerequisite: Graduate student status. 1 semester hour.

CHGN580/MLGN501. STRUCTURE OF MATERIALS (II) Application of X-ray diffraction techniques for crystal and molecular structure determination of minerals, inorganic and organometallic compounds. Topics include the heavy atom method, data collection by moving film techniques and by diffractometers, Fourier methods, interpretation of Patterson maps,

refinement methods, direct methods. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

CHGN581. ELECTROCHEMISTRY (I) Introduction to theory and practice of electrochemistry. Electrode potentials, reversible and irreversible cells, activity concept. Interionic attraction theory, proton transfer theory of acids and bases, mechanisms and fates of electrode reactions. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

CHGN583/MLGN583. PRINCIPLES AND APPLICATIONS OF SURFACE ANALYSIS TECHNIQUES (II) Instrumental techniques for the characterization of surfaces of solid materials; Applications of such techniques to polymers, corrosion, metallurgy, adhesion science, microelectronics. Methods of analysis discussed: x-ray photoelectron spectroscopy (XPS), auger electron spectroscopy (AES), ion scattering spectroscopy (ISS), secondary ion mass spectrometry (SIMS), Rutherford backscattering (RBS), scanning and transmission electron microscopy (SEM, TEM), energy and wavelength dispersive x-ray analysis; principles of these methods, quantification, instrumentation, sample preparation. Prerequisite: B.S. in Metallurgy, Chemistry, Chemical Engineering, Physics, or consent of instructor. 3 hours lecture; 3 semester hours.

CHGN584/ChEN584. FUNDAMENTALS OF CATALYSIS (II) The basic principles involved in the preparation, characterization, testing and theory of heterogeneous and homogeneous catalysts are discussed. Topics include chemisorption, adsorption isotherms, diffusion, surface kinetics, promoters, poisons, catalyst theory and design, acid base catalysis and soluble transition metal complexes. Examples of important industrial applications are given. Prerequisite: CHGN222 or consent of instructor. 3 hours lecture; 3 semester hours.

CHGN585. CHEMICAL KINETICS (II) Study of kinetic phenomena in chemical systems. Attention devoted to various theoretical approaches. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

CHGN598. SPECIAL TOPICS IN CHEMISTRY (I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

CHGN599. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

CHGN660. GRADUATE SEMINAR, Ph.D. (I, II) Required of all candidates for the doctoral degree in chemistry or geochemistry. Students must register for this course each semester after completing CHGN560. Presentation of a graded nonthesis seminar and attendance at all department seminars are required. Prerequisite: CHGN560 or equivalent. 1 semester hour.

CHGN698. SPECIAL TOPICS IN CHEMISTRY (I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

CHGN699. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

CHGN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

CHGN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

Geochemistry Courses

CHGC503. INTRODUCTION TO GEOCHEMISTRY (I)

A comprehensive introduction to the basic concepts and principles of geochemistry, coupled with a thorough overview of the related principles of thermodynamics. Topics covered include: nucleosynthesis, origin of earth and solar system, chemical bonding, mineral chemistry, elemental distributions and geochemical cycles, chemical equilibrium and kinetics, isotope systematics, and organic and biogeochemistry. Prerequisite: Introductory chemistry, mineralogy and petrology, or consent of instructor. 4 hours lecture, 4 semester hours.

CHGC504. METHODS IN GEOCHEMISTRY (II) Sampling of natural earth materials including rocks, soils, sediments, and waters. Preparation of naturally heterogeneous materials, digestions, and partial chemical extractions. Principles of instrumental analysis including atomic spectroscopy, mass separations, and chromatography. Quality assurance and quality control. Interpretation and assessment of geochemical data using statistical methods. Prerequisite: Graduate standing in geochemistry or environmental science and engineering. 2 hours lecture; 2 semester hours.

CHGC505. INTRODUCTION TO ENVIRONMENTAL CHEMISTRY (II) Processes by which natural and anthropogenic chemicals interact, react, and are transformed and redistributed in various environmental compartments. Air, soil, and aqueous (fresh and saline surface and groundwaters) environments are covered, along with specialized environments such as waste treatment facilities and the upper atmosphere. Meets with CHGN403. CHGN403 and CHGC505 may not both be taken for credit. Prerequisites: SYGN101, CHGN 124 and DCGN209 or permission of instructor. 3 hours lecture; 3 semester hours.

CHGC506. WATER ANALYSIS LABORATORY (I) Instrumental analysis of water samples using spectroscopy and chromatography. Methods for field collection of water samples and field measurements. The development of laboratory skills for the use of ICP-AES, HPLC, ion chromatography, and GC. Laboratory techniques focus on standard methods for the measurement of inorganic and organic constituents in water samples. Methods of data analysis are also presented. Prerequisite: Introductory chemistry, graduate standing or consent of instructor. 3 hour laboratory, 1 hour lecture, 2 semester hours.

CHGC509/GEGN509. INTRODUCTION TO AQUEOUS GEOCHEMISTRY (I) Analytical, graphical and interpretive methods applied to aqueous systems. Thermodynamic properties of water and aqueous solutions. Calculations and graphical expression of acid-base, redox and solution-mineral equilibria. Effect of temperature and kinetics on natural aqueous systems. Adsorption and ion exchange equilibria between clays and oxide phases. Behavior of trace elements and complexation in aqueous systems. Application of organic geochemistry to natural aqueous systems. Light stable and unstable isotopic studies applied to aqueous systems. Prerequisite: DCGN209 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours.

CHGC511. GEOCHEMISTRY OF IGNEOUS ROCKS (II) A survey of the geochemical characteristics of the various types of igneous rock suites. Application of major element, trace element, and isotope geochemistry to problems of their origin and modification. Prerequisite: Undergraduate mineralogy and petrology or consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

CHGC527/GEGN527. ORGANIC GEOCHEMISTRY OF FOSSIL FUELS AND ORE DEPOSITS (II) A study of organic carbonaceous materials in relation to the genesis and modification of fossil fuel and ore deposits. The biological origin of the organic matter will be discussed with emphasis on contributions of microorganisms to the nature of these deposits. Biochemical and thermal changes which convert the organic compounds into petroleum, oil shale, tar sand, coal and other carbonaceous matter will be studied. Principal analytical techniques used for the characterization of organic matter in the geosphere and for evaluation of oil and gas source potential will be discussed. Laboratory exercises will emphasize source rock evaluation, and oil-source rock and oil-oil correlation methods. Prerequisite: CHGN221, GEGN438, or consent of instructor. 2 hours lecture; 3 hours lab; 3 semester hours. Offered alternate years.

CHGC555. ENVIRONMENTAL ORGANIC CHEMISTRY (II) A study of the chemical and physical interactions which determine the fate, transport and interactions of organic chemicals in aquatic systems, with emphasis on chemical transformations of anthropogenic organic contaminants. Prerequisites: A course in organic chemistry and CHGN503, Advanced Physical Chemistry or its equivalent, or consent of instructor. Offered in alternate years. 3 hours lecture; 3 semester hours.

CHGC562/CHGN462. MICROBIOLOGY AND THE ENVIRONMENT (II) This course will cover the basic fundamentals of microbiology, such as structure and function of prokaryotic versus eukaryotic cells; viruses; classification of micro-organisms; microbial metabolism, energetics, genetics, growth and diversity; microbial interactions with plants, animals, and other microbes. Additional topics covered will include various aspects of environmental microbiology such as global biogeochemical cycles, bioleaching, bioremediation, and wastewater treatment. Prerequisite: ESGN301 or consent of Instructor.

3 hours lecture, 3 semester hours. Offered alternate years.

CHGC563. ENVIRONMENTAL MICROBIOLOGY (I)

An introduction to the microorganisms of major geochemical importance, as well as those of primary importance in water pollution and waste treatment. Microbes and sedimentation, microbial leaching of metals from ores, acid mine water pollution, and the microbial ecology of marine and freshwater habitats are covered. Prerequisite: Consent of instructor. 1 hour lecture, 3 hours lab; 2 semester hours. Offered alternate years.

CHGC564. BIOGEOCHEMISTRY AND GEOMICROBIOLOGY (I)

Designed to give the student an understanding of the role of living things, particularly microorganisms, in the shaping of the earth. Among the subjects will be the aspects of living processes, chemical composition and characteristics of biological material, origin of life, role of microorganisms in weathering of rocks and the early diagenesis of sediments, and the origin of petroleum, oil shale, and coal. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

CHGC610. NUCLEAR AND ISOTOPIC GEOCHEMISTRY

(II) A study of the principles of geochronology and stable isotope distributions with an emphasis on the application of these principles to important case studies in igneous petrology and the formation of ore deposits. U, Th, and Pb isotopes, K-Ar, Rb-Sr, oxygen isotopes, sulfur isotopes, and carbon isotopes included. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours Offered alternate years.

CHGC699A. SELECTED TOPICS IN GEOCHEMISTRY (I, II)

Detailed study of a geochemical topic under direction of a member of the staff. Work on the same or a different topic may be continued through later semesters and additional credits earned. Prerequisite: Consent of instructor. 1 to 3 semester hours.

CHGC699B. SPECIAL TOPICS IN AQUEOUS AND

SEDIMENTARY GEOCHEMISTRY (I, II) Detailed study of a specific topic in the area of aqueous or sedimentary geochemistry under the direction of a member of the staff. Work on the same or a different topic may be continued through later semesters and additional credits earned. Prerequisite: Consent of instructor. 1 to 3 semester hours.

CHGC699C. SPECIAL TOPICS IN ORGANIC AND

BIOGEOCHEMISTRY (I, II) Detailed study of a specific topic in the areas of organic geochemistry or biogeochemistry under the direction of a member of the staff. Work on the same or a different topic may be continued through later semesters and additional credits earned. Prerequisite: Consent of instructor. 1 to 3 semester hours.

CHGC699D. SPECIAL TOPICS IN PETROLOGIC

GEOCHEMISTRY (I, II) Detailed study of a specific topic in the area of petrologic geochemistry under the direction of a member of the staff. Work on the same or a different topic may be continued through later semesters and additional credits earned. Prerequisite: Consent of instructor. 1 to 3 semester hours.

Economics and Business

RODERICK G. EGGERT, Professor and Division Director
JOHN T. CUDDINGTON, William J. Coulter Professor
CAROL A. DAHL, Professor
GRAHAM A. DAVIS, Professor
MICHAEL R. WALLS, Professor
EDWARD J. BALISTRERI, Associate Professor
MICHAEL B. HEELEY, Associate Professor
ALEXANDRA M. NEWMAN, Associate Professor
DANIEL KAFFINE, Assistant Professor
STEFFEN REBENNACK, Assistant Professor
JOY M. GODESIABOIS, Teaching Associate Professor
SCOTT HOUSER, Teaching Associate Professor
JOHN M. STERMOLE, Teaching Associate Professor
ANN DOZORETZ, Teaching Assistant Professor
FRANKLIN J. STERMOLE, Professor Emeritus
JOHN E. TILTON, University Emeritus Professor
ROBERT E. D. WOOLSEY, Professor Emeritus

Degrees Offered:

- Master of Science (Mineral and Energy Economics)
- Doctor of Philosophy (Mineral and Energy Economics)
- Master of Science (Engineering and Technology Management)

Mineral and Energy Economics Program

Description:

In an increasingly global and technical world, government and industry leaders in the mineral and energy areas require a strong foundation in economic and business skills. The Division of Economics and Business offers such skills in unique programs leading to M.S. and Ph.D. degrees in Mineral and Energy Economics. Course work and research in Mineral and Energy Economics emphasize the application of economic principles and business methods to mineral, energy, and related environmental and technological issues.

Students in the Mineral and Energy Economics Program select from one of two areas of specialization: Economics and Public Policy (E&PP) or Quantitative Business Methods/Operations Research (QBM/OR). The E&PP specialization focuses on the optimal use of scarce energy and mineral resources with a global perspective. It provides institutional knowledge coupled with economics, mathematical and statistical tools to analyze and understand how the world of energy and minerals works to guide and shape industry change. The QBM/OR specialization emphasizes the application of quantitative business methods such as optimization, simulation, decision analysis, and project management to minerals and energy related manufacturing, exploration, resource allocation, and other decision-making processes.

Fields of Research

Faculty members carry out applied research in a variety of areas including international trade, resource economics, environmental economics, industrial organization, metal market analysis, energy economics, applied microeconomics, applied econometrics, management theory and practice, finance and

investment analysis, exploration economics, decision analysis, utility theory, and corporate risk policy.

Mineral and Energy Economics Program Requirements:

M.S. Degree Students choose from either the thesis or non-thesis option in the Master of Science (M.S.) Program and are required to complete a minimum total of 36 credits (*a typical course has 3 credits*). Initial admission is only to the non-thesis program. Admission to the thesis option requires subsequent application after at least one full-time equivalent semester in the program. Coursework is valid for seven years towards the M.S. degree; any exceptions must be approved by the division director and student advisor.

Non-thesis option

- 18 credits of core courses
- 12 credits from one or both specializations
- 6 credits of approved electives or a minor from another department

Thesis option

- 18 credits of core courses
- 12 research credits
- 6 credits from one or both specializations

Ph.D. Degree Doctoral students develop a customized curriculum to fit their needs. The degree requires a minimum of 72 graduate credit hours that includes course work and a thesis. Coursework is valid for ten years towards a Ph.D. degree; any exceptions must be approved by the division director and student advisor.

Course work

- 24 credits of core courses
 - 12 credits from one or both specializations
 - 12 credits in a minor or elective credits
- require advisor and committee approval

Research credits

24 research credits. The student's faculty advisor and the doctoral thesis committee must approve the student's program of study and the topic for the thesis.

Qualifying Examination Process

Upon completion of the core course work, students must pass qualifying written examinations to become a candidate for the Ph.D. degree. The qualifying exam is given in two parts in summers of the first and second years. In addition, at the discretion of a student's doctoral committee, a student may be required to complete assignments or examinations (or both) that are more directly related to the thesis topic.

Following a successful thesis-proposal defense and prior to the final thesis defense, a student is required to present a completed research paper (or dissertation chapter) in a research seminar at CSM. The research presentation must be considered satisfactory by at least three CSM faculty members in attendance.

Minor from Another Department

Non-thesis M.S. students may apply six elective credits towards a nine hour minor in another department. A minor is ideal for those students who want to enhance or gain knowledge in another field while gaining the economic and business skills to help them move up the career ladder. For example, a petroleum, chemical, or mining engineer might want to learn more about environmental engineering, a geophysicist or geologist might want to learn the latest techniques in their profession, or an economic policy analyst might want to learn about political risk. Students should check with the minor department for the opportunities and requirements for a minor.

Transfer Credits

Non-thesis M.S. students may transfer up to 6 credits (9 credits for a thesis M.S.). The student must have achieved a grade of B or better in all graduate transfer courses and the transfer credit must be approved by the student's advisor and the Division Director. Students who enter the Ph.D. program may transfer up to 24 hours of graduate-level course work from other institutions toward the Ph.D. degree subject to the restriction that those courses must not have been used as credit toward a Bachelor degree. The student must have achieved a grade of B or better in all graduate transfer courses and the transfer must be approved by the student's Doctoral Thesis Committee and the Division Director.

Unsatisfactory Progress

In addition to the institutional guidelines for unsatisfactory progress as described elsewhere in this bulletin: Unsatisfactory progress will be assigned to any full-time student who does not pass the core courses EBGN509 and EBGN510 in first fall semester of study and EBGN511 and EBGN590 in the first spring semester of study. Unsatisfactory progress will also be assigned to any students who do not complete requirements as specified in their admission letter. Part-time students develop an approved course plan with their advisor.

Combined BS/MS Program

Students enrolled in CSM's Combined Undergraduate/Graduate Program may double count 6 hours from their undergraduate course-work towards the non-thesis graduate program provided the courses satisfy the M.S. requirements.

Dual Degree

The M.S. degree may be combined with a second degree from the IFP School (Paris, France) in Petroleum Economics and Management (see <http://www.ifp.fr>). This dual-degree program is geared to meet the needs of industry and government. Our unique program trains the next generation of technical, analytical and managerial professionals vital to the future of the petroleum and energy industries

These two world-class institutions offer a rigorous and challenging program in an international setting. The program gives a small elite group of students a solid economics foundation combined with quantitative business skills, the histori-

cal and institutional background, and the interpersonal and intercultural abilities to in the fast paced, global world of oil and gas.

Degrees: After studying in English for only 16 months (8 months at CSM and 8 months at IFP) the successful student of Petroleum Economics and Management (PEM) receives not 1 but 2 degrees:

- ◆ Masters of Science in Mineral and Energy Economics from CSM and
- ◆ Diplôme D'Ingénieur or Mastère Spécialisé from IFP

Important: Applications for admission to the joint degree program should be submitted for consideration by March 1st to begin the program the following fall semester in August. A limited number of students are selected for the program each year.

Prerequisites for the Mineral and Energy Economics Programs:

Students must have completed the following undergraduate prerequisite courses with a grade of B or better:

1. Principles of Microeconomics;
2. One semester of college-level Calculus;
3. Probability and Statistics

Students will only be allowed to enter in the spring semester if they have completed all three prerequisites courses previously, as well as undergraduate courses in mathematical economics and natural resource economics.

Required Course Curriculum in Mineral and Energy Economics:

All M.S. and Ph.D. students in Mineral and Energy Economics are required to take a set of core courses that provide basic tools for the more advanced and specialized courses in the program.

1. M.S. Curriculum

a. Core Courses (18 credits)

EBGN509 Mathematical Economics
EBGN510 Natural Resource Economics
EBGN511 Microeconomics
EBGN512 Macroeconomics
EBGN525 Operations Research Methods
EBGN590 Econometrics and Forecasting

b. Area of Specialization Courses (12 credits for M.S. non-thesis option or 6 credits for M.S. thesis option)

Economics & Public Policy

EBGN495 Economic Forecasting
EBGN530 Economics of International Energy Markets
EBGN535 Economics of Metal Industries and Markets
EBGN536 Mineral Policies and International Investment
EBGN541 International Trade

EBGN542 Economic Development
EBGN570 Environmental Economics
EBGN610 Advanced Natural Resources
EBGN611 Advanced Microeconomics
EBGN690 Advanced Econometrics

Quantitative Business Methods/Operations Research

EBGN504 Economic Evaluation and Investment Decision
Methods
EBGN505 Industrial Accounting
EBGN528 Industrial Systems Simulation
EBGN545 Corporate Finance
EBGN546 Investments and Portfolio Management
EBGN547 Financial Risk Management
EBGN552 Nonlinear Programming
EBGN555 Linear Programming
EBGN556 Network Models
EBGN557 Integer Programming
EBGN559 Supply Chain Management
EBGN560 Decision Analysis
EBGN561 Stochastic Models in Management Science
EBGN575 Advanced Mining and Energy Valuation
EBGN580 Exploration Economics
EBGN655 Advanced Linear Programming
EBGN657 Advanced Integer Programming
EBGN690 Advanced Econometrics

2. Ph.D. Curriculum

a. Common Core Courses (15 credits)

EBGN509 Mathematical Economics
EBGN510 Natural Resource Economics
EBGN511 Microeconomics
EBGN590 Econometrics and Forecasting
EBGN695 Research Methodology

b. Extended Core Courses - Economics (9 credits)

EBGN611 Advanced Microeconomics
EBGN600-level course*
EBGN600-level course*

*EBGN695 not eligible

Students who have not taken and passed a course in macroeconomics at any level are also required to take EBG512 Macroeconomics or equivalent.

d. Area of Specialization Courses (12 credits)

Economics & Public Policy

EBGN495 Economic Forecasting
EBGN530 Economics of International Energy Markets
EBGN535 Economics of Metal Industries and Markets
EBGN536 Mineral Policies and International Investment
EBGN541 International Trade
EBGN542 Economic Development

EBGN570 Environmental Economics
EBGN610 Advanced Natural Resources

Quantitative Business Methods/Operations Research

EBGN504 Economic Evaluation and Investment Decision
Methods
EBGN505 Industrial Accounting
EBGN525 Operations Research Methods
EBGN528 Industrial Systems Simulation
EBGN545 Corporate Finance
EBGN546 Investments and Portfolio Management
EBGN547 Financial Risk Management
EBGN552 Nonlinear Programming
EBGN555 Linear Programming
EBGN556 Network Models
EBGN557 Integer Programming
EBGN559 Supply Chain Management
EBGN560 Decision Analysis
EBGN561 Stochastic Models in Management Science
EBGN575 Advanced Mining and Energy Valuation
EBGN580 Exploration Economics
EBGN655 Advanced Linear Programming
EBGN657 Advanced Integer Programming

***Engineering and Technology Management
Program Description:***

The Division also offers an M.S. degree in Engineering and Technology Management (ETM). The ETM degree program is designed to integrate the technical elements of engineering practice with the managerial perspective of modern engineering and technology management. A major focus is on the business and management principles related to this integration. The ETM Program provides the analytical tools and managerial perspective needed to effectively function in a highly competitive and technologically complex business economy.

Students in the ETM Program may select from one of two areas of degree specialization: Operations/Engineering Management or Strategy and Innovation. The Operations/Engineering Management specialization emphasizes valuable techniques for managing large engineering and technical projects effectively and efficiently. In addition, special emphasis is given to advanced operations research, optimization, and decision making techniques applicable to a wide array of business and engineering problems. The Strategy and Innovation specialization teaches the correct match between organizational strategies and structures to maximize the competitive power of technology. This specialization has a particular emphasis on management issues associated with the modern business enterprise.

***Engineering and Technology Management
Program Requirements:***

Students choose either the thesis or non-thesis option and complete a minimum of 30 credit hours. Initial admission is only to the non-thesis program. Admission to the thesis op-

tion requires subsequent application after at least one full-time equivalent semester in the program. Coursework is valid for seven years towards the M.S. degree in ETM; any exceptions must be approved by the division director and student advisor.

Non-thesis option

18 credits of core courses
12 credits from one or both specializations

Thesis option

18 credits of core courses
6 research credits
6 credits from one or both specializations

Students must receive approval from their advisor in order to apply non-EB Division courses towards their ETM degree. Thesis students are required to complete 6 credit hours of thesis credit and complete a Master's level thesis under the direct supervision of the student's faculty advisor.

Further Degree Requirements

All thesis and non-thesis ETM Program students have two additional degree requirements: (1) the "Executive-in-Residence" seminar series; and (2) the ETM Communications Seminar. All students are required to attend the ETM Program "Executive-in-Residence" seminar series during at least one semester of their attendance at CSM. The "Executive-in-Residence" series features executives from industry who pass on insight and knowledge to graduate students preparing for positions in industry. This series facilitates active involvement in the ETM program by industry executives through teaching, student advising activities and more. Every fall semester the "Executive-in-Residence" will present 5-7 one hour seminars on a variety of topics related to leadership and strategy in the engineering and technology sectors. In addition, all students are required to attend a two-day Communications Seminar in their first fall semester of study in the ETM Program. The seminar will provide students a comprehensive approach to good quality communication skills, including presentation proficiency, organizational skills, professional writing skills, meeting management, as well as other professional communication abilities. The Communications Seminar is designed to better prepare students for the ETM learning experience, as well as their careers in industry

Transfer Credits

Students who enter the M.S. in Engineering and Technology Management program may transfer up to 6 graduate course credits into the degree program. The student must have achieved a grade of B or better in all graduate transfer courses and the transfer credit must be approved by the student's advisor and the Chair of the ETM Program.

Prerequisites for ETM Program:

1. Probability and Statistics (MATH323 or MATH530), and
2. Engineering Economics (EBGN321 or EBGN504).

Students not demonstrating satisfactory standing in these areas may be accepted; however, they will need to complete the deficiency prior to enrolling in courses that require these subjects as prerequisites. It is strongly suggested that students complete any deficiencies prior to enrolling in graduate degree course work.

Required Curriculum M.S. Degree Engineering and Technology Management

Thesis and non-thesis students are required to complete the following 18 hours of core courses:

a. Core Courses (18 credits)

EBGN505 Industrial Accounting
EBGN515 Economics and Decision Making
EBGN525 Operations Research Methods
EBGN545 Corporate Finance
EBGN563 Management of Technology
EBGN585 Engineering and Technology Management Capstone (to be taken during the final semester of coursework)

b. Areas of Specialization (12 credits required for non-thesis option or 6 credits required for thesis option)

Operations/Engineering Management:

EBGN528 Industrial Systems Simulation
EBGN552 Nonlinear Programming
EBGN553 Project Management
EBGN555 Linear Programming
EBGN556 Network Models
EBGN557 Integer Programming
EBGN559 Supply Chain Management
EBGN560 Decision Analysis
EBGN561 Stochastic Models in Management Science
EBGN568 Advanced Project Analysis
EBGN655 Advanced Linear Programming
EBGN657 Advanced Integer Programming

Strategy and Innovation:

EBGN564 Managing New Product Development
EBGN565 Marketing for Technology-Based Companies
EBGN566 Technology Entrepreneurship
EBGN567 Business Law and Technology
EBGN569 Business and Leadership Ethics
EBGN571 Marketing Research
EBGN572 International Business Strategy
EBGN573 Entrepreneurial Finance
EBGN574 Inventing, Patenting, and Licensing

Course Descriptions in the Mineral and Energy Economics Program and the Engineering and Technology Management Program

EBGN504 ECONOMIC EVALUATION AND INVESTMENT DECISION METHODS Time value of money concepts of present worth, future worth, annual worth, rate of return and break-even analysis are applied to after-tax economic analysis of mineral, petroleum and general investments. Related topics emphasize proper handling of (1)

inflation and escalation, (2) leverage (borrowed money), (3) risk adjustment of analysis using expected value concepts, and (4) mutually exclusive alternative analysis and service producing alternatives. Case study analysis of a mineral or petroleum investment situation is required. Students may not take EBG504 for credit if they have completed EBG321.

EBGN505 INDUSTRIAL ACCOUNTING Concepts from both financial and managerial accounting. Preparation and interpretation of financial statements and the use of this financial information in evaluation and control of the organization. Managerial concepts include the use of accounting information in the development and implementation of a successful global corporate strategy, and how control systems enhance the planning process.

EBGN509 MATHEMATICAL ECONOMICS This course reviews and re-enforces the mathematical and computer tools that are necessary to earn a graduate degree in Mineral Economics. It includes topics from differential and integral calculus; probability and statistics; algebra and matrix algebra; difference equations; and linear, mathematical and dynamic programming. It shows how these tools are applied in an economic and business context with applications taken from the mineral and energy industries. It requires both analytical as well as computer solutions. At the end of the course you will be able to appreciate and apply mathematics for better personal, economic and business decision making. Prerequisites: Principles of Microeconomics, MATH111; or permission of instructor.

EBGN510 NATURAL RESOURCE ECONOMICS The threat and theory of resource exhaustion; commodity analysis and the problem of mineral market instability; cartels and the nature of mineral pricing; the environment; government involvement; mineral policy issues; and international mineral trade. This course is designed for entering students in mineral economics. Prerequisite: Principles of Microeconomics or permission of instructor.

EBGN511 MICROECONOMICS The first of two courses dealing with applied economic theory. This part concentrates on the behavior of individual segments of the economy, the theory of consumer behavior and demand, the theory of production and costs, duality, welfare measures, price and output level determination by business firms, and the structure of product and input markets. Prerequisites: Principles of Microeconomics, MATH111, EBG509, EBG510; or permission of instructor.

EBGN512 MACROECONOMICS This course will provide an introduction to contemporary macroeconomic concepts and analysis. Macroeconomics is the study of the behavior of the economy as an aggregate. Topics include the equilibrium level of inflation, interest rates, unemployment and the growth in national income. The impact of government fiscal and monetary policy on these variables and the business cycle, with particular attention to the effects on the mineral

industry. Prerequisites: Principles of Microeconomics, MATH111; or permission of instructor.

EBGN515 ECONOMICS AND DECISION MAKING The application of microeconomic theory to business strategy. Understanding the horizontal, vertical, and product boundaries of the modern firm. A framework for analyzing the nature and extent of competition in a firm's dynamic business environment. Developing strategies for creating and sustaining competitive advantage.

EBGN525 OPERATIONS RESEARCH METHODS The core of this course is a scientific approach to planning and decision-making problems that arise in business. The course covers deterministic optimization models (linear programming, integer programming and network modeling) and a brief introduction to stochastic (probabilistic) models with Monte-Carlo simulation. Applications of the models are covered using spreadsheets. The intent of the course is to enhance logical modeling ability and to develop quantitative managerial and spreadsheet skills. The models cover applications in the areas of energy and mining, marketing, finance, production, transportation, logistics and work-force scheduling. Prerequisite: MATH111 or permission of instructor.

EBGN528 INDUSTRIAL SYSTEMS SIMULATION The course focuses on creating computerized models of real or proposed complex systems for performance evaluation. Simulation provides a cost effective way of pre-testing proposed systems and answering "what-if" questions before incurring the expense of actual implementations. The course is instructed in the state-of-the-art computer lab (CTLM), where each student is equipped with a personal computer and interacts with the instructor during the lecture. Professional version of a widely used commercial software package, "Arena", is used to build models, analyze and interpret the results. Other business analysis and productivity tools that enhance the analysis capabilities of the simulation software are introduced to show how to search for optimal solutions within the simulation models. Both discrete-event and continuous simulation models are covered through extensive use of applications including call centers, various manufacturing operations, production/inventory systems, bulk-material handling and mining, port operations, high-way traffic systems and computer networks. Prerequisites: MATH111, MATH530¹; or permission of instructor.

EBGN530 ECONOMICS OF INTERNATIONAL ENERGY MARKETS Application of models to understand markets for oil, gas, coal, electricity, and renewable energy resources. Models, modeling techniques, and issues included are supply and demand, market structure, transportation models, game theory, futures markets, environmental issues, energy policy, energy regulation, input/output models, energy conservation, and dynamic optimization. The emphasis in the course is on the development of appropriate models and their application to current issues in energy markets. Prerequisites: Principles

of Microeconomics, MATH111, EBG509, EBG510, EBG511; or permission of instructor.

EBGN535 ECONOMICS OF METAL INDUSTRIES AND MARKETS Metal supply from main product, byproduct, and secondary production. Metal demand and intensity of use analysis. Market organization and price formation. Public policy, comparative advantage, and international metal trade. Metals and economic development in the developing countries and former centrally planned economies. Environmental policy and mining and mineral processing. Students prepare and present a major research paper. Prerequisites: Principles of Microeconomics, MATH111, EBG509, EBG510, EBG511; or permission of instructor.

EBGN536 MINERAL POLICIES & INTERNATIONAL INVESTMENT Identification and evaluation of international mineral investment policies and company responses using economic, business and legal concepts. Assessment of policy issues in light of stakeholder interests and needs. Theoretical issues are introduced and then applied to case studies, policy drafting, and negotiation exercises to assure both conceptual and practical understanding of the issues. Special attention is given to the formation of national policies and corporate decision making concerning fiscal regimes, project financing, environmental protection, land use and local community concerns and the content of exploration and extraction agreements. Prerequisites: Principles of Microeconomics, MATH111, EBG509, EBG510, EBG511; or permission of instructor.

EBGN541 INTERNATIONAL TRADE Theories and evidence on international trade and development. Determinants of static and dynamic comparative advantage. The arguments for and against free trade. Economic development in non-industrialized countries. Sectoral development policies and industrialization. The special problems and opportunities created by extensive mineral resource endowments. The impact of value-added processing and export diversification on development. Prerequisites: Principles of Microeconomics, MATH111, EBG509, EBG511; or permission of instructor.

EBGN542 ECONOMIC DEVELOPMENT Role of energy and minerals in the development process. Sectoral policies and their links with macroeconomic policies. Special attention to issues of revenue stabilization, resource largesse effects, downstream processing, and diversification. Prerequisites: Principles of Microeconomics, MATH111, EBG509, EBG511, EBG512; or permission of instructor.

EBGN545 CORPORATE FINANCE The fundamentals of corporate finance as they pertain to the valuation of investments, firms, and the securities they issue. Included are the relevant theories associated with capital budgeting, financing decisions, and dividend policy. This course provides an

in-depth study of the theory and practice of corporate financial management including a study of the firm's objectives, investment decisions, long-term financing decisions, and working capital management. Prerequisite: EBG505² or permission of instructor.

EBGN546 INVESTMENT AND PORTFOLIO MANAGEMENT This course covers institutional information, valuation theory and empirical analysis of alternative financial investments, including stocks, bonds, mutual funds, ETS, and (to a limited extent) derivative securities. Special attention is paid to the role of commodities (esp. metals and energy products) as an alternative investment class. After an overview of time value of money and arbitrage and their application to the valuation of stocks and bonds, there is extensive treatment of optimal portfolio selection for risk averse investors, mean-variance efficient portfolio theory, index models, and equilibrium theories of asset pricing including the capital asset pricing model (CAPM) and arbitrage pricing theory (APT). Market efficiency is discussed, as are its implications for passive and active approaches to investment management. Investment management functions and policies, and portfolio performance evaluation are also considered. Prerequisites: Principles of Microeconomics, MATH111, MATH530¹; or permission of instructor.

EBGN547 FINANCIAL RISK MANAGEMENT Analysis of the sources, causes and effects of risks associated with holding, operating and managing assets by individuals and organizations; evaluation of the need and importance of managing these risks; and discussion of the methods employed and the instruments utilized to achieve risk shifting objectives. The course concentrates on the use of derivative assets in the risk management process. These derivatives include futures, options, swaps, swaptions, caps, collars and floors. Exposure to market and credit risks will be explored and ways of handling them will be reviewed and critiqued through analysis of case studies from the mineral and energy industries. Prerequisites: Principles of Microeconomics, MATH111, MATH530¹, EBG505²; EBG545 or EBG546; or permission of instructor. Recommended: EBG509, EBG511.

EBGN552 NONLINEAR PROGRAMMING As an advanced course in optimization, this course will address both unconstrained and constrained nonlinear model formulation and corresponding algorithms (e.g., Gradient Search and Newton's Method, and Lagrange Multiplier Methods and Reduced Gradient Algorithms, respectively). Applications of state-of-the-art hardware and software will emphasize solving real-world problems in areas such as mining, energy, transportation, and the military. Prerequisite: MATH111; EBG525 or EBG555; or permission of instructor.

EBGN553 PROJECT MANAGEMENT An introductory course focusing on analytical techniques for managing projects and on developing skills for effective project leadership and

management through analysis of case studies. Topics include project portfolio management, decomposition of project work, estimating resource requirements, planning and budgeting, scheduling, analysis of uncertainty, resource loading and leveling, project monitoring and control, earned value analysis and strategic project leadership. Guest speakers from industry discuss and amplify the relevance of course topics to their specific areas of application (construction, product development, engineering design, R&D, process development, etc.). Students learn Microsoft Project and complete a course project using this software, demonstrating proficiency analyzing project progress and communicating project information to stakeholders. Prerequisite: EBG504³ or permission of instructor.

EBGN555 LINEAR PROGRAMMING This course addresses the formulation of linear programming models, examines linear programs in two dimensions, covers standard form and other basics essential to understanding the Simplex method, the Simplex method itself, duality theory, complementary slackness conditions, and sensitivity analysis. As time permits, multi-objective programming and stochastic programming are introduced. Applications of linear programming models discussed in this course include, but are not limited to, the areas of manufacturing, finance, energy, mining, transportation and logistics, and the military. Prerequisite: MATH111; MATH332 or EBG509; or permission of instructor. 3 hours lecture; 3 semester hours.

EBGN556 NETWORK MODELS Network models are linear programming problems that possess special mathematical structures. This course examines a variety of network models, specifically, spanning tree problems, shortest path problems, maximum flow problems, minimum cost flow problems, and transportation and assignment problems. For each class of problem, we present applications in areas such as manufacturing, finance, energy, mining, transportation and logistics, and the military. We also discuss an algorithm or two applicable to each problem class. As time permits, we explore combinatorial problems that can be depicted on graphs, e.g., the traveling salesman problem and the Chinese postman problem, and discuss the tractability issues associated with these problems in contrast to “pure” network models. Prerequisites: MATH111; EBG525 or EBG555; or permission of the instructor.

EBGN557 INTEGER PROGRAMMING This course addresses the formulation of linear integer programming models, examines the standard branch-and-bound algorithm for solving such models, and covers advanced topics related to increasing the tractability of such models. These advanced topics include the application of cutting planes and strong formulations, as well as decomposition and reformulation techniques, e.g., Lagrangian relaxation, Benders decomposition, column generation. Prerequisites: MATH111; EBG525 or EBG555; or permission of instructor.

EBGN559 SUPPLY CHAIN MANAGEMENT The focus of the course is to show how a firm can achieve better “supply-demand matching” through the implementation of rigorous mathematical models and various operational/tactical strategies. We look at organizations as entities that must match the supply of what they produce with the demand for their products. A considerable portion of the course is devoted to mathematical models that treat uncertainty in the supply-chain. Topics include managing economies of scale for functional products, managing market-mediation costs for innovative products, make-to order versus make-to-stock systems, quick response strategies, risk pooling strategies, supply-chain contracts and revenue management. Additional “special topics” may be introduced, such as reverse logistics issues in the supply-chain or contemporary operational and financial hedging strategies, as time permits. Prerequisites: MATH111, MATH530¹; or permission of instructor.

EBGN560 DECISION ANALYSIS Introduction to the science of decision making and risk theory. Application of decision analysis and utility theory to the analysis of strategic decision problems. Focuses on the application of quantitative methods to business problems characterized by risk and uncertainty. Choice problems such as decisions concerning major capital investments, corporate acquisitions, new product introductions, and choices among alternative technologies are conceptualized and structured using the concepts introduced in this course. Prerequisite: EBG504³ or permission of instructor.

EBGN561 STOCHASTIC MODELS IN MANAGEMENT SCIENCE The course introduces tools of “probabilistic analysis” that are frequently used in the formal studies of management. We see methodologies that help to quantify the dynamic relationships of sequences of “random” events that evolve over time. Topics include static and dynamic Monte-Carlo simulation, discrete and continuous time Markov Chains, probabilistic dynamic programming, Markov decision processes, queuing processes and networks, Brownian motion and stochastic control. Applications from a wide range of fields will be introduced including marketing, finance, production, logistics and distribution, energy and service systems. In addition to an intuitive understanding of analytical techniques to model stochastic processes, the course emphasizes how to use related software packages for managerial decision-making. Prerequisites: MATH111, MATH530¹; or permission of instructor.

EBGN563 MANAGEMENT OF TECHNOLOGY Case studies and reading assignments explore strategies for profiting from technology assets and technological innovation. The roles of strategy, core competencies, product and process development, manufacturing, R&D, marketing, strategic partnerships, alliances, intellectual property, organizational architectures, leadership and politics are explored in the context of technological innovation. The critical role of organizational knowledge and learning in a firm’s ability to lever-

age technological innovation to gain competitive advantage is explored. The relationships between an innovation, the competencies of the innovating firm, the ease of duplication of the innovation by outsiders, the nature of complementary assets needed to successfully commercialize an innovation and the appropriate strategy for commercializing the innovation are developed. Students explore the role of network effects in commercialization strategies, particularly with respect to standards wars aimed at establishing new dominant designs. Prerequisite: EBG504³ recommended.

EBGN564 MANAGING NEW PRODUCT DEVELOPMENT Develops interdisciplinary skills required for successful product development in today's competitive marketplace. Small product development teams step through the new product development process in detail, learning about available tools and techniques to execute each process step along the way. Each student brings his or her individual disciplinary perspective to the team effort, and must learn to synthesize that perspective with those of the other students in the group to develop a sound, marketable product. Prerequisite: EBG563 recommended.

EBGN565 MARKETING FOR TECHNOLOGY-BASED COMPANIES This class explores concepts and practices related to marketing in this unique, fast-paced environment, including the defining characteristics of high-technology industries; different types and patterns of innovations and their marketing implications; the need for (and difficulties in) adopting a customer-orientation; tools used to gather marketing research/intelligence in technology-driven industries; use of strategic alliances and partnerships in marketing technology; adaptations to the "4 P's"; regulatory and ethical considerations in technological arenas. Prerequisite: Permission of instructor.

EBGN566 TECHNOLOGY ENTREPRENEURSHIP Introduces concepts related to starting and expanding a technological-based corporation. Presents ideas such as developing a business and financing plan, role of intellectual property, and the importance of a good R&D program. Prerequisite: Permission of instructor.

EBGN567 BUSINESS LAW AND TECHNOLOGY Computer software and hardware are the most complex and rapidly developing intellectual creations of modern man. Computers provide unprecedented power in accessing and manipulating data. Computers work in complex systems that require standardization and compatibility to function. Each of these special features has engendered one or more bodies of law. Complex intellectual creation demands comprehensive intellectual property protection. Computer technology, however, differs fundamentally from previous objects of intellectual property protection, and thus does not fit easily into traditional copyright and patent law. This course covers topics that relate to these complex special features of computer and technology. Prerequisite: Permission of instructor.

EBGN568 ADVANCED PROJECT ANALYSIS An advanced course in economic analysis that will look at more complex issues associated with valuing investments and projects. Discussion will focus on development and application of concepts in after-tax environments and look at other criteria and their impact in the decision-making and valuation process. Applications to engineering and technology aspects will be discussed. Effective presentation of results will be an important component of the course. Prerequisite: EBG504³ or permission of instructor.

EBGN569 BUSINESS ETHICS This business and leadership ethics course is designed to immerse you in organizational ethical decision-making processes, issues, organizational control mechanisms, and benefits of developing comprehensive and due diligence ethics programs. As a business practitioner, most activities both inside and outside the organization have ethical dimensions. Particularly, many business functions represent boundary spanning roles between the organization and outside constituents and as such present challenges in the areas of: honesty and fairness, deceptive advertising, price fixing and anti-trust, product misrepresentation and liability, billing issues. This course explores organizational successes and failures to better understand how to manage this area. Prerequisite: Permission of instructor.

EBGN570 ENVIRONMENTAL ECONOMICS The role of markets and other economic considerations in controlling pollution; the effect of environmental policy on resource allocation incentives; the use of benefit/cost analysis in environmental policy decisions and the associated problems with measuring benefits and costs. Prerequisites: Principles of Microeconomics, MATH111, EBG509, EBG510; or permission of instructor.

EBGN571 MARKETING RESEARCH The purpose of this course is to gain a deep understanding of the marketing research decisions facing product managers in technology based companies. While the specific responsibilities of a product manager vary across industries and firms, three main activities common to the position are: (1) analysis of market information, (2) marketing strategy development, and (3) implementing strategy through marketing mix decisions. In this course students will develop an understanding of available marketing research methods and the ability to use marketing research information to make strategic and tactical decisions. Prerequisite: MATH530¹.

EBGN572 INTERNATIONAL BUSINESS STRATEGY The purpose of this course is to gain understanding of the complexities presented by managing businesses in an international environment. International business has grown rapidly in recent decades due to technological expansion, liberalization of government policies on trade and resource movements, development of institutions needed to support and facilitate international transactions, and increased global

competition. Due to these factors, foreign countries increasingly are a source of both production and sales for domestic companies. Prerequisite: Permission of instructor.

EBGN573 ENTREPRENEURIAL FINANCE Entrepreneurial activity has been a potent source of innovation and job generation in the global economy. In the U.S., the majority of new jobs are generated by new entrepreneurial firms. The financial issues confronting entrepreneurial firms are drastically different from those of established companies. The focus in this course will be on analyzing the unique financial issues which face entrepreneurial firms and to develop a set of skills that has wide applications for such situations. Prerequisite: EBG505 or permission of instructor. Corequisite: EBG545 or permission of instructor.

EBGN574 INVENTING, PATENTING, AND LICENSING The various forms of intellectual property, including patents, trademarks, copyrights, trade secrets and unfair competition are discussed; the terminology of inventing, patenting and licensing is reviewed, and an overview of the complete process is given; the statutes most frequently encountered in dealing with patents (35 USC §101, §102, §103 and §112) are introduced and explained; the basics of searching the prior art are presented; participants 'walk through' case histories illustrating inventing, patenting, licensing, as well as patent infringement and litigation; the importance of proper documentation at all stages of the process is explained; the "do's" and "don't" of disclosing inventions are presented; various types of agreements are discussed including license agreements; methods for evaluating the market potential of new products are presented; the resources available for inventors are reviewed; inventing and patenting in the corporate environment are discussed; the economic impacts of patents are addressed. Prerequisite: Permission of instructor. Offered in Field session and Summer session only.

EBGN575 ADVANCED MINING AND ENERGY VALUATION The use of stochastic and option pricing techniques in mineral and energy asset valuation. The Hotelling Valuation Principle. The measurement of political risk and its impact on project value. Extensive use of real cases. Prerequisites: Principles of Microeconomics, MATH111, EBG504³, EBG505², EBG509, EBG510, EBG511; or permission of instructor.

EBGN580 EXPLORATION ECONOMICS Exploration planning and decision making for oil and gas, and metallic minerals. Risk analysis. Historical trends in exploration activity and productivity. Prerequisites: Principles of Microeconomics, EBG510; or permission of instructor. Offered when student demand is sufficient.

EBGN585 ENGINEERING AND TECHNOLOGY MANAGEMENT CAPSTONE This course represents the culmination of the ETM Program. This course is about the strategic management process – how strategies are developed and implemented in organizations. It examines senior man-

agement's role in formulating strategy and the role that all an organization's managers play in implementing a well thought out strategy. Among the topics discussed in this course are (1) how different industry conditions support different types of strategies; (2) how industry conditions change and the implication of those changes for strategic management; and (3) how organizations develop and maintain capabilities that lead to sustained competitive advantage. This course consists of learning fundamental concepts associated with strategic management process and competing in a web-based strategic management simulation to support the knowledge that you have developed. Prerequisites: MATH530¹, EBG504³; or permission of instructor.

EBGN590 ECONOMETRICS AND FORECASTING Using statistical techniques to fit economic models to data. Topics include ordinary least squares and single equation regression models; two stage least squares and multiple equation econometric models; specification error, serial correlation, heteroskedasticity; distributive lag; applications to mineral commodity markets; hypothesis testing; forecasting with econometric models, time series analysis, and simulation. Prerequisites: MATH111, MATH530¹, EBG509; or permission of instructor.

EBGN598 SPECIAL TOPICS IN ECONOMICS AND BUSINESS Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Repeatable for credit under different titles.

EBGN599 INDEPENDENT STUDY Individual research or special problem projects supervised by a faculty member when a student and instructor agree on a subject matter, content, and credit hours. Contact the Economics and Business Division office for credit limits toward the degree.

EBGN610 ADVANCED NATURAL RESOURCE ECONOMICS Optimal resource use in a dynamic context using mathematical programming, optimal control theory and game theory. Constrained optimization techniques are used to evaluate the impact of capital constraints, exploration activity and environmental regulations. Offered when student demand is sufficient. Prerequisites: Principles of Microeconomics, MATH111, MATH530¹, EBG509, EBG510, EBG511; or permission of instructor.

EBGN611 ADVANCED MICROECONOMICS A second graduate course in microeconomics, emphasizing state-of-the-art theoretical and mathematical developments. Topics include consumer theory, production theory and the use of game theoretic and dynamic optimization tools. Prerequisites: Principles of Microeconomics, MATH111, MATH530¹, EBG509, EBG511; or permission of instructor.

EBGN655 ADVANCED LINEAR PROGRAMMING As an advanced course in optimization, this course will expand upon topics in linear programming. Specific topics to be covered include advanced formulation, column generation,

interior point method, stochastic optimization, and numerical stability in linear programming. Applications of state-of-the-art hardware and software will emphasize solving real-world problems in areas such as mining, energy, transportation and the military. Prerequisites: EBG555 or permission of instructor.

EBGN657 ADVANCED INTEGER PROGRAMMING As an advanced course in optimization, this course will expand upon topics in integer programming. Specific topics to be covered include advanced formulations, Benders Decomposition, mixed integer programming cuts, constraint programming, rounding heuristics, and persistence. Applications of state-of-the-art hardware and software will emphasize solving real-world problems in areas such as mining, energy, transportation and the military. Prerequisites: EBG557 or permission of instructor.

EBGN690 ADVANCED ECONOMETRICS A second course in econometrics. Compared to EBG590, this course provides a more theoretical and mathematical understanding of econometrics. Matrix algebra is used and model construction and hypothesis testing are emphasized rather than forecasting. Prerequisites: Principles of Microeconomics, MATH111, MATH530¹, EBG509, EBG590; or permission of instructor. Recommended: EBG511.

EBGN695 RESEARCH METHODOLOGY Lectures provide an overview of methods used in economic research relating to EPP and QBA/OR dissertations in Mineral Economics and information on how to carry out research and present research results. Students will be required to write and present a research paper that will be submitted for publication. It is expected that this paper will lead to a Ph.D. dissertation proposal. It is a good idea for students to start thinking about potential dissertation topic areas as they study for their qualifier. This course is also recommended for students writing Master's thesis or who want guidance in doing independent research relating to the economics and business aspects of energy, minerals and related environmental and technological topics. Prerequisites: MATH530¹, EBG509, EBG510, EBG511, EBG590 or permission of instructor.

EBGN698 SPECIAL TOPICS IN ECONOMICS AND BUSINESS Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Repeatable for credit under different titles.

EBGN699 INDEPENDENT STUDY Individual research or special problem projects supervised by a faculty member when a student and instructor agree on a subject matter, content, and credit hours. Contact the Economics and Business Division office for credit limits toward the degree.

EBGN705. GRADUATE RESEARCH: MASTER OF SCIENCE Research credit hours required for completion of the Master of Science with Thesis degree. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

EBGN706. GRADUATE RESEARCH: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the Doctor of Philosophy degree. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

Notes

¹ MATH323 may be substituted for MATH530.

² EBG305 and EBG306 together may be substituted for EBG505 with permission.

³ EBG321 may be substituted for EBG504.

Engineering

KEVIN L. MOORE, Gerard August Dobelman Distinguished Professor and Interim Division Director

MARTE S. GUTIERREZ, James R. Paden Chair Distinguished Professor

ROBERT J. KEE, George R. Brown Distinguished Professor

D. VAUGHAN GRIFFITHS, Professor

ROBERT H. KING, Professor

NING LU, Professor

NIGEL T. MIDDLETON, Senior Vice President for Strategic Enterprises, Professor

MICHAEL MOONEY, Professor

GRAHAM G. W. MUSTOE, Professor

PANKAJ K. (PK) SEN, Professor

JOEL M. BACH, Associate Professor

JOHN R. BERGER, Associate Professor

CRISTIAN V. CIOBANU, Associate Professor

WILLIAM A. HOFF, Associate Professor

PANOS D. KIOUSIS, Associate Professor

MARCELO GODOY SIMOES, Associate Professor

JOHN P. H. STEELE, Associate Professor

NEAL SULLIVAN, Associate Professor

TYRONE VINCENT, Associate Professor

RAY RUICHONG ZHANG, Associate Professor

GREGORY BOGIN, Assistant Professor

ROBERT J. BRAUN, Assistant Professor

KATHRYN JOHNSON, Clare Boothe Luce Assistant Professor

SALMAN MOHAGHEGHI, Assistant Professor

ANTHONY J. PETRELLA, Assistant Professor

JASON PORTER, Assistant Professor

ANNE SILVERMAN, Assistant Professor

CAMERON TURNER, Assistant Professor

MICHAEL WAKIN, Assistant Professor

JUDITH WANG, Assistant Professor

RAVEL F. AMMERMAN, Teaching Professor

JOSEPH P. CROCKER, Teaching Professor

RICHARD PASSAMANECK, Teaching Professor

VIBHUTI DAVE, Teaching Associate Professor

EDWARD RIEDEL, Teaching Associate Professor

JEFFREY SCHOWALTER, Teaching Associate Professor

CANDACE S. SULZBACH, Teaching Associate Professor

ALEXANDRA WAYLLACE, Teaching Associate Professor

JINSONG HUANG, Research Associate Professor

HUAYANG ZHU, Research Associate Professor

CHRISTOPHER B. DRYER, Research Assistant Professor

JOAN P. GOSINK, Emerita Professor

MICHAEL B. McGRATH, Emeritus Professor

DAVID MUNOZ, Emeritus Associate Professor

KARL R. NELSON, Emeritus Associate Professor

GABRIEL M. NEUNZERT, Emeritus Associate Professor

CATHERINE K. SKOKAN, Emerita Associate Professor

Note: Faculty for the environmental engineering specialty are listed in the Environmental Science and Engineering section of this Bulletin.

Degrees Offered:

Master of Science (Engineering)

Doctor of Philosophy (Engineering)

Program Overview:

The Engineering Division offers engineering graduate degrees with an option to specialize in one of the three disciplines—Civil, Electrical or Mechanical Engineering. Students may also choose a more interdisciplinary degree with a specialty title "Engineering Systems." The program demands academic rigor and depth yet also addresses real-world engineering problems. The Division of Engineering has eight areas of research activity that stem from the core fields of Civil, Electrical, and Mechanical Engineering; these areas are: (1) Geotechnical Engineering and (2) Structural Engineering, which are strongly aligned with the Civil Engineering Specialty. (3) Energy Systems and Power Electronics, and (4) Information and Systems Sciences, which are strongly aligned with the Electrical Engineering Discipline. (5) Bioengineering, (6) Energy Conversion Systems and Thermal Sciences, and (7) Material Mechanics, which are aligned with the Mechanical Engineering specialty. Finally, (8) Robotics includes elements from both the Electrical and Mechanical disciplines. Note that in many cases, individual research projects encompass more than one research area.

Geotechnical Engineering has current activity in computational and analytical geomechanics, probabilistic geotechnics, experimental and theoretical investigations into coupled flows and unsaturated soil behavior, and intelligent geo-systems including geo-construction sensing and automation. The geotechnical faculty and students work primarily within the Civil Specialty of the Engineering graduate programs, however strong interdisciplinary ties are maintained with other groups in Engineering and with other Departments at CSM.

Structural Engineering focuses on frontier, multidisciplinary research in the following areas: high strength and self-consolidating concrete, experimental and computational structural dynamics, vibration control, damage diagnosis, and advanced data processing and analysis for sensory systems, disaster assessment and mitigation, and structural nondestructive evaluation.

Energy Systems and Power Electronics is focused on both fundamental and applied research in the interrelated fields of conventional electric power systems and electric machinery, renewable energy and distributed generation, energy economics and policy issues, power quality, power electronics and drives. The overall scope of research encompasses a broad spectrum of electrical energy applications including investor-owned utilities, rural electric associations, manufacturing facilities, regulatory agencies, and consulting engineering firms.

Information and Systems Sciences Group is an interdisciplinary research area that encompasses the fields of control systems, communications, signal and image processing, compressive sensing, robotics, and mechatronics. Focus areas include intelligent and learning control systems, fault detection and system identification, computer vision and pattern recog-

nition, sensor development, mobile manipulation and autonomous systems. Applications can be found in renewable energy and power systems, materials processing, sensor and control networks, bio-engineering, intelligent structures, and geosystems.

BioEngineering focuses on the application of engineering principles to the musculoskeletal system and other connective tissues. Research activities include experimental, computational, and theoretical approaches with applications in the areas of computer assisted surgery and medical robotics, medical imaging, patient specific biomechanical modeling, intelligent prosthetics and implants, bioinstrumentation, and supermolecular biomaterials. The Bioengineering group has strong research ties with other campus departments, the local medical community, and industry partners.

Energy Conversion Systems and Thermal Sciences is a research area with a wide array of multidisciplinary applications including clean energy systems, materials processing, combustion, and biofuels and renewable energy. Graduate students in this area typically specialize in Mechanical Engineering but also have the opportunity to specialize in interdisciplinary programs such as Materials Science.

Material Mechanics investigations consider solid-state material behavior as it relates to microstructural evolution and control, nano-mechanics, functionally graded materials, biomaterial analysis and characterization, artificial biomaterial design, and fracture mechanics. Research in this area tends to have a strong computational physics component covering a broad range of length and time scales that embrace ab initio calculations, molecular dynamics, Monte Carlo and continuum modeling. These tools are used to study metallic and ceramic systems as well as natural biomaterials. Strong ties exist between this group and activities within the campus communities of physics, materials science, mathematics and chemical engineering.

Robotics is an emerging area at CSM that merges research in mechanical design, control systems, sensing, and mechatronics to develop automated and autonomous systems that can be used to carry out tasks that are dirty, dangerous, dull, or difficult.

Program Details

The M.S. Engineering degree (Thesis or Non-Thesis Option) requires 30 credit hours. Requirements for the thesis M.S. are 24 hours of coursework and 6 hours of thesis research. The non-thesis option requires 30 hours of coursework. For the M.S. degree, a maximum of 9 credits can be transferred in from another institution (note that these courses must not have been used to satisfy the requirements for an undergraduate degree). Graduate level courses taken at other universities for which a grade equivalent to a "B" or better was received will be considered for transfer credit via a petition to the Division Director.

The Division of Engineering also offers five year combined BS/MS degree programs. These programs offer an expedited graduate school application process and allow students to begin graduate coursework while still finishing their undergraduate degree requirements. This program is described in the undergraduate catalog and is in place for Engineering students. In addition, the five year program is offered in collaboration with the Departments of Physics and Chemistry and allows students to obtain specific engineering skills that complement their physics or chemistry background. The Physics five-year program offers tracks in Electrical Engineering and Mechanical Engineering. Details on these five-year programs can be found in the CSM Undergraduate Bulletin. Course schedules for these five-year programs can be obtained in the Engineering, Physics and Chemistry Departmental Offices.

The Ph.D. Engineering degree requires 72 credit hours of course work and research credits. Graduate level courses taken at other universities for which a grade equivalent to a "B" or better was received will be considered for transfer credit via a petition to the Division Director (note that these courses must not have been used to satisfy the requirements for an undergraduate degree).

Students must have an advisor from the Engineering Division Graduate Faculty to direct and monitor their academic plan, research and independent studies. Master of Science (thesis option) students must have at least three members on their graduate committee, two of whom must be permanent faculty in the Engineering Division. Ph.D. graduate committees must have at least five members; at least three members must be permanent faculty in the Engineering Division, and at least one member must be from the department in which the student is pursuing a minor program, if applicable.

Ph.D. Qualifying Exam. Students wishing to enroll in the Engineering PhD program will be required to pass a Qualifying Exam. Normally, full-time PhD candidates will take the Qualifying Exam in their first year, but it must be taken within three semesters of entering the program. Part-time candidates will normally be expected to take the Qualifying Exam within no more than six semesters of entering the program.

The purpose of the Qualifying Exam is to assess some of the attributes expected of a successful PhD student. Each specialty area (Civil, Electrical, Mechanical and Engineering Systems) will administer their own PhD Qualifying Exams; however, the agreed objectives are to assess the students in the following three categories.

- To determine the student's ability to review, synthesize and apply fundamental concepts.
- To determine the creative and technical potential of the student to solve open-ended and challenging problems.
- To determine the student's technical communication skills.

Ph.D. Qualifying exams will typically be held in each regular semester to accommodate graduate students admitted in either the Fall or Spring. In the event of a student failing the Qualifying exam, she/he will be given one further opportunity to pass the exam in the following semester. A second failure of the Qualifying Exam in a given specialty would lead to removal of the student from the Ph.D. program.

After passing the Qualifying Examination, the Ph.D. student is allowed up to 18 months to prepare a written Thesis Proposal and present it formally to the graduate committee and other interested faculty.

Admission to Candidacy. Full-time students must complete the following requirements within two calendar years of enrolling in the Ph.D. program.

- Have a Thesis Committee appointment form on file in the Graduate Office:
- Have passed the Ph.D. Qualifying Exam demonstrating adequate preparation for, and satisfactory ability to conduct doctoral research.

Upon completion of these requirements, students must complete an Admission to Candidacy form. This form must be signed by the Thesis Committee and the Division Director and filed with the Graduate Office.

At the conclusion of the M.S. (Thesis Option) and Ph.D. programs, the student will be required to make a formal presentation and defense of her/his thesis research.

Prerequisites

The minimum requirements for admission for the M.S., and Ph.D. degrees in Engineering are a baccalaureate degree in engineering, computer science, a physical science, or math with a grade-point average of 3.0 or better on a 4.0 scale; Graduate Record Examination score of 650 (math) and a TOEFL score of 550 or higher (paper based), 213 (computer based), or 79 (internet based) for applicants whose native language is not English. Applicants from an engineering program at CSM are not required to submit GRE scores.

The Engineering Graduate committee evaluating an applicant may require that the student take undergraduate remedial coursework to overcome technical deficiencies, which does not count toward the graduate program. The committee will decide whether to recommend to the Dean of Graduate Studies and Research regular or provisional admission, and may ask the applicant to come for an interview.

As stipulated by the CSM Graduate School, no more than 9 400-level credits of course work may be counted towards any graduate degree. In general, the student cannot use 400 level course credits that have been previously used to obtain the Bachelor of Science degree. This requirement must be taken into account as students choose courses for each degree program detailed below. For all of the Engineering Degrees, a maximum of 6 Independent Study course units, as appropriate

to the degree structure, can be used to fulfill degree requirements.

Civil Engineering Specialty (EGGN-CE)

There are two main emphasis areas within the Civil Engineering specialty in: (1) Geotechnical engineering, and (2) Structural engineering. However thesis research activities will regularly overlap with the other emphasis areas within the Division as listed in the Program Description above. The intent is to offer a highly flexible curriculum that will be attractive to candidates seeking Civil Engineering careers in either industry or academe. In addition to the Civil Engineering courses offered within the Engineering Division, technical electives will be available from other CSM departments such as Environmental Science and Engineering, Geological Engineering and Mining, as well as Electrical and Mechanical courses from within the Engineering Division.

M.S. Degree (EGGN-CE)

Must take at least three courses from the list of Engineering (Civil Specialty) Courses.	9 cr
EGGN504 Engineering (Civil) Seminar	1 cr
Technical Electives (Thesis option: Courses must be approved by the Thesis Committee)	14 cr
(Non-Thesis option: Courses must be approved by the Faculty Advisor)	20 cr
Non-thesis students may include up to 6 cr hours of Independent Study (EGGN 599)	
Thesis Research (Thesis Option)	6 cr
Total	30 cr

Ph.D. Degree (EGGN-CE)

Must take at least three courses from the list of Civil Engineering Courses	9 cr
EGGN504 Engineering Systems (Civil) Seminar	1 cr
Technical Electives Approved by the graduate committee	38 cr
Thesis Research	24 cr
Total	72 cr

Ph.D. Qualifying Exam (Civil Specialty)

Engineering (Civil Specialty) students wishing to enroll in the PhD program will be required to pass a Qualifying Exam. Normally, full time PhD. students will take the Qualifying Exam in their first year, but it must be taken within three semesters of entering the program.

The exam will have two parts:

1. The Advisor will coordinate with the Civil faculty to generate a written take-home exam based on materials covered in the student's area of interest. This will typically involve two questions, and may cover material from the Engineering (Civil Specialty) core courses.

2. A written report (approx 10 pages) and oral presentation based on a topic that will be chosen by the graduate student's committee. The report will typically be a review paper on a research theme that will be related to the student's area of interest and likely thesis topic. The purpose of this requirement, is to examine some of the attributes expected of a successful PhD candidate. These include, but are not restricted to:

- ◆ The ability to perform a literature review through libraries and internet sites;
- ◆ The ability to distill information into a written report;
- ◆ The ability to produce a high quality written and oral presentation.

The research theme for the written report will be provided at the same time as the questions in part one above. All written material will be due one week later. As early as possible after that time, a one hour meeting will be scheduled for the student to make his/her oral presentation. After the oral presentation, the student will be questioned on the presentation and on any other issues relating to the written report and take home examination.

Electrical Engineering Specialty (EGGN-EE)

Within the Electrical Engineering specialty, there are two emphasis areas: (1) Information and Systems Sciences, and (2) Energy Systems and Power Electronics. Students are encouraged to decide between emphasis areas before pursuing an advanced degree. Students are also encouraged to speak to members of the EE graduate faculty before registering for classes and to select an academic advisor as soon as possible.

M.S. Degree (EGGN-EE)

Select from the list of core Electrical Engineering Courses within one track	12 cr
EGGN504 Engineering (Electrical) Seminar	1 cr
Technical Electives (approved by thesis committee or advisor for non-thesis option)	11 cr
EGGN705 Graduate Research Credit: Master of Science (thesis students)	
Or	
Electrical Engineering Electives (taught by an approved professor in one of the EE specialty tracks)	6 cr
Total	30 cr

Ph.D. Degree (EGGN-EE)

Select from the list of core Electrical Engineering Courses within one track	12 cr
EGGN504 Engineering (Electrical) Seminar	1 cr
Technical Electives (approved by thesis committee)	35 cr
EGGN706 Graduate Research Credit: Doctor of Philosophy	24 cr
Total	72 cr

Ph.D. Qualifying Exam (Electrical Specialty)

Doctoral students must pass a Qualifying Examination, which is intended to gauge the student's capability to pursue research in the Electrical Engineering specialty. The Qualifying Examination includes both written and oral sections. The written section is based on material from the Division's undergraduate Engineering degree with Electrical Specialty. The oral part of the exam covers either two of the track courses (of the student's choice) in the Electrical Specialty, or a paper from the literature chosen by the student and the student's advisor. The student's advisor and two additional Electrical Specialty faculty members (typically from the student's thesis committee representing their track) administer the oral exam.

Normally, full time Ph.D. students will take both parts of the Qualifying Examination in their first year, but they must both be taken within three semesters of entering the graduate program.

Mechanical Engineering Specialty (EGGN-ME)

Within the Mechanical Engineering specialty, there are three emphasis areas: (1) Material Mechanics, (2) Energy Conversion Systems and Thermal Sciences, and (3) Bioengineering. Within the material mechanics emphasis area, materials processing, materials simulation and process control are investigated from perspectives ranging from fundamental physical underpinnings to industrial application. Within the thermal sciences emphasis area, the focus is upon energy conversion devices as framed by traditional subjects such as fluid mechanics, heat transfer, and combustion. Within the Bioengineering emphasis area, coursework and research projects focus on the musculoskeletal system and other corrective tissues. Students within all emphasis areas are required to complete a set of core classes intended to prepare them for both theoretical and experimental aspects of research in mechanical engineering. The program has strong ties to the chemical engineering, materials science and physics communities, and students will typically take courses in one or more of these areas after completing the core class requirements.

M.S. Degree (EGGN-ME)

<i>Required Core:</i>	
EGGN501 Advanced Engineering Measurements	4 cr
EGGN502 Advanced Engineering Analysis	4 cr
EGGN504 Engineering Systems (Mechanical) Seminar	1 cr
From the list of Mechanical Engineering Courses (Thesis Option: Courses must be approved by the thesis committee)	9 cr
<i>or</i>	
(Non-Thesis Option: Courses must be approved by the faculty advisor)	15 cr
Thesis Research (Thesis option)	6 cr
Technical Electives (thesis option: approved by thesis committee; non-thesis option: approved by faculty advisor)	6 cr
Total	30 cr

Ph.D. Degree (EGGN-ME)*Required Core:*

EGGN501 Advanced Engineering Measurements	4 cr
EGGN502 Advanced Engineering Analysis	4 cr
EGGN504 Engineering (Mechanical) Seminar	1 cr
From the list of Mechanical Engineering Courses	18 cr
Thesis Research	24 cr
Technical Electives (must be approved by the thesis committee)	21 cr
<i>Total</i>	72 cr

Ph.D. Qualifying Exam (Mechanical Specialty)

Doctoral students must pass a Qualifying Examination, which is intended to gauge the academic qualifications of the candidate for conducting dissertation research in Mechanical Engineering. The qualifying examination is based on one of three concentration areas (thermo-fluids, mechanics of materials, and biomechanics) and includes both a written and oral examination. This examination is comprehensive in nature and is designed to address material from both the student's undergraduate and initial graduate course work. The student is expected to demonstrate adequate breadth and depth of knowledge as well as an ability to analyze and address new problems related to the concentration area.

Engineering Systems Specialty (EGGN)

Graduate students who choose an interdisciplinary education in Engineering Systems may do so using the curriculum below.

M.S. Degree (EGGN)*Required Core:*

EGGN501 Advanced Engineering Measurements	4 cr
EGGN502 Advanced Engineering Analysis	4 cr
EGGN504 Engineering Systems (Any Specialty) Seminar	1 cr
Technical Electives (Thesis Option: Courses must be approved by the graduate thesis committee)	15 cr
(Non-Thesis Option: Courses must be approved by the faculty advisor)	21 cr
Thesis Research (Thesis Option)	6 cr
<i>Total</i>	30 cr

Ph.D. Degree (EGGN)*Required Core:*

EGGN501 Advanced Engineering Measurements	4 cr
EGGN502 Advanced Engineering Analysis	4 cr
EGGN504 Engineering Systems (Any Specialty) Seminar	1 cr
Technical Electives (must be approved by the graduate thesis committee)	39 cr
Thesis Research	24 cr
<i>Total</i>	72 cr

Courses Offered Under Each Of The Engineering Specialties:**Engineering (Civil Specialty)**

EGGN501 Advanced Engineering Measurements	4 cr
EGGN502 Advanced Engineering Analysis	4 cr
EGGN531 Soil Dynamics	3 cr
EGGN533 Unsaturated Soil Mechanics	3 cr
EGGN534 Soil Behavior	3 cr
EGGN541 Advanced Structural Theory	3 cr
EGGN542 Finite Element Methods for Engineers	3 cr
EGGN546 Advanced Engineering Vibration	3 cr
EGGN547 Timber and Masonry Design	3 cr
EGGN548 Advanced Soil Mechanics	3 cr
EGGN549 Advanced Design of Steel Structures	3 cr
EGGN556 Design of Reinf. Concrete Structures II	3 cr
EGGN557 Structural Dynamics	3 cr
EGGN560 Numerical Methods for Engineers	3 cr

Engineering (Electrical Specialty)**Required Core: Energy Systems and Power Electronics Track**

EGGN580 Power Quality	3 cr
EGGN582 Renewable Energy and Distributed Generation	3 cr
EGGN583 Advanced Electrical Machine Dynamics	3 cr
EGGN584 Power Distribution Systems Engineering	3 cr
EGGN545 Advanced High Power Electronics	3 cr
EGGN586 High Voltage AC and DC Transmission	3 cr
EGGN587 Power System Operations and Management	3 cr

Required Core: Information and Systems Sciences

EGGN510 Image and Multidimensional Signal Processing	3 cr
EGGN511 Sparse Signal Processing	3 cr
EGGN515 Mathematical Methods for Signals and Systems	3 cr
EGGN517 Advanced Control Theory and Design	3 cr
EGGN518 Robot Mechanics and Control	3 cr

Other EE Courses:

EGGN512 Computer Vision	3 cr
EGGN513 Wireless Systems Design	3 cr
EGGN514 Advanced Robot Control	3 cr
EGGN516 RF and Microwave Engineering	3 cr
EGGN519 Estimation Theory and Kalman Filtering	3 cr
EGGN521 Mechatronics	3 cr
EGGN581 Modern Adjustable Speed Electric Drives	3 cr
EGGN589 Design and Control of Wind Energy Systems	3 cr
EGGN617 Intelligent Control Systems	3 cr
EGGN618 Nonlinear Adaptive Control	3 cr
EGGN683 Computer Methods in Electric Power Systems	3 cr

Engineering (Mechanical Specialty)		EGGN542	Finite Element Methods for Engineers	3 cr	
EGGN503	Modern Engineering Design and Project Management	3 cr	EGGN545	Boundary Element Analysis	3 cr
EGGN514	Advanced Robot Control	4 cr	EGGN546	Advanced Engineering Vibration	3 cr
EGGN515	Mathematical Methods for Signals and Systems	3 cr	EGGN552	Viscous Flow and Boundary Layers	3 cr
EGGN517	Theory and Design of Advanced Control Systems	3 cr	EGGN560	Numerical Methods for Engineers	3 cr
EGGN518	Robot Mechanics: Kinematics, Dynamics and Control	3 cr	EGGN566	Combustion	3 cr
EGGN521	Mechatronics	3 cr	EGGN569	Fuel Cell Science And Technology	3 cr
EGGN525	Musculoskeletal Biomechanics	3 cr	EGGN573	Introduction to Computational Techniques for Fluid Dynamics and Transport Phenomena	3 cr
EGGN527	Prosthetic and Implant Engineering	3 cr	EGGN593	Engineering Design Optimization	3 cr
EGGN528	Computational Biomechanics	3 cr	EGGN617	Intelligent Control	3 cr
EGGN530	Biomedical Instrumentation	3 cr	EGGN619	Intelligent Structures	3 cr
EGGN532	Fatigue and Fracture	3 cr	Any graduate level course taught by a member of the CSM Mechanical Engineering faculty is also a member of the list of acceptable Mechanical Engineering Courses.		
EGGN535	Introduction to Discrete Element Methods	3 cr			

Table 1. Summary of courses required for the Master of Science Degree In Engineering Systems

Master of Science, Engineering				
	Engineering Systems	Civil	Electrical	Mechanical
Core	EGGN 501, 502, 504 9 cr	EGGN 504 and choose from list 10 cr	EGGN 504 and 4 courses from one of two track areas. 13 cr	EGGN 501, 502, 504 9 cr
Technical Electives and Other Courses with Advisor Approval	Choose 15 cr (thesis), 21 cr (non-thesis)	Choose 14 cr (thesis), 20 cr (non-thesis) from list and/or other technical courses	Choose 11 cr technical electives (thesis) additional 6 credits EE electives for non-thesis	Choose 9 cr (thesis) or 15 cr (non-thesis) from list plus 6 cr of other technical courses
Thesis Research (thesis only)	6 cr	6 cr	6 cr	6 cr

Table 2. Summary of courses required for the Ph.D. Degree In Engineering

Doctor of Philosophy, Engineering				
	Engineering Systems	Civil	Electrical	Mechanical
Core	EGGN 501, 502, 504 9 cr	EGGN 504 and choose from list 10 cr	EGGN 504 and 4 courses from one of two track areas. 13 cr	EGGN 501, 502, 504 9 cr
Minor	12 cr	12 cr	12 cr	12 cr
Technical Electives and Other Courses with Advisor Approval	27 cr	26 cr from list and/or other technical courses	Choose 23 cr technical electives	Choose 18 cr from list plus 9 cr of other technical courses
Thesis Research (thesis only)	24 cr	24 cr	24 cr	24 cr

Description of Courses

EGGN400/MNGN400. INTRODUCTION TO ROBOTICS (I, II) Overview and introduction to the science and engineering of intelligent mobile robotics and robotic manipulators. Covers guidance and force sensing, perception of the environment around a mobile vehicle, reasoning about the environment to identify obstacles and guidance path features and adaptively controlling and monitoring the vehicle health. A lesser emphasis is placed on robot manipulator kinematics, dynamics, and force and tactile sensing. Surveys manipulator and intelligent mobile robotics research and development. Introduces principles and concepts of guidance, position, and force sensing; vision data processing; basic path and trajectory planning algorithms; and force and position control. Prerequisite: CSCI261, EGGN381. 3 hours lecture; 3 semester hours.

EGGN403. THERMODYNAMICS II (I) Thermodynamic relations, Maxwell's Relations, Clapeyron equation, fugacity, mixtures and solutions, thermodynamics of mixing, Gibbs function, activity coefficient, combustion processes, first and second law applied to reacting systems, third law of thermodynamics, real combustion processes, phase and chemical equilibrium, Gibbs rule, equilibrium of multi-component systems, simultaneous chemical reaction of real combustion processes, ionization, application to real industrial problems. Prerequisite: EGGN351, EGGN371. 3 hours lecture; 3 semester hours.

EGGN408. INTRODUCTION TO SPACE EXPLORATION (I) Overview of extraterrestrial applications of science and engineering by covering all facets of human and robotic space exploration, including its history, current status, and future opportunities in the aerospace and planetary science fields. Subtopics include: the space environment, space transportation systems, destinations (Low-Earth orbit, Moon, Mars, asteroids, other planets), current research, missions, and projects, the international and commercial perspectives, and discussion of potential career opportunities. This seminar-style class is taught by CSM faculty, engineers and scientists from space agencies and research organizations, aerospace industry experts, and visionaries and entrepreneurs of the private space commerce sector. Prerequisites: None; 1 hour lecture; 1 semester hour.

EGGN410. MECHANICAL DESIGN USING GD&T (II) The mechanical design process can be broadly grouped into three phases: requirements and concept, design and analysis, details and drawing package. In this class students will learn concepts and techniques for the details and drawing package phase of the design process. The details of a design are critical to the success of a design project. The details include selection and implementation of a variety of mechanical components such as fasteners (threaded, keys, retaining rings), bearing and bushings. Fits and tolerances will also be covered. Statistical tolerance analysis will be used to verify that an assembly will fit together and to optimize the design.

Mechanical drawings have become sophisticated communication tools that are used throughout the processes of design, manufacturing, and inspection. Mechanical drawings are interpreted either by the ANSI or ISO standard which includes Geometric Dimensioning and Tolerancing (GD&T). In this course the student will learn to create mechanical drawings that communicate all of the necessary information to manufacture the part, inspect the part, and allow the parts to be assembled successfully. Prerequisite: EGGN235. 3 hours lecture, 3 semester hours.

EGGN411. MACHINE DESIGN (I, II) Introduction to the principles of mechanical design. Consideration of the behavior of materials under static and cyclic loading; failure considerations. Application of the basic theories of mechanics, kinematics, and mechanics of materials to the design of basic machine elements, such as shafts, keys, and coupling; journal bearings, antifriction bearings, wire rope, gearing; brakes and clutches, welded connections and other fastenings. Prerequisite: EPIC251, EGGN315 or PHGN350, and EGGN320. 3 hours lecture; 3 hours lab; 4 semester hours.

EGGN413. COMPUTER AIDED ENGINEERING (I, II) This course introduces the student to the concept of computer-aided engineering. The major objective is to provide the student with the necessary background to use the computer as a tool for engineering analysis and design. The Finite Element Analysis (FEA) method and associated computational engineering software have become significant tools in engineering analysis and design. This course is directed to learning the concepts of FEA and its application to civil and mechanical engineering analysis and design. Note that critical evaluation of the results of a FEA using classical methods (from statics and mechanics of materials) and engineering judgment is employed throughout the course. Prerequisite: EGGN320. 3 hours lecture; 3 semester hours.

EGGN417. MODERN CONTROL DESIGN (I) Control system design with an emphasis on observer-based methods, from initial open-loop experiments to final implementation. The course begins with an overview of feedback control design technique from the frequency domain perspective, including sensitivity and fundamental limitations. State space realization theory is introduced, and system identification methods for parameter estimation are introduced. Computer-based methods for control system design are presented. Prerequisites: EGGN307. 3 hours lecture, 3 semester hours.

EGGN422. ADVANCED MECHANICS OF MATERIALS (I, II) General theories of stress and strain; stress and strain transformations, principal stresses and strains, octahedral shear stresses, Hooke's law for isotropic material, and failure criteria. Introduction to elasticity and energy methods. Torsion of noncircular and thin-walled members. Unsymmetrical bending and shear-center, curved beams, and beams on elastic foundations. Introduction to plate theory. Thick-walled cylinders and contact stresses. Prerequisite: EGGN320. 3 hours lecture; 3 semester hours.

EGGN425/BELS425. MUSCULOSKELETAL BIOMECHANICS (II) This course is intended to provide engineering students with an introduction to musculoskeletal biomechanics. At the end of the semester, students should have a working knowledge of the special considerations necessary to apply engineering principles to the human body. The course will focus on the biomechanics of injury since understanding injury will require developing an understanding of normal biomechanics. Prerequisite: DCGN421, EGGN320, EGGN325/BELS325, (or instructor permission). 3 hours lecture; 3 semester hours.

EGGN427/BELS427 PROSTHETIC AND IMPLANT ENGINEERING Prosthetics and implants for the musculoskeletal and other systems of the human body are becoming increasingly sophisticated. From simple joint replacements to myoelectric limb replacements and functional electrical stimulation, the engineering opportunities continue to expand. This course builds on musculoskeletal biomechanics and other BELS courses to provide engineering students with an introduction to prosthetics and implants for the musculoskeletal system. At the end of the semester, students should have a working knowledge of the challenges and special considerations necessary to apply engineering principles to augmentation or replacement in the musculoskeletal system. Prerequisites: Musculoskeletal Biomechanics (EGGN/BELS425 or EGGN/BELS525) 3 hours lecture; 3 semester hours. Fall Semester even years.

EGGN428/BELS428 COMPUTATIONAL BIOMECHANICS Computational Biomechanics provides an introduction to the application of computer simulation to solve some fundamental problems in biomechanics and bioengineering. Musculoskeletal mechanics, medical image reconstruction, hard and soft tissue modeling, joint mechanics, and inter-subject variability will be considered. An emphasis will be placed on understanding the limitations of the computer model as a predictive tool and the need for rigorous verification and validation of computational techniques. Clinical application of biomechanical modeling tools is highlighted and impact on patient quality of life is demonstrated. Prerequisites: EGGN413 Computer Aided Engineering, EGGN325/BELS325 Introduction to Biomedical Engineering. 3 hours lecture; 3 semester hours. Fall Semester odd years.

EGGN430/BELS430. BIOMEDICAL INSTRUMENTATION The acquisition, processing, and interpretation of biological signals present many unique challenges to the Biomedical Engineer. This course is intended to provide students with an introduction to, and appreciation for, many of these challenges. At the end of the semester, students should have a working knowledge of the special considerations necessary to gathering and analyzing biological signal data. Prerequisite: EGGN250, DCGN381, EGGN325/BELS325, (or permission of instructor). 3 hours lecture; 3 semester hours. Fall Semester odd years.

EGGN431. SOIL DYNAMICS (II) Soil Dynamics combines engineering vibrations with soil mechanics, analysis, and design. Students will learn to apply basic principles of dynamics towards the analysis and design of civil infrastructure systems when specific issues as raised by the inclusion of soil materials must be considered. Prerequisites: EGGN320, EGGN361, and MATH225. 3 hours lecture; 3 semester hours.

EGGN433. SURVEYING II (I) Engineering projects with local control using levels, theodolites and total stations, including surveying applications of civil engineering work in the "field". Also includes engineering astronomy and computer generated designs; basic road design including centerline staking, horizontal and vertical curves, slope staking and earthwork volume calculations. Use of commercial software for final plan/profile and earthwork involved for the road project data collected in the field. Conceptual and mathematical knowledge of applying GPS data to engineering projects. Some discussion of the principles and equations of projections (Mercator, Lambert, UTM, State Plane, etc.) and their relationship to the databases of coordinates based on (North American Datum) NAD '27, NAD '83 and (High Accuracy Reference Network) HARN. Prerequisite: EGGN234. 2 hours lecture; 8-9 field work days; 3 semester hours.

EGGN435. HIGHWAY AND TRAFFIC ENGINEERING The emphasis of this class is on the multi-disciplinary nature of highway and traffic engineering and its application to the planning and design of transportation facilities. In the course of the class the students will examine design problems that will involve: geometric design, surveying, traffic operations, hydrology, hydraulics, elements of bridge design, statistics, highway safety, transportation planning, engineering ethics, soil mechanics, pavement design, economics, environmental science. 3 credit hours. Taught on demand.

EGGN441. ADVANCED STRUCTURAL ANALYSIS Introduction to advanced structural analysis concepts. Non-prismatic structures. Arches, Suspension and cable-stayed bridges. Structural optimization. Computer Methods. Structures with nonlinear materials. Internal force redistribution for statically indeterminate structures. Graduate credit requires additional homework and projects. Prerequisite: EGGN342. 3 hour lectures, 3 semester hours. Taught on Demand.

EGGN442. FINITE ELEMENT METHODS FOR ENGINEERS (II) A course combining finite element theory with practical programming experience in which the multi-disciplinary nature of the finite element method as a numerical technique for solving differential equations is emphasized. Topics covered include simple "structural" element, solid elasticity, steady state analysis, transient analysis. Students get a copy of all the source code published in the course textbook. Prerequisite: EGGN320. 3 hours lecture; 3 semester hours.

EGGN444. DESIGN OF STEEL STRUCTURES (I, II) To learn application and use the American Institute of Steel Construction (AISC) Steel Construction Manual. Course develops an understanding of the underlying theory for the design specifications. Students learn basic steel structural member design principles to select the shape and size of a structural member. The design and analysis of tension members, compression members, flexural members, and members under combined loading is included, in addition to basic bolted and welded connection design. Prerequisite: EGGN342. 3 hours lecture; 3 semester hours.

EGGN445. DESIGN OF REINFORCED CONCRETE STRUCTURES (I, II) This course provides an introduction to the materials and principles involved in the design of reinforced concrete. It will allow students to develop an understanding of the fundamental behavior of reinforced concrete under compressive, tensile, bending, and shear loadings, and gain a working knowledge of strength design theory and its application to the design of reinforced concrete beams, columns, slabs, and footings. Prerequisite: EGGN342. 3 hours lecture; 3 semester hours.

EGGN447. TIMBER AND MASONRY DESIGN The course develops the theory and design methods required for the use of timber and masonry as structural materials. The design of walls, beams, columns, beam-columns, shear walls, and structural systems are covered for each material. Gravity, wind, snow, and seismic loads are calculated and utilized for design. Prerequisite: EGGN320 or equivalent. 3 hours lecture; 3 semester hours. Spring odd years.

EGGN448. ADVANCED SOIL MECHANICS Advanced soil mechanics theories and concepts as applied to analysis and design in geotechnical engineering. Topics covered will include seepage, consolidation, shear strength and probabilistic methods. The course will have an emphasis on numerical solution techniques to geotechnical problems by finite elements and finite differences. Prerequisite: EGGN361. 3 hour lectures, 3 semester hours. Fall even years.

EGGN450. MULTIDISCIPLINARY ENGINEERING LABORATORY III (I, II) Laboratory experiments integrating electrical circuits, fluid mechanics, stress analysis, and other engineering fundamentals using computer data acquisition and transducers. Students will design experiments to gather data for solving engineering problems. Examples are recommending design improvements to a refrigerator, diagnosing and predicting failures in refrigerators, computer control of a hydraulic fluid power circuit in a fatigue test, analysis of structural failures in an off-road vehicle and redesign, diagnosis and prediction of failures in a motor/generator system. Prerequisites: DCGN381, EGGN250, EGGN352, EGGN350, EGGN351, EGGN320; concurrent enrollment in EGGN407. 3 hours lab; 1 semester hour.

EGGN460. NUMERICAL METHODS FOR ENGINEERS(S) Introduction to the use of numerical methods in the solution of problems encountered in engineering analysis and design, e.g. linear simultaneous equations (e.g. analysis of elastic materials, steady heat flow); roots of nonlinear equations (e.g. vibration problems, open channel flow); eigenvalue problems (e.g. natural frequencies, buckling and elastic stability); curve fitting and differentiation (e.g. interpretation of experimental data, estimation of gradients); integration (e.g. summation of pressure distributions, finite element properties, local averaging); ordinary differential equations (e.g. forced vibrations, beam bending) All course participants will receive source code consisting of a suite of numerical methods programs. Prerequisite: CSCI260 or 261, MATH225, EGGN320. 3 hours lecture; 3 semester hours.

EGGN464. FOUNDATIONS (I, II) Techniques of subsoil investigation, types of foundations and foundation problems, selection of and basis for design of foundation types. Prerequisite: EGGN461. 3 hours lecture; 3 semester hours.

EGGN465. UNSATURATED SOIL MECHANICS The focus of this course is on soil mechanics for unsaturated soils. It provides an introduction to thermodynamic potentials in partially saturated soils, chemical potentials of adsorbed water in partially saturated soils, phase properties and relations, stress state variables, measurements of soil water suction, unsaturated flow laws, measurement of unsaturated permeability, volume change theory, effective stress principle, and measurement of volume changes in partially saturated soils. The course is designed for seniors and graduate students in various branches of engineering and geology that are concerned with unsaturated soil's hydrologic and mechanics behavior. Prerequisites: EGGN461 or consent of instructor. 3 hours lecture; 3 semester hours. Taught on demand.

EGGN469. FUEL CELL SCIENCE AND TECHNOLOGY (I) Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical-thermodynamics and materials-science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. Prerequisites: EGGN371 or ChEN357 or MTGN351, or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN471. HEAT TRANSFER (I, II) Engineering approach to conduction, convection, and radiation, including steady-state conduction, nonsteady-state conduction, internal heat generation conduction in one, two, and three dimensions, and combined conduction and convection. Free and forced convection including laminar and turbulent flow, internal and external flow. Radiation of black and grey surfaces, shape factors and electrical equivalence. Prerequisite: MATH225, EGGN351, EGGN371 or PHGN 341. 3 hours lecture; 3 semester hours.

EGGN473. FLUID MECHANICS II (II) Review of elementary fluid mechanics and engineering, two-dimensional external flows, boundary layers, flow separation; Compressible flow, isentropic flow, normal and oblique shocks, Prandtl-Meyer expansion fans, Fanno and Rayleigh flow; Introduction to flow instabilities (e.g., Kelvin-Helmholtz instability, Raleigh Benard convection). Prerequisite: EGGN351 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN478. ENGINEERING VIBRATIONS (I) Applications of dynamics to design, mechanisms and machine elements. Kinematics and kinetics of planar linkages. Analytical and graphical methods. Four-bar linkage, slider-crank, quick-return mechanisms, cams, and gears. Analysis of nonplanar mechanisms. Static and dynamic balancing of rotating machinery. Free and forced vibrations and vibration isolation. Prerequisite: EGGN315; concurrent enrollment in MATH225. 3 hours lecture; 3 semester hours.

EGGN 481. DIGITAL SIGNAL PROCESSING. (I) This course introduces the mathematical and engineering aspects of digital signal processing (DSP). An emphasis is placed on the various possible representations for discrete-time signals and systems (in the time, z -, and frequency domains) and how those representations can facilitate the identification of signal properties, the design of digital filters, and the sampling of continuous-time signals. Advanced topics include sigma-delta conversion techniques, multi-rate signal processing, and spectral analysis. The course will be useful to all students who are concerned with information bearing signals and signal processing in a wide variety of application settings, including sensing, instrumentation, control, communications, signal interpretation and diagnostics, and imaging. Prerequisite: EGGN388 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN482. MICROCOMPUTER ARCHITECTURE AND INTERFACING (I) Microprocessor and microcontroller architecture focusing on hardware structures and elementary machine and assembly language programming skills essential for use of microprocessors in data acquisition, control and instrumentation systems. Analog and digital signal conditioning, communication, and processing. A/D and D/A converters for microprocessors. RS232 and other communication standards. Laboratory study and evaluation of microcomputer system; design and implementation of interfacing projects. Prerequisite: EGGN384 or consent of instructor. 3 hours lecture; 3 hours lab; 4 semester hours.

EGGN483. ANALOG & DIGITAL COMMUNICATION SYSTEMS (II) Signal classification; Fourier transform; filtering; sampling; signal representation; modulation; demodulation; applications to broadcast, data transmission, and instrumentation. Prerequisite: EGGN388 or consent of department. 3 hours lecture; 3 hours lab; 4 semester hours.

EGGN484. POWER SYSTEMS ANALYSIS (I) 3-phase power systems, per-unit calculations, modeling and equivalent circuits of major components, voltage drop, fault calculations, symmetrical components and unsymmetrical faults, system grounding, power-flow, selection of major equipment, design of electric power distribution systems. Prerequisite: EGGN389. 3 hours lecture; 3 semester hours.

EGGN485. INTRODUCTION TO HIGH POWER ELECTRONICS (II) Power electronics are used in a broad range of applications from control of power flow on major transmission lines to control of motor speeds in industrial facilities and electric vehicles, to computer power supplies. This course introduces the basic principles of analysis and design of circuits utilizing power electronics, including AC/DC, AC/AC, DC/DC, and DC/AC conversions in their many configurations. Prerequisite: EGGN385 and EGGN389. 3 hours lecture; 3 semester hours.

EGGN486. PRACTICAL DESIGN OF SMALL RENEWABLE ENERGY SYSTEMS This course provides the fundamentals to understand and analyze renewable energy powered electric circuits. It covers practical topics related to the design of alternative energy based systems. It is assumed the students will have some basic and broad knowledge of the principles of electrical machines, thermodynamics, electronics, and fundamentals of electric power systems. One of the main objectives of the course is to focus on the interdisciplinary aspects of integration of the alternative sources of energy, including hydropower, wind power, photovoltaic, and energy storage for those systems. Power electronic systems will be discussed and how those electronic systems can be used for stand-alone and grid-connected electrical energy applications. Prerequisite: EGGN382 or consent of instructor. 3 hours lecture; 3 semester hours. Taught on demand.

EGGN487. ANALYSIS AND DESIGN OF ADVANCED ENERGY SYSTEMS (II) Electric power grid or the interconnected power network is one of the most complex systems. Evaluating the system operation and planning for future expansion, reliability and security analysis has become increasingly more complex. The common techniques utilized in the design include commercially available software. The PowerWorld Simulator in one of the most commonly used such software and will be featured in this class. Emphasis will be focused on determining how the power flow within a large system is controlled and understanding the factors that influence voltage regulation and reactive power control. Contingency analysis, evaluating system improvements, and planning for future expansion will also be featured. Short circuit currents resulting from symmetrical and unsymmetrical faults will also be calculated. Prerequisites: EGGN484 and/or consent of instructor. 2 hours lecture; 3 hours laboratory; 3 semester hours.

EGGN490 SUSTAINABLE ENGINEERING DESIGN (I) This course is a comprehensive introduction into concept of sustainability and sustainable development from an engineer-

ing point of view. It involves the integration of engineering and statistical analysis through a Life Cycle Assessment tool, allowing a quantitative, broad-based consideration any process or product design and their respective impacts on environment, human health and the resource base. The requirements for considering social implications are also discussed. Prerequisites: Senior or graduate standing, or consent of instructor.; 3 hours lecture, 3 semester hours.

EGGN491. SENIOR DESIGN I (I, II) (WI) This course is the first of a two-semester capstone course sequence giving the student experience in the engineering design process. Realistic open-ended design problems are addressed for real world clients at the conceptual, engineering analysis, and the synthesis stages and include economic and ethical considerations necessary to arrive at a final design. Students are assigned to interdisciplinary teams and exposed to processes in the areas of design methodology, project management, communications, and work place issues. Strong emphasis is placed on this being a process course versus a project course. This is a writing-across-the-curriculum course where students' written and oral communication skills are strengthened. The design projects are chosen to develop student creativity, use of design methodology and application of prior course work paralleled by individual study and research. Prerequisite: Field session appropriate to the student's specialty and EPIC251. For Mechanical Specialty students, concurrent enrollment or completion of EGGN 411. For Civil Specialty students, concurrent enrollment or completion of any one of EGGN444, EGGN445, EGGN447, or EGGN464. 1-2 hour lecture; 6 hours lab; 3 semester hours.

EGGN492. SENIOR DESIGN II (I, II) This is the second of a two-semester course sequence to give the student experience in the engineering design process. This course will consist of a single comprehensive design project covering the entire semester. Design integrity and performance are to be demonstrated by building a prototype or model and performing pre-planned experimental tests, wherever feasible. Prerequisite: EGGN491. 1 hour lecture; 6 hours lab; 3 semester hours.

EGGN493. ENGINEERING DESIGN OPTIMIZATION The application of gradient, stochastic and heuristic optimization algorithms to linear and nonlinear optimization problems in constrained and unconstrained design spaces. Students will consider problems with continuous, integer and mixed-integer variables, problems with single or multiple objectives and the task modeling design spaces and constraints. Design optimization methods are becoming of increasing importance in engineering design and offer the potential to reduce design cycle times while improving design quality by leveraging simulation and historical design data. Prerequisites: MATH213 and MATH225 (Required), CSCI260 or CSCI261 or other experience with computer programming languages (Suggested). 3 hours lecture; 3 semester hours. Spring even years.

EGGN497. SUMMER PROGRAMS

EGGN498. SPECIAL TOPICS IN ENGINEERING (I, II) Pilot course or special topics course. Topics chosen from special interest of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

EGGN499. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit under different topics/experiences.

Graduate Courses

500-level courses are open to qualified seniors with the permission of the department and Dean of the Graduate School.

EGGN501. ADVANCED ENGINEERING MEASUREMENTS (I) Introduction to the fundamentals of measurements within the context of engineering systems. Topics that are covered include: errors and error analysis, modeling of measurement systems, basic electronics, noise and noise reduction, and data acquisition systems. Prerequisite: EGGN250, DCGN381 or equivalent, and MATH323 or equivalent; graduate student status or consent of the instructor. 3 hours lecture, 1 hour lab; 4 semester hours.

EGGN502. ADVANCED ENGINEERING ANALYSIS (I) Introduce advanced mathematical and numerical methods used to solve engineering problems. Analytic methods include series solutions, special functions, Sturm-Liouville theory, separation of variables, and integral transforms. Numerical methods for initial and boundary value problems include boundary, domain, and mixed methods, finite difference approaches for elliptic, parabolic, and hyperbolic equations, Crank-Nicolson methods, and strategies for nonlinear problems. The approaches are applied to solve typical engineering problems. Prerequisite: This is an introductory graduate class. The student must have a solid understanding of linear algebra, calculus, ordinary differential equations, and Fourier theory. 3 hours lecture; 1 hour lab.

EGGN503. ADVANCED ENGINEERING DESIGN METHODS (I) Introduction to contemporary and advanced methods used in engineering design. Includes, need and problem identification, methods to understand the customer, the market and the competition. Techniques to decompose design problems to identify functions. Ideation methods to produce form from function. Design for X topics. Methods for prototyping, modeling, testing and evaluation of designs. Embodiment and detailed design processes. Prerequisites: EGGN491 and EGGN492, equivalent senior design project experience or industrial design experience, graduate standing or consent of the Instructor. 3 hours lecture; 3 semester hours. Taught on demand.

EGGN504. ENGINEERING SYSTEMS SEMINAR (I, II)
This is a seminar forum for graduate students to present their research projects, critique others' presentations, understand the breadth of engineering projects both within their specialty area and across the Division, hear from leaders of industry about contemporary engineering as well as socio-economical and marketing issues facing today's competitive global environment. In order to improve communication skills, each student is required to present a seminar in this course before his/her graduation from the Engineering graduate program. Prerequisite: Graduate standing. 1 hour seminar, 1 semester hour. Repeatable; maximum 1 hour granted toward degree requirements.

EGGN510. IMAGE AND MULTIDIMENSIONAL SIGNAL PROCESSING (I) This course provides the student with the theoretical background to allow them to apply state of the art image and multi-dimensional signal processing techniques. The course teaches students to solve practical problems involving the processing of multidimensional data such as imagery, video sequences, and volumetric data. The types of problems students are expected to solve are automated mensuration from multi-dimensional data, and the restoration, reconstruction, or compression of multidimensional data. The tools used in solving these problems include a variety of feature extraction methods, filtering techniques, segmentation techniques, and transform methods. Students will use the techniques covered in this course to solve practical problems in projects. Prerequisite: EGGN388 or equivalent. 3 hours lecture; 3 semester hours.

EGGN511. SPARSE SIGNAL PROCESSING (II) This course presents a mathematical tour of sparse signal representations and their applications in modern signal processing. The classical Fourier transform and traditional digital signal processing techniques are extended to enable various types of computational harmonic analysis. Topics covered include time-frequency and wavelet analysis, filter banks, nonlinear approximation of functions, compression, signal restoration, and compressive sensing. Prerequisites: EGGN481 and EGGN515, or consent of the instructor. 3 hours lecture; 3 semester hours.

EGGN512. COMPUTER VISION (II) Computer vision is the process of using computers to acquire images, transform images, and extract symbolic descriptions from images. This course concentrates on how to recover the structure and properties of a possibly dynamic three-dimensional world from its two-dimensional images. We start with an overview of image formation and low level image processing, including feature extraction techniques. We then go into detail on the theory and techniques for estimating shape, location, motion, and recognizing objects. Applications and case studies will be discussed from areas such as scientific image analysis, robotics, machine vision inspection systems, photogrammetry, multimedia, and human interfaces (such as face and gesture recognition). Design ability and hands-on projects will be emphasized, using image processing software and

hardware systems. Prerequisite: Linear algebra, Fourier transforms, knowledge of C programming language. 3 hours lecture; 3 semester hours.

EGGN513. WIRELESS COMMUNICATION SYSTEMS
This course explores aspects of electromagnetics, stochastic modeling, signal processing, and RF/microwave components as applied to the design of wireless systems. In particular, topics on (a) physical and statistical models to represent the wireless channel, (b) advanced digital modulation techniques, (c) temporal, spectral, code-division and spatial multiple access techniques, (d) space diversity techniques and (d) the effects of RF/microwave components on wireless systems will be discussed. Pre-requisite: EGGN 386, EGGN 483, and consent of instructor. 3 hours lecture; 3 semester hours. Taught on demand.

EGGN514/MNGN514. ADVANCED ROBOT CONTROL
The focus is on mobile robotic vehicles. Topics covered are: navigation, mining applications, sensors, including vision, problems of sensing variations in rock properties, problems of representing human knowledge in control systems, machine condition diagnostics, kinematics, and path planning real time obstacle avoidance. Prerequisite: EGGN307 or consent of instructor. 3 hours lecture; 3 hours lab; 4 semester hours. Spring semester of odd years.

EGGN515. MATHEMATICAL METHODS FOR SIGNALS AND SYSTEMS (I) An introduction to mathematical methods for modern signal processing using vector space methods. Topics include signal representation in Hilbert and Banach spaces; linear operators and the geometry of linear equations; LU, Cholesky, QR, eigen- and singular value decompositions. Applications to signal processing and linear systems are included throughout, such as Fourier analysis, wavelets, adaptive filtering, signal detection, and feedback control.

EGGN516. RF AND MICROWAVE ENGINEERING This course teaches the basics of RF/microwave design including circuit concepts, modeling techniques, and test and measurement techniques, as applied to wireless communication systems. RF/microwave concepts that will be discussed are: scattering parameters, impedance matching, microstrip and coplanar transmission lines, power dividers and couplers, filters, amplifiers, oscillators, and diode mixers and detectors. Students will learn how to design and model RF/microwave components such as impedance matching networks, amplifiers and oscillators on Ansoft Designer software, and will build and measure these circuits in the laboratory. Prerequisites: EGGN385, EGGN386, EGGN483, and consent of instructor. 3 hours lecture, 3 semester hours. Taught on demand.

EGGN517. THEORY AND DESIGN OF ADVANCED CONTROL SYSTEMS (II) This course will introduce and study the theory and design of multivariable and nonlinear control systems. Students will learn to design multivariable

controllers that are both optimal and robust, using tools such as state space and transfer matrix models, nonlinear analysis, optimal estimator and controller design, and multi-loop controller synthesis Prerequisite: EGGN417 or consent of instructor. 3 hours lecture; 3 semester hours. Spring semester.

EGGN518. ROBOT MECHANICS: KINEMATICS, DYNAMICS, AND CONTROL (I) Mathematical representation of robot structures. Mechanical analysis including kinematics, dynamics, and design of robot manipulators. Representations for trajectories and path planning for robots. Fundamentals of robot control including, linear, nonlinear and force control methods. Introduction to off-line programming techniques and simulation. Prerequisite: EGGN307, EGGN400 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN519. ESTIMATION THEORY AND KALMAN FILTERING Estimation theory considers the extraction of useful information from raw sensor measurements in the presence of signal uncertainty. Common applications include navigation, localization and mapping, but applications can be found in all fields where measurements are used. Mathematic descriptions of random signals and the response of linear systems are presented. The discrete-time Kalman Filter is introduced, and conditions for optimality are described. Implementation issues, performance prediction, and filter divergence are discussed. Adaptive estimation and nonlinear estimation are also covered. Contemporary applications will be utilized throughout the course. Pre-requisite: EGGN 515 and MATH 534 or equivalent. Spring semester of odd years.

EGGN521. MECHATRONICS Fundamental design of electromechanical systems with embedded microcomputers and intelligence. Design of microprocessor based systems and their interfaces. Fundamental design of machines with active sensing and adaptive response. Microcontrollers and integration of micro-sensors and micro-actuators in the design of electromechanical systems. Introduction to algorithms for information processing appropriate for embedded systems. Smart materials and their use as actuators. Students will do projects involving the design and implementation of smart-systems. Prerequisite: DCGN 381 and EGGN482 recommended. 3 hours lecture; 3 semester hours. Spring semester of even years.

EGGN525/BELS525. MUSCULOSKELETAL BIOMECHANICS (II) This course is intended to provide graduate engineering students with an introduction to musculoskeletal biomechanics. At the end of the semester, students should have a working knowledge of the special considerations necessary to apply engineering principles to the human body. The course will focus on the biomechanics of injury since understanding injury will require developing an understanding of normal biomechanics. Prerequisites: DCGN421 Statics, EGGN320 Mechanics of Materials, EGGN325/BELS325

Introduction to Biomedical Engineering (or instructor permission). 3 hours lecture; 3 semester hours.

EGGN527/BELS527. PROSTHETIC AND IMPLANT ENGINEERING Prosthetics and implants for the musculoskeletal and other systems of the human body are becoming increasingly sophisticated. From simple joint replacements to myoelectric limb replacements and functional electrical stimulation, the engineering opportunities continue to expand. This course builds on musculoskeletal biomechanics and other BELS courses to provide engineering students with an introduction to prosthetics and implants for the musculoskeletal system. At the end of the semester, students should have a working knowledge of the challenges and special considerations necessary to apply engineering principles to augmentation or replacement in the musculoskeletal system. Prerequisites: Musculoskeletal Biomechanics (EGGN/BELS425 or EGGN/BELS525), 3 hours lecture; 3 semester hours. Fall even years.

EGGN528/BELS528. COMPUTATIONAL BIOMECHANICS Computational Biomechanics provides and introduction to the application of computer simulation to solve some fundamental problems in biomechanics and bioengineering. Musculoskeletal mechanics, medical image reconstruction, hard and soft tissue modeling, joint mechanics, and inter-subject variability will be considered. An emphasis will be placed on understanding the limitations of the computer model as a predictive tool and the need for rigorous verification and validation of computational techniques. Clinical application of biomechanical modeling tools is highlighted and impact on patient quality of life is demonstrated. Prerequisite: EGGN413, EGGN325 or consent of instructor. 3 hours lecture; 3 semester hours. Fall odd years.

EGGN530/BELS530. BIOMEDICAL INSTRUMENTATION The acquisition, processing, and interpretation of biological signals presents many unique challenges to the Biomedical Engineer. This course is intended to provide students with the knowledge to understand, appreciate, and address these challenges. At the end of the semester, students should have a working knowledge of the special considerations necessary to gathering and analyzing biological signal data. Prerequisites: EGGN250 MEL I, DCGN381 Introduction to Electrical Circuits, Electronics, and Power, EGGN325/BELS325 Introduction to Biomedical Engineering (or permission of instructor). 3 hours lecture; 3 semester hours. Fall odd years.

EGGN531. SOIL DYNAMICS (II) Dynamic phenomena in geotechnical engineering, e.g., earthquakes, pile and foundation vibrations, traffic, construction vibrations; behavior of soils under dynamic loading, e.g., small, medium and large strain behavior, soil liquefaction; wave propagation through soil and rock; laboratory and field techniques to assess dynamic soil properties; analysis and design of shallow and

deep foundations subjected to dynamic loading; analysis of construction vibrations. Prerequisites: EGGN361, EGGN315, EGGN464 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN532/MTGN545. FATIGUE AND FRACTURE (I) Basic fracture mechanics as applied to engineering materials, S-N curves, the Goodman diagram, stress concentrations, residual stress effects, effect of material properties on mechanisms of crack propagation. Prerequisite: Consent of department. 3 hours lecture; 3 semester hours. Fall semesters, odd numbered years.

EGGN533. UNSATURATED SOIL MECHANICS The focus of this course is on soil mechanics for unsaturated soils. It provides an introduction to thermodynamic potentials in partially saturated soils, chemical potentials of adsorbed water in partially saturated soils, phase properties and relations, stress state variables, measurements of soil water suction, unsaturated flow laws, measurement of unsaturated permeability, volume change theory, effective stress principle, and measurement of volume changes in partially saturated soils. The course is designed for seniors and graduate students in various branches of engineering and geology that are concerned with unsaturated soil's hydrologic and mechanics behavior. Prerequisites: EGGN461 or consent of instructor. 3 hours lecture; 3 semester hours. Spring even years.

EGGN534. SOIL BEHAVIOR (I) The focus of this course is on interrelationships among the composition, fabric, and geotechnical and hydrologic properties of soils that consist partly or wholly of clay. The course will be divided into two parts. The first part provides an introduction to the composition and fabric of natural soils, their surface and pore-fluid chemistry, and the physico-chemical factors that govern soil behavior. The second part examines what is known about how these fundamental characteristics and factors affect geotechnical properties, including the hydrologic properties that govern the conduction of pore fluid and pore fluid constituents, and the geomechanical properties that govern volume change, shear deformation, and shear strength. The course is designed for graduate students in various branches of engineering and geology that are concerned with the engineering and hydrologic behavior of earth systems, including geotechnical engineering, geological engineering, environmental engineering, mining engineering, and petroleum engineering. Prerequisites: EGGN461 Soil Mechanics or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN535. INTRODUCTION TO DISCRETE ELEMENT METHODS (DEMS) (I) Review of particle/rigid body dynamics, numerical DEM solution of equations of motion for a system of particles/rigid bodies, linear and nonlinear contact and impact laws dynamics, applications of DEM in mechanical engineering, materials processing and geomechanics. Prerequisites: EGGN320, EGGN315 and some scientific programming experience in C/C++ or Fortran or

the consent of the instructor. 3 hours lecture; 3 semester hours Spring semester of even numbered years.

EGGN536. HILLSLOPE HYDROLOGY AND STABILITY (I) Introduction of shallow landslide occurrence and socio-economic dynamics. Roles of unsaturated flow and stress in shallow landslides. Slope stability analysis based on unsaturated effective stress conceptualization. Computer modeling of unsaturated flow and stress distributions in hillslope. Prediction of precipitation induced shallow landslides. Prerequisite: EGGN461. 3 hours lecture; 3 semester hours.

EGGN541. ADVANCED STRUCTURAL ANALYSIS (I) Introduction to advanced structural analysis concepts. Non-prismatic structures. Arches, Suspension and cable-stayed bridges. Structural optimization. Computer Methods. Structures with nonlinear materials. Internal force redistribution for statically indeterminate structures. Graduate credit requires additional homework and projects. Prerequisite: EGGN342. 3 hour lectures, 3 semester hours.

EGGN542. FINITE ELEMENT METHODS FOR ENGINEERS (II) A course combining finite element theory with practical programming experience in which the multidisciplinary nature of the finite element method as a numerical technique for solving differential equations is emphasized. Topics covered include simple "structural" elements, beams on elastic foundations, solid elasticity, steady state analysis and transient analysis. Some of the applications will lie in the general area of geomechanics, reflecting the research interests of the instructor. Students get a copy of all the source code published in the course textbook. Prerequisite: Consent of the instructor. 3 hours lecture; 3 semester hours.

EGGN545. BOUNDARY ELEMENT METHODS (II) Development of the fundamental theory of the boundary element method with applications in elasticity, heat transfer, diffusion, and wave propagation. Derivation of indirect and direct boundary integral equations. Introduction to other Green's function based methods of analysis. Computational experiments in primarily two dimensions. Prerequisite: EGGN502, EGGN540 or consent of instructor. 3 hours lecture; 3 semester hours Spring Semester, odd numbered years.

EGGN546. ADVANCED ENGINEERING VIBRATION (II) Vibration theory as applied to single- and multi-degree-of-freedom systems. Free and forced vibrations to different types of loading-harmonic, impulse, periodic and general. Natural frequencies. Role of Damping. Importance of resonance. Modal superposition method. Prerequisite: EGGN315, 3 hours lecture; 3 semester hours.

EGGN547. TIMBER AND MASONRY DESIGN The course develops the theory and design methods required for the use of timber and masonry as structural materials. The design of walls, beams, columns, beam-columns, shear walls, and structural systems are covered for each material. Gravity, wind, snow, and seismic loads are calculated and utilized

for design. Connection design and advanced seismic analysis principles are introduced. Prerequisite: EGGN342 or equivalent. 3 hours lecture; 3 semester hours. Spring odd years.

EGGN548. ADVANCED SOIL MECHANICS Advanced soil mechanics theories and concepts as applied to analysis and design in geotechnical engineering. Topics covered will include seepage, consolidation, shear strength, failure criteria and constitutive models for soil. The course will have an emphasis on numerical solution techniques to geotechnical problems by finite elements and finite differences. Prerequisites: A first course in soil mechanics or consent of instructor. 3 Lecture Hours, 3 semester hours. Fall even years.

EGGN549. ADVANCED DESIGN OF STEEL STRUCTURES The course extends the coverage of steel design to include the topics: slender columns, beam-columns, frame behavior, bracing systems and connections, stability, moment resisting connections, composite design, bolted and welded connections under eccentric loads and tension, and semi-rigid connections. Prerequisite: EGGN444 or equivalent. 3 hours lecture; 3 semester hours. Spring even years.

EGGN552. VISCOUS FLOW AND BOUNDARY LAYERS (I) This course establishes the theoretical underpinnings of fluid mechanics, including fluid kinematics, stress-strain relationships, and derivation of the fluid-mechanical conservation equations. These include the mass-continuity and Navier-Stokes equations as well as the multi-component energy and species-conservation equations. Fluid-mechanical boundary-layer theory is developed and applied to situations arising in chemically reacting flow applications including combustion, chemical processing, and thin-film materials processing. Prerequisite: EGGN473, or CHEN430 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN556. Design of Reinforced Concrete Structures II. Advanced problems in the analysis and design of concrete structures, design of slender columns; biaxial bending; two-way slabs; strut and tie models; lateral and vertical load analysis of multistory buildings; introduction to design for seismic forces; use of structural computer programs. Prerequisite: EGGN445. 3 hour lectures, 3 semester hours. Delivered in the spring of even numbered years.

EGGN557. STRUCTURAL DYNAMICS. An introduction to the dynamics and earthquake engineering of structures is provided. Subjects include the analysis of linear and nonlinear single-degree and multi-degree of freedom structural dynamics. The link between structural dynamics and code-based analysis and designs of structures under earthquake loads is presented. The focus applications of the course include single story and multi-story buildings, and other types of structures that under major earthquake may respond in the inelastic range. Prerequisites: EGGN342 Structural Theory or consent of the instructor. Once every three semesters starting Fall of 2011. 3 semester hours.

EGGN560. NUMERICAL METHODS FOR ENGINEERS (S) Introduction to the use of numerical methods in the solution of commonly encountered problems of engineering analysis. Structural/solid analysis of elastic materials (linear simultaneous equations); vibrations (roots of nonlinear equations, initial value problems); natural frequency and beam buckling (eigenvalue problems); interpretation of experimental data (curve fitting and differentiation); summation of pressure distributions (integration); beam deflections (boundary value problems). All course participants will receive source code of all the numerical methods programs published in the course textbook which is coauthored by the instructor. Prerequisite: MATH225 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN566. COMBUSTION (I) An introduction to combustion. Course subjects include: the development of the Chapman-Jouget solutions for deflagration and detonation, a brief review of the fundamentals of kinetics and thermochemistry, development of solutions for diffusion flames and premixed flames, discussion of flame structure, pollutant formation, and combustion in practical systems. Prerequisite: EGGN473, or CHEN430 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN569/MLGN569/CHEN569/MTGN569/EGGN/469/CHEN469. FUEL CELL SCIENCE AND TECHNOLOGY (I) Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical-thermodynamics and materials-science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. 3 credit hours.

EGGN573. INTRODUCTION TO COMPUTATIONAL TECHNIQUES FOR FLUID DYNAMICS AND TRANSPORT PHENOMENA (II) Introduction to Computational Fluid Dynamics (CFD) for graduate students with no prior knowledge of this topic. Basic techniques for the numerical analysis of fluid flows. Acquisition of hands-on experience in the development of numerical algorithms and codes for the numerical modeling and simulation of flows and transport phenomena of practical and fundamental interest. Capabilities and limitations of CFD. Prerequisite: EGGN473 or consent of instructor. 3 hours lecture; 3 semester hours.

EGGN580. ELECTRIC POWER QUALITY (II) Electric power quality (PQ) deals with problems exhibited by voltage, current and frequency that typically impact end-users (customers) of an electric power system. This course is designed to familiarize the concepts of voltage sags, harmonics, momentary disruptions, and waveform distortions arising from various sources in the system. A theoretical and mathematical basis for various indices, standards, models, analyses techniques, and good design procedures will be presented. Additionally, sources of power quality problems and some

remedies for improvement will be discussed. The course bridges topics between power systems and power electronics. Prerequisite: EGGN484 and EGGN485 or instructor approval. 3 lecture hours; 3 semester hours.

EGGN581. MODERN ADJUSTABLE SPEED ELECTRIC DRIVES An introduction to electric drive systems for advanced applications. The course introduces the treatment of vector control of induction and synchronous motor drives using the concepts of general flux orientation and the feed-forward (indirect) and feedback (direct) voltage and current vector control. AC models in space vector complex algebra are also developed. Other types of drives are also covered, such as reluctance, stepper-motor and switched-reluctance drives. Digital computer simulations are used to evaluate such implementations. Pre-requisite: Familiarity with power electronics and power systems, such as covered in EGGN484 and EGGN485. 3 lecture hours; 3 semester hours. Spring semester of even years.

EGGN582. RENEWABLE ENERGY AND DISTRIBUTED GENERATION A comprehensive electrical engineering approach on the integration of alternative sources of energy. One of the main objectives of this course is to focus on the inter-disciplinary aspects of integration of the alternative sources of energy which will include most common and also promising types of alternative primary energy: hydropower, wind power, photovoltaic, fuel cells and energy storage with the integration to the electric grid. Pre-requisite: It is assumed that students will have some basic and broad knowledge of the principles of electrical machines, thermodynamics, power electronics, direct energy conversion, and fundamentals of electric power systems such as covered in basic engineering courses plus EGGN484 and EGGN485. 3 lecture hours; 3 semester hours. Fall semester of odd years.

EGGN583. ADVANCED ELECTRICAL MACHINE DYNAMICS This course deals primarily with the two rotating AC machines currently utilized in the electric power industry, namely induction and synchronous machines. The course is divided in two halves: the first half is dedicated to induction and synchronous machines are taught in the second half. The details include the development of the theory of operation, equivalent circuit models for both steady-state and transient operations, all aspects of performance evaluation, IEEE methods of testing, and guidelines for industry applications including design and procurement. Prerequisites: EGGN484 or equivalent, and/or consent of instructor. 3 lecture hours; 3 semester hours. Spring semester of even years.

EGGN584. POWER DISTRIBUTION SYSTEMS ENGINEERING This course deals with the theory and applications of problems and solutions as related to electric power distribution systems engineering from both ends: end-users like large industrial plants and electric utility companies. The primary focus of this course is on the medium voltage (4.16 kV – 69 kV) power systems. Some references will be made

to the LV power system. The course includes: per-unit methods of calculations; voltage drop and voltage regulation; power factor improvement and shunt compensation; short-circuit calculations; theory and fundamentals of symmetrical components; unsymmetrical faults; overhead distribution lines and power cables; basics and fundamentals of distribution protection. Prerequisites: EGGN484 or equivalent, and/or consent of instructor. 3 lecture hours; 3 semester hours. Fall semester of odd years.

EGGN585. ADVANCED HIGH POWER ELECTRONICS Basic principles of analysis and design of circuits utilizing high power electronics. AC/DC, DC/AC, AC/AC, and DC/DC conversion techniques. Laboratory project comprising simulation and construction of a power electronics circuit. Prerequisites: EGGN385; EGGN389 or equivalent. 3 hours lecture; 3 semester hours. Fall semester even years.

EGGN586. HIGH VOLTAGE AC AND DC POWER TRANSMISSION This course deals with the theory, modeling and applications of HV and EHV power transmission systems engineering. The primary focus is on overhead AC transmission line and voltage ranges between 115 kV – 500 kV. HVDC and underground transmission will also be discussed. The details include the calculations of line parameters (RLC); steady-state performance evaluation (voltage drop and regulation, losses and efficiency) of short, medium and long lines; reactive power compensation; FACTS devices; insulation coordination; corona; insulators; sag-tension calculations; EMTP, traveling wave and transients; fundamentals of transmission line design; HV and EHV power cables: solid dielectric, oil-filled and gas-filled; Fundamentals of DC transmission systems including converter and filter. Prerequisites: EGGN484 or equivalent, and/or consent of instructor. 3 lecture hours; 3 semester hours. Fall semester of even years.

EGGN587. POWER SYSTEM OPERATION AND MANAGEMENT (I) This course presents a comprehensive exposition of the theory, methods, and algorithms for Energy Management Systems (EMS) in the power grid. It will focus on (1) modeling of power systems and generation units, (2) methods for dispatching generating resources, (3) methods for accurately estimating the state of the system, (4) methods for assessing the security of the power system, and (5) an overview of the market operations in the grid. Prerequisite: EGGN484. 3 lecture hours; 3 semester hours.

EGGN589. DESIGN AND CONTROL OF WIND ENERGY SYSTEMS (II) Wind energy provides a clean, renewable source for electricity generation. Wind turbines provide electricity at or near the cost of traditional fossil-fuel fired power plants at suitable locations, and the wind industry is growing rapidly as a result. Engineering R&D can still help to reduce the cost of energy from wind, improve the reliability of wind turbines and wind farms, and help to improve acceptance of wind energy in the public and political arenas. This course

provides an overview of the design and control of wind energy systems. Prerequisite: EGGN307. 3 hours lecture; 3 semester hours.

EGGN593. ENGINEERING DESIGN OPTIMIZATION
The application of gradient, stochastic and heuristic optimization algorithms to linear and nonlinear optimization problems in constrained and unconstrained design spaces. Students will consider problems with continuous, integer and mixed-integer variables, problems with single or multiple objectives and the task modeling design spaces and constraints. Design optimization methods are becoming of increasing importance in engineering design and offer the potential to reduce design cycle times while improving design quality by leveraging simulation and historical design data. Prerequisites: Experience with computer programming languages, Graduate or Senior Standing or consent of the instructor. 3 hours lecture; 3 semester hours. Spring, even numbered years.

EGGN597. SUMMER PROGRAMS

EGGN598. SPECIAL TOPICS IN ENGINEERING (I, II)
Pilot course of special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually course is offered only once. Prerequisite: Consent of the instructor. Variable credit; 1 to 6 hours. Repeatable for credit under different titles.

EGGN599. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 hours. Repeatable for credit to a maximum of 6 hours.

EGGN617. INTELLIGENT CONTROL SYSTEMS Fundamental issues related to the design on intelligent control systems are described. Neural networks analysis for engineering systems are presented. Neural-based learning, estimation, and identification of dynamical systems are described. Qualitative control system analysis using fuzzy logic is presented. Fuzzy mathematics design of rule-based control, and integrated human-machine intelligent control systems are covered. Real-life problems from different engineering systems are analyzed. Prerequisite: EGGN517 or consent of instructor. 3 hours lecture; 3 semester hours. Taught on demand.

EGGN618. NONLINEAR AND ADAPTIVE CONTROL
This course presents a comprehensive exposition of the theory of nonlinear dynamical systems and the applications of this theory to adaptive control. It will focus on (1) methods of characterizing and understanding the behavior of systems that can be described by nonlinear ordinary differential equations, (2) methods for designing controllers for such systems,

(3) an introduction to the topic of system identification, and (4) study of the primary techniques in adaptive control, including model-reference adaptive control and model predictive control. Prerequisite: EGGN517 or consent of instructor. 3 hours lecture; 3 semester hours. Taught on demand.

EGGN683. COMPUTER METHODS IN ELECTRIC POWER SYSTEMS This course deals with the computer methods and numerical solution techniques applied to large scale power systems. Primary focus includes load flow, short circuit, voltage stability and transient stability studies and contingency analysis. The details include the modeling of various devices like transformer, transmission lines, FACTS devices, and synchronous machines. Numerical techniques include solving a large set of linear or non-linear algebraic equations, and solving a large set of differential equations. A number of simple case studies (as per IEEE standard models) will be performed. Prerequisites: EGGN583, 584 and 586 or equivalent, and/or consent of instructor; a strong knowledge of digital simulation techniques. 3 lecture hours; 3 semester hours. Taught on demand.

EGGN698. SPECIAL TOPICS IN ENGINEERING (I, II)
Pilot course of special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually course is offered only once. Prerequisite: Consent of the Instructor. Variable credit; 1 to 6 hours. Repeatable for credit under different titles.

EGES699. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 hours. Repeatable for credit under different topics/experience.

EGGN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

EGGN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

Environmental Science and Engineering

JOHN E. McCRAY, Professor and Division Director

JÖRG DREWES, Professor

TISSA ILLANGASEKARE, Professor and AMAX Distinguished Chair

ROBERT L. SIEGRIST, Professor

RONALD R.H. COHEN, Associate Professor

LINDA A. FIGUEROA, Associate Professor

JUNKO MUNAKATA MARR, Associate Professor

JOHN R. SPEAR, Associate Professor

TZAHY Y. CATH, Assistant Professor

CHRISTOPHER P. HIGGINS, Assistant Professor

JONATHAN O. SHARP, Assistant Professor

PEI XU, Research Associate Professor

TOSHIHIRO SAKAKI, Research Assistant Professor

KATHRYN LOWE, Senior Research Associate

PAUL B. QUENEAU, Adjunct Professor

PATRICK RYAN, Adjunct Professor

DANIEL T. TEITELBAUM, Adjunct Professor

BRUCE D. HONEYMAN, Emeritus Professor

Degrees Offered:

Master of Science (Environmental Science and Engineering)

Doctor of Philosophy (Environmental Science and Engineering)

Program Description:

The Environmental Science and Engineering (ESE) Division offers programs of study in environmental science and engineering within the context of risk-based decision-making, environmental law and policy leading to M.S. and Ph.D. graduate degrees as well as supporting several undergraduate degrees. Programs are designed to prepare students to investigate and analyze environmental systems and assess risks to public health and ecosystems as well as evaluate and design natural and engineered solutions to mitigate risks and enable beneficial outcomes. Programs of study are interdisciplinary in scope, and consequently the appropriate coursework may be obtained from multiple departments at CSM as well as other local universities.

To achieve the Master of Science (M.S.) degree, full-time students may elect the Non-Thesis option, based exclusively upon coursework and project activities, or the Thesis option, in which laboratory and/or field research is incorporated into the curriculum under the guidance of a faculty advisor. For working professional or part time M.S. students the ESE Executive Program is offered, consisting of an evening curriculum leading to a Non-Thesis M.S. degree. ESE also offers a combined baccalaureate/masters degree program in which CSM students obtain an undergraduate degree as well as a Thesis or Non-Thesis M.S. in Environmental Science and Engineering. Please see the Combined Undergraduate/Graduate Programs sections in the *Graduate and Undergraduate Bulletins* for additional information. The

availability of daytime, evening, and summer courses allows all students a high degree of flexibility in planning their coursework to achieve their degrees in a timely fashion.

To achieve the Doctor of Philosophy (Ph.D.) degree, students are expected to complete a combination of coursework and original research, under the guidance of a faculty advisor and Doctoral committee, that culminates in a significant scholarly contribution to a specialized field in environmental science or engineering. The Ph.D. Program may build upon one of the ESE M.S. Programs or a comparable M.S. Program at another university. Full-time enrollment is expected and leads to the greatest success, although part-time enrollment may be allowed under special circumstances.

The ESE Division offers areas of emphasis for study such as: Water Treatment, Reclamation & Reuse, Contaminant Hydrology & Water Resources, Applied Environmental Microbiology & Biotechnology, and Environmental Remediation, that correspond to areas of significant career opportunities for graduates as well as expertise and active research by members of the ESE faculty. Each area of emphasis is designed to give students a rigorous, in-depth background in the subject matter relevant to the area while allowing opportunity, through electives, for breadth and exploration of related areas. For more information on ESE curriculum please refer to the Division Website at <http://www.mines.edu/academic/envsci/>.

The ESE M.S. and Ph.D. Programs have been admitted to the Western Regional Graduate Program (WRGP/WICHE), a recognition that designates this curriculum as unique within the Western United States. An important benefit of this designation is that students from Alaska, Arizona, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming are given the tuition status of Colorado residents.

Combined Degree Program Option

CSM undergraduate students have the opportunity to begin work on a M.S. degree in Environmental Science and Engineering while completing their Bachelor's degree. The CSM Combined Degree Program provides the vehicle for students to use undergraduate coursework as part of their Graduate Degree curriculum. For more information please contact the ESE Office or visit <http://ese.mines.edu/>.

Program Requirements:

M.S. Non-Thesis Option: 30 total credit hours, consisting of coursework (27 h), Independent Study (ESGN599A) (3-6 h), and seminar.

M.S. Thesis Option: 30 total credit hours, consisting of coursework (24 h), seminar, and research (6h). Students must also write and orally defend a research thesis.

Students in the ESE M.S. degree program who are not registered full time must be enrolled in the part time ESE Executive Program.

Ph.D.: 72 total credit hours, consisting of area of emphasis coursework (at least 18 h), seminar, and research (at least 24 h). Students must also successfully complete written and oral qualifying examinations, prepare and present a dissertation proposal, and write and defend a doctoral dissertation. PhD students are also expected to submit the dissertation work for publication in scholarly journals.

Prerequisites:

- ◆ baccalaureate degree: required, preferably in a science or engineering discipline
- ◆ college calculus I & II: two semesters required
- ◆ college physics: one semester required, one year highly recommended
- ◆ college chemistry I & II: two semesters required
- ◆ college statistics: one semester required

Required Curriculum:

The curriculum consists of common core and elective courses that may be focused toward specialized areas of emphasis. Students will work with their academic advisors to establish plans of study that best fit their individual interests and goals. Each student will develop and submit a plan of study during the first semester of enrollment; this plan must be submitted with the admission to candidacy form. Electives may be chosen freely from courses offered at CSM and other local universities. Please visit the ESE website for a complete outline of curriculum requirements and options. (<http://ese.mines.edu>).

Fields of Research:

Research encompasses areas including 1) development of innovative processes for water and wastewater treatment, reclamation and reuse; 2) applications of biological processes in environmental remediation, water treatment, and renewable energy generation; 3) understanding fundamental chemical and radiochemical processes governing the fate and transport of contaminants, and engineering these processes to achieve environmental goals; 4) geological, hydrological, and biological characterization of pristine and anthropogenically disturbed natural systems, both for elucidating natural system function and for informing remediation and restoration efforts; and 5) mathematical representation and modeling of hydrological and hydrogeological phenomena in soil and water systems. In support of these research activities, ESE has modern facilities, including state-of-the-art laboratories for water/waste treatment, environmental radiochemistry, and biotechnology. Specialized facilities include the Integrated Environmental Teaching Lab (IETL) complex, Advanced Water Technology Center (AQWATEC), Center for Experimental Study of Subsurface Environmental Processes (CESEP), CSM/City of Golden Water Treatment Pilot Plant, and the Mines Park Test Sites.

Description of Courses

ESGN401. FUNDAMENTALS OF ECOLOGY Biological and ecological principles are discussed and industrial examples of their use are given. Analysis of ecosystem processes, such as erosion, succession, and how these processes relate to engineering activities, including engineering design and plant operation, are investigated. Criteria and performance standards are analyzed for facility siting, pollution control, and mitigation of impacts. North American ecosystems are analyzed. Concepts of forestry, range, and wildlife management are integrated as they apply to all the above. Three to four weekend field trips will be arranged during the semester. Prerequisite: ESGN301 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN440. ENVIRONMENTAL POLLUTION: SOURCES, CHARACTERISTICS, TRANSPORT AND FATE This course describes the environmental behavior of inorganic and organic chemicals in multimedia environments, including water, air, sediment, and biota. Sources and characteristics of contaminants in the environment are discussed as broad categories, with some specific examples from various industries. Attention is focused on the persistence, reactivity, and partitioning behavior of contaminants in environmental media. Both steady and unsteady state multimedia environmental models are developed and applied to contaminated sites. The principles of contaminant transport in surface water, groundwater and air are also introduced. The course provides students with the conceptual basis and mathematical tools for predicting the behavior of contaminants in the environment. Prerequisite: ESGN353 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN453/EGGN453. WASTEWATER ENGINEERING The goal of this course is to familiarize students with the fundamental phenomena involved in wastewater treatment processes (theory) and the engineering approaches used in designing such processes (design). This course will focus on the physical, chemical and biological processes applied to liquid wastes of municipal origin. Treatment objectives will be discussed as the driving force for wastewater treatment. Prerequisite: ESGN353 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN454/EGGN454. WATER SUPPLY ENGINEERING This course presents contemporary issues relating to the supply of safe drinking water to the public. The theory and design of conventional potable water treatment unit processes and operations as well as water distribution systems will be covered. Prerequisite: ESGN353 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN455. SOLID AND HAZARDOUS WASTE ENGINEERING This course provides an introduction and overview of the engineering aspects of solid and hazardous waste management. The focus is on control technologies for solid wastes from common municipal and industrial sources

and the end-of-pipe waste streams and process residuals that are generated in some key industries. Prerequisite: ESGN/EGGN353 and ESGN/EGGN354. 3 hours lecture; 3 semester hours.

ESGN456/EGGN456. SCIENTIFIC BASIS OF ENVIRONMENTAL REGULATIONS This course offers a critical examination of the experiments, calculations, and assumptions underpinning numerical and narrative standards contained in federal and state environmental regulations. Top-down investigations of the historical development of selected regulatory guidelines and permitting procedures will be discussed, and students will design improved regulations. Prerequisite: ESGN353 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN457/EGGN457. SITE REMEDIATION ENGINEERING This course describes the engineering principles and practices associated with the characterization and remediation of contaminated sites. Methods for site characterization and risk assessment will be highlighted with emphasis on remedial action screening processes, technology principles, and conceptual design. Common isolation and containment and *in situ* and *ex situ* treatment technology will be covered. Computerized decision-support tools will be used and case studies will be presented. Prerequisites: ESGN354 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN460. ONSITE WATER RECLAMATION AND REUSE Appropriate solutions to water and sanitation in the U.S. and globally need to be effective in protecting public health and preserving water quality while also being acceptable, affordable and sustainable. Onsite and decentralized systems have the potential to achieve these goals in rural areas, peri-urban developments, and urban centers in small and large cities. Moreover they can improve water use efficiency, conserve energy and enable distributed energy generation, promote green spaces, restore surface waters and aquifers, and stimulate new green companies and jobs. A growing array of approaches, devices and technologies have evolved that include point-of-use water purification, waste source separation, conventional and advanced treatment units, localized natural treatment systems, and varied resource recovery and recycling options. This course focuses on the engineering selection, design, and implementation of onsite and decentralized systems for water reclamation and reuse. Topics covered include process analysis and system planning, water and waste stream attributes, water and resource conservation, confined unit and natural system treatment technologies, effluent collection and clustering, recycling and reuse options, and system management. Prerequisite: ESGN/EGGN353 or consent of instructor. 3 hours lecture; 3 semester hours.

ESGN462/MTGN527/MTGN462. SOLID WASTE MINIMIZATION AND RECYCLING The objective of this course is to place the student into the role of a plant manager with process responsibility for waste minimization, focusing on recycling. Emphasis is on proven and emerging solutions, especially those associated with heavy metals, as well as understanding of alternative raw materials and process technologies in combination with creativity and sensitivity to economic realities. Prerequisites: ESGN500 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN463 POLLUTION PREVENTION: FUNDAMENTALS AND PRACTICE The objective of this course is to introduce the principles of pollution prevention, environmentally benign products and processes, and manufacturing systems. The course provides a thorough foundation in pollution prevention concepts and methods. Engineers and scientists are given the tools to incorporate environmental consequences into decision-making. Sources of pollution and its consequences are detailed. Focus includes sources and minimization of industrial pollution; methodology for life-cycle assessments and developing successful pollution prevention plans; technological means for minimizing the use of water, energy, and reagents in manufacturing; and tools for achieving a sustainable society. Materials selection, process and product design, and packaging are also addressed. Prerequisite: EGGN/ESGN353 or EGGN/ESGN354 or consent of instructor. 3 hours lecture; 3 semester hours.

ESGN490. ENVIRONMENTAL LAW (I) Specially designed for the needs of the environmental quality engineer, scientist, planner, manager, government regulator, consultant, or advocate. Highlights include how our legal system works, environmental law fundamentals, all major US EPA/state enforcement programs, the National Environmental Policy Act, air and water pollutant laws, risk assessment and management, and toxic and hazardous substance laws (RCRA, CERCLA, TSCA, LUST, etc). Prerequisites: ESGN353 or ESGN354, or consent of instructor. 3 hours lecture; 3 semester hours.

Graduate Courses

ESGN500. ENVIRONMENTAL WATER CHEMISTRY This course provides an introduction to chemical equilibria in natural waters and engineered systems. Topics covered include chemical thermodynamics and kinetics, acid/base chemistry, open and closed carbonate systems, precipitation reactions, coordination chemistry, adsorption and redox reactions. Prerequisites: none. 3 hours lecture; 3 semester hours.

ESGN500L. ENVIRONMENTAL WATER CHEMISTRY LABORATORY This course provides students with laboratory exercises that complement lectures given in ESGN500. Topics covered include thermodynamics, weak acids and bases, buffers, metal-ion complexation and oxidation/reduction reactions. This course must be taken concurrently with ESGN500. Prerequisite: co-enrollment in ESGN500. 3 hours laboratory; 1 semester hour.

ESGN501. RISK ASSESSMENT This course evaluates the basic principles, methods, uses, and limitations of risk assessment in public and private sector decision making. Emphasis is on how risk assessments are made and how they are used in policy formation, including discussion of how risk assessments can be objectively and effectively communicated to decision makers and the public. Prerequisite: ESGN502 and one semester of statistics or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN502. ENVIRONMENTAL LAW This is a comprehensive introduction to U.S. Environmental Law, Policy, and Practice, especially designed for the professional engineer, scientist, planner, manager, consultant, government regulator, and citizen. It will prepare the student to deal with the complex system of laws, regulations, court rulings, policies, and programs governing the environment in the USA. Course coverage includes how our legal system works, sources of environmental law, the major USEPA enforcement programs, state/local matching programs, the National Environmental Policy Act (NEPA), air and water pollution (CAA, CWA), EPA risk assessment training, toxic/hazardous substances laws (RCRA, CERCLA, EPCRA, TSCA, LUST, etc.), and a brief introduction to international environmental law. Prerequisites: none. 3 hours lecture; 3 semester hours.

ESGN503. ENVIRONMENTAL POLLUTION: SOURCES, CHARACTERISTICS, TRANSPORT AND FATE This course describes the environmental behavior of inorganic and organic chemicals in multimedia environments, including water, air, sediment and biota. Sources and characteristics of contaminants in the environment are discussed as broad categories, with some specific examples from various industries. Attention is focused on the persistence, reactivity, and partitioning behavior of contaminants in environmental media. Both steady and unsteady state multimedia environmental models are developed and applied to contaminated sites. The principles of contaminant transport in surface water, groundwater, and air are also introduced. The course provides students with the conceptual basis and mathematical tools for predicting the behavior of contaminants in the environment. Prerequisite: none. 3 hours lecture; 3 semester hours.

ESGN504. WATER AND WASTEWATER TREATMENT Unit operations and processes in environmental engineering are discussed in this course, including physical, chemical, and biological treatment processes for water and wastewater. Treatment objectives, process theory, and practice are considered in detail. Prerequisites: Consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN505. EXPERIMENTAL DESIGN AND ENVIRONMENTAL DATA ANALYSIS This course covers experimental design and analysis for studies of environmental media, including those involving characterization and assessment, treatment, and remediation technologies, and compliance monitoring. Principal media covered are water and waste-

waters, soil and sediments, and surface and ground waters. Topics covered include properties of environmental datasets, data quality objectives, statistical designs for data collection, methods of sample collection and analysis, data analysis and visualization, inference making. Issues of data worth and sufficiency for decision making will also be addressed. Laboratory includes gravimetric, electrometric, spectrophotometric, chromatographic, and microbiological analyses. Prerequisite: Consent of instructor. 3 hours lecture and laboratory; 3 semester hours.

ESGN506. ADVANCED WATER TREATMENT ENGINEERING AND WATER REUSE This course presents issues relating to theory, design, and operation of advanced water and wastewater treatment unit processes and water reuse systems. Topics include granular activated carbon (GAC), advanced oxidation processes (O₃/H₂O₂), UV disinfection, pressure-driven, current-driven, and osmotic-driven membranes (MF, UF, NF, RO, electrodialysis, and forward osmosis), and natural systems such as riverbank filtration (RBF) and soil-aquifer treatment (SAT). The course is augmented by ESGN506L offering hands-on experience using bench- and pilot-scale unit operations. Prerequisite: ESGN 453/454/504/530 or consent of instructor. 3 hours lecture; 3 semester hours.

ESGN506L. ADVANCED WATER TREATMENT ENGINEERING AND WATER REUSE - LABORATORY. This course provides hands-on experience using bench- and pilot-scale unit operations and computer exercises using state-of-the-art software packages to design advanced water treatment unit processes. Topics include adsorption processes onto powdered and granular activated carbon, low-pressure membrane processes (microfiltration, ultrafiltration), and high-pressure and current-driven membrane processes (nanofiltration, reverse osmosis, and electrodialysis). The course is a highly recommended component of ESGN506A and meets 5 - 6 times during the semester to support the work in 506A. Co- or Pre-requisite: ESGN506 or consent of instructor. 1 semester hour.

ESGN510. ENVIRONMENTAL RADIOCHEMISTRY This course covers the phenomena of radioactivity (e.g., modes of decay, methods of detection and biological effects) and the use of naturally occurring and artificial radionuclides as tracers for environmental processes. Discussions of tracer applications will range from oceanic trace element scavenging to contaminant transport through groundwater aquifers. Prerequisites: ESGN500 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN511. ENVIRONMENTAL STEWARDSHIP OF NUCLEAR RESOURCES The stewardship of nuclear resources spans the entire nuclear fuel cycle, which includes mining and milling through chemical processing on the front end of the materials life cycle. On the back end, stewardship continues from materials removal from the power plant during re-

fueling or facility decommissioning, through storage, recycling and disposal, as well as the management of activated or contaminated materials generated during facility decommissioning. Each stage in the fuel cycle has a different risk of public exposure through different pathways and the presence of different isotopes. These risks are an integral part in considering the long-term efficacy of nuclear as an energy alternative. Furthermore, nuclear energy has long been vilified in public opinion forums via emotional responses. Stewardship extends beyond quantification of risks to the incorporation and communication of these risks and the associated facts regarding nuclear power to the public at large. Prerequisite: Graduate standing or consent of instructor. 3 hours lecture; 3 semester hours.

ESGN513. LIMNOLOGY This course covers the natural chemistry, physics, and biology of lakes as well as some basic principles concerning contamination of such water bodies. Topics include heat budgets, water circulation and dispersal, sedimentation processes, organic compounds and their transformations, radionuclide limnology, redox reactions, metals and other major ions, the carbon dioxide system, oxygen, nutrients; planktonic, benthic and other communities, light in water and lake modeling. Prerequisite: none. 3 hours lecture; 3 semester hours.

ESGN520. SURFACE WATER QUALITY MODELING This course will cover modeling of water flow and quality in rivers, lakes, and reservoirs. Topics will include introduction to common analytical and numerical methods used in modeling surface water flow, water quality, modeling of kinetics, discharge of waste water into surface systems, sedimentation, growth kinetics, dispersion, and biological changes in lakes and rivers. Prerequisites: ESGN440 or ESGN503 recommended, or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN522. SUBSURFACE CONTAMINANT TRANSPORT This course will investigate physical, chemical, and biological processes governing the transport and fate of contaminants in the saturated and unsaturated zones of the subsurface. Basic concepts in fluid flow, groundwater hydraulics, and transport will be introduced and studied. The theory and development of models to describe these phenomena, based on analytical and simple numerical methods, will also be discussed. Applications will include prediction of extents of contaminant migration and assessment and design of remediation schemes. Prerequisites: ESGN503 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN525. CHEMISTRY OF THE SOIL/WATER INTERFACE The fate of many elements in the soil/water environment is regulated by sorption reactions. The content of this course focuses on the physical chemistry of reactions occurring at the soil-particle/water interface. The emphasis is on the use of surface complexation models to interpret solute sorption

at the particle/water interface. Prerequisites: ESGN500 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN527. WATERSHED SYSTEMS ANALYSIS Basic principles of watershed systems analysis required for water resources evaluation, watershed-scale water quality issues, and watershed-scale pollutant transport problems. The dynamics of watershed-scale processes and the human impact on natural systems, and for developing remediation strategies are studied, including terrain analysis and surface and subsurface characterization procedures and analysis. Prerequisite: none. 3 hours lecture per week; 3 semester hours.

ESGN528. MATHEMATICAL MODELING OF ENVIRONMENTAL SYSTEMS This is an advanced graduate-level course designed to provide students with hands-on experience in developing, implementing, testing, and using mathematical models of environmental systems. The course will examine why models are needed and how they are developed, tested, and used as decision-making or policy-making tools. Typical problems associated with environmental systems, such as spatial and temporal scale effects, dimensionality, variability, uncertainty, and data insufficiency, will be addressed. The development and application of mathematical models will be illustrated using a theme topic such as Global Climate Change, *In Situ* Bioremediation, or Hydrologic Systems Analysis. Prerequisites: ESGN503 and knowledge of basic statistics and computer programming. 3 hours lecture; 3 semester hours.

ESGN530. ENVIRONMENTAL ENGINEERING PILOT PLANT LABORATORY This course provides an introduction to bench and pilot-scale experimental methods used in environmental engineering. Unit operations associated with water and wastewater treatment for real-world treatment problems are emphasized, including multi-media filtration, oxidation processes, membrane treatment, and disinfection processes. Investigations typically include: process assessment, design and completion of bench- and pilot-scale experiments, establishment of analytical methods for process control, data assessment, up-scaling and cost estimation, and project report writing. Projects are conducted both at CSM and at the City of Golden Water Treatment Pilot Plant Laboratory. Prerequisites: ESGN500 and ESGN504 or consent of the instructor. 6 hours laboratory; 4 semester hours.

ESGN541/BELS541. MICROBIAL PROCESSES, ANALYSIS AND MODELING Microorganisms facilitate the transformation of many organic and inorganic constituents. Tools for the quantitative analysis of microbial processes in natural and engineered systems are presented. Stoichiometries, energetics, mass balances and kinetic descriptions of relevant microbial processes allow the development of models for specific microbial systems. Simple analytical models and complex models that require computational solutions will be presented. Systems analyzed

include suspended growth and attached growth reactors for municipal and industrial wastewater treatment as well as in-situ bioremediation systems. Prerequisites: ESGN500, ESGN504 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN544/BELS544. **AQUATIC TOXICOLOGY** This course provides an introduction to assessment of the effects of toxic substances on aquatic organisms, communities, and ecosystems. Topics include general toxicological principles, water quality standards, sediment quality guidelines, quantitative structure-activity relationships, single species and community-level toxicity measures, regulatory issues, and career opportunities. The course includes hands-on experience with toxicity testing and subsequent data reduction. Prerequisite: none. 2.5 hours lecture; 1 hour laboratory; 3 semester hours.

ESGN545/BELS545. **ENVIRONMENTAL TOXICOLOGY** This course provides an introduction to general concepts of ecology, biochemistry, and toxicology. The introductory material will provide a foundation for understanding why, and to what extent, a variety of products and by-products of advanced industrialized societies are toxic. Classes of substances to be examined include metals, coal, petroleum products, organic compounds, pesticides, radioactive materials, and others. Prerequisite: none. 3 hours lecture; 3 semester hours.

ESGN552. **RECLAMATION OF DISTURBED LANDS** Basic principles and practices in reclaiming disturbed lands are considered in this course, which includes an overview of present legal requirements for reclamation and basic elements of the reclamation planning process. Reclamation methods, including recontouring, erosion control, soil preparation, plant establishment, seed mixtures, nursery stock, and wildlife habitat rehabilitation, will be examined. Practitioners in the field will discuss their experiences. Prerequisite: consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN555. **ENVIRONMENTAL ORGANIC CHEMISTRY** A study of the chemical and physical interactions which determine the fate, transport and interactions of organic chemicals in aquatic systems, with emphasis on chemical transformations of anthropogenic organic contaminants. Prerequisites: A course in organic chemistry and CHGN503, Advanced Physical Chemistry or its equivalent, or consent of instructor. Offered in alternate years. 3 hours lecture; 3 semester hours.

ESGN556. **MINING AND THE ENVIRONMENT** The course will cover many of the environmental problems and solutions associated with each aspect of mining and ore dressing processes. Mining is a complicated process that differs according to the type of mineral sought. The mining process can be divided into four categories: Site Development; Extraction; Processing; Site Closure. Procedures for hard rock metals mining; coal mining; underground and sur-

face mining; and in situ mining will be covered in relation to environmental impacts. Beneficiation, or purification of metals will be discussed, with cyanide and gold topics emphasized. Site closure will be focused on; stabilization of slopes; process area cleanup; and protection of surface and ground water. After discussions of the mining and beneficiation processes themselves, we will look at conventional and innovative measures to mitigate or reduce environmental impact.

ESGN562/MTGN527. **SOLID WASTE MINIMIZATION AND RECYCLING** This course will examine, using case studies, ways in which industry applies engineering principles to minimize waste formation and to meet solid waste recycling challenges. Both proven and emerging solutions to solid waste environmental problems, especially those associated with metals, will be discussed. Prerequisite: ESGN 500. 3 hours lecture; 3 semester hours.

ESGN563 **POLLUTION PREVENTION: FUNDAMENTALS AND PRACTICE** The objective of this course is to introduce the principles of pollution prevention, environmentally benign products and processes, and manufacturing systems. The course provides a thorough foundation in pollution prevention concepts and methods. Engineers and scientists are given the tools to incorporate environmental consequences into decision-making. Sources of pollution and its consequences are detailed. Focus includes sources and minimization of industrial pollution; methodology for life-cycle assessments and developing successful pollution prevention plans; technological means for minimizing the use of water, energy, and reagents in manufacturing; and tools for achieving a sustainable society. Materials selection, process and product design, and packaging are also addressed. 3 hours lecture; 3 semester hours.

ESGN571. **ENVIRONMENTAL PROJECT MANAGEMENT** This course investigates environmental project management and decision making from government, industry, and contractor perspectives. Emphasis is on (1) economics of project evaluation; (2) cost estimation methods; (3) project planning and performance monitoring; (4) and creation of project teams and organizational/communications structures. Extensive use of case studies. Prerequisite: consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN575. **HAZARDOUS WASTE SITE REMEDIATION** This course covers remediation technologies for hazardous waste contaminated sites, including site characteristics and conceptual model development, remedial action screening processes, and technology principles and conceptual design. Institutional control, source isolation and containment, subsurface manipulation, and *in situ* and *ex situ* treatment processes will be covered, including unit operations, coupled processes, and complete systems. Case studies will be used and computerized tools for process selection and design will be employed. Prerequisite: ESGN500 and ESGN503, or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN575L. HAZARDOUS WASTE SITE REMEDIATION: TREATABILITY TESTING This laboratory module is designed to provide hands-on experience with treatability testing to aid selection and design of remediation technologies for a contaminated site. The course will be comprised of laboratory exercises in Coolbaugh Hall and possibly some field site work near CSM. Pre-requisite: ESGN575 or consent of instructor. 2 hours laboratory; 1 semester hour.

ESGN586. MOLECULAR MICROBIAL ECOLOGY AND THE ENVIRONMENT This course explores the diversity of microbiota in a few of the countless environments of our planet. Topics include microbial ecology (from a molecular perspective), microbial metabolism, pathogens, extreme environments, engineered systems, oxidation / reduction of metals, bioremediation of both organics and inorganics, microbial diversity, phylogenetics, analytical tools and bioinformatics. The course has an integrated laboratory component for applied molecular microbial ecology to learn microscopy, DNA extraction, PCR, gel electrophoresis, cloning, sequencing, data analysis and bioinformatic applications. Prerequisite: College Biology and/or CHGC 562, CHGC 563 or equivalent and enrollment in the ESE graduate program. 3 hours lecture, some field trips; 3 semester hours..

ESGN590. ENVIRONMENTAL SCIENCE AND ENGINEERING SEMINAR Research presentations covering current research in a variety of environmental topics.

ESGN591. ANALYSIS OF ENVIRONMENTAL IMPACT Techniques for assessing the impact of mining and other activities on various components of the ecosystem. Training in the procedures of preparing Environmental Impact Statements. Course will include a review of pertinent laws and acts (i.e. Endangered Species Act, Coordination Act, Clean Air Act, etc.) that deal with environmental impacts. Prerequisite: consent of the instructor. 3 hours lecture, some field trips; 3 semester hours.

ESGN593. ENVIRONMENTAL PERMITTING AND REGULATORY COMPLIANCE The purpose of this course is to acquaint students with the permit writing process, developing information requirements for permit applications, working with ambiguous regulations, negotiating with permit writers, and dealing with public comment. In addition, students will develop an understanding of the process of developing an economic and legally defensible regulatory compliance program. Prerequisite: ESGN502 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN596. GEOMICROBIAL SYSTEMS This course explores the functional activities and biological significance of microorganisms in geological and engineered systems. Topics will include microorganisms as geochemical agents of change, mechanisms and thermodynamics of microbial respiration, applications of analytical and molecular tools, and the impact of microbes on the fate and transport of problematic

water pollutants. Emphasis will be placed on critical analysis and communication of peer-reviewed literature on these topics. Prerequisites: ESGN 500 and ESGN 586 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN598. SPECIAL TOPICS IN ENVIRONMENTAL SCIENCE Topics are chosen from special interests of instructor and students; see website for current offerings. Each topic is usually offered only once. Prerequisite: consent of the instructor. Variable class and semester hours. Repeatable for credit under different titles.

ESGN599. INDEPENDENT STUDY Individual master's level research or special project supervised by a faculty member. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable class and semester hours. Repeatable for credit under different titles for up to 6 credit hours total.

ESGN602. INTERNATIONAL ENVIRONMENTAL LAW The course covers an introductory survey of International Environmental Law, including multi-nation treaties, regulations, policies, practices, and politics governing the global environment. It surveys the key issues of sustainable development, natural resources projects, transboundary pollution, international trade, hazardous waste, climate change, and protection of ecosystems, wildlife, and human life. New international laws are changing the rules for engineers, project managers, scientists, teachers, businesspersons, and others both in the US and abroad, and this course is especially designed to keep professionals fully, globally informed and add to their credentials for international work. Prerequisites: ESGN502 or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN622. MULTIPHASE CONTAMINANT TRANSPORT Principles of multiphase and multicomponent flow and transport are applied to contaminant transport in the unsaturated and saturated zones. Focus is on immiscible phase, dissolved phase, and vapor phase transport of low solubility organic contaminants in soils and aquifer materials. Topics discussed include: capillarity, interphase mass transfer, modeling, and remediation technologies. Prerequisites: ESGN500 or equivalent, ESGN503 or ESGN522 or equivalent, or consent of the instructor. 3 hours lecture; 3 semester hours.

ESGN698. ADVANCED SPECIAL TOPICS IN ENVIRONMENTAL SCIENCE Topics chosen from special interests of instructor(s) and students; see website for current offerings. Each topic is usually offered only once. Prerequisite: consent of the instructor. Variable class and semester hours. Repeatable for credit under different titles.

ESGN699. ADVANCED INDEPENDENT STUDY Individual doctoral level research or special project supervised by a faculty member. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable class and semester hours. Repeatable for credit under different titles.

ESGN705. GRADUATE RESEARCH: MASTER OF SCIENCE Research credit hours required for completion of the Master of Science with Thesis degree. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

ESGN706. GRADUATE RESEARCH: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the Doctor of Philosophy degree. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

Geochemistry

JOHN D. HUMPHREY, Associate Professor Geology and Geological Engineering and Department Head
JOHN B. CURTIS, Professor Geology and Geological Engineering
WENDY J. HARRISON, Professor Geology and Geological Engineering and Associate Provost
MURRAY W. HITZMAN, Professor, Charles F. Fogarty Professor of Economic Geology
PATRICK MACCARTHY, Professor Chemistry and Geochemistry
RICHARD F. WENDLANDT, Professor Geology and Geological Engineering
JAMES F. RANVILLE, Associate Professor Chemistry and Geochemistry
E. CRAIG SIMMONS, Associate Professor Chemistry and Geochemistry
JOHN R. SPEAR, Associate Professor Environmental Science and Engineering
BETTINA M. VOELKER, Associate Professor Chemistry and Geochemistry
NIGEL M. KELLY, Assistant Professor Geology and Geological Engineering
THOMAS MONECKE, Assistant Professor Geology and Geological Engineering
JONATHAN O. SHARP, Assistant Professor Environmental Science and Engineering
DONALD L. MACALADY, Professor Emeritus Chemistry and Geochemistry
SAMUEL B. ROMBERGER, Professor Emeritus Geology and Geological Engineering
THOMAS R. WILDEMAN, Professor Emeritus Chemistry and Geochemistry
L. GRAHAM CLOSS, Associate Professor Emeritus of Geology and Geological Engineering

Degrees Offered:

Professional Masters in Environmental Geochemistry
Master of Science (Geochemistry)
Doctor of Philosophy (Geochemistry)

Program Description:

The Geochemistry Program is an interdisciplinary graduate program administered by the Department of Geology and Geological Engineering and the Department of Chemistry and Geochemistry. The geochemistry faculty from each department are responsible for the operations of the program. Students reside in either the Department of Geology and Geological Engineering or the Department of Chemistry and Geochemistry.

The program comprises a core group of courses, required of all students unless individually exempted by the Geochemistry Committee of the Whole based on previous background. Descriptions for individual classes may be found in the sections of the Graduate Bulletin for each of the participating departments. For classes with "CHGC" and "CHGN" prefixes see the section for Chemistry and Geochemistry; for classes with "GEGN" and "GEOL" prefixes see the section for Geology and Geological Engineering.

Students determine their program of study in consultation with the advisor or thesis committee. Students entering with background in chemistry will take more coursework in geology to strengthen their backgrounds in this discipline; the converse is true for students with a background in geology.

Professional Masters in Environmental Geochemistry

Introduction

The Professional Masters in Environmental Geochemistry program is intended to provide: (1) an opportunity for CSM undergraduates to obtain, as part of a fifth year of study, a Master in addition to the Bachelor degree; and (2) additional education for working professionals in the area of geochemistry as it applies to problems relating to the environment. This is a non-thesis Master degree program administered by the Geochemistry program, and may be completed as part of a combined degree program by individuals already matriculated as undergraduate students at CSM, or by individuals already holding undergraduate or advanced degrees and who are interested in a graduate program that does not have the traditional research requirement. The program consists primarily of coursework in geochemistry and allied fields with an emphasis on environmental applications. No research is required though the program does allow for independent study, professional development, internship, and cooperative experience.

Application

Undergraduate students at CSM must declare an interest during their third year to allow for planning of coursework that will apply towards the program. These students must have an overall GPA of at least 3.0. Students majoring in other departments besides the Department of Geology and Geological Engineering and the Department of Chemistry and Geochemistry may want to decide on the combined degree program option earlier to be sure prerequisites are satisfied. Applicants other than CSM undergraduates who are applying for this non-thesis Master degree program must follow the same procedures that all prospective graduate students follow. However, the requirement of the general GRE may be waived.

Prerequisites

Each entering student will have an entrance interview with members of the geochemistry faculty. Each department recognizes that entering students may not be proficient in both areas. A placement examination in geology and/or chemistry may be required upon the discretion of the interviewing faculty. If a placement examination is given, the results may be used to establish deficiency requirements. Credit toward a graduate degree will not be granted for courses taken to fulfill deficiencies.

Requirements

A minimum of 30 credit hours are required, with an overall GPA of at least 3.0. The overall course requirements will depend on the background of the individual, but may be tailored to professional objectives.

A 10 credit-hour program consists of:

GEGN466*: Groundwater Engineering,
CHGC503: Introduction to Geochemistry,
CHGC509: Aqueous Geochemistry.

*If this course is transferred from the undergraduate program, another course out of the core areas listed below must be substituted.

In addition, 14 credit hours must be selected from the following core areas: geochemical methods, geographic information system, geological data analysis, groundwater engineering or modeling, hydrothermal geochemistry, isotope geochemistry, physical chemistry, microbiology, mineralogy, organic geochemistry, and thermodynamics. This selection of courses must include at least one laboratory course.

CHGN503: Advanced Physical Chemistry,
CHGC504: Methods in Geochemistry,
CHGC506: Water Analysis Laboratory,
GEOL512: Mineralogy and Crystal Chemistry,
CHGC527: Organic Geochemistry of Fossil Fuels and Ore Deposits,
GEOL530: Clay Characterization,
GEGN532: Geological Data Analysis,
GEOL550: Integrated Basin Modeling,
CHGC555: Environmental Organic Chemistry,
CHGC562: Microbiology and the Environment,
CHGC563: Environmental Microbiology Laboratory,
CHGC564: Biogeochemistry and Geomicrobiology,
GEGN575: Applications of Geographic Information Systems,
GEGN581: Advanced Groundwater Engineering
GEGN583: Mathematical Modeling of Groundwater Systems,
ESGN586: Molecular Microbial Ecology and the Environment,
CHGC610: Nuclear and Isotopic Geochemistry,
GEGN683: Advanced Groundwater Modeling.

The selection of courses mentioned in the previous paragraph must include at least one laboratory course (CHGC506 or GEOL530).

An additional 6 credit-hours of free electives may be selected to complete the 30 credit-hour requirement. Free electives may be selected from the course offerings of the Department of Geology and Geological Engineering, the Department of Chemistry and Geochemistry, or the Environmental Science and Engineering Division, and may also be independent study credits taken to fulfill a research cooperative, or other professional development experience. A course program will be designed in advanced through consultation between the student and an advisor from the Geochemistry Committee of the Whole.

Master of Science and Doctor of Philosophy Prerequisites

Each entering student will have an entrance interview with members of the Geochemistry faculty. Each department recognizes that entering students may not be proficient in both areas. A placement examination in geology and/or chemistry may be required upon the discretion of the interviewing faculty. If a placement examination is given, the results may be used to establish deficiency requirements. Credit toward a graduate degree will not be granted for courses taken to fulfill deficiencies.

Requirements

The Master of Science (Geochemistry) degree requires a minimum of 36 semester hours including at least 24 semester hours of course work and 12 hours of research credits. To ensure breadth of background, the course of study for the Master of Science (Geochemistry) degree must include:

CHGC503: Introduction to Geochemistry,
CHGC504: Methods in Geochemistry.

Master of Science (Geochemistry) students must take two courses selected from the following list:

CHGN503: Advanced Physical Chemistry,
CHGC509: Introduction to Aqueous Geochemistry,
GEOL512: Mineralogy and Crystal Chemistry,
CHGC513: Hydrothermal Geochemistry,
CHGC514: Geochemical Thermodynamics and Kinetics,
CHGC610: Nuclear and Isotopic Geochemistry.

In addition, all students must complete a one hour laboratory course selected from several available. Master of Science (Geochemistry) students must also complete an appropriate thesis, based upon original research they have conducted. A thesis proposal and course of study must be approved by the student's thesis committee before the student begins substantial work on the thesis research.

The requirement for the Doctor of Philosophy (Geochemistry) program will be established individually by a student's thesis committee, but must meet the minimum requirements presented below. The Doctor of Philosophy (Geochemistry)

program will require a minimum of 72 credit hours. At least 24 hours must be research credit and at least 18 hours must be course work. Up to 24 hours of course credit may be transferred from previous graduate-level work upon approval of the thesis committee. Research credits may not be transferred. Students who enter the Doctor of Philosophy (Geochemistry) program with a thesis-based Master of Science degree from another institution may transfer up to 36 semester hours, upon approval of the thesis committee, in recognition of the course work and research completed for that degree.

Doctor of Philosophy (Geochemistry) students must take:
CHGC503: Introduction to Geochemistry,
CHGC504: Methods in Geochemistry,
CHGC514: Geochemical Thermodynamics and Kinetics.

In addition, all students must take a one hour laboratory course, plus two additional courses selected from the following list:

CHGN503: Advanced Physical Chemistry,
CHGC509: Introduction to Aqueous Geochemistry,
GEOL512: Mineralogy and Crystal Chemistry,
CHGC513: Hydrothermal Geochemistry,
CHGC610: Nuclear and Isotopic Geochemistry

Doctor of Philosophy (Geochemistry) students must also complete an appropriate thesis, based upon original research they have conducted. A thesis proposal and course of study must be approved by the student's thesis committee before the student begins substantial work on the thesis research.

Master of Science (Geochemistry) and Doctor of Philosophy (Geochemistry) students resident in the Department of Chemistry and Geochemistry or the Department of Geology and Geological Engineering shall adhere to the seminar rules and requirements of the department of residence.

Qualifying Examination

Doctor of Philosophy (Geochemistry) students must take a qualifying examination. It is expected that this exam will be completed within three years of matriculation or after the bulk of course work is finished, whichever occurs earlier. This examination will be administered by the student's thesis committee and will consist of an oral and a written examination, administered in a format to be determined by the thesis committee. Two negative votes in the thesis committee constitute failure of the examination.

In case of failure of the qualifying examination, a re-examination may be given upon the recommendation of the thesis committee and approval of the Dean of Graduate Studies. Only one re-examination may be given.

Tuition

The Master of Science (Geochemistry) and Doctor of Philosophy (Geochemistry) programs have been admitted to the Western Regional Graduate Program. This entity recognizes the Geochemistry Program as unique in the region. Designation of the Geochemistry Program by Western Regional Graduate program allows residents of western states to enroll in the program at Colorado resident tuition rates. Eligible states include Alaska, Arizona, California, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, South Dakota, Utah, Washington and Wyoming.

Geology and Geological Engineering

JOHN D. HUMPHREY, Associate Professor and Department Head
JOHN B. CURTIS, Professor
WENDY J. HARRISON, Professor and Associate Provost
MURRAY W. HITZMAN, Professor, Charles F. Fogarty Professor of Economic Geology
JOHN E. McCRAY, Professor and Division Director, Environmental Science and Engineering
PAUL SANTI, Professor
STEPHEN A. SONNENBERG, Professor, Charles Boettcher Distinguished Chair in Petroleum Geology
RICHARD F. WENDLANDT, Professor
DAVID A. BENSON, Associate Professor
JERRY D. HIGGINS, Associate Professor
REED M. MAXWELL, Associate Professor
PIRET PLINK-BJORKLUND, Associate Professor
BRUCE TRUDGILL, Associate Professor
WEI ZHOU, Associate Professor
JENNIFER L. ASCHOFF, Assistant Professor
NIGEL M. KELLY, Assistant Professor
YVETTE KUIPER, Assistant Professor
THOMAS MONECKE, Assistant Professor
CHRISTIAN V. SHOREY, Teaching Associate Professor
CHARLES F. KLUTH, Distinguished Scientist
DAVID PYLES, Research Professor
DONNA S. ANDERSON, Research Associate Professor
MASON DYKSTRA, Research Associate Professor
NICHOLAS B. HARRIS, Research Associate Professor
KARIN HOAL, Research Associate Professor
MAEVE BOLAND, Research Assistant Professor
MARY CARR, Research Assistant Professor
THOMAS L.T. GROSE, Professor Emeritus
JOHN D. HAUN, Professor Emeritus
NEIL F. HURLEY, Professor Emeritus
RICHARD W. HUTCHINSON, Professor Emeritus
KEENAN LEE, Professor Emeritus
EILEEN POETER, Professor Emerita
SAMUEL B. ROMBERGER, Professor Emeritus
A. KEITH TURNER, Professor Emeritus
JOHN E. WARME, Professor Emeritus
ROBERT J. WEIMER, Professor Emeritus
L. GRAHAM CLOSS, Associate Professor Emeritus
TIMOTHY A. CROSS, Associate Professor Emeritus
GREGORY S. HOLDEN, Associate Professor Emeritus
ERIC P. NELSON, Associate Professor Emeritus

Degrees Offered:

Professional Master Degree
(Petroleum Reservoir Systems) (Non-Thesis)
Professional Master Degree (Mineral Exploration)
(Non-Thesis)
Professional Master Degree (Geochemistry) (Non-Thesis)
Master of Engineering (Geological Engineer) (Non-Thesis)
Master of Science (Geology)
Master of Science (Geological Engineering)
Master of Science (Geochemistry)
Master of Science (Hydrology), Thesis option
Master of Science (Hydrology), Non-thesis option
Doctor of Philosophy (Geology)

Doctor of Philosophy (Geochemistry)
Doctor of Philosophy (Geological Engineering)
Doctor of Philosophy (Hydrology)

Program Description:

The Department of Geology and Geological Engineering offers Master of Science and Doctor of Philosophy degrees in Geology and Geochemistry; and Master of Engineering, Master of Science and Doctor of Philosophy degrees in Geological Engineering. Professional Master Degrees are offered in Petroleum Reservoir Systems, Mineral Exploration, and Geochemistry. Geological Engineering degrees require possession or acquisition of an undergraduate engineering degree or its equivalent.

Graduate students desiring to study ground water, engineering geology/geotechnics, mining engineering geology and some environmental applications are generally expected to pursue the Geological Engineering degree. Students desiring to study petroleum or minerals exploration or development sciences, geochemistry and/or geology generally pursue Geology or Geochemistry degrees. Students are initially admitted to either geoscience or geological engineering degree programs and must receive approval of the GE department Graduate Advisory Committee to switch degree category.

Program Requirements:

Geology Degrees:

The **Master of Science (Geology)** program will require 36 semester hours of course and research credit hours (a maximum of 9 credit hours may be 400-level course work). Twelve of the 36 credit hours must be research credits. To ensure breadth of background, the course of study for the Master of Science (Geology) degree must include at least one graduate course in each of the fields of stratigraphy/ sedimentology, structural geology/tectonics, and petrology. At the discretion of the student's Thesis Advisory Committee, an appropriate course may be substituted for one (and only one) of the fields above. Students must also complete GEOL507 (Graduate Seminar), as part of their course programs. All Master of Science (Geology) candidates must also complete an appropriate thesis, based upon original research they have conducted. A thesis proposal and course of study must be approved by the student's Thesis Advisory Committee before the candidate begins substantial work on the thesis research.

The requirement for **Doctor of Philosophy (Geology)** program will be established individually by a student's Doctoral Thesis Advisory Committee, but must meet the minimum requirements presented below. The Doctor of Philosophy (Geology) academic program will require a minimum of 72 hours of course and research credit hours (a maximum of 9 credit hours may be 400-level course work). All students must complete a minimum of 24 research credit hours and must complete a minimum of 48 course credit hours. Up to 24 relevant course credit hours may be awarded by the student's Doctoral Thesis Advisory Committee for completion

of a Master of Science degree (at CSM or elsewhere). To ensure breadth of background, the course of study to the degree of Doctor of Philosophy (Geology) must include at least one graduate course in each of the fields of stratigraphy/sedimentology, structural geology/tectonics, and petrology (this breadth requirement may be satisfied by courses already taken as part of a Master of Science degree). At the discretion of the student's Doctoral Thesis Advisory Committee, an appropriate course may be substituted for one (and only one) of the fields above. In addition, students must complete GEOL 608 (History of Geological Concepts) or an appropriate equivalent approved by the Doctoral Thesis Advisory Committee. All Doctor of Philosophy (Geology) students must pass a qualifying examination and must complete an appropriate thesis based upon original research they have conducted. A thesis proposal and course of study must be approved by the student's Doctoral Thesis Advisory Committee before the student begins substantial work on the thesis research.

Prospective students should submit the results of the Graduate Record Examination with their application for admission to graduate study. In the event that it is not possible, because of geographic and other restrictions, to take the Graduate Record Examination prior to enrolling at Colorado School of Mines, enrollment may be granted on a provisional basis subject to satisfactory completion of the examination within the first year of residence.

Prerequisites:

Geology Program:

The candidate for the degree of Master of Science (Geology) or Doctor of Philosophy (Geology) must have completed the following or equivalent subjects, for which credit toward an advanced degree will not be granted.

- General Geology
- Structural Geology
- Field Geology (6 weeks)
- Mineralogy
- Petrology
- Stratigraphy
- Chemistry (3 semesters, including at least 1 semester of physical or organic)
- Mathematics (2 semesters of calculus)
- An additional science course (other than geology) or advanced mathematics
- Physics (2 semesters)

Professional Master Degree Programs:

Candidates for the Professional Master Degree must possess an appropriate geosciences undergraduate degree or its equivalent. Prerequisites are the same as those required for the Master of Science (Geology) Degree.

Engineering Programs:

The candidate for the degree of Master of Engineering (Geological Engineer), Master of Science (Geological Engi-

neering) or Doctor of Philosophy (Geological Engineering) must have completed the following or equivalent subjects. Graduate credit may be granted for courses at or above the 400 level, if approved by the student's advisory committee.

Mathematics:

Four semesters including: Calculus (2 semesters) and one semester of any two of: calculus III, differential equations, probability and statistics, numerical analysis, linear algebra, operations research, optimization.

Basic Science:

Chemistry (2 semesters)
Mineralogy and Petrology
Physics (2 semesters)
Stratigraphy or Sedimentation
Physical Geology
Computer Programming or GIS

Engineering Science:

Structural Geology and one semester in four of the following subjects:
Physical Chemistry or Thermodynamics
Statics
Mechanics of Materials
Fluid Mechanics
Dynamics
Soil Mechanics
Rock Mechanics

Engineering Design:

Field Geology

As part of the graduate program each student must take one semester in two of the following subjects if such courses were not taken for a previous degree:

Mineral Deposits/Economic Geology
Hydrogeology
Engineering Geology

and also as part of the graduate program one semester in three of the following subjects if such courses were not taken for a previous degree:

Foundation Engineering
Engineering Hydrology
Geomorphology
Airphoto Interpretation, Photogeology, or Remote Sensing
Petroleum Geology
Introduction to Mining
Introductory Geophysics
Engineering Geology Design
Mineral Exploration Design
Groundwater Engineering Design
Other engineering design courses as approved by the program committee

Professional Master in Mineral Exploration

This non-thesis, master degree program is designed for working professionals who want to increase their knowledge

and skills, while gaining a thorough up-date of advances across the spectrum of economic geology, mineral exploration techniques, and mining geosciences. Admission to the program is competitive. Preference will be given to applicants with a minimum of two years of industrial or equivalent experience.

The program requires a minimum of 30 credit hours. A minimum of 15 credit hours must be accumulated in five of the following core areas: mineral deposits, mineral exploration, applied geophysics, applied geochemistry, applied structural geology, field geology, and economic evaluation. An additional 15 credit hours may be selected from the course offerings of the Department of Geology and Geological Engineering and allied departments including Mining Engineering, Economics and Business, Geophysics, Chemistry and Geochemistry, Metallurgy and Materials Science, and Environmental Sciences.

Selection of courses will be undertaken in consultation with the academic advisor. Up to 9 credit hours may be at the 400-level. All other credits towards the degree must be 500-level or above. A maximum of 9 credit hours may be independent study focusing on a topic relevant to the mineral exploration and mining industries.

Prerequisites: Admission to the program is generally restricted to individuals holding a four-year undergraduate degree in earth sciences. Candidates for the degree of Professional Master in Mineral Exploration must have completed the following or equivalent subjects, for which credit toward the advanced degree will not be granted. These are general geology, structural geology, field geology, mineralogy, petrology, chemistry (2 semesters), mathematics (2 semesters of calculus), physics (1 semester), and an additional science course other than geology.

Professional Master in Petroleum Reservoir Systems

This is a non-thesis, interdisciplinary master degree program jointly administered by the departments of Geology and Geological Engineering, Geophysics, and Petroleum Engineering. This program consists only of coursework in petroleum geoscience and engineering. No research is required.

General Administration:

The three participating departments share oversight for this program through a committee consisting of one faculty member from each of the three departments. Students gain admission to the program by application to any of the three sponsoring departments. Students are administered by that department into which they first matriculate.

Requirements:

The program requires a minimum of 36 credit hours. Up to 9 credit hours may be at the 400 level. All other credits toward the degree must be 500 level or above.

9 hours must consist of:

1 course selected from the following:

GPGN419/PEGN 419 Well Log Analysis and Formation Evaluation

GPGN519/PEGN519 Advanced Formation Evaluation

2 courses selected from the following:

GEGN439/GPGN439/PEGN439 Multi-Disciplinary Petroleum Design

GEGN503/GPGN503/PEGN503 Integrated Exploration and Development I

GEGN504/GPGN504/PEGN504 Integrated Exploration and Development II

9 additional hours must consist of one course each from the 3 participating departments.

The remaining 18 hours may consist of graduate courses from any of the 3 participating departments, or other courses approved by the committee. Up to 6 hours may consist of independent study, including an industry project.

Geological Engineering Degrees:

The **Master of Engineering (Non-Thesis) Program in Geological Engineering** outlined below may be completed by individuals already holding undergraduate or advanced degrees or as a **combined degree program** (see Graduate Degrees and Requirements section of this bulletin) by individuals already matriculated as undergraduate students at The Colorado School of Mines. The program is comprised of 36 credit hours with 30 course credit hours and 6 credit hours of independent study (GEGN 599). Up to nine credit hours can be at the 400 level and the remainder will be 500 or 600 level. For the combined degree program, courses recommended as appropriate for double counting may be chosen from GEGN 403, 439, 469, and 470. The typical program plan includes 15 course credit hours in both the fall and the spring terms followed by 6 independent study credit hours during the summer term. The non-thesis degree includes three areas of specialization (engineering geology/geotechnics, ground-water engineering, and mining geological engineering).

All Master of Engineering (Non-Thesis) program will include the following core requirements:

GEGN532 Geological Data Analysis (3)

GEGN599 Independent Study in Geological Engineering (6)

GEGN599 requires a project and report that demonstrate competence in the application of geological engineering principles that merits a grade of B or better. The project topic and content of the report is determined by the student's advisor, in consultation with the student, and is approved by the Geological Engineering Graduate Program Committee. The format of the report will follow the guidelines for a professional journal paper.

The student, in consultation with the advisor, must prepare a formal program of courses and independent study topic for approval by the Geological Engineering Graduate Program

Committee. The program must be submitted to the committee on or before the end of the first week of classes of the first semester.

The most common difficulty in scheduling completion of the degree involves satisfaction of prerequisites. Common deficiency courses are Statics, Mechanics of Materials, and Fluid Mechanics. These are essential to the engineering underpinnings of the degree. An intense program at CSM involving 18 credit hours each semester including Statics in the fall and Fluid Mechanics in the spring and 9 credits in the summer including Mechanics of Materials, allows these classes to be taken along with the standard program. Some students may choose to take these prerequisites elsewhere before arriving on the CSM campus.

Engineering Geology/Geotechnics Specialty (Non-Thesis)

Students working towards a Masters of Engineering (non-thesis) with specialization in Engineering Geology/Geotechnics must meet the prerequisite course requirements listed later in this section. Required courses for the degree are:

GEGN468 Engineering Geology & Geotechnics (4)

GEGN467 Groundwater Engineering (4)

GEGN532 Geological Data Analysis (3)

GEGN570 Case Histories in Engineering Geology (3), *or*

GEGN571 Advanced Engineering Geology (3)

GEGN573 Geological Engineering Site Investigation (3)

GEGN599 Independent Study in Geological Engineering (6)

GEGN671 Landslides: Investigation, Analysis & Mitigation (3), *or*

GEGN672 Advanced Geotechnics (3)

Electives* (10)

*Electives and course substitutions are approved by the Geological Engineering Graduate Program Committee and must be consistent with the program specialization. As part of their elective courses, students are required to have an advanced course in both soil and rock engineering. Possibilities for other electives include graduate-level rock mechanics and rock engineering, soil mechanics and foundations, ground water, site characterization, geographical information systems (GIS), project management and geophysics, for example.

Ground Water Engineering/Hydrogeology Specialty (Non-Thesis)

Students working towards a Masters of Engineering (non-thesis) with specialization in Ground Water Engineering and Hydrogeology must meet the prerequisite course requirements listed later in this section. Required courses for the degree (36 hours) are:

GEGN467 Ground Water Engineering (3) Fall

GEGN532 Geological Data Analysis (3) Fall

GEGN681 Vadose Zone Hydrology (3) Fall, *or*

GEGN581 Advanced Hydrogeology (3) Fall

GEGN509 Aqueous Geochemistry (3) Fall, *or*

ESGN500 Environmental Water Chemistry (3)
Fall or Spring

GEGN583 Mathematical Modeling of Ground Water Systems (3) Spring

GEGN470 Ground Water Engineering Design (3)
Spring, *or*

ESGN575 Hazardous Waste Site Remediation (3) Spring

GEGN575 Applications of Geographic Information Systems (3) Fall or Spring

GEGN599 Independent Study in Geological Engineering (6) Summer

Electives* (9)

*Electives and course substitutions are approved by the Geological Engineering Graduate Program Committee and must be consistent with the program specialization. As part of their elective courses, students are required to have at least one additional advanced course in hydrogeochemistry. Possibilities for other electives include courses in site characterization, environmental science and engineering, geographical information systems (GIS), geochemistry, and geophysics, for example.

Mining Geological Engineering Specialty (Non-Thesis)

Students working towards a Masters of Engineering (non-thesis) with specialization in Mining Geology must meet the prerequisite course requirements listed later in this section. Required courses for the degree are:

GEGN468 Engineering Geology & Geotechnics (4), *or*
GEGN467 Groundwater Engineering (4)
GEGN532 Geological Data Analysis (3)
GEOL515 Advanced Mineral Deposits(3)
MNGN523. Special Topics-Surface Mine Design (2), *or*
MNGN523 Special Topics-Underground Mine Design (2)

Electives* (3)

GEGN518 Mineral Exploration (3) *or* GEGN/MNGN528 Mining Geology (3)

GEOL505. Applied Structural Geology (3)

GEOL520 New Developments in the Geology and Exploration of Ore Deposits (2)

Electives* (6)

GEGN599 Independent Study in Geological Engineering (6)

*Electives and course substitutions are approved by the Geological Engineering Graduate Program Committee and must be consistent with the program specialization. Typically, the elective courses are selected from the following topical areas: mineral deposits geology, ore microscopy, applied geophysics, applied geochemistry, remote sensing, engineering geology, environmental geology, engineering economics / management, mineral processing, geostatistics, geographic information systems, environmental or exploration and mining law, and computers sciences.

The **Master of Science Degree Program in Geological Engineering** requires a minimum of 36 semester hours of course and project/research credit hours (a maximum of 9 credit hours may be 400-level course work), plus a Graduate Thesis. The degree includes three areas of specialization (engineering geology/geotechnics, groundwater engineering, and mining geological engineering) with common requirements as follows:

1. GEGN532 Geological Data Analysis (3)
2. At least twelve hours of research credits are required: Master of Science Research (GEGN705).
3. At least 24 course credit hours are required, and must be approved by the student's thesis committee.

The content of the thesis is to be determined by the student's advisory committee in consultation with the student. The Masters thesis must demonstrate creative and comprehensive ability in the development or application of geological engineering principles. The format of the thesis will follow the guidelines described under the *Thesis Writer's Guide*.

In addition to the common course requirements, the Master of Science degree with **specialization in Engineering Geology/Geotechnics** requires:

GEGN467 Groundwater Engineering (4)
GEGN468 Engineering Geology & Geotechnics (4)
GEGN570 Case Histories in Engineering Geology (3)

And at least two of the following courses:

GEGN571 Advanced Engineering Geology (3)
GEGN573 Geological Engineering Site Investigation (3)
GEGN671 Landslides: Investigation, Analysis & Mitigation
GEGN672 Advanced Geotechnics (3)

Typically, the additional courses are selected from the following topical areas: engineering geology, groundwater engineering, groundwater modeling, soil mechanics and foundations, rock mechanics, underground construction, seismic hazards, geomorphology, geographic information systems, construction management, finite element modeling, waste management, environmental engineering, environmental law, engineering management, and computer programming.

In addition to the common course requirements, the Master of Science degree with **specialization in Ground Water** also requires the following courses:

GEGN467 Groundwater Engineering (4)
GEGN468 Engineering Geology & Geotechnics (4)
GEGN572 Ground-Water Engineering (3)
GEGN583 Mathematical Modeling Of Groundwater (3)

2 courses selected as follows:

ESGN500 Environmental Water Chemistry (3) *or*
GEGN509/CHGC509 (3) Introduction To Aqueous Geochemistry

ESGN503 Environmental Pollution (3) *or*
GEGN581 (3) Advanced Groundwater

As nearly all ground water software is written in Fortran, if the student does not know Fortran, a Fortran course must be taken before graduation, knowledge of other computer languages is encouraged

In addition to the common course requirements, the Master of Science degree with **specialization in Mining Geology** also requires:

1. GEGN528 Mining Geology (3) or GEGN518 Mineral Exploration (3)
2. Specialty Areas (17 credits minimum.)

This will include about 5–6 courses (predominantly at 500 and 600 level) selected by the student in conjunction with the Masters program advisory committee. Specialty areas might include: mineral deposits geology, mineral exploration, mining geology, mineral processing, applied geophysics, applied geochemistry, engineering geology, environmental geology, geostatistics, geographic information systems, environmental or exploration and mining law, engineering economics/management, and computer sciences.

The **Doctor of Philosophy (Geological Engineering)** degree requires a minimum of 72 hours course work and research combined. Requirements include the same courses as for the Master of Science (Geological Engineering) with the additions noted below. After completing all coursework and an admission to candidacy application, the Dissertation is completed under GEGN706 Graduate Research Doctor Of Philosophy. The content of the dissertation is to be determined by the student's advisory committee in consultation with the student. The dissertation must make a new contribution to the geological engineering profession. The format of the dissertation will follow the guidelines described under the Thesis Writer's Guide. A minimum of 24 research credits must be taken. Up to 24 course credit hours may be awarded by the candidate's Doctoral Thesis Advisory Committee for completion of a Master of Science degree (at CSM or elsewhere).

In addition to the common course requirements, a PhD **specializing in Engineering Geology/Geotechnics** requires additional course work tailored to the student's specific interests and approved by the doctoral program committee. (Typically, the additional courses are selected from the following topical areas: engineering geology, groundwater engineering, groundwater modeling, soil mechanics and foundations, rock mechanics, underground construction, seismic hazards, geomorphology, geographic information systems, construction management, finite element modeling, waste management, environmental engineering, environmental law, engineering management, and computer programming.)

In addition to the common course requirements listed previously, a PhD **specializing in Ground Water** also requires:

GEGN581 (3) Advanced Groundwater Engineering
GEGN669 (3) Advanced Topics In Engineering
Hydrogeology
GEGN681 (3) Vadose Zone Hydrology
GEGN683 (3) Advanced Ground Water Modeling

and additional course work tailored to the student's specific interests, which are likely to include chemistry, engineering, environmental science, geophysics, math (particularly Partial Differential Equations), microbiology, organic chemistry, contaminant transport, soil physics, optimization, shallow resistivity or seismic methods. The student's advisory committee has the authority to approve elective courses and any substitutions for required courses.

In addition to the common course requirements, a PhD **specializing in Mining Geology** also requires:

GEGN468. Engineering Geology & Geotechnics (4) *or*
GEGN467. Groundwater Engineering (4)

GEGN518. Mineral Exploration (3) *or*
GEGN528. Mining Geology (3)

GEOLOGY505. Applied Structural Geology (3)

GEOLOGY515. Advanced Mineral Deposits (3)

GEOLOGY520 New Developments in the Geology and Exploration of Ore Deposits (2)

MNGN523. Special Topics-Surface Mine Design (2) *or*
MNGN523. Special Topics- Underground Mine Design (2)

Additional course work suited to the student's specific interests and approved by the doctoral program committee. (Typically, the additional courses are selected from the following topical areas: mineral deposits geology, mineral exploration, mining geology, mineral processing, applied geophysics, applied geochemistry, engineering geology, environmental geology, geostatistics, geographic information systems, environmental or exploration and mining law, engineering economics/management, and computer sciences).

Geochemistry

The Geochemistry Program is an interdisciplinary graduate program administered by the departments of Geology and Geological Engineering and Chemistry and Geochemistry. The geochemistry faculty from each department are responsible for the operations of the program. Student reside in either Department. Please see the Geochemistry section of the Bulletin for detailed information on this degree program.

Hydrologic Science and Engineering

The Hydrologic Science and Engineering (HSE) Program is an interdisciplinary graduate program comprised of faculty from several different CSM departments. Please see the Hydrologic Science and Engineering section of the Bulletin for detailed information on this degree program.

Qualifying Examination

Ph.D. students in Geology, Geological Engineering, Geochemistry, and Hydrologic Science and Engineering must

pass a qualifying examination by the end of the second year of their programs. This timing may be adjusted for part-time students. This examination will be administered by the student's Doctoral committee and will consist of an oral and a written examination, administered in a format to be determined by the Doctoral Committee. Two negative votes in the Doctoral Committee constitute failure of the examination.

In case of failure of the qualifying examination, a re-examination may be given upon the recommendation of the Doctoral Committee and approval of the Graduate Dean. Only one re-examination may be given.

Description of Courses

GEGN401. MINERAL DEPOSITS (I) Introductory presentation of magmatic, hydrothermal, and sedimentary metallic ore deposits. Chemical, petrologic, structural, and sedimentological processes that contribute to ore formation. Description of classic deposits representing individual deposit types. Review of exploration sequences. Laboratory consists of hand specimen study of host rock-ore mineral suites and mineral deposit evaluation problems. Prerequisite: DCGN209, GEGN307, GEGN316, or consent of instructor. 3 hours lecture, 3 hours lab; 4 semester hours.

GEGN403. MINERAL EXPLORATION DESIGN (II) (WI) Exploration project design: commodity selection, target selection, genetic models, alternative exploration approaches and associated costs, exploration models, property acquisition, and preliminary economic evaluation. Lectures and laboratory exercises to simulate the entire exploration sequence from inception and planning through implementation to discovery, with initial ore reserve calculations and preliminary economic evaluation. Prerequisite: GEGN401 and EPIC264. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN404. ORE MICROSCOPY (II) Identification of ore minerals using reflected light microscopy, micro-hardness, and reflectivity techniques. Interpretation of common ore mineral textures, including those produced by magmatic segregation, open space filling, replacement, exsolution, and recrystallization. Guided research on the ore mineralogy and ore textures of classical ore deposits. Prerequisite: GEOL321, GEGN401, or consent of instructor. 6 hours lab; 3 semester hours.

GEOC407. ATMOSPHERE, WEATHER AND CLIMATE (II) An introduction to the Earth's atmosphere and its role in weather patterns and long term climate. Provides basic understanding of origin and evolution of the atmosphere, Earth's heat budget, global atmospheric circulation and modern climatic zones. Long- and short-term climate change including paleoclimatology, the causes of glacial periods and global warming, and the depletion of the ozone layer. Causes and effects of volcanic eruptions on climate, El Nino, acid rain, severe thunderstorms, tornadoes, hurricanes, and avalanches are also discussed. Microclimates and weather patterns common in Colorado. Prerequisite: Completion of CSM

freshman technical core, or equivalent. 3 hours lecture; 3 semester hours. Offered alternate years.

GEOC408. INTRODUCTION TO OCEANOGRAPHY (II) An introduction to the scientific study of the oceans, including chemistry, physics, geology, biology, geophysics, and mineral resources of the marine environment. Lectures from pertinent disciplines are included. Recommended background: basic college courses in chemistry, geology, mathematics, and physics. 3 hours lecture; 3 semester hours. Offered alternate years.

GEOL410. PLANETARY GEOLOGY (II) Geology of the terrestrial planets and moons, specifically the Moon and Mars. Emphasis will be placed on the geomorphology, planetary materials, geologic structure, geologic history, and natural resource potential of terrestrial planetary bodies. Lectures present the knowledge of materials, geomorphic processes, and geologic history. Prerequisite: SYGN101. 2 hours lecture; 2 semester hours.

GEGN432. GEOLOGICAL DATA MANAGEMENT (I) Techniques for managing and analyzing geological data, including statistical analysis procedures and computer programming. Topics addressed include elementary probability, populations and distributions, estimation, hypothesis testing, analysis of data sequences, mapping, sampling and sample representativity, linear regression, and overview of univariate and multivariate statistical methods. Practical experience with principles of software programming and statistical analysis for geological applications via supplied software and data sets from geological case histories. Prerequisites: Senior standing in Geological Engineering or permission of instructor. 1 hour lecture, 6 hours lab; 3 semester hours.

GEGN438. PETROLEUM GEOLOGY (I) Source rocks, reservoir rocks, types of traps, temperature and pressure conditions of the reservoir, theories of origin and accumulation of petroleum, geology of major petroleum fields and provinces of the world, and methods of exploration of petroleum. Term report required. Laboratory consists of well log analysis, stratigraphic correlation, production mapping, hydrodynamics and exploration exercises. Prerequisites: GEOL308 or GEOL309; GEOL314 or GEOL315; GEGN316 or GPGN486 or PEGN316. 3 hours lecture, 3 hours lab; 4 semester hours.

GEGN439/GPGN439/PEGN439. MULTI-DISCIPLINARY PETROLEUM DESIGN (II) (WI) This is a multidisciplinary design course that integrates fundamentals and design concepts in geological, geophysical, and petroleum engineering. Students work in integrated teams consisting of students from each of the disciplines. Multiple open-end design problems in oil and gas exploration and field development, including the development of a prospect in an exploration play and a detailed engineering field study, are assigned. Several detailed written and oral presentations are made throughout the semester. Project economics including risk analysis are

an integral part of the course. Prerequisites: GP majors: GPGN302, 303 and EPIC268. PE majors: PEGN316, PEGN414, PEGN422, PEGN423, PEGN424 (or concurrent) GEOL308 and EPIC251; GE Majors: GEOL308 or GEOL309, GEGN438, GEGN316, and EPIC264. 2 hours lecture, 3 hours lab; 3 hours lecture; 3 semester hours.

GEOL443. UNDERGRADUATE FIELD SEMINAR (I, II, SUM 1, SUM 2) Special advanced classroom and field programs emphasizing detailed study of some aspects of the geology of an area or region. Field studies normally conducted away from the Golden campus. Classroom course content dependent on area of study. Consent of instructor and/or Department Head required. Fees assessed for field and living expenses and transportation. 1 to 3 semester hours; may be repeated for credit with consent of instructor.

GEGN466. GROUNDWATER ENGINEERING (I) Theory of groundwater occurrence and flow. Relation of groundwater to surface water; potential distribution and flow; theory of aquifer tests; water chemistry, water quality, and contaminant transport. Laboratory sessions on water budgets, water chemistry, properties of porous media, solutions to hydraulic flow problems, analytical and digital models, and hydrogeologic interpretation. Prerequisite: mathematics through calculus and MATH225, GEOL309, GEOL315, and GEGN351, or consent of instructor. 3 hours lecture, 3 semester hours.

GEGN467. GROUNDWATER ENGINEERING (I) Theory of groundwater occurrence and flow. Relation of groundwater to surface water; potential distribution and flow; theory of aquifer tests; water chemistry, water quality, and contaminant transport. Laboratory sessions on water budgets, water chemistry, properties of porous media, solutions to hydraulic flow problems, analytical and digital models, and hydrogeologic interpretation. Prerequisite: mathematics through calculus and MATH225, GEOL309, GEOL314 or GEOL315, and GEGN351, or consent of instructor. 3 hours lecture, 3 hours lab; 4 semester hours.

GEGN468. ENGINEERING GEOLOGY AND GEOTECHNICS (I) Application of geology to evaluation of construction, mining, and environmental projects such as dams, waterways, tunnels, highways, bridges, buildings, mine design, and land-based waste disposal facilities. Design projects including field, laboratory, and computer analysis are an important part of the course. Prerequisite: MNGN321 and concurrent enrollment in EGGN361/EGGN363 or consent of instructor. 3 hours lecture, 3 hours lab, 4 semester hours.

GEGN469. ENGINEERING GEOLOGY DESIGN (II) (WI) This is a capstone design course that emphasizes realistic engineering geologic/geotechnics projects. Lecture time is used to introduce projects and discussions of methods and procedures for project work. Several major projects will be assigned and one to two field trips will be required. Students work as individual investigators and in teams. Final written

design reports and oral presentations are required. Prerequisite: GEGN468 or equivalent and EPIC264. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN470. GROUND-WATER ENGINEERING DESIGN (II) (WI) Application of the principles of hydrogeology and ground-water engineering to water supply, geotechnical, or water quality problems involving the design of well fields, drilling programs, and/or pump tests. Engineering reports, complete with specifications, analysis, and results, will be required. Prerequisite: GEGN467 or equivalent or consent of instructor and EPIC264. 2 hours lecture, 3 hours lab; 3 semester hours.

GEOL470/GPGN470. APPLICATIONS OF SATELLITE REMOTE SENSING (II) An introduction to geoscience applications of satellite remote sensing of the Earth and planets. The lectures provide background on satellites, sensors, methodology, and diverse applications. Topics include visible, near infrared, and thermal infrared passive sensing, active microwave and radio sensing, and geodetic remote sensing. Lectures and labs involve use of data from a variety of instruments, as several applications to problems in the Earth and planetary sciences are presented. Students will complete independent term projects that are presented both written and orally at the end of the term. Prerequisites: PHGN200 and MATH225 or consent of instructor. 2 hours lecture, 2 hours lab; 3 semester hours.

GEGN473. GEOLOGICAL ENGINEERING SITE INVESTIGATION (II) (WI) Methods of field investigation, testing, and monitoring for geotechnical and hazardous waste sites, including: drilling and sampling methods, sample logging, field testing methods, instrumentations, trench logging, foundation inspection, engineering stratigraphic column and engineering soils map construction. Projects will include technical writing for investigations (reports, memos, proposals, workplans). Class will culminate in practice conducting simulated investigations (using a computer simulator). 3 hours lecture; 3 semester hours.

GEGN475. APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS (II) An introduction to Geographic Information Systems (GIS) and their applications to all areas of geology and geological engineering. Lecture topics include: principles of GIS, data structures, digital elevation models, data input and verification, data analysis and spatial modeling, data quality and error propagation, methods of GIS evaluation and selection. Laboratories will use personal computer systems for GIS projects, as well as video presentations. Prerequisite: SYGN101. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN481. ADVANCED HYDROGEOLOGY (I) Lectures, assigned readings, and discussions concerning the theory, measurement, and estimation of ground water parameters, fractured-rock flow, new or specialized methods of well hydraulics and pump tests, tracer methods, and well con-

struction design. Design of well tests in variety of settings. Prerequisites: GEGN467 or consent of instructor. 3 hours lecture; 3 semester hours.

GEGN483. MATHEMATICAL MODELING OF GROUNDWATER SYSTEMS (II) Lectures, assigned readings, and direct computer experience concerning the fundamentals and applications of analytical and finite-difference solutions to ground water flow problems as well as an introduction to inverse modeling. Design of computer models to solve ground water problems. Prerequisites: Familiarity with computers, mathematics through differential and integral calculus, and GEGN467. 3 hours lecture; 3 semester hours.

GEGN/GEOL497. SPECIAL SUMMER PROGRAMS (S)

GEGN/GEOL498. SEMINAR IN GEOLOGY OR GEOLOGICAL ENGINEERING (I, II) Special topics classes, taught on a one-time basis. May include lecture, laboratory and field trip activities. Prerequisite: Approval of instructor and department head. Variable credit; 1 to 3 semester hours. Repeatable for credit under different topics.

GEGN499. INDEPENDENT STUDY IN ENGINEERING GEOLOGY OR ENGINEERING HYDROGEOLOGY (I, II) Individual special studies, laboratory and/or field problems in geological engineering or engineering hydrogeology. Prerequisite: Approval of instructor and department head. Variable credit; 1 to 3 semester hours. Repeatable for credit.

GEOL499. INDEPENDENT STUDY IN GEOLOGY (I, II) Individual special studies, laboratory and/or field problems in geology. Prerequisite: Approval of instructor and department. Variable credit; 1 to 3 semester hours. Repeatable for credit.

Courses

The following courses are not all offered each academic year. Any of those offered for which fewer than five students have registered may be omitted in any semester. All 500-level courses are open to qualified seniors with permission of the department and Dean of Graduate School. The 600-level courses are open only to students enrolled in the Graduate School.

GEOL501. APPLIED STRATIGRAPHY (I) Review of basic concepts in siliciclastic and carbonate sedimentology and stratigraphy. Introduction to advanced concepts and their application to exploration and development of fossil fuels and stratiform mineral deposits. Modern facies models and sequence-stratigraphic concepts applied to solving stratigraphic problems in field and subsurface settings. Prerequisites: GEOL314 or equivalent or consent of instructor. 3 hours lecture, 4 hours lab; 4 semester hours.

GEOL502. STRUCTURAL METHODS FOR SEISMIC INTERPRETATION (I) A practical course that covers the wide variety of structural methods and techniques that are essential to produce a valid and coherent interpretation of 2D and 3D seismic reflection data in structurally complex areas. Topics covered include: Extensional tectonics, fold and thrust

belts, salt tectonics, inversion tectonics and strike-slip fault systems. Laboratory exercises are based on seismic datasets from a wide variety of structural regimes from across the globe. The course includes a 4 day field trip to SE Utah. Prerequisite: GEOL309 and GEOL 314 or GEOL 315, or equivalents, or consent of instructor. 3 hours lecture/lab; 3 semester hours.

GEGN503/GPGN503/PEGN503. INTEGRATED EXPLORATION AND DEVELOPMENT (I) Students work alone and in teams to study reservoirs from fluvial-deltaic and valley fill depositional environments. This is a multidisciplinary course that shows students how to characterize and model subsurface reservoir performance by integrating data, methods and concepts from geology, geophysics and petroleum engineering. Activities and topics include field trips to surface outcrops, well logs, borehole cores, seismograms, reservoir modeling of field performance, written exercises and oral team presentations. Prerequisite: Consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours. Offered fall semester, odd years.

GEGN504/GPGN504/PEGN504. INTEGRATED EXPLORATION AND DEVELOPMENT (I) Students work in multidisciplinary teams to study practical problems and case studies in integrated subsurface exploration and development. The course addresses emerging technologies and timely topics with a general focus on carbonate reservoirs. Activities include field trips, 3D computer modeling, written exercises and oral team presentation. Prerequisite: Consent of instructor. 3 hours lecture and seminar; 3 semester hours. Offered fall semester, even years.

GEOL505. APPLIED STRUCTURAL GEOLOGY (II) Structural geology with emphasis on solving problems in field and lab exercises using systematic analysis by geometric and mapping techniques. Interpretation of the structural aspects of ore control, fossil fuels, and environmental geology. Relationships between mechanical properties and structural behavior of geological materials. Prerequisite: GEGN316 or equivalent. 2 hours lecture, 4 hours lab; 3 semester hours.

GEOL507. GRADUATE SEMINAR (II) Recent geologic ideas and literature reviewed. Preparation and oral presentation of short papers. 1 hour seminar; 1 semester hour. Required of all geology candidates for advanced degrees during their enrollment on campus.

GEGN509/CHGC509. INTRODUCTION TO AQUEOUS GEOCHEMISTRY (II) Analytical, graphical and interpretive methods applied to aqueous systems. Thermodynamic properties of water and aqueous solutions. Calculation and graphical expression of acid-base, redox and solution-mineral equilibria. Effect of temperature and kinetics on natural aqueous systems. Adsorption and ion exchange equilibria between clays and oxide phases. Behavior of trace elements and complexation in aqueous systems. Application of organic geochemistry to natural aqueous systems. Light stable and un-

stable isotopic studies applied to aqueous systems. Prerequisite: DCGN209 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours.

GEOL512. MINERALOGY AND CRYSTAL CHEMISTRY (I) Relationships among mineral chemistry, structure, crystallography, and physical properties. Systematic treatments of structural representation, defects, mineral stability and phase transitions, solid solutions, substitution mechanisms, and advanced methods of mineral identification and characterization. Applications of principles using petrological and environmental examples. Prerequisites: GEOL321, DCGN209 or equivalent or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours. Offered alternate years.

GEOL513/CHGC513. HYDROTHERMAL GEOCHEMISTRY (II) Geochemistry of high-temperature aqueous systems. Examines fundamental phase relationships in model systems at elevated temperatures and pressures. Major and trace element behavior during fluid-rock interaction. Theory and application of stable isotopes as applied to hydrothermal mineral deposits. Review of the origin of hydrothermal fluids and mechanisms of transport and deposition of ore minerals. Includes the study of the geochemistry of magmatic aqueous systems, geothermal systems, and submarine hydrothermal vents. Prerequisites: GEGN401 or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

GEOL514. BUSINESS OF ECONOMIC GEOLOGY (II) Examines the business side of mineral exploration including company structure, fundraising, stock market rules and regulations, and legal environment. Reviews the types of minerals exploration companies, differences between mineral sectors, rules and practices of listing a minerals company on a stock exchange, and legal requirements of listing and presenting data to stockholders. The course is centered on lectures by industry representatives from the Denver area. Includes participation in a technical conference in Vancouver or Toronto and meetings with lawyers, stockbrokers, and geoscientists working in the mineral industry. Prerequisites: GEGN401 or consent of instructor. 3 hours lecture and seminar; 3 semester hours. Offered alternate years when student demand is sufficient.

GEOL515. ADVANCED MINERAL DEPOSITS (I) Geology of mineral systems at a deposit, district, and regional scale formed by magmatic-hydrothermal, sedimentary/basinal, and metamorphic processes. Emphasis will be placed on a systems approach to evaluating metal and sulfur sources, transportation paths, and traps. Systems examined will vary by year and interest of the class. Involves a team-oriented research project that includes review of current literature and laboratory research. Prerequisites: GEGN401 or consent of instructor. 1 hour lecture, 5 hours lab; 3 semester hours. Repeatable for credit.

GEOL516. ADVANCED MINERAL DEPOSITS - IGNEOUS AND HYDROTHERMAL SYSTEMS (II) Geology of mineral systems at a deposit, district, and regional scale related to igneous processes. Emphasis will be placed on a systems approach to evaluating metal and sulfur sources, transportation paths, and traps. Systems examined will vary by year and interest of the class. Involves a team-oriented research project that includes review of current literature and laboratory research. Prerequisites: GEGN401 or consent of instructor. 1 hour lecture, 5 hours lab; 3 semester hours. Offered alternate years.

GEGN517. FIELD METHODS FOR ECONOMIC GEOLOGY (II) Methods of field practices related to mineral exploration and mining. Lithology, structural geology, alteration, and mineralization vein-type precious metal deposits. Mapping is conducted both underground at the Edgar Test Mine and above ground in the Idaho Springs area. Drill core and rock chips from different deposit types are utilized. Technical reports are prepared for each of four projects. Class is run on Saturday (9 am-4 pm) throughout the semester. Prerequisites: GEGN401 or consent of instructor. 6 hours lab and seminar; 3 semester hours. Offered alternate years when student demand is sufficient.

GEGN518. MINERAL EXPLORATION (II) Mineral industry overview, deposit economics, target selection, deposit modeling, exploration technology, international exploration, environmental issues, program planning, proposal development. Team development and presentation of an exploration proposal. Prerequisite: GEOL515, GEOL520, or equivalent. 2 hours lecture/seminar, 3 hours lab; 3 semester hours. Offered when student demand is sufficient.

GEOL519. ABITIBI GEOLOGY AND EXPLORATION FIELD SCHOOL (II, S) Methods of field practices related to mineral exploration and mining. Regional and deposit-scale geology of Archean mineral deposits, including lode gold deposits and volcanic-hosted massive sulfide deposits. Includes mineral prospect evaluation, structural geology, physical volcanology, deposit definition, alteration mapping, mining methods, ore processing, and metallurgy. Core logging, underground stope mapping, open pit mapping, litho-geochemical sampling, and field-analytical techniques. Course involves a seminar in the spring semester that focuses on the geology and deposit types in the area to be visited. An intense 14-day field trip is run in the summer semester. Each day includes up to 4 hours of instruction in the field and 4 hours of team-oriented field exercises. Prerequisites: Consent of instructor. 6 hours lab and seminar; 2 semester hours in spring, 1 semester hour in summer. Offered alternate years when student demand is sufficient.

GEOL520. NEW DEVELOPMENTS IN THE GEOLOGY AND EXPLORATION OF ORE DEPOSITS (I, II) Each topic unique and focused on a specific mineral deposit type or timely aspects of economic geology. Review of the geo-

logical and geographic setting of a specific magmatic, hydrothermal, or sedimentary mineral deposit type. Detailed study of the physical and chemical characteristics of selected deposits and mining districts. Theory and application of geological field methods and geochemical investigations. Includes a discussion of genetic models, exploration strategies, and mining methods. Prerequisites: GEGN401 or consent of instructor. 2 hours lecture; 2 semester hours. Repeatable for credit.

GEOL521. FIELD AND ORE DEPOSIT GEOLOGY (I, S) Field study of major mineral deposit districts inside and outside of the USA. Examines regional and deposit-scale geology. Underground and open pit mine visits and regional traverses. Topics addressed include deposit definition, structural geology, alteration mapping, mining methods, and ore processing. Course involves a seminar in the spring semester that focuses on the geology and deposit types in the area to be visited. An intense 10-14 day field trip is run in the summer semester. Prerequisites: Consent of instructor. 6 hours lab and seminar; 2 semester hours in spring, 1 semester hour in summer. Offered alternate years when student demand is sufficient. Repeatable for credit.

GEOL522. TECTONICS AND SEDIMENTATION (II) Application and integration of advanced sedimentologic and stratigraphic concepts to understand crustal deformation at a wide range of spatial- and time-scales. Key concepts include: growth-strata analysis, interpretation of detrital composition (conglomerate unroofing sequences and sandstone provenance trends), paleocurrent deflection and thinning trends, tectonic control on facies distribution and basic detrital zircon and fission track analysis. Students will read a wide range of literature to explore the utility and limitation of traditional "tectonic signatures" in stratigraphy, and will work on outcrop and subsurface datasets to master these concepts. Special attention is paid to fold-thrust belt, extensional and salt-related deformation. The course has important applications in Petroleum Geology, Geologic Hazards, and Hydrogeology. Required: 2-3 fieldtrips, class presentations, and a final paper that is written in a peer-reviewed journal format. Prerequisites: GEOL314 or equivalent, and GEOL309 or equivalent. 3 hours lecture and seminar; 3 semester hours. Offered even years.

GEOL525. TECTONOTHERMAL EVOLUTION OF THE CONTINENTS (I) Evolution of the continental crust with a specific focus on processes occurring at collisional margins. Emphasis will be on the application of metamorphic processes and concepts., including integration of major, trace, and isotopic geochemistry of rocks and minerals to interpreting and understanding the tectonic and thermal evolution of the crust through space and time. Laboratory emphasizes the interpretation of metamorphic textures and assemblages within the context of geochemistry and deformation, and the application of thermodynamic principles to the understanding of the thermal history of rocks and ter-

rains. Prerequisite: Appropriate undergraduate optical mineralogy and petrology coursework (GEOL321 and GEOL307, or equivalent) or consent of instructor. 2 hours lecture and seminar, 3 hours lab; 3 semester hours. Offered alternate years.

GEGN527/CHGC527. ORGANIC GEOCHEMISTRY OF FOSSIL FUELS AND ORE DEPOSITS (II) A study of organic carbonaceous materials in relation to the genesis and modification of fossil fuel and ore deposits. The biological origin of the organic matter will be discussed with emphasis on contributions of microorganisms to the nature of these deposits. Biochemical and thermal changes which convert the organic compounds into petroleum, oil shale, tar sand, coal, and other carbonaceous matter will be studied. Principal analytical techniques used for the characterization of organic matter in the geosphere and for evaluation of oil and gas source potential will be discussed. Laboratory exercises will emphasize source rock evaluation, and oil-source rock and oil-oil correlation methods. Prerequisite: CHGN221, GEGN438, or consent of instructor. 2 hours lecture; 3 hours lab; 3 semester hours. Offered alternate years.

GEGN528/MNGN528. MINING GEOLOGY (II) Role of geology and the geologist in the development and production stages of a mining operation. Topics addressed: mining operation sequence, mine mapping, drilling, sampling, reserve estimation, economic evaluation, permitting, support functions. Field trips, mine mapping, data evaluation exercises, and term project. Prerequisite: GEGN401 or permission of instructors. 2 hours lecture/seminar, 3 hours lab; 3 semester hours. Offered alternate years when student demand is sufficient.

GEGN530. CLAY CHARACTERIZATION (I) Clay mineral structure, chemistry and classification, physical properties (flocculation and swelling, cation exchange capacity, surface area and charge), geological occurrence, controls on their stabilities. Principles of X-ray diffraction, including sample preparation techniques, data collection and interpretation, and clay separation and treatment methods. The use of scanning electron microscopy to investigate clay distribution and morphology. Methods of measuring cation exchange capacity and surface area. Prerequisite: GEGN206 or equivalent, or consent of instructor. 1 hour lecture, 2 hours lab; 1 semester hour.

GEGN532. GEOLOGICAL DATA ANALYSIS (I or II) Techniques and strategy of data analysis in geology and geological engineering: basic statistics review, analysis of data sequences, mapping, sampling and sample representativity, univariate and multivariate statistics, geostatistics, and geographic information systems (GIS). Practical experience with geological applications via supplied software and data sets from case histories. Prerequisites: Introductory statistics course (MATH323 or MATH530 equivalent) or permission of instructor. 2 hours lecture/discussion; 3 hours lab; 3 semester hours.

GEOL545. INTRODUCTION TO REMOTE SENSING (I) Theory and application of remote sensing techniques using visible, infrared, and microwave electromagnetic energy. Spectral information from cameras and scanning instruments, including infrared photography, radar imagery, Landsat imagery, and imaging spectroscopy. Survey of applications to geology and global change. Lab interpretation of remote sensing imagery and introduction to digital image processing. 2 hours lecture, 3 hours lab; 3 semester hours.

GEOL546. GEOLOGIC APPLICATIONS OF REMOTE SENSING (II) Application of remote sensing to regional geologic studies and to mineral and energy resource assessments. Study of remote sensing techniques, including spectral analysis, lineament analysis, and digital image processing. Reviews of case studies and current literature. Student participation in discussion required. Prerequisite: GEOL545 or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

GEOL550. INTEGRATED BASIN MODELING (I) This course introduces students to principal methods in computer-based basin modeling: structural modeling and tectonic restoration; thermal modeling and hydrocarbon generation; and stratigraphic modeling. Students apply techniques to real data set that includes seismic and well data and learn to integrate results from multiple approaches in interpreting a basin's history. The course is primarily a lab course. Prerequisite: Consent of instructor. A course background in structural geology, sedimentology/stratigraphy or organic geochemistry will be helpful. 1 hour lecture, 5 hours labs; 3 semester hours.

GEOL551. APPLIED PETROLEUM GEOLOGY (II) Subjects to be covered include computer subsurface mapping and cross sections, petrophysical analysis of well data, digitizing well logs, analyzing production decline curves, creating hydrocarbon-porosity-thickness maps, volumetric calculations, seismic structural and stratigraphic mapping techniques, and basin modeling of hydrocarbon generation. Students are exposed to three software packages used extensively by the oil and gas industry. Prerequisite: GEGN438 or GEOL609 or consent of instructor. 3 hours lecture; 3 semester hours.

GEOL552. UNCONVENTIONAL PETROLEUM SYSTEMS (II) Unconventional petroleum systems have emerged as a critical and indispensable part of current US production and potential future reserves. Each of the 5 unconventional oil and 4 unconventional gas systems will be discussed: what are they, world wide examples, required technology to evaluate and produce, environmental issues, and production/resource numbers. The oil part of the course will be followed by looking at cores from these systems. The gas part of the course will include a field trip to the Denver, Eagle, and Piceance Basins in Colorado to see outstanding outcrops of actual producing units. Prerequisites: GEGN438 or GEOL609, GEGN527 or consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

GEOL553. GEOLOGY AND SEISMIC SIGNATURES OF RESERVOIR SYSTEMS (II) This course is a comprehensive look at the depositional models, log signatures, characteristics, and seismic signatures for all the main reservoirs we explore for and produce from in the subsurface. The first half is devoted to the clastic reservoirs (12 in all); the second part to the carbonate reservoirs (7 total). The course will utilize many hands-on exercises using actual seismic lines for the various reservoir types. Prerequisites: GEOL501 or GEOL314. 3 hours lecture; 3 semester hours. Offered alternate years.

GEGN570. CASE HISTORIES IN GEOLOGICAL ENGINEERING AND HYDROGEOLOGY (I) Case histories in geological and geotechnical engineering, ground water, and waste management problems. Students are assigned problems and must recommend solutions and/or prepare defendable work plans. Discussions center on the role of the geological engineer in working with government regulators, private-sector clients, other consultants, and other special interest groups. Prerequisite: GEGN467, GEGN468, GEGN469, GEGN470 or consent of instructor. 3 hours lecture; 3 semester hours.

GEOL570/GPGN570. APPLICATIONS OF SATELLITE REMOTE SENSING (II) An introduction to geoscience applications of satellite remote sensing of the Earth and planets. The lectures provide background on satellites, sensors, methodology, and diverse applications. Topics include visible, near infrared, and thermal infrared passive sensing, active microwave and radio sensing, and geodetic remote sensing. Lectures and labs involve use of data from a variety of instruments, as several applications to problems in the Earth and planetary sciences are presented. Students will complete independent term projects that are presented both written and orally at the end of the term. Prerequisites: PHGN200 and MATH225 or consent of instructor. 2 hours lecture, 2 hours lab; 3 semester hours.

GEGN571. ADVANCED ENGINEERING GEOLOGY (I) Emphasis will be on engineering geology mapping methods, and geologic hazards assessment applied to site selection and site assessment for a variety of human activities. Prerequisite: GEGN468 or equivalent. 2 hours lecture, 3 hours lab; 3 semester hours. Offered alternate years.

GEGN573. GEOLOGICAL ENGINEERING SITE INVESTIGATION (II) Methods of field investigation, testing, and monitoring for geotechnical and hazardous waste sites, including: drilling and sampling methods, sample logging, field testing methods, instrumentation, trench logging, foundation inspection, engineering stratigraphic column and engineering soils map construction. Projects will include technical writing for investigations (reports, memos, proposals, workplans). Class will culminate in practice conducting simulated investigations (using a computer simulator). 3 hours lecture; 3 semester hours.

GEGN575. APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS (II) An introduction to Geographic Information Systems (GIS) and their applications to all areas of geology and geological engineering. Lecture topics include: principles of GIS, data structures, digital elevation models, data input and verification, data analysis and spatial modeling, data quality and error propagation, methods of GIS evaluation and selection. Laboratories will use Macintosh and DOS-based personal computer systems for GIS projects, as well as video-presentations. Visits to local GIS laboratories, and field studies will be required. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN578. GIS PROJECT DESIGN (I, II) Project implementation of GIS analysis. Projects may be undertaken by individual students, or small student teams. Documentation of all project design stages, including user needs assessment, implementation procedures, hardware and software selection, data sources and acquisition, and project success assessment. Various GIS software may be used; projects may involve 2-dimensional GIS, 3-dimensional subsurface models, or multi-dimensional time-series analysis. Prerequisite: Consent of instructor. Variable credit, 1-3 semester hours, depending on project. Offered on demand.

GEOL580/GPGN580/MNGN580. INDUCED SEISMICITY (II) Earthquakes are sometimes caused by the activities of man. These activities include mining and quarrying, petroleum and geothermal energy production, building water reservoirs and dams, and underground nuclear testing. This course will help students understand the characteristics and physical causes of man-made earthquakes and seismicity induced in various situations. Students will read published reports and objectively analyze the seismological and ancillary data therein to decide if the causative agent was man or natural processes. Prerequisites: Undergraduate geology and physics. 3 hours lecture; 3 semester hours. Offered spring semester, odd years.

GEGN581. ADVANCED GROUNDWATER ENGINEERING (I) Lectures, assigned readings, and discussions concerning the theory, measurement, and estimation of ground water parameters, fractured-rock flow, new or specialized methods of well hydraulics and pump tests, tracer methods. Prerequisite: GEGN467 or consent of instructor. 3 hours lecture; 3 semester hours.

GEGN/ESGN582. INTEGRATED SURFACE WATER HYDROLOGY (I) This course provides a quantitative, integrated view of the hydrologic cycle. The movement and behavior of water in the atmosphere (including boundary layer dynamics and precipitation mechanisms), fluxes of water between the atmosphere and land surface (including evaporation, transpiration, precipitation, interception and through fall) and connections between the water and energy balances (including radiation and temperature) are discussed at a range of spatial and temporal scales. Additionally, movement of water along the land surface (overland flow

and snow dynamics) and in the subsurface (saturated and unsaturated flow) as well as surface-subsurface exchanges and runoff generation are also covered. Finally, integration and connections within the hydrologic cycle and scaling of river systems are discussed. Prerequisites: Groundwater Engineering (GEGN466/467), Fluid Mechanics (GEGN351/EGGN351), math up to differential equations, or equivalent classes as determined by the instructor. 3 hours lecture; 3 semester hours.

GEGN583. MATHEMATICAL MODELING OF GROUNDWATER SYSTEMS (II) Lectures, assigned readings, and direct computer experience concerning the fundamentals and applications of finite-difference and finite-element numerical methods and analytical solutions to ground water flow and mass transport problems. Prerequisite: A knowledge of FORTRAN programming, mathematics through differential and integral calculus, and GEGN467 or consent of instructor. 3 hours lecture; 3 semester hours.

GEGN584. FIELD METHODS IN HYDROLOGY (I) Design and implementation of tests that characterize surface and subsurface hydrologic systems, including data logger programming, sensor calibration, pumping tests, slug tests, infiltration tests, stream gauging and dilution measurements, and geophysical (EM, resistivity, and/or SP) surveys. Prerequisites: Groundwater Engineering (GEGN466/467), Surface Water Hydrology (ESGN582) or equivalent classes as determined by the instructor. 2 hours lecture; 5 hours lab and field exercises one day of the week. Days TBD by instructor; 3 semester hours.

GEGN/GEOL597. SPECIAL SUMMER PROGRAMS (S)

GEGN/GEOL598. SEMINAR IN GEOLOGY OR GEOLOGICAL ENGINEERING (I, II) Special topics classes, taught on a one-time basis. May include lecture, laboratory and field trip activities. Prerequisite: Approval of instructor and department head. Variable credit; 1 to 3 semester hours. Repeatable for credit under different topics.

GEGN599. INDEPENDENT STUDY IN ENGINEERING GEOLOGY OR ENGINEERING HYDROGEOLOGY (I, II) Individual special studies, laboratory and/or field problems in geological engineering or engineering hydrogeology. Prerequisite: Approval of instructor and department head. Variable credit; 1 to 6 credit hours. Repeatable for credit.

GEOL599. INDEPENDENT STUDY IN GEOLOGY (I, II) Individual special studies, laboratory and/or field problems in geology. Prerequisite: Approval of instructor and department. Variable credit; 1 to 3 semester hours. Repeatable for credit.

GEOL608. HISTORY OF GEOLOGICAL CONCEPTS (II) Lectures and seminars concerning the history and philosophy of the science of geology; emphasis on the historical development of basic geologic concepts. 3 hours lecture and seminar; 3 semester hours. Required of all doctoral candidates in department. Offered alternate years.

GEOL609. ADVANCED PETROLEUM GEOLOGY (II) Subjects to be covered involve consideration of basic chemical, physical, biological and geological processes and their relation to modern concepts of oil/gas generation (including source rock deposition and maturation), and migration/accumulation (including that occurring under hydrodynamic conditions). Concepts will be applied to the historic and predictive occurrence of oil/gas to specific Rocky Mountain areas. In addition to lecture attendance, course work involves review of topical papers and solution of typical problems. Prerequisite: GEGN438 or consent of instructor. 3 hours lecture; 3 semester hours.

GEOL610. ADVANCED SEDIMENTOLOGY (II) Keynote lectures and a seminar series on the physical depositional processes, as the basic processes and key restrictions for building stratigraphy. Linkage of physical processes with depositional environments and stratigraphy. Learning the key observations for recognizing depositional environments in outcrops and cores. Linkage to well logs. Seminars, field trips, field labs and report required. Prerequisite: GEOL 501 or equivalent. 3 hours lecture and seminar; 3 semester hours. Offered alternate years.

GEOL611. DYNAMIC STRATIGRAPHY (II) Keynote lectures and a seminar series on the dynamics of depositional systems; understanding the dynamics of the depositional processes, depositional environments and how they behave in changing sea-level and sediment supply conditions; from basic processes to sequence stratigraphy of the siliciclasti systems. Field trips and report required. Prerequisite: GEOL501 or equivalent. 3 hours lecture and seminar; 3 semester hours. Offered alternate years.

GEOL613. GEOLOGIC RESERVOIR CHARACTERIZATION (I or II) Principles and practice of characterizing petroleum reservoirs using geologic and engineering data, including well logs, sample descriptions, routine and special core analysis and well tests. Emphasis is placed on practical analysis of such data sets from a variety of clastic petroleum reservoirs worldwide. These data sets are integrated into detailed characterizations, which then are used to solve practical oil and gas field problems. Prerequisites: GEGN438, GEOL501, GEOL505/605 or equivalents. 3 hours lecture; 3 semester hours.

GEOL614. PETROLEUM GEOLOGY OF DEEP-WATER CLASTIC DEPOSITIONAL SYSTEMS (I) Course combines local and regional deep-water sedimentology, sequence stratigraphy, reservoir geology, interpretation of outcrops, reflection seismic records, cores and well logs. Focus is on depositional processes, facies and their interpretation within deep-water depositional systems, turbidite models and their evolution, control of reservoir characteristics and performance, turbidites within a sequence stratigraphic framework, and the global occurrence of turbidite reservoirs. Laboratory exercises on seismic, well log, and core interpretation. Seven

day field trip to study classic turbidites in Arkansas and to develop individual field mapping and interpretation projects. Prerequisites: GEGN438, GEOL501 or equivalents. 3 hours lecture, 3 hours lab; 4 semester hours. Offered alternate years.

GEOL617. THERMODYNAMICS AND MINERAL PHASE EQUILIBRIA (I) Basic thermodynamics applied to natural geologic systems. Evaluation of mineral-vapor mineral solution, mineral-melt, and solid solution equilibria with special emphasis on oxide, sulfide, and silicate systems. Experimental and theoretical derivation, use, and application of phase diagrams relevant to natural rock systems. An emphasis will be placed on problem solving rather than basic theory. Prerequisite: DCGN209 or equivalent or consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

GEOL621. PETROLOGY OF DETRITAL ROCKS (II) Compositions and textures of sandstones, siltstones, and mudrocks. Relationship of compositions and textures of provenance, environment of deposition, and burial history. Development of porosity and permeability. Laboratory exercises emphasize use of petrographic thin sections, x-ray diffraction analysis, and scanning electron microscopy to examine detrital rocks. A term project is required, involving petrographic analysis of samples selected by student. Prerequisites: GEGN206, GEOL321 or equivalent or consent of instructor. 2 hours lecture and seminar, 3 hours lab; 3 semester hours. Offered on demand.

GEOL624. CARBONATE SEDIMENTOLOGY AND PETROLOGY (II) Processes involved in the deposition of carbonate sediments with an emphasis on Recent environments as analogs for ancient carbonate sequences. Carbonate facies recognition through bio- and lithofacies analysis, three-dimensional geometries, sedimentary dynamics, sedimentary structures, and facies associations. Laboratory stresses identification of Recent carbonate sediments and thin section analysis of carbonate classification, textures, non-skeletal and biogenic constituents, diagenesis, and porosity evolution. Prerequisite: GEGN321 and GEOL 314 or consent of instructor. 2 hours lecture/seminar, 2 hours lab; 3 semester hours.

GEOL628. ADVANCED IGNEOUS PETROLOGY (I) Igneous processes and concepts, emphasizing the genesis, evolution, and emplacement of tectonically and geochemically diverse volcanic and plutonic occurrences. Tectonic controls on igneous activity and petrochemistry. Petrographic study of igneous suites, mineralized and non-mineralized, from diverse tectonic settings. Prerequisites: GEOL321, GEGN206. 2 hours lecture, 3 hours lab; 3 semester hours. Offered alternate years.

GEOL642. FIELD GEOLOGY (S) Field program operated concurrently with GEGN316 field camp to familiarize the student with basic field technique, geologic principles, and regional geology of Rocky Mountains. Prerequisite: Under-

graduate degree in geology and GEGN316 or equivalent. During summer field session; 1 to 3 semester hours.

GEOL643. GRADUATE FIELD SEMINARS (I, II, S) Special advanced field programs emphasizing detailed study of some aspects of geology. Normally conducted away from the Golden campus. Prerequisite: Restricted to Ph.D. or advanced M.S. candidates. Usually taken after at least one year of graduate residence. Background requirements vary according to nature of field study. Consent of instructor and department head is required. Fees are assessed for field and living expenses and transportation. 1 to 3 semester hours; may be repeated for credit with consent of instructor.

GEOL645. VOLCANOLOGY (II) Assigned readings and seminar discussions on volcanic processes and products. Principal topics include pyroclastic rocks, craters and calderas, caldron subsidence, diatremes, volcanic domes, origin and evolution of volcanic magmas, and relation of volcanism to alteration and mineralization. Petrographic study of selected suites of lava and pyroclastic rocks in the laboratory. Prerequisite: Consent of instructor. 1 hour seminar, 6 hours lab; 3 semester hours.

GEOL653. CARBONATE DIAGENESIS AND GEOCHEMISTRY(II) Petrologic, geochemical, and isotopic approaches to the study of diagenetic changes in carbonate sediments and rocks. Topics covered include major near-surface diagenetic environments, subaerial exposure, dolomitization, burial diagenesis, carbonate aqueous equilibria, and the carbonate geochemistry of trace elements and stable isotopes. Laboratory stresses thin section recognition of diagenetic textures and fabrics, x-ray diffraction, and geochemical/isotopic approaches to diagenetic problems. Prerequisite: GEOL624 or equivalent or consent of instructor. 4 to 6 hours lecture/seminar/lab; 3 semester hours.

GEGN669. ADVANCED TOPICS IN ENGINEERING HYDROGEOLOGY (I, II) Review of current literature and research regarding selected topics in hydrogeology. Group discussion and individual participation. Guest speakers and field trips may be incorporated into the course. Prerequisite: Consent of instructor. 1 to 2 semester hours; may be repeated for credit with consent of instructor.

GEGN670. ADVANCED TOPICS IN GEOLOGICAL ENGINEERING (I, II) Review of current literature and research regarding selected topics in engineering geology. Group discussion and individual participation. Guest speakers and field trips may be incorporated into the course. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Repeatable for credit under different topics.

GEGN671. LANDSLIDES: INVESTIGATION, ANALYSIS & MITIGATION (I) Geological investigation, analysis, and design of natural rock and soil slopes and mitigation of unstable slopes. Topics include landslide types and processes, triggering mechanisms, mechanics of movements, landslide

investigation and characterization, monitoring and instrumentation, soil slope stability analysis, rock slope stability analysis, rock fall analysis, stabilization and risk reduction measures. Prerequisites: GEGN468, EGGN 361, MNGN321, (or equivalents) or consent of instructor. 3 hours lecture; 3 semester hours.

GEGN672. ADVANCED GEOTECHNICS (II) Geological analysis, design, and stabilization of natural soil and rock slopes and rock foundations; computer modeling of slopes; use of specialized methods in earth construction. Prerequisite: GEGN468, EGGN361/EGGN363 and MNGN321. 3 hours lecture; 3 semester hours.

GEGN673. ADVANCED GEOLOGICAL ENGINEERING DESIGN (II) Application of geological principles and analytical techniques to solve complex engineering problems related to geology, such as mitigation of natural hazards, stabilization of earth materials, and optimization of construction options. Design tools to be covered will include problem solving techniques, optimization, reliability, maintainability, and economic analysis. Students will complete independent and group design projects, as well as a case analysis of a design failure. 3 hours lecture; 3 semester hours. Offered alternate years.

GEGN681. VADOSE ZONE HYDROLOGY (II) Study of the physics of unsaturated groundwater flow and contaminant transport. Fundamental processes and data collection methods will be presented. The emphasis will be on analytic solutions to the unsaturated flow equations and analysis of field data. Application to non-miscible fluids, such as gasoline, will be made. The fate of leaks from underground tanks will be analyzed. Prerequisites: GEGN467 or equivalent; Math through Differential Equations; or consent of instructor. 3 hours lecture; 3 semester hours.

GEGN682. FLOW AND TRANSPORT IN FRACTURED ROCK (I) Explores the application of hydrologic and engineering principles to flow and transport in fractured rock. Emphasis is on analysis of field data and the differences between flow and transport in porous media and fractured rock. Teams work together throughout the semester to solve problems using field data, collect and analyze field data, and do independent research in flow and transport in fractured rock. Prerequisites: GEGN581 or consent of instructor. 3 hours lecture; 3 credit hours. Offered alternate years.

GEGN683. ADVANCED GROUND WATER MODELING (II) Flow and solute transport modeling including: 1) advanced analytical modeling methods; 2) finite elements, random-walk, and method of characteristics numerical methods; 3) discussion of alternative computer codes for modeling and presentation of the essential features of a number of codes; 4) study of selection of appropriate computer codes for specific modeling problems; 5) application of models to ground water problems; and 6) study of completed modeling

projects through literature review, reading and discussion. Prerequisite: GEOL/CHGC509 or GEGN583, and GEGN585 or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN/GEOL698. SEMINAR IN GEOLOGY OR GEOLOGICAL ENGINEERING (I, II) Special topics classes, taught on a one-time basis. May include lecture, laboratory and field trip activities. Prerequisite: Approval of instructor and department head. Variable credit; 1 to 3 semester hours. Repeatable for credit under different titles.

GEGN699. INDEPENDENT STUDY IN ENGINEERING GEOLOGY OR ENGINEERING HYDROGEOLOGY(I, II) Individual special studies, laboratory and/or field problems in geological engineering or engineering hydrogeology. Prerequisite: Approval of instructor and department head. Variable credit; 1 to 6 credit hours. Repeatable for credit.

GEOL699. INDEPENDENT STUDY IN GEOLOGY (I, II). Individual special studies, laboratory and/or field problems in geology. Prerequisite: Approval of instructor and department. Variable credit; 1 to 3 semester hours. Repeatable for credit.

GEGN/GEOL705 GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

GEGN/GEOL706 GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

Geochemical Exploration

GEGX571. GEOCHEMICAL EXPLORATION (I) Dispersion of trace metals from mineral deposits and their discovery. Laboratory consists of analysis and statistical interpretation of data of soils, stream sediments, vegetation, and rock in connection with field problems. Term report required. Prerequisite: Consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

Geophysics

TERENCE K. YOUNG, Professor and Department Head
MICHAEL L. BATZLE, Baker Hughes Professor of Petrophysics and Borehole Geophysics
THOMAS L. DAVIS, Professor
DAVE HALE, Charles Henry Green Professor of Exploration Geophysics
GARY R. OLHOEFT, Professor
ROEL K. SNIEDER, Keck Foundation Professor of Basic Exploration Science
ILYA D. TSVANKIN, Professor
THOMAS M. BOYD, Associate Professor and Dean of Graduate Studies
YAOGUO LI, Associate Professor
ANDRÉ REVIL, Associate Professor
PAUL SAVA, Associate Professor
JEFFREY ANDREWS-HANNA, Assistant Professor
NORMAN BLEISTEIN, Research Professor and University Emeritus Professor
KENNETH L. LARNER, Research Professor and University Emeritus Professor
ROBERT D. BENSON, Research Associate Professor
RICHARD KRAHENBUHL, Research Assistant Professor
STEPHEN J. HILL, Adjunct Associate Professor
DAVID J. WALD, Adjunct Associate Professor
GAVIN P. HAYES, Adjunct Assistant Professor
CHARLES P. ODEN, Adjunct Assistant Professor
WARREN B. HAMILTON, Distinguished Senior Scientist
MISAC N. NABIGHIAN, Distinguished Senior Scientist
FRANK A. HADSELL, Emeritus Professor
ALEXANDER A. KAUFMAN, Emeritus Professor
GEORGE V. KELLER, Emeritus Professor
PHILLIP R. ROMIG, JR., Emeritus Professor

Degrees Offered

Professional Masters in Petroleum Reservoir Systems
Master of Science (Geophysics)
Master of Science (Geophysical Engineering)
Doctor of Philosophy (Geophysics)
Doctor of Philosophy (Geophysical Engineering)

Program Description

Geophysicists study and explore the Earth's interior through physical measurements collected at the earth's surface, in boreholes, from aircraft, and from satellites. Using a combination of mathematics, physics, geology, chemistry, hydrology, and computer science, a geophysicist analyzes these measurements to infer properties and processes within the Earth's complex interior. Non-invasive imaging beneath the surface of Earth and other planets by geophysicists is analogous to non-invasive imaging of the interior of the human body by medical specialists.

Geophysics is an interdisciplinary field - a rich blend of disciplines such as geology, physics, mathematics, computer science, and electrical engineering. Professionals working in the field of geophysics come from programs in these allied disciplines as well as from formal programs in geophysics.

The Earth supplies all materials needed by our society, serves as the repository of used products, and provides a home to all its inhabitants. Therefore, geophysics and geophysical engineering have important roles to play in the solution of challenging problems facing the inhabitants of this planet, such as providing fresh water, food, and energy for Earth's growing population, evaluating sites for underground construction and containment of hazardous waste, monitoring non-invasively the aging infrastructures (natural gas pipelines, water supplies, telecommunication conduits, transportation networks) of developed nations, mitigating the threat of geohazards (earthquakes, volcanoes, landslides, avalanches) to populated areas, contributing to homeland security (including detection and removal of unexploded ordnance and land mines), evaluating changes in climate and managing humankind's response to them, and exploring other planets.

Energy companies and mining firms employ geophysicists to explore for hidden resources around the world. Engineering firms hire geophysical engineers to assess the Earth's near-surface properties when sites are chosen for large construction projects and waste-management operations. Environmental organizations use geophysics to conduct groundwater surveys and to track the flow of contaminants. On the global scale, geophysicists employed by universities and government agencies (such as the United States Geological Survey, NASA, and the National Oceanographic and Atmospheric Administration) try to understand such Earth processes as heat flow, gravitational, magnetic, electric, thermal, and stress fields within the Earth's interior. For the past decade, 100% of CSM's geophysics graduates have found employment in their chosen field, with about 20% choosing to pursue further graduate studies.

Founded in 1926, the Department of Geophysics at the Colorado School of Mines is recognized and respected around the world for its programs in applied geophysical research and education. With 20 active faculty members and small class sizes, students receive individualized attention in a close-knit environment. Given the interdisciplinary nature of geophysics, the graduate curriculum requires students to become thoroughly familiar with geological, mathematical, and physical theory, in addition to exploring the theoretical and practical aspects of the various geophysical methodologies.

Research Emphasis

The Department conducts research in a wide variety of areas mostly related, but not restricted, to applied geophysics. Candidates interested in the research activities of a specific faculty member are encouraged to obtain a copy of the Department's view book and to contact that faculty member directly. To give prospective candidates an idea of the types of research activities available in geophysics at CSM, a list of the recognized research groups operating within the Department of Geophysics is given below.

The Center for Wave Phenomena (CWP) is a research group with a total of four faculty members from the Department of Geophysics. With research sponsored by some 29 companies worldwide in the petroleum-exploration industry, plus U.S. government agencies, CWP emphasizes the development of theoretical and computational methods for imaging of the Earth's subsurface, primarily through use of the reflection seismic method. Researchers have been involved in forward and inverse problems of wave propagation as well as data processing for data obtained where the subsurface is complex, specifically where it is both heterogeneous and anisotropic. Further information about CWP can be obtained at <http://www.cwp.mines.edu>.

The Reservoir Characterization Project (RCP) integrates the acquisition and interpretation of multicomponent, three-dimensional seismic reflection and downhole data, with the geology and petroleum engineering of existing oil fields, in an attempt to understand the complex properties of petroleum reservoirs. RCP is a multidisciplinary group with faculty members from Geophysics, Petroleum Engineering, and Geology. More information about RCP can be obtained at <http://www.mines.edu/academic/geophysics/rcp>.

The Center for Gravity, Electrical & Magnetic Studies (CGEM) in the Department of Geophysics is an academic research center that focuses heavily on the quantitative interpretation of gravity, magnetic, electrical and electromagnetic, and surface nuclear magnetic resonance (NMR) data in applied geophysics. The center brings together the diverse expertise of faculty and students in these different geophysical methods and works towards advancing the state of art in geophysical data interpretation for real-world problems. The emphases of CGEM research are processing and inversion of applied geophysical data. The primary areas of application include petroleum exploration, mineral exploration, unexploded ordnance (UXO) detection and discrimination. In addition, environmental problems, infrastructure mapping, agriculture geophysics, archaeology, geothermal exploration, hydro-geophysics, natural hazard monitoring, and crustal studies are also major research areas within the Center. There are currently five major research groups within CGEM: Gravity and Magnetics Research Consortium (GMRC); Unexploded Ordinance (UXO) research group; Hydro-Geophysics research group; the Geothermal Exploration group; and the NMR group. Research fundings are provided by petroleum and mining companies, SERDP, ERDC, and other agencies. More information about CGEM is available on the web at: <http://geophysics.mines.edu/cgem/>.

The Center for Rock Abuse is a rock-physics laboratory focusing on research in rock and fluid properties for exploration and reservoir monitoring. The primary goal of exploration and production geophysics is to identify fluids, specifically hydrocarbons, in rocks. Current projects center on fluid dis-

tributions in rocks and how these distributions affect characteristics such as wave attenuation, velocity dispersion and seismic signature. <http://crusher.mines.edu>

The Group for Hydrogeophysics and Porous Media focuses on combining geoelectrical methods (DC resistivity, complex conductivity, self-potential, gravity and EM) with rock physics models at various scales and for various applications including the study of contaminant plumes, geothermal systems, leakage in earth dams and embankments, and active volcanoes. Website: <http://www.andre-revil.com/research.html>

The Planetary Geophysics Group investigates the geophysical evolution of the terrestrial planets and moons of our solar system using a combination of numerical modeling and geophysical data analysis. Research areas include planetary geodynamics, tectonics, and hydrology. More information is available at <http://inside.mines.edu/~jcahanna/>.

Program Requirements

The Department offers both traditional, research-oriented graduate programs and a non-thesis professional education program designed to meet specific career objectives. The program of study is selected by the student, in consultation with an advisor, and with thesis committee approval, according to the student's career needs and interests. Specific degrees have specific requirements as detailed below.

Geophysical Engineering Program Objectives

The principal objective for students pursuing the PhD in Geophysics or the PhD in Geophysical Engineering is: Geophysics PhD graduates will be regarded by their employers as effective teachers and/or innovative researchers in their early-career peer group. In support of this objective, the PhD programs in the Department of Geophysics are aimed at achieving these student outcomes:

- ◆ Graduates will command superior knowledge of Geophysics and fundamental related disciplines.
- ◆ Graduates will independently be able to conduct research leading to significant new knowledge and Geophysical techniques.
- ◆ Graduates will be able to report their findings orally and in writing.

The chief objective for students pursuing the M.S. degree in Geophysics or Geophysical Engineering is: Geophysics M.S. graduates will be regarded by their employers as effective practitioners addressing earth, energy and environmental problems with geophysical techniques. In support of this objective, the M.S. programs in the Department of Geophysics aim to achieve these student outcomes:

- ◆ Graduates will command superior knowledge of Geophysics and fundamental related disciplines.
- ◆ Graduates will be able to conduct original research that results in new knowledge and Geophysical techniques.

- ◆ Graduates will be able to report their findings orally and in writing.

Professional Masters in Petroleum Reservoir Systems

This is a multi-disciplinary, non-thesis master's degree for students interested in working as geoscience professionals in the petroleum industry. The Departments of Geophysics, Petroleum Engineering, and Geology and Geological Engineering share oversight for the Professional Masters in Petroleum Reservoir Systems program through a committee consisting of one faculty member from each department. Students gain admission to the program by application to any of the three sponsoring departments. Students are administered by that department into which they first matriculate. A minimum of 36 hours of course credit is required to complete the Professional Masters in Petroleum Reservoir Systems program. Up to 9 credits may be earned by 400 level courses. All other credits toward the degree must be 500 level or above. At least 9 hours must consist of:

- (1) 1 course selected from the following:

GPGN419/PEGN419 Well Log Analysis and Formation Evaluation
GPGN519/PEGN519 Advanced Formation Evaluation

- (2) 2 courses selected from the following:

GEGN439/GPGN439/PEGN439 Multi-Disciplinary Petroleum Design
GEGN503/GPGN503/PEGN503 Integrated Exploration and Development
GEGN504/GPGN504/PEGN504 Integrated Exploration and Development

Also 9 additional hours must consist of one course each from the 3 participating departments. The remaining 18 hours may consist of graduate courses from any of the 3 participating departments, or other courses approved by the committee. Up to 6 hours may consist of independent study, including an industry project.

Master of Science Degrees: Geophysics and Geophysical Engineering

Students may obtain a Master of Science Degree in either Geophysics or Geophysical Engineering. Both degrees have the same coursework and thesis requirements, as described below. Students are normally admitted into the Master of Science in Geophysics program. If, however, a student would like to obtain the Master of Science in Geophysical Engineering, the course work and thesis topic must meet the following requirements. Note that these requirements are in addition to those associated with the Master of Science in Geophysics.

- ◆ Students must complete, either prior to their arrival at CSM or while at CSM, no fewer than 16 credits of engineering coursework. What constitutes coursework considered as engineering is determined by the Geophysics faculty.

- ◆ In the opinion of the Geophysics faculty, the student's dissertation topic must be appropriate for inclusion as part of an Engineering degree.

For either Master of Science degree, a minimum of 26 course credits is required accompanied by a minimum of 12 credits of graduate research. While individual courses constituting the degree are determined by the student, and approved by their advisor and thesis committee, courses applied to all M.S. degrees must satisfy the following criteria:

- ◆ All course, research, transfer, residence, and thesis requirements are as described in Registration and Tuition Classification and Graduate Degrees and Requirements sections of this document.

- ◆ All credits applied to the degree must be at the 400 (senior) level or above.

- ◆ Students must include the following courses in their Master degree program

LICM501 – Professional Oral Communication
(1 credit)

GPGN581 – Graduate Seminar (1 credit)

GPGN705 – Graduate Research – Master of Science
(12 credits in addition to the required 26 course credits).

- ◆ Additional courses may also be required by the student's advisor and committee to fulfill background requirements as described below.

As described in the Master of Science, Thesis and Thesis Defense section of this bulletin, all M.S. candidates must successfully defend their M.S. thesis in an open oral Thesis Defense. The guidelines of the Thesis Defense enforced by the Department of Geophysics follow those outlined in the Graduate Bulletin, with one exception. The Department of Geophysics requires students submit the final draft of their written thesis to their Thesis Committee no less than three weeks prior to the thesis defense date.

Doctor of Philosophy Degrees:

Geophysics and Geophysical Engineering

We invite applications to our PhD program not only from those individuals with a background in geophysics, but also from those whose background is in allied disciplines such as geology, physics, mathematics, computer science, and electrical engineering.

Students may obtain a Doctor of Philosophy Degree in either Geophysics or Geophysical Engineering. Both degrees have the same coursework and thesis requirements, as described below. Students are normally admitted into the Ph.D. in Geophysics program. If, however, a student would like to obtain the Ph.D. in Geophysical Engineering, the course work and thesis topic must meet the following requirements. Note that these requirements are in addition to those associated with the Ph.D. in Geophysics.

- ◆ Students must complete, either prior to their arrival at CSM or while at CSM, no fewer than 16 credits of engineering coursework. What constitutes coursework considered as engineering is determined by the Geophysics faculty.

- ◆ In the opinion of the Geophysics faculty, the student's dissertation topic must be appropriate for inclusion as part of an Engineering degree.

For the Doctor of Philosophy Degree (Ph.D.), at least 72 credits beyond the Bachelor's degree are required. No fewer than 24 research credits are required. At least 12 credit hours must be completed in a minor program approved by the candidate's PhD Thesis Committee. Up to 36 course credits can be awarded by the candidate's committee for completion of a thesis-based Master's Degree at another institution. While individual courses constituting the degree are determined by the student, and approved by the student's advisor and committee, courses applied to all Ph.D. degrees must satisfy the following criteria:

- ◆ All course, research, minor degree programs, transfer, residence, and thesis requirements are as described in Registration and Tuition Classification and Graduate Degrees and Requirements sections of this document.

- ◆ All credits applied to the degree must be at the 400 (senior) level or above.

- ◆ Students must include the following courses in their Ph.D. program

LICM501 – Professional Oral Communication (1 credit)

GPGN681 – Graduate Seminar (1 credit)

GPGN706 – Graduate Research – Doctor of Philosophy
(minimum 24 credits)

Choose two of the following:

SYGN501 – The Art of Science (1 credit)

SYGN600 – College Teaching (2 credits)

LAIS601 – Academic Publishing (2 or 3 credits)

- ◆ Additional courses may also be required by the student's advisor and committee to fulfill background requirements described below.

Students in the Doctoral program are also required to participate in a practical teaching experience. This must be the equivalent of a minimum two-week experience within a single semester and include:

- ◆ Developing and presenting instructional materials of lectures;
- ◆ Developing and teaching the laboratory exercises if the course has a lab component;
- ◆ Evaluating students' homework and laboratory reports, if appropriate; and
- ◆ Holding office hours if necessary.

In the Doctoral program, students must demonstrate the potential for successful completion of independent research and enhance the breadth of their expertise by completing a Doctoral Research Qualifying Examination no later than two years from the date of enrollment in the program. An extension of one additional year may be petitioned by students through their Thesis Committees.

In the Department of Geophysics, the Doctoral Research Qualifying Examination consists of the preparation, presentation, and defense of one research project and a thesis proposal. The research project and thesis proposal used in this process must conform to the standards posted on the Department of Geophysics web site.

As described in the Doctor of Philosophy, Thesis Defense section of this bulletin, all Ph.D. candidates must successfully defend their Ph.D. thesis in an open oral Thesis Defense. The guidelines of the Thesis Defense enforced by the Department of Geophysics follow those outlined in the Graduate Bulletin, with one exception. The Department of Geophysics requires students submit the final draft of their written thesis to their Thesis Committee no less than three weeks prior to the thesis defense date.

Acceptable Thesis Formats

In addition to traditional dissertations, the Department of Geophysics also accepts dissertations that are compendia of papers published or submitted to peer-reviewed journals. The following guidelines are applied by the Department in determining the suitability of a thesis submitted as a series of written papers.

- ◆ All papers included in the dissertation must have a common theme, as approved by a student's thesis committee.
- ◆ Papers should be submitted for inclusion in a dissertation in a common format and typeset.
- ◆ In addition to the individual papers, students must prepare abstract, introduction, discussion, and conclusions sections of the thesis that tie together the individual papers into a unified dissertation.
- ◆ A student's thesis committee might also require the preparation and inclusion of various appendices with the dissertation in support of the papers prepared explicitly for publication.

Graduate Program Background Requirements

All graduate programs in Geophysics require that applicants have a background that includes the equivalent of adequate undergraduate preparation in the following areas:

- ◆ Mathematics – Linear Algebra or Linear Systems, Differential Equations, Computer Programming
- ◆ Physics – Classical Physics
- ◆ Geology – Structural Geology and Stratigraphy

- ◆ Geophysics – Geophysical Field Methods and courses that include theory and application in three of the following areas: gravity/magnetics, seismic, electrical/electromagnetics, borehole geophysics, and physics of the earth
- ◆ In addition, candidates in the Doctoral program are required to have no less than one year of college level or two years of high school courses in a single foreign language.

Description of Courses

GPGN404. DIGITAL ANALYSIS (I) The fundamentals of one-dimensional digital signal processing as applied to geophysical investigations are studied. Students explore the mathematical background and practical consequences of the sampling theorem, convolution, deconvolution, the Z and Fourier transforms, windows, and filters. Emphasis is placed on applying the knowledge gained in lecture to exploring practical signal processing issues. This is done through homework and in-class practicum assignments requiring the programming and testing of algorithms discussed in lecture. Prerequisites: MATH213, MATH225, and MATH348 or PHGN311, or consent of instructor. Knowledge of a computer programming language is assumed. 2 hours lecture, 2 hours lab; 3 semester hours.

GPGN409. INVERSION (II) The fundamentals of inverse problem theory as applied to geophysical investigation are studied. Students explore the fundamental concepts of inversion in a Bayesian framework as well as practical methods for solving discrete inverse problems. Topics studied include Monte Carlo methods, optimization criteria, convex optimization methods, and error and resolution analysis. Weekly homework assignments addressing either theoretical or numerical problems through programming assignments illustrate the concepts discussed in class. Prerequisites: MATH213, MATH225, GPGN404 and MATH348 or PHGN311, or consent of instructor. Knowledge of a programming language is assumed. 3 hours lecture, 3 semester hours.

GPGN411. ADVANCED GRAVITY AND MAGNETIC METHODS (I) Instrumentation for land surface, borehole, sea floor, sea surface, and airborne operations. Reduction of observed gravity and magnetic values. Theory of potential field effects of geologic distributions. Methods and limitations of interpretation. Prerequisite: GPGN303. 3 hours lecture, 3 hours lab; 4 semester hours.

GPGN419/PEGN419. WELL LOG ANALYSIS AND FORMATION EVALUATION (I) The basics of core analysis and the principles of all common borehole instruments are reviewed. The course shows (computer) interpretation methods that combine the measurements of various borehole instruments to determine rock properties such as porosity, permeability, hydrocarbon saturation, water salinity, ore grade, ash-content, mechanical strength, and acoustic veloc-

ity. The impact of these parameters on reserves estimates of hydrocarbon reservoirs and mineral accumulations is demonstrated. Prerequisite: MATH225, MATH348 or PHGN311, GPGN302 and GPGN303. 3 hours lecture, 2 hours lab; 3 semester hours.

GPGN420. ADVANCED ELECTRICAL AND ELECTROMAGNETIC METHODS (I) In-depth study of the application of electrical and electromagnetic methods to crustal studies, minerals exploration, oil and gas exploration, and groundwater. Laboratory work with scale and mathematical models coupled with field work over areas of known geology. Prerequisite: GPGN302 and GPGN303, or consent of instructor. 3 hours lecture, 3 hours lab; 4 semester hours.

GPGN432. FORMATION EVALUATION (II) The basics of core analysis and the principles of all common borehole instruments are reviewed. The course teaches interpretation methods that combine the measurements of various borehole instruments to determine rock properties such as porosity, permeability, hydrocarbon saturation, water salinity, ore grade and ash content. The impact of these parameters on reserve estimates of hydrocarbon reservoirs and mineral accumulations is demonstrated. Geophysical topics such as vertical seismic profiling, single well and cross-well seismic are emphasized in this course, while formation testing, and cased hole logging are covered in GPGN419/PEGN419 presented in the fall. The laboratory provides on-line course material and hands-on computer log evaluation exercises. Prerequisites: MATH225, GPGN302 and GPGN303. 3 hours lecture, 3 hours lab; 4 semester hours. Only one of the two courses GPGN432 and GPGN419/PEGN419 can be taken for credit.

GPGN438. GEOPHYSICS PROJECT DESIGN (I, II) Complementary design course for geophysics restricted elective course(s). Application of engineering design principles to geophysics through advanced work, individual in character, leading to an engineering report or senior thesis and oral presentation thereof. Choice of design project is to be arranged between student and individual faculty member who will serve as an advisor, subject to department head approval. Prerequisites: GPGN302 and GPGN303 and completion of or concurrent enrollment in geophysics method courses in the general topic area of the project design. Credit variable, 1 to 3 hours. Repeatable for credit up to a maximum of 3 hours.

GPGN439. GEOPHYSICS PROJECT DESIGN (II)
GEGN439/PEGN439. MULTI-DISCIPLINARY PETROLEUM DESIGN (II). This is a multidisciplinary design course that integrates fundamentals and design concepts in geological, geophysical, and petroleum engineering. Students work in integrated teams consisting of students from each of the disciplines. Multiple open-end design problems in oil and gas exploration and field development, including the development of a prospect in an exploration play a detailed engineering field study, are assigned. Several detailed written and oral presentations are made throughout the se-

mester. Project economics, including risk analysis, are an integral part of the course. Prerequisites: GP majors: GPGN302 and GPGN303; GE majors: GEOL308 or GEOL309, GEGN316, GEGN438; PE majors: PEGN316, PEGN414, PEGN422, PEGN423, PEGN424 (or concurrent). 2 hours lecture, 3 hours lab; 3 semester hours.

GPGN461. ADVANCED SEISMIC METHODS (I) Historical survey. Propagation of body and surface waves in elastic media; transmission and reflection at single and multiple interfaces; energy relationships; attenuation factors, data processing (including velocity interpretation, stacking, and migration) interpretation techniques including curved ray methods. Acquisition, processing, and interpretation of laboratory model data; seismic processing using an interactive workstation. Prerequisite: GPGN302 and concurrent enrollment in GPGN404, or consent of instructor. 3 hours lecture, 3 hours lab; 4 semester hours.

GPGN470/GEOL470. APPLICATIONS OF SATELLITE REMOTE SENSING (II) An introduction to geoscience applications of satellite remote sensing of the Earth and planets. The lectures provide background on satellites, sensors, methodology, and diverse applications. Topics include visible, near infrared, and thermal infrared passive sensing, active microwave and radio sensing, and geodetic remote sensing. Lectures and labs involve use of data from a variety of instruments, as several applications to problems in the Earth and planetary sciences are presented. Students will complete independent term projects that are presented both written and orally at the end of the term. Prerequisites: PHGN200 and MATH225 or consent of instructor. 2 hours lecture, 2 hours lab; 3 semester hours.

GPGN475. PLANETARY GEOPHYSICS (I) Of the solid planets and moons in our Solar System, no two bodies are exactly alike. This class will provide an overview of the observed properties of the planets and moons, cover the basic physical processes that govern their evolution, and then investigate how the planets differ and why. The overarching goals are to develop a quantitative understanding of the processes that drive the evolution of planetary surfaces and interiors, and to develop a deeper understanding of the Earth by placing it in the broader context of the Solar System. Prerequisites: PHGN100, MATH225, and GEGN205 or GEOL410. Senior or graduate standing recommended. 3 hours lecture; 3 semester hours.

GPGN486. GEOPHYSICS FIELD CAMP (S) Introduction to geological and geophysical field methods. The program includes exercises in geological surveying, stratigraphic section measurements, geological mapping, and interpretation of geological observations. Students conduct geophysical surveys related to the acquisition of seismic, gravity, magnetic, and electrical observations. Students participate in designing the appropriate geophysical surveys, acquiring the observations,

reducing the observations, and interpreting these observations in the context of the geological model defined from the geological surveys. Prerequisites: GEOL308 or GEOL309, GPGN302, GPGN303, and GPGN315 or consent of instructor. Repeatable to a maximum of 6 hours.

GPGN498. SPECIAL TOPICS IN GEOPHYSICS (I, II) New topics in geophysics. Each member of the academic faculty is invited to submit a prospectus of the course to the department head for evaluation as a special topics course. If selected, the course can be taught only once under the 498 title before becoming a part of the regular curriculum under a new course number and title. Prerequisite: Consent of department. Credit – variable, 1 to 6 hours. Repeatable for credit under different titles.

GPGN499. GEOPHYSICAL INVESTIGATION (I, II) Individual project; instrument design, data interpretation, problem analysis, or field survey. Prerequisite: Consent of department. “Independent Study” form must be completed and submitted to the Registrar. Credit dependent upon nature and extent of project. Variable 1 to 6 credit hours. Repeatable for credit.

Graduate Courses

500-level courses are open to qualified seniors with the permission of the department and Dean of the Graduate School. 600-level courses are open only to students enrolled in the Graduate School.

GPGN503/GEGN503/PEGN503. INTEGRATED EXPLORATION AND DEVELOPMENT (I) Students work alone and in teams to study reservoirs from fluvial-deltaic and valley fill depositional environments. This is a multidisciplinary course that shows students how to characterize and model subsurface reservoir performance by integrating data, methods and concepts from geology, geophysics and petroleum engineering. Activities include field trips, computer modeling, written exercises and oral team presentations. Prerequisite: GEOL501 or consent of instructors. 2 hours lecture, 3 hours lab; 3 semester hours. Offered fall semester, odd years.

GPGN504/GEGN504/PEGN504. INTEGRATED EXPLORATION AND DEVELOPMENT (I) Students work in multidisciplinary teams to study practical problems and case studies in integrated subsurface exploration and development. Students will learn and apply methods and concepts from geology, geophysics and petroleum engineering to timely design problems in oil and gas exploration and field development. Activities include field trips, computer modeling, written exercises and oral team presentations. Prerequisite: GPGN/GEGN/PEGN503 or consent of instructors. 3 hours lecture and seminar; 3 semester hours. Offered fall semester, even years.

GPGN507. NEAR-SURFACE FIELD METHODS (I) Students design and implement data acquisition programs for all forms of near-surface geophysical surveys. The result

of each survey is then modeled and discussed in the context of field design methods. Prerequisite: Consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours. Offered fall semester, even years.

GPGN509. PHYSICAL AND CHEMICAL PROPERTIES AND PROCESSES IN ROCK, SOILS, AND FLUIDS (I) Physical and chemical properties and processes that are measurable with geophysical instruments are studied, including methods of measurement, interrelationships between properties, coupled processes, and processes which modify properties in pure phase minerals and fluids, and in mineral mixtures (rocks and soils). Investigation of implications for petroleum development, minerals extraction, groundwater exploration, and environmental remediation. Prerequisite: Consent of instructor. 3 hours lecture, 3 semester hours.

GPGN511. ADVANCED GRAVITY AND MAGNETIC EXPLORATION (II) Field or laboratory projects of interest to class members; topics for lecture and laboratory selected from the following: new methods for acquiring, processing, and interpreting gravity and magnetic data, methods for the solution of two- and three-dimensional potential field problems, Fourier transforms as applied to gravity and magnetics, the geologic implications of filtering gravity and magnetic data, equivalent distributions, harmonic functions, inversions. Prerequisite: GPGN411 or consent of instructor. 3 hours lecture, 3 hours lab and field; 4 semester hours. Offered fall semester, even years.

GPGN519/PEGN519. ADVANCED FORMATION EVALUATION (II) A detailed review of well logging and other formation evaluation methods will be presented, with the emphasis on the imaging and characterization of hydrocarbon reservoirs. Advanced logging tools such as array induction, dipole sonic, and imaging tools will be discussed. The second half of the course will offer in parallel sessions: for geologists and petroleum engineers on subjects such as pulsed neutron logging, nuclear magnetic resonance, production logging, and formation testing; for geophysicists on vertical seismic profiling, cross well acoustics and electro-magnetic surveys. Prerequisite: GPGN419/PEGN419 or consent of instructor. 3 hours lecture; 3 semester hours.

GPGN520. ELECTRICAL AND ELECTROMAGNETIC EXPLORATION (I) Electromagnetic theory. Instrumentation. Survey planning. Processing of data. Geologic interpretations. Methods and limitations of interpretation. Prerequisite: GPGN302 and GPGN303, or consent of instructor. 3 hours lecture, 3 hours lab; 4 semester hours. Offered fall semester, odd years.

GPGN521. ADVANCED ELECTRICAL AND ELECTROMAGNETIC EXPLORATION (II) Field or laboratory projects of interest to class members; topics for lecture and laboratory selected from the following: new methods for acquiring, processing and interpreting electrical and electromagnetic data, methods for the solution of two- and

three-dimensional EM problems, physical modeling, integrated inversions. Prerequisite: GPGN422 or GPGN520, or consent of instructor. 3 hours lecture, 3 hours lab; 4 semester hours. Offered spring semester, even years.

GPGN530. APPLIED GEOPHYSICS (II) Introduction to geophysical techniques used in a variety of industries (mining, petroleum, environmental and engineering) in exploring for new deposits, site design, etc. The methods studied include gravity, magnetic, electrical, seismic, radiometric and borehole techniques. Emphasis on techniques and their applications are tailored to student interests. The course, intended for non-geophysics students, will emphasize the theoretical basis for each technique, the instrumentation used and data collection, processing and interpretation procedures specific to each technique so that non-specialists can more effectively evaluate the results of geophysical investigations. Prerequisites: PHGN100, PHGN200, MATH111, GEGN401 or consent of the instructor. 3 hours lecture; 3 semester hours.

GPGN540. MINING GEOPHYSICS (I) Introduction to gravity, magnetic, electric, radiometric and borehole techniques used primarily by the mining industry in exploring for new deposits but also applied extensively to petroleum, environmental and engineering problems. The course, intended for graduate geophysics students, will emphasize the theoretical basis for each technique, the instrumentation used and data collection, processing and interpretation procedures specific to each technique. Prerequisites: GPGN321, GPGN322, MATH111, MATH112, MATH213. 3 hours lecture; 3 semester hours.

GPGN551/MATH693. WAVE PHENOMENA SEMINAR (I, II) Students will probe a range of current methodologies and issues in seismic data processing, and discuss their ongoing and planned research projects. Topic areas include: Statics estimation and compensation, deconvolution, multiple suppression, wavelet estimation, imaging and inversion, anisotropic velocity and amplitude analysis, seismic interferometry, attenuation and dispersion, extraction of stratigraphic and lithologic information, and correlation of surface and borehole seismic data with well log data. Every student registers for GPGN551 in the first semester in residence and receives a grade of PRG. The grade is changed to a letter grade after the student's presentation of thesis research. Prerequisite: Consent of department. 1 hour seminar; 1 semester hour.

GPGN552. INTRODUCTION TO SEISMOLOGY (I) Introduction to basic principles of elasticity including Hooke's law, equation of motion, representation theorems, and reciprocity. Representation of seismic sources, seismic moment tensor, radiation from point sources in homogeneous isotropic media. Boundary conditions, reflection/transmission coefficients of plane waves, plane-wave propagation in stratified media. Basics of wave propagation in attenuative media, brief description of seismic modeling methods. Prerequisite:

GPGN461 or consent of instructor. 3 hours lecture; 3 semester hours.

GPGN553. INTRODUCTION TO SEISMOLOGY (II) This course is focused on the physics of wave phenomena and the importance of wave-theory results in exploration and earthquake seismology. Includes reflection and transmission problems for spherical waves, methods of steepest descent and stationary phase, point-source radiation in layered isotropic media, surface and non-geometrical waves. Discussion of seismic modeling methods, fundamentals of wave propagation in anisotropic and attenuative media. Prerequisite: GPGN552 or consent of instructor. 3 hours lecture; 3 semester hours. Offered spring semester, even years.

GPGN555. INTRODUCTION TO EARTHQUAKE SEISMOLOGY (II) Introductory course in observational, engineering, and theoretical earthquake seismology. Topics include: seismogram interpretation, elastic plane waves and surface waves, source kinematics and constraints from seismograms, seismicity and earthquake location, magnitude and intensity estimates, seismic hazard analysis, and earthquake induced ground motions. Students interpret digital data from globally distributed seismic stations. Prerequisite: GPGN461. 3 hours lecture; 3 semester hours. Offered spring semester, odd years.

GPGN558. SEISMIC DATA INTERPRETATION (II) Practical interpretation of seismic data used in exploration for hydrocarbons. Integration with other sources of geological and geophysical information. Prerequisite: GPGN461, GEOL501 or equivalent or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

GPGN561. SEISMIC DATA PROCESSING I (I) Introduction to basic principles underlying the processing of seismic data for suppression of various types of noise. Includes the rationale for and methods for implementing different forms of gain to data, and the use of various forms of stacking for noise suppression, such as diversity stacking of Vibroseis data, normal-moveout correction and common-midpoint stacking, optimum-weight stacking, beam steering and the stack array. Also discussed are continuous and discrete one- and two-dimensional data filtering, including Vibroseis correlation, spectral whitening, moveout filtering, data interpolation, slant stacking, and the continuous and discrete Radon transform for enhancing data resolution and suppression of multiples and other forms of coherent noise. Prerequisite: GPGN461 or consent of instructor. 3 hours lecture; 3 semester hours. Offered fall semester, even years.

GPGN562. SEISMIC DATA PROCESSING II (II) The student will gain understanding of applications of deterministic and statistical deconvolution for wavelet shaping, wavelet compression, and multiple suppression. Both reflection-based and refraction-based statistics estimation and correction for 2-D and 3-D seismic data will be covered, with some atten-

tion to problems where subsurface structure is complex. Also for areas of complex subsurface structure, students will be introduced to analytic and interactive methods of velocity estimation. Where the near-surface is complex, poststack and prestack imaging methods, such as layer replacement are introduced to derive dynamic corrections to reflection data. Also discussed are special problems related to the processing of multi-component seismic data for enhancement of shear-wave information, and those related to processing of vertical seismic profile data for separation of upgoing and downgoing P- and S- wave arrivals. Prerequisite: GPGN461 and GPGN561 or consent of instructor. 3 hours lecture; 3 semester hours. Offered spring semester, odd years.

GPGN570/GEOL570. APPLICATIONS OF SATELLITE REMOTE SENSING (II) An introduction to geoscience applications of satellite remote sensing of the Earth and planets. The lectures provide background on satellites, sensors, methodology, and diverse applications. Topics include visible, near infrared, and thermal infrared passive sensing, active microwave and radio sensing, and geodetic remote sensing. Lectures and labs involve use of data from a variety of instruments, as several applications to problems in the Earth and planetary sciences are presented. Students will complete independent term projects that are presented both written and orally at the end of the term. Prerequisites: PHGN200 and MATH225 or consent of instructor. 2 hours lecture, 2 hours lab; 3 semester hours.

GPGN574. GROUNDWATER GEOPHYSICS (II) Description of world groundwater aquifers. Effects of water saturation on the physical properties of rocks. Use of geophysical methods in the exploration, development and production of groundwater. Field demonstrations of the application of the geophysical methods in the solution of some groundwater problems. Prerequisite: Consent of instructor. 3 hours lecture, 3 hours lab; 4 semester hours.

GPGN575 PLANETARY GEOPHYSICS Of the solid planets and moons in our Solar System, no two bodies are exactly alike. This class will provide an overview of the observed properties of the planets and moons, cover the basic physical processes that govern their evolution, and then investigate how the planets differ and why. The overarching goals are to develop a quantitative understanding of the processes that drive the evolution of planetary surfaces and interiors, and to develop a deeper understanding of the Earth by placing it in the broader context of the Solar System. Prerequisites: Graduate standing. 3 hours lecture; 3 semester hours.

GPGN576 SPECIAL TOPICES IN THE PLANETARY SCIENCES Students will read and discuss papers on a particular topic in the planetary sciences. The choice of topic will change each semester. The emphasis is on key topics related to the current state and evolution of the solid planets and moons in our solar system. Readings will include both semi-

nal papers and current research on the topic. Students will take turns presenting summaries of the papers and leading the ensuing discussion. Prerequisites: Graduate standing, or senior standing and permission of the instructor. 1 hour lecture; 1 semester hour. Repeatable for credit.

GPGN580/GEOL580/MNGN580. INDUCED SEISMICITY (II) Earthquakes are sometimes caused by the activities of man. These activities include mining and quarrying, petroleum and geothermal energy production, building water reservoirs and dams, and underground nuclear testing. This course will help students understand the characteristics and physical causes of man-made earthquakes and seismicity induced in various situations. Students will read published reports and objectively analyze the seismological and ancillary data therein to decide if the causative agent was man or natural processes. Prerequisite: basic undergraduate geology and physics. 3 hours lecture; 3 semester hours.

GPGN581. GRADUATE SEMINAR – MS (I, II) Presentation describing results of MS thesis research. All theses must be presented in seminar before corresponding degree is granted. Every MS student registers for GPGN581 only in his/her first semester in residence and receives a grade of PRG. Thereafter, students must attend the weekly Heiland Distinguished Lecture every semester in residence. The grade of PRG is changed to a letter grade after the student's presentation of MS thesis research. 1 hour seminar, 1 semester hour.

GPGN597. SUMMER PROGRAMS

GPGN598. SPECIAL TOPICS IN GEOPHYSICS (I, II) New topics in geophysics. Each member of the academic faculty is invited to submit a prospectus of the course to the department head for evaluation as a special topics course. If selected, the course can be taught only once under the 598 title before becoming a part of the regular curriculum under a new course number and title. Prerequisite: Consent of department. Credit-variable, 1 to 6 hours. Repeatable for credit under different titles.

GPGN599. GEOPHYSICAL INVESTIGATIONS MS (I, II) Individual project; instrument design, data interpretation, problem analysis, or field survey. Prerequisite: Consent of department and "Independent Study" form must be completed and submitted to the Registrar. Credit dependent upon nature and extent of project. Variable 1 to 6 hours. Repeatable for credit.

GPGN605. INVERSION THEORY (II) Introductory course in inverting geophysical observations for inferring earth structure and processes. Techniques discussed include: Monte-Carlo procedures, Marquardt-Levenburg optimization, and generalized linear inversion. In addition, aspects of probability theory, data and model resolution, uniqueness considerations, and the use of a priori constraints are presented. Students are required to apply the inversion methods described to a problem of their choice and present the results

as an oral and written report. Prerequisite: MATH225 and knowledge of a scientific programming language. 3 hours lecture; 3 semester hours.

GPGN606. SIMULATION OF GEOPHYSICAL DATA (II) Efficiency of writing and running computer programs. Review of basic matrix manipulation. Utilization of existing CSM and department computer program libraries. Some basic and specialized numerical integration techniques used in geophysics. Geophysical applications of finite elements, finite differences, integral equation modeling, and summary representation. Project resulting in a term paper on the use of numerical methods in geophysical interpretation. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. Offered spring semester, odd years.

GPGN651. ADVANCED SEISMOLOGY (I) In-depth discussion of wave propagation and seismic processing for anisotropic, heterogeneous media. Topics include influence of anisotropy on plane-wave velocities and polarizations, traveltimes analysis for transversely isotropic models, anisotropic velocity-analysis and imaging methods, point-source radiation and Green's function in anisotropic media, inversion and processing of multicomponent seismic data, shear-wave splitting, and basics of seismic fracture characterization. Prerequisites: GPGN552 and GPGN553 or consent of instructor. 3 hours lecture; 3 semester hours.

GPGN658. SEISMIC WAVEFIELD IMAGING (I) Seismic imaging is the process that converts seismograms, each recorded as a function of time, to an image of the earth's subsurface, which is a function of depth below the surface. The course emphasizes imaging applications developed from first principles (elastodynamics relations) to practical methods applicable to seismic wavefield data. Techniques discussed include reverse-time migration and migration by wavefield extrapolation, angle-domain imaging, migration velocity analysis and analysis of angle-dependent reflectivity. Students do independent term projects presented at the end of the term, under the supervision of a faculty member or guest lecturer. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

GPGN660. MATHEMATICS OF SEISMIC IMAGING AND MIGRATION (II) During the past 40 years geophysicists have developed many techniques (known collectively as "migration") for imaging geologic structures deep within the Earth's subsurface. Beyond merely imaging strata, migration can provide information about important physical properties of rocks, necessary for the subsequent drilling and development of oil- and gas-bearing formations within the Earth. In this course the student will be introduced to the mathematical theory underlying seismic migration, in the context of "inverse scattering imaging theory." The course is heavily oriented toward problem solving. 3 hours lecture; 3 semester hours. Offered spring semester, odd years.

GPGN681. GRADUATE SEMINAR – PHD (I, II) Presentation describing results of Ph.D. thesis research. All theses must be presented in seminar before corresponding degree is granted. Every PhD student registers for GPGN681 only in his/her first semester in residence and receives a grade of PRG. Thereafter, students must attend the weekly Heiland Distinguished Lecture every semester in residence. The grade of PRG is changed to a letter grade after the student's presentation of PhD thesis research. 1 hour seminar; 1 semester hour.

GPGN698. SPECIAL TOPICS IN GEOPHYSICS (I, II) New topics in geophysics. Each member of the academic faculty is invited to submit a prospectus of the course to the department head for evaluation as a special topics course. If selected, the course can be taught only once under the 698 title before becoming a part of the regular curriculum under a new course number and title. Prerequisite: Consent of instructor. Credit – variable, 1 to 6 hours. Repeatable for credit under different topics.

GPGN699. GEOPHYSICAL INVESTIGATION-PHD (I, II) Individual project; instrument design, data interpretation, problem analysis, or field survey. Prerequisite: Consent of department and "Independent Study" form must be completed and submitted to the Registrar. Credit dependent upon nature and extent of project, not to exceed 6 semester hours. Repeatable for credit.

GPGN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

GPGN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy-thesis. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

Hydrologic Science and Engineering

DAVID BENSON, Associate Professor and HSE Director, Geology & Geological Engineering

RONALD R.H. COHEN, Associate Professor and HSE Associate Director, Environmental Science & Engineering

Department of Chemistry and Geochemistry

JAMES RANVILLE, Associate Professor

BETTINA VOELKER, Associate Professor

Division of Environmental Science and Engineering

JOHN MCCRAY, Professor & Director, Environmental Science & Engineering

ROBERT L. SIEGRIST, University Emeritus Professor

TISSA ILLANGASEKARE, Professor and AMAX Chair

JÖRG DREWES, Professor

LINDA FIGUEROA, Associate Professor

JUNKO MUNAKATA MARR, Associate Professor

JOHN SPEAR, Associate Professor

TZAHY CATH, Assistant Professor

CHRISTOPHER HIGGINS, Assistant Professor

JONATHAN SHARP, Assistant Professor

Division of Engineering

MARTE GUTIERREZ, Professor

NING LU, Professor

Department of Geology and Geological Engineering

JOHN HUMPHREY, Associate Professor and Director

EILEEN POETER, Emerita Professor

REED MAXWELL, Associate Professor

Department of Geophysics

DAVID HALE, Professor

GARY OLHOEFT, Professor

YAOGUO LI, Associate Professor

ANDRE REVIL, Associate Professor

JEFF ANDREWS-HANNAH, Assistant Professor

Division of Liberal Arts & International Studies

HUSSEIN AMERY, Professor

Degrees Offered:

Master of Science (Hydrology), Thesis option

Master of Science (Hydrology), Non-thesis option

Doctor of Philosophy (Hydrology)

Program Description:

The Hydrologic Science and Engineering (HSE) Program is an interdisciplinary graduate program comprised of faculty from several different CSM departments.

The program offers programs of study in fundamental hydrologic science and applied hydrology with engineering applications. Our program encompasses ground-water hydrogeology, surface-water hydrology, vadose-zone hydrology, watershed hydrology, contaminant transport and fate, contaminant remediation, hydrogeophysics, and water policy/law. Students may elect to follow the Science or the Engineering Track.

HSE requires a core study of 4 formal graduate courses. Programs of study are interdisciplinary in nature, and coursework is obtained from multiple departments at CSM and is ap-

proved for each student by the student's advisor and thesis Committee.

To achieve the Master of Science (M.S.) degree, students may elect the Non-Thesis option, based exclusively upon coursework and a project report, or the Thesis option. The thesis option is comprised of coursework in combination with individual laboratory, modeling and/or field research performed under the guidance of a faculty advisor and presented in a written thesis approved by the student's committee.

HSE also offers a combined baccalaureate/masters degree program in which CSM students obtain an undergraduate degree as well as a Thesis or Non-thesis M.S. in Hydrology. In the Combined Degree Program as many as six credit hours may be counted towards the B.S. and M.S. degree requirements. Please see the Combined Undergraduate/Graduate Programs sections in the Graduate and Undergraduate Bulletins for additional information.

To achieve the Doctor of Philosophy (Ph.D.) degree, students are expected to complete a combination of coursework and novel, original research, under the guidance of a faculty advisor and Doctoral committee, which culminates in a significant scholarly contribution to a specialized field in hydrologic sciences or engineering. Full-time enrollment is expected and leads to the greatest success, although part-time enrollment may be allowed under special circumstances. All doctoral students must complete the full-time, on-campus residency requirements described in the general section of the *Graduate Bulletin*.

Currently, students will apply to the hydrology program through the Graduate School and be assigned to the HSE participating department or division of the student's HSE advisor. Participating units include: Chemistry and Geochemistry, Engineering, Environmental Science and Engineering (ESE), Geology and Geological Engineering (GE), Geophysical Engineering, Mining Engineering (ME), and Petroleum Engineering (PE). HSE is part of the Western Regional Graduate Program, a recognition that designates these programs as unique within the Western United States. An important benefit of this designation is that students from several western states are given the tuition status of Colorado residents. These states include Alaska, Arizona, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming.

For more information on HSE curriculum please refer to the HSE website at hydrology.mines.edu.

Combined Degree Program Option:

CSM undergraduate students have the opportunity to begin work on a M.S. degree in Hydrology while completing their Bachelor's degree. The CSM Combined Degree Program provides the vehicle for students to complete graduate coursework while still an undergraduate student. For more information please contact the HSE program faculty.

Program Requirements:

M.S. Non-Thesis Option: 36 total credit hours, consisting of coursework (30 h), and Independent Study (6 h) working on a research project with HSE faculty, including a written report.

M.S. Thesis Option: 30 total credit hours, consisting of coursework (24 h), and research (6 h). Students must also write and orally defend a research thesis.

Ph.D.: 72 total credit hours, consisting of coursework (at least 15 h), and research (at least 24 h). Students must also successfully complete qualifying examinations, write and defend a dissertation proposal, write and defend a doctoral dissertation, and are expected to submit the dissertation work for publication in scholarly journals.

Thesis Committee Requirements

Students must meet the general requirements listed in the graduate bulletin section *Graduate Degrees and Requirements*. In addition, the student's advisor or co-advisor must be an HSE faculty member. For M.S. thesis students, at least two committee members must be members of the HSE faculty. For doctoral students, at least 3 members must be a member of the HSE faculty.

Prerequisites Science Track:

- ◆ baccalaureate degree in a science or engineering discipline
- ◆ college calculus: two semesters required
- ◆ differential equations: one semester required
- ◆ college physics: one semester required
- ◆ college chemistry: one year required
- ◆ fluid mechanics, one semester required
- ◆ college statistics: one semester required

Prerequisites Engineering Track:

- ◆ baccalaureate degree in a science or engineering discipline
- ◆ college calculus: two semesters required
- ◆ differential equations: one semester required
- ◆ college physics: two semesters required
- ◆ college chemistry: two years required
- ◆ college statistics: one semester required
- ◆ statics, one semester required
- ◆ mechanics of materials, one semester required
- ◆ dynamics, one semester required
- ◆ thermodynamics, one semester required
- ◆ fluid mechanics: one semester required
- ◆ engineering design (equivalent of a 400-level capstone design course or ESGN 451 - Hydraulic Problems)

Note that some pre-requisites may be completed in the first few semesters of the graduate program if approved by the hydrology program faculty. Graduate courses may be used to fulfill one or more of these requirements after approval by the HSE Graduate Admissions Committee and the student's Thesis Committee.

Required Curriculum:

Students will work with their academic advisors and graduate thesis committees to establish plans of study that best fit their individual interests and goals. Each student will develop and submit a plan of study to their advisor during the first semester of enrollment. Doctoral students may transfer in credits from an earned M.S. graduate program according to requirements listed in the Graduate Degrees and Requirements section of the graduate bulletin, and after approval by the student's thesis committee. Recommended pre-requisite courses may be taken for credit during the first year a student is enrolled in HSE. In some cases, graduate courses may satisfy one or more pre-requisites if approved by the hydrology program faculty.

SCIENCE TRACK:

Curriculum areas of emphasis consist of core courses, and electives. Core courses include the following:

- Ground Water Engineering (GEGN466)
- Surface-Water Hydrology (GEGN582)
- Environmental Water Chemistry (ESGN500)
- Subsurface Contaminant Fate and Transport (ESGN522)
- Or
- Surface Water Quality Modeling (ESGN520)

HSE seminar is also required and will typically have a 598 course number. These are one-credit reading and discussion seminars. PhD students are required to complete at least two during their studies, and M.S. students must complete one seminar. The seminar courses are taught nearly every semester, with different topics depending on the instructor. Students who plan to incorporate hydrochemistry into their research may elect to replace ESGN 500 with a two-course combination that includes an aqueous inorganic chemistry course (CHGC 509) and an environmental organic chemistry course (ESGN 555).

A grade of B- or better is required in all core classes for graduation.

Elective courses may be chosen from a list approved by the HSE program faculty with one free elective that may be chosen from any of the graduate courses offered at CSM and other local universities. A list of these courses can be found on the HSE website.

ENGINEERING TRACK:

Curriculum areas of emphasis consist of core courses, and electives. Core courses include all core courses in the Science Track and a relevant Capstone Design Course (e.g. Ground Water Engineering GEGN 470)

Elective courses may be chosen from a list approved by the HSE program faculty with one free elective that may be chosen from any of the graduate courses offered at CSM and other local universities. At least half of the elective credits must come from the following list:

GEGN 581	Analytical Hydrology
GEGN 683	Advanced Groundwater Modeling
ESGN 622	Multiphase Fluids Transport
GEGN 681	Vadose-Zone Hydrology
GEGN 584	Advanced Hydrogeology
GEGN 682	Flow And Transport In Fractured Rock
ESGN 575	Hazardous Waste Site Remediation
GEGN 585	Hydrochemical Modeling
GEGN 684	Chemical Modeling of Aqueous Systems
EGGN 454	Water Supply Engineering
ESGN 603	Water Reuse and Treatment
EGES 533	Unsaturated Soil Mechanics
EGES 534	Soil Behavior
EGES 553	Engineering Hydrology
EGES 554	Open Channel Flow
GEGN 532	Geological Data Analysis
GEGN 575	Applications of GIS
GEGN 542	Advanced Engineering Geomorphology
GEGN 573	Site Investigation
ESGN 601	Risk Assessment
ESGN 598	Numerical Methods for Modeling of Water and Environmental Systems

Interdisciplinary

Degrees Offered:

- Master of Science (Interdisciplinary)
- Doctor of Philosophy (Interdisciplinary)

Program Description:

In addition to its traditional degree programs, Mines offers innovative, interdisciplinary, research-based degree programs that fit the institutional role and mission, but cannot easily be addressed within a single discipline or degree program. Specialities offered under this option are provided for a limited time during which faculty from across campus come together to address relevant, timely, interdisciplinary issues. The Interdisciplinary Graduate Program is intended to 1) encourage faculty and students to participate in broadly interdisciplinary research, 2) provide a mechanism by which a rigorous academic degree program may be tightly coupled to this interdisciplinary research, and 3) provide a mechanism for faculty to develop and market test, timely and innovative interdisciplinary degree programs in the hope that, if successful, may become full-fledged, stand-alone degree programs in the future.

Program Requirements:

Graduates of the Interdisciplinary Graduate Program must meet all institutional requirements for graduation and the requirements of the Speciality under which they are admitted.

Program Management:

Overall management and oversight of the Interdisciplinary Degree Program is undertaken by a Program Oversight Committee consisting of the

- ◆ Dean of Graduate Studies (Chair and Program Director),
- ◆ One Representative from the Faculty Senate,
- ◆ One Representative from Department Heads/Division Directors, and
- ◆ One Faculty Representative from each active Speciality Areas.

The role of the Oversight Committee is fourfold.

- ◆ *Speciality Oversight:* includes advising and assisting faculty in the creation of new Speciality areas, periodic Speciality review and termination of Specialities having exceed the allowed time limits,
- ◆ *Speciality Mentoring:* includes providing assistance to, and support of existing Specialities as they move toward applying for full degree status,
- ◆ *Program Advocacy:* includes promotion of program at the institutional level, and promotion, development and support of new Speciality areas with individual groups of faculty, and

- ◆ *Council Representation*: upon the advise of the directors of the individual Specialities offered, the Oversight Committee appoints an Interdisciplinary Degree program representative to Graduate Council.

Speciality Requirements and Approval Processes

Specialities must meet the following minimum requirements.

- ◆ Speciality area must be, within the context of Mines, interdisciplinary in nature. That is, expertise that would be reasonably expected to be required to deliver the speciality must span multiple degree programs at Mines.
- ◆ Faculty participating in the Speciality must be derived from no fewer than two separate home units.
- ◆ There must be a minimum of six tenure/tenure-track core faculty participating in the Speciality.

The package of materials to be reviewed for Speciality approval must, at a minimum, include the following items:

- ◆ descriptive overview of Speciality degree area,
- ◆ list of participating Faculty and the Departments/Divisions in which they are resident,
- ◆ name of Speciality to be included on the transcript,
- ◆ listing and summary description of all Speciality degree requirements,
- ◆ a description of how program quality is overseen by participating Speciality faculty including the Admission to Candidacy process to be used within the Speciality,
- ◆ a copy of Bylaws (i.e., operating parameters that define how the Speciality is managed, how faculty participate, how admissions is handled, etc.) under which the Speciality and its faculty operate,
- ◆ a listing and justification for any additional resources needed to offer the Speciality, and
- ◆ a draft of the Graduate Bulletin text that will be used to describe the Speciality in the Interdisciplinary Degree section of Bulletin.

Materials for Speciality approval must be approved by all of the following groups. Faculty advancing a Speciality should seek approval from each group in the order in which they are presented below.

- ◆ Faculty and Department Heads/Division Directors of each of the departments/divisions contributing staffing to the Speciality,
- ◆ Interdisciplinary Program Oversight Committee,
- ◆ Graduate Council,
- ◆ Faculty Senate, and
- ◆ Provost.

Failure to receive approval at any level constitutes an institutional decision to not offer the Speciality as described.

Full-Fledged Degree Creation and Speciality Time Limits:

Documentation related to specific program Specialities, as published in the Graduate Bulletin, includes the inception semester of the Speciality. For Specialities garnering significant enrollment and support by participating academic faculty, the Program Oversight Committee encourages the participating faculty to seek approval – both on campus, and through the Board of Trustees and DHE – for a stand alone degree program. Upon approval, all students still in the Speciality will be moved to the full-fledged degree program.

Admissions to all doctoral-level Specialities will be allowed for a maximum of 7 years after the Speciality inception date. Specialities may apply to the Oversight Committee for a one-time extension to this time limit that shall not exceed 3 additional years. If successful, the Oversight Committee shall inform Graduate Council and the Faculty Senate of the extension.

Specialities:

Operations Research with Engineering (initiated Fall, 2011)

KADRI DAGDELEN, Professor, (MN)

DINESH MEHTA, Professor, (CS)

MICHAEL WALLS, Professor, (EB)

CRISTIAN CIOBANU, Associate Professor, (EG)

MARK KUCHTA, Associate Professor, (MN)

ALEXANDRA NEWMAN, Associate Professor, (EB)

LUIS TENORIO, Associate Professor, (MA)

TYRONE VINCENT, Associate Professor, (EG)

ANDRZEJ SZYMCZAK, Assistant Professor, (MA)

AMANDA HERING, Assistant Professor, (MA)

STEFFEN REBENNACK, Assistant Professor, (EB)

CAMERON TURNER, Assistant Professor, (EG)

JUAN CARLOS MADENI, Research Faculty & Teaching Associate Professor, (MT)

Degrees Offered:

Doctor of Philosophy (Interdisciplinary); Speciality (Operations Research with Engineering)

Program Description:

Operations Research (OR) involves mathematically modeling physical systems (both naturally occurring and man-made) with a view to determining a course of action for the system to either improve or optimize its functionality. Examples of such systems include, but are not limited to, manufacturing systems, chemical processes, socio-economic systems, mechanical systems (e.g., those that produce energy), and mining systems. The ORE PhD Program will allow students to complete an interdisciplinary doctoral degree in Operations Research with Engineering by taking courses and conducting research in five departments/divisions: Mathematical & Computer Sciences, Engineering, Economics & Business, Mining, and Metallurgical & Materials Engineering.

Speciality Requirements:

Doctoral students develop a customized curriculum to fit their needs. The degree requires a minimum of 72 graduate credit hours that includes course work and a thesis. Course-work is valid for ten years towards a Ph.D. degree; any exceptions must be approved by the Director of the ORE program and student advisor.

Course Work

24 credits of core courses

12 credits from electives

Research Credits

At least 24 research credits. The student's faculty advisor and the doctoral thesis committee must approve the student's program of study and the topic for the thesis.

Qualifying Examination Process and Thesis Proposal

Upon completion of the core course work, students must pass qualifying written examinations to become a candidate for the Ph.D. ORE degree. The proposal defense should be done within ten months of passing the qualifying exam.

Transfer Credits

Students may transfer up to 24 hours of graduate-level course work from other institutions toward the Ph.D. degree subject to the restriction that those courses must not have been used as credit toward a Bachelor degree. The student must have achieved a grade of B or better in all graduate transfer courses and the transfer must be approved by the student's Doctoral Thesis Committee and the Director of the ORE program.

Unsatisfactory Progress

In addition to the institutional guidelines for unsatisfactory progress as described elsewhere in this bulletin: Unsatisfactory progress will be assigned to any full-time student who does not pass the prerequisite and core courses CSCI262, EBGN555, MTGN450/ MLGN550, and MATH530 in first fall semester of study and either EGGN593 or EBGN552, and CSCI 406 in the first spring semester of study. Unsatisfactory progress will also be assigned to any students who do not complete requirements as specified in their admission letter. Any exceptions to the stipulations for unsatisfactory progress must be approved by the ORE committee. Part-time students develop an approved course plan with their advisor.

Prerequisites

Students must have completed the following undergraduate prerequisite courses with a grade of B or better:

- ◆ Programming (CSCI 261)
- ◆ Data Structures (CSCI 262)

Students entering in the fall semester must have completed the Programming (CSCI 261) prerequisite or equivalent. Students will only be allowed to enter in the spring semester if they have developed a course program such that they are able to take the qualifying exam within 3 semesters.

Required Course Curriculum

All Ph.D. students are required to take a set of core courses that provides basic tools for the more advanced and specialized courses in the program.

Core Courses (24 credits)

- CSCI/MATH406 Algorithms
- EGGN593/ EBGN552 Engineering Design Optimization/Nonlinear Programming
- MATH530 Statistical Methods I
- EBGN555 Linear Programming
- EBGN557 Integer programming
- EBGN556 Network Models
- EGGN502 Interdisciplinary Modeling and Simulation
- EBGN561 or MATH438 Stochastic processes

Area of Specialization Courses (12 credits)

- EBGN528 or MATH/CSCI 542 Simulation
- MTGN450/MLGN550 Statistical Process Control/Design of Experiments
- EBGN560 Decision Analysis
- EBGN598 Advanced Decision Analysis
- EGGN517 Theory and Design of Advanced Control Systems
- EBGN655 Advanced Linear Programming
- EBGN657 Advanced Integer Programming
- CSCI562 Applied Algorithms and Data Structures
- MNGN536 OR in Mining
- MNGN538 Geostatistics
- EBGN509 Mathematical Economics
- EBGN575 Real Options and Pricing
- MATH531 Statistical Methods II
- XXXX598 Special Topics (Requires Approval of the Advisor and ORE Program Director)

Liberal Arts and International Studies

ELIZABETH VAN WIE DAVIS, Professor and Division Director
CARL MITCHAM, Professor
HUSSEIN A. AMERY, Associate Professor
TINA L. GIANQUITTO, Associate Professor
KATHLEEN J. HANCOCK, Associate Professor and Director,
MIPER Graduate Program
JOHN R. HEILBRUNN, Associate Professor
JON LEYDENS, Associate Professor
JUAN C. LUCENA, Associate Professor
KENNETH OSGOOD, Associate Professor and Director, McBride
Honors Program
JAMES D. STRAKER, Associate Professor
JASON DELBORNE, Assistant Professor
SYLVIA GAYLORD, Assistant Professor
DERRICK HUDSON, Assistant Professor
JENNIFER SCHNEIDER, Assistant Professor
JAMES V. JESUDASON, Teaching Professor
ROBERT KLIMEK, Teaching Professor
TONI LEFTON, Teaching Professor
SANDY WOODSON, Teaching Professor and Undergraduate
Advisor
DAN MILLER, Teaching Associate Professor and Assistant Division
Director
ROSE PASS, Teaching Associate Professor
JONATHAN H. CULLISON, Teaching Assistant Professor
PAULA A. FARCA, Teaching Assistant Professor
CORTNEY E. HOLLES, Teaching Assistant Professor
SHIRA RICHMAN, Teaching Assistant Professor
BETTY J. CANNON, Emerita Associate Professor
W. JOHN CIESLEWICZ, Emeritus Professor
DONALD I. DICKINSON, Emeritus Professor
WILTON ECKLEY, Emeritus Professor
T. GRAHAM HEREFORD, Emeritus Professor
JOHN A. HOGAN, Emeritus Professor
BARBARA M. OLDS, Emerita Professor
KATHLEEN H. OCHS, Emerita Associate Professor
EUL-SOO PANG, Emeritus Professor
LAURA J. PANG, Emerita Associate Professor
ANTON G. PEGIS, Emeritus Professor
THOMAS PHILIPOSE, University Emeritus Professor
ARTHUR B. SACKS, Emeritus Professor
JOSEPH D. SNEED, Emeritus Professor
KAREN B. WILEY, Emerita Associate Professor
ROBERT E.D. WOOLSEY, Emeritus Professor

Degrees Offered:

Master of International Political Economy of Resources

Non-Degree Certificates Offered:

International Political Economy Graduate Certificates
Graduate Certificate in Science, Technology, Engineering,
and Policy

Non-Degree Minor Offered:

Science, Technology, Engineering, and Policy
Graduate Individual Minor

Program Description:

As the 21st century unfolds, individuals, communities, and nations face major challenges in energy, natural resources, and the environment. While these challenges demand practical ingenuity from engineers and applied scientists, solutions must also take into account social, political, economic, cultural, ethical, and global contexts. CSM students, as citizens and future professionals, confront a rapidly changing society that demands core technical skills complemented by flexible intelligence, original thought, and cultural sensitivity.

Courses in Liberal Arts and International Studies (LAIS) expand students' professional capacities by providing opportunities to explore the humanities, social sciences, and fine arts. Our curricula encourage the development of critical thinking skills that will help students make more informed choices as national and world citizens - promoting more complex understandings of justice, equality, culture, history, development, and sustainability. Students study ethical reasoning, compare and contrast different economies and cultures, and develop arguments from data and analyze globalization. LAIS courses also foster creativity by offering opportunities for self-discovery. Students conduct literary analyses, improve communication skills, play music, learn media theory, and write poetry. These experiences foster intellectual agility, personal maturity, and respect for the complexity of our world.

The Division of Liberal Arts & International Studies offers a graduate degree, the Master of International Political Economy of Resources (MIPER); two graduate certificates in International Political Economy (IPE); a graduate certificate in Science, Technology, Engineering, and Policy (STEP); and a graduate individual minor.

Requirements for a Master of International Political Economy of Resources (MIPER)

The objective of the MIPER program is to develop professional analytical skills in resources development and management; issues of regional and global security and risk issues affecting resources industry; and broader concerns of culture, religion and politics. MIPER is designed to give engineers and applied scientists detailed knowledge of the global political economy, with the goal of preparing them for jobs in multinational corporations in resources sectors—as well as governmental and nongovernmental jobs. Through seminars and lectures; analyzing papers and books on the resources industries, on countries and cultures around the world, and on international political economy theories; and researching, writing and presenting analytical papers, graduates will become better leaders and decision-makers in their respective fields. The MIPER program has expanded to include students with social science backgrounds interested in resource issues, mid-level career engineers looking to deepen

their understanding of the global economy, international students working in their home states' resource industries, and military officers seeking higher education.

The Master of International Political Economy of Resources (MIPER) provides students with either a thesis-based or non-thesis professional degree that requires 36 semester hours. Please see the website <https://miper.mines.edu/> for more information on specific courses associated with the degree.

Non-thesis option

15 credits of core courses
21 credits of elective courses

Thesis option

15 credits of core courses
15 credits of elective courses
6 credits of research hours

Combined Undergraduate/Graduate Degree Programs

Some students may earn the master's degree as part of CSM's Combined Undergraduate/Graduate programs. Students participating in the combined degree program may double count up to 6 semester hours of 400-level course work from their undergraduate course work.

Please note that CSM students interested in pursuing a Combined Undergraduate/Graduate program are encouraged to make an initial contact with the MIPER Director after completion of the first semester of their sophomore year for counseling on degree application procedures, admissions standards, and degree completion requirements.

See "Combined Undergraduate/Graduate Degree Programs" elsewhere in this bulletin for further details.

Admission Requirements

The requirements for admission into LAIS Graduate Programs are as follows:

1. An undergraduate degree with a cumulative grade point average (GPA) at or above 3.0 (4.0 scale) or be a CSM undergraduate with a minimum GPA of 3.0 in LAIS course work.
2. The GRE is required. Under certain circumstances, the GRE requirements can be waived.
3. A TOEFL score of 580 (paper test), 237 (computer test), or 92-93 (Internet test) or higher is required for students who are non-native English speakers.

IPE Graduate Certificates

The IPE Graduate Certificate program is divided into two parts: (1) the first 15 credit hour certificate focuses on the IPE theories, methods, and models; and (2) the second 15 credit hour certificate focuses on specialization, such as re-

gional development (Asia-Pacific, Latin America, Africa, Russia, Eurasia, and the Middle East), international or comparative political economy issues, and specific themes like trade, finance, the environment, gender and ethnicity. Admissions requirements are the same as for the degree program. Please see the MIPER Director for more information.

Science, Technology, Engineering, and Policy
Graduate Minor and Certificate (STEP)

The STEP graduate minor for the MS degree requires a minimum 9 semester hours of course work. The STEP graduate minor for the PhD degree requires a minimum 12 semester hours of course work. The STEP graduate certificate requires a minimum 15 semester hours of course work.

In all cases, the required course work must include LAIS 586 Science and Technology Policy. Other courses may be selected from a list of recommended courses posted and regularly updated on the LAIS Science and Technology Policy Studies web site, a list which includes some courses from other academic units. Among non-LAIS courses, the MS minor is limited to one such course and the PhD minor and graduate certificate are limited to two such courses. With the approval of the LAIS STEP adviser, it is also possible to utilize a limited number of other courses from the CSM Bulletin as well as transfer courses from other institutions.

Graduate Individual Minor

Graduate students in departments and divisions other than LAIS may earn a minor in the Division if they complete 12 hours of course work from the LAIS course offerings, including Special Topics (LAIS 598 courses) or Independent Study (LAIS 599) chosen in consultation with an LAIS advisor. Note: The Graduate Individual Minor must be approved by the student's graduate committee and by the LAIS Division.

Description of Courses:

Humanities and Social Sciences (LAIS)

LAIS521. ENVIRONMENTAL PHILOSOPHY AND POLICY Analyzes environmental ethics and philosophy including the relation of philosophical perspectives to policy decision making. Critically examines often unstated ethical and/or philosophical assumptions about the environment and how these may complicate and occasionally undermine productive policies. Policies that may be considered include environmental protection, economic development, and energy production and use. 3 hours seminar; 3 semester hours.

LAIS523. ADVANCED SCIENCE COMMUNICATION Examines historical and contemporary case studies where science communication (or mis-communication) played key roles in shaping policy outcomes and/or public perceptions. Examples will include historical as well as recent controversies. Students will study, analyze, and write about science communication and policy theories related to scientific uncertainty; the role of the scientist as communicator; and

media ethics. Students will also be exposed to a number of strategies for managing encounters with the media as well as tools for assessing their communication responsibilities and capacities. 3 hours seminar; 3 semester hours.

LAIS525. MEDIA AND THE ENVIRONMENT Considers how messages about the environment and environmentalism are communicated in the mass media, fine arts, and popular culture. Introduces students to key readings in communications, media studies, and cultural studies in order to understand the many ways in which the images, messages, and politics of “nature” are constructed. Students will analyze their role as science or technology communicators and will participate in the creation of communications projects related to environmental research on campus. 3 hours seminar; 3 semester hours.

LAIS531 RELIGION AND SECURITY Scrutinizes the central topics in religion and society. Develops an analysis of civil society in 21st century contexts and connects this analysis with leading debates about the relationship of religion and security. Creates an understanding of diverse religious traditions from the perspective of how they view security. 3 hours lecture and discussion; 3 semester hours.

LAIS535. LATIN AMERICAN DEVELOPMENT Explores the political economy of current and recent past development strategies, models, efforts, and issues in Latin America, one of the most dynamic regions of the world today. Development is understood to be a nonlinear, complex set of processes involving political, economic, social, cultural, and environmental factors whose ultimate goal is to improve the quality of life for individuals. The role of both the state and the market in development processes will be examined. Topics to be covered will vary as changing realities dictate but will be drawn from such subjects as inequality of income distribution; the role of education and health care; region-markets; the impact of globalization; institution-building; corporate-community-state interfaces; neoliberalism; privatization; democracy; and public policy formulation as it relates to development goals. 3 hours lecture and discussion; 3 semester hours.

LAIS537. ASIAN DEVELOPMENT Explores the historical development of Asia Pacific from agrarian to post-industrial eras; its economic, political, and cultural transformation since World War II, contemporary security issues that both divide and unite the region; and globalization processes that encourage Asia Pacific to forge a single trading bloc. 3 hours lecture and discussion; 3 semester hours.

LAIS539. MIDDLE EAST DEVELOPMENT Uses economic, political, social and historical dynamics to help understand the development trajectories in the Middle East during recent decades. This research-intensive graduate seminar discusses the development of Middle Eastern societies from their tribal and agrarian roots to post-industrial

ones, and reflects on the pursuant contemporary security issues that both divide and unite the region, as well as analyzing the effects of globalization on economies and socio-political trends. 3 hours seminar; 3 semester hours.

LAIS541. AFRICAN DEVELOPMENT Provides a broad overview of the political economy of Africa. Its goal is to give students an understanding of the possibilities of African development and the impediments that currently block its economic growth. Despite substantial natural resources, mineral reserves, and human capital, most African countries remain mired in poverty. The struggles that have arisen on the continent have fostered thinking about the curse of natural resources where countries with oil or diamonds are beset with political instability and warfare. Readings give first an introduction to the continent followed by a focus on the specific issues that confront African development today. 3 hours lecture and discussion; 3 semester hours.

LAIS542. NATURAL RESOURCES AND WAR IN AFRICA Examines the relationship between natural resources and wars in Africa. It begins by discussing the complexity of Africa with its several many languages, peoples, and geographic distinctions. Among the most vexing challenges for Africa is the fact that the continent possesses such wealth and yet still struggles with endemic warfare, which is hypothetically caused by greed and competition over resource rents. Readings are multidisciplinary and draw from policy studies, economics, and political science. Students will acquire an understanding of different theoretical approaches from the social sciences to explain the relationship between abundant natural resources and war in Africa. The course helps students apply the different theories to specific cases and productive sectors. 3 hours lecture and discussion; 3 semester hours.

LAIS545. INTERNATIONAL POLITICAL ECONOMY Introduces students to the field of International Political Economy (IPE). IPE scholars examine the intersection between economics and politics, with a focus on interactions between states, organizations, and individuals around the world. Students will become familiar with the three main schools of thought on IPE: Realism (mercantilism), Liberalism, and Historical Structuralism (including Marxism and feminism) and will evaluate substantive issues such as the role of international organizations (the World Trade Organization, the World Bank, and the International Monetary Fund), the monetary and trading systems, regional development, international development, foreign aid, debt crises, multinational corporations, and globalization. 3 hours seminar; 3 semester hours.

LAIS546. GLOBALIZATION Assesses the historical development of international political economy as a discipline. Originally studied as the harbinger of today's political science, economics, sociology, anthropology, and history, International Political Economy is the multidisciplinary study of the relationship between states and markets. A fuller understanding will be achieved through research and data analysis as well as interpre-

tation of case studies. Prerequisites: LAIS345 and any 400-level IPE course, or two equivalent courses. 3 hours lecture and discussion; 3 semester hours.

LAIS548. GLOBAL ENVIRONMENTAL POLITICS AND POLICY - Examines the increasing importance of environmental policy and politics in international political economy and global international relations. Using historical analysis and interdisciplinary environmental studies perspectives, this course explores global environmental problems that have prompted an array of international and global regimes and other approaches to deal with them. It looks at the impact of environmental policy and politics on development, and the role that state and non-state actors play, especially in North-South relations and in the pursuit of sustainability. Prerequisites: any two IPE courses at the 300-level; or one IPE course at the 400 level; or one IPE course at the 300 level and one environmental policy/issues course at the 400 level. 3 hours lecture and discussion; 3 semester hours.

LAIS550. POLITICAL RISK ASSESSMENT Uses social science analytical tools and readings as well as indices prepared by organizations, such as the World Bank and the International Monetary Fund, to create assessments of the political, social, economic, environmental and security risks that multinational corporations may face as they expand operations around the world. Students will develop detailed political risk reports for specific countries that teams collectively select. Prerequisite: LAIS 545, IPE Minor, or instructor's permission. 3 hours seminar; 3 semester hours.

LAIS552. CORRUPTION AND DEVELOPMENT Addresses the problem of corruption and its impact on development. Readings are multidisciplinary and include policy studies, economics, and political science. Students will acquire an understanding of what constitutes corruption, how it negatively affects development, and what they, as engineers in a variety of professional circumstances, might do in circumstances in which bribe paying or taking might occur. 3 hours lecture and discussion; 3 semester hours.

LAIS553. ETHNIC CONFLICT IN THE GLOBAL PERSPECTIVE Studies core economic, cultural, political, and psychological variables that pertain to ethnic identity and ethnic contention, and analyzes their operation in a wide spectrum of conflict situations around the globe. Considers ethnic contention in institutionalized contexts, such as the politics of affirmative action, as well as in non-institutionalized situations, such as ethnic riots and genocide. Concludes by asking what can be done to mitigate ethnic conflict and what might be the future of ethnic group identification. 3 hours seminar; 3 semester hours.

LAIS555. INTERNATIONAL ORGANIZATIONS Familiarizes students with the study of international organizations: how they are created, how they are organized and what they try to accomplish. By the end of the semester, students will

be familiar with the role of international organization in the world system as well as the analytical tools used to analyze them. 3 hours lecture and discussion; 3 semester hours.

LAIS556. POWER & POLITICS IN EURASIA Covers the major international and domestic issues affecting the countries that once comprised the Soviet Union. Collectively called Eurasia because it bridges Europe and Asia, the region includes Russia, Azerbaijan, Belarus, Kazakhstan, Ukraine, and ten other countries. Begins with an overview of the Soviet Union and its collapse in 1991, and then focuses on the major political, economic and security dilemmas facing the Eurasian states. Examines how the US, China, European Union and other countries, as well as international organizations such as the World Bank, affect policies in the region. Special attention will be paid to oil, natural gas, and other energy sectors. 3 hours lecture and discussion; 3 semester hours.

LAIS557 INTRODUCTION TO CONFLICT MANAGEMENT Introduces graduate students to the issue of international conflict management with an emphasis on conflict in resource abundant countries. Its goal is to develop analytic tools to acquire a systematic means to think about conflict management in the international political economy and to assess and react to such events. The course addresses the causes of contemporary conflicts with an initial focus on weak states, armed insurgencies, and ethnic conflict. It then turns to intra-state war as a failure of conflict management before discussing state failure, intractable conflicts, and efforts to build peace and reconstruct failed, post-conflict states. 3 hours lecture and discussion; 3 semester hours.

LAIS558. NATURAL RESOURCES AND DEVELOPMENT Examines the relationship between natural resources and development. It begins by discussing theories of development and how those theories account for specific choices among resource abundant countries. From the theoretical readings, students examine sector specific topics in particular cases. These subjects include oil and natural gas in African and Central Asian countries; hard rock mining in West Africa and East Asia; gemstone mining in Southern and West Africa; contracting in the extractive industries; and corporate social responsibility. Readings are multidisciplinary and draw from policy studies, economics, and political science to provide students an understanding of different theoretical approaches from the social sciences to explain the relationship between abundant natural resources and development. 3 hours lecture and discussion; 3 semester hours.

LAIS560. GLOBAL GEOPOLITICS Examines geopolitical theories and how they help us explain and understand contemporary developments in the world. Empirical evidence from case studies help students develop a deeper understanding of the interconnections between the political, economic, social, cultural and geographic dimensions of governmental policies and corporate decisions. Prerequisites: any two IPE

courses at the 300-level, or one IPE course at the 400 level. 3 hours lecture and discussion; 3 semester hours.

LAIS 564 QUANTITATIVE METHODS FOR THE SOCIAL SCIENCES Teaches basic methods of quantitative empirical research in the social sciences. Places social science in the broader context of scientific inquiry by addressing the role of observation and hypothesis testing in the social sciences. The focus is on linear regression and group comparisons, with attention to questions of research design, internal validity, and reliability. 3 hours lecture and discussion; 3 semester hours.

LAIS565 SCIENCE, TECHNOLOGY, AND SOCIETY Provides an introduction to foundational concepts, themes, and questions developed within the interdisciplinary field of science and technology studies (STS). Readings address anthropological understandings of laboratory practice, sociological perspectives on the settling of techno-scientific controversies, historical insights on the development of scientific institutions, philosophical stances on the interactions between technology and humans, and relationships between science and democracy. Students complete several writing assignments, present material from readings and research, and help to facilitate discussion. 3 hours lecture and discussion; 3 semester hours.

LAIS570. HISTORY OF SCIENTIFIC THOUGHT Offers a critical examination of the history of scientific thought, investigation, discovery, and controversy in a range of historical contexts. Examines the transition from descriptive and speculative science to quantitative and predictive science, to help students appreciate the broad context of science, technology, and social relations. 3 hours lecture and discussion; 3 semester hours.

LAIS577 ENGINEERING AND SUSTAINABLE COMMUNITY DEVELOPMENT Analyzes the relationship between engineering and sustainable community development (SCD) from historical, political, ethical, cultural, and practical perspectives. Students will study and analyze different dimensions of sustainability, development, and "helping", and the role that engineering might play in each. Will include critical explorations of strengths and limitations of dominant methods in engineering problem solving, design and research for working in SCD. Through case-studies, students will analyze and evaluate projects in SCD and develop criteria for their evaluation. 3 hours lecture and discussion; 3 semester hours.

LAIS578. ENGINEERING AND SOCIAL JUSTICE Explores the meaning of social justice in different areas of social life and the role that engineers and engineering can play in promoting or defending social justice. Begins with students' exploration of their own social locations, alliances, and resistances to social justice through critical engagement of interdisciplinary readings that challenge engineering mindsets. Offers understandings of why and how engineer-

ing has on occasion been aligned with or divergent from specific social justice issues and causes. 3 hours seminar; 3 semester hours.

LAIS586. SCIENCE AND TECHNOLOGY POLICY Examines current issues relating to science and technology policy in the United States and, as appropriate, in other countries. 3 hours lecture and discussion; 3 semester hours.

LAIS587. ENVIRONMENTAL POLITICS AND POLICY Explores environmental policies and the political and governmental processes that produce them. Group discussion and independent research on specific environmental issues. Primary but not exclusive focus on the U.S. 3 hours lecture and discussion; 3 semester hours.

LAIS588. WATER POLITICS AND POLICY Examines water policies and the political and governmental processes that produce them, as an example of natural resource politics and policy in general. Group discussion and independent research on specific politics and policy issues. Primary but not exclusive focus on the U.S. 3 hours lecture and discussion; 3 semester hours.

LAIS589. NUCLEAR POWER AND PUBLIC POLICY A general introduction to research and practice concerning policies and practices relevant to the development and management of nuclear power. Corequisite: PHGN590 Nuclear Reactor Physics or instructor consent. 3 hours lecture and seminar; 3 semester hours.

LAIS590 ENERGY AND SOCIETY Begins with a brief introduction to global energy production and conservation, focusing on particular case studies that highlight relationships among energy, society, and community in different contexts. Critically examines conflicts driven by energy development as well as energy successes and failures where communities, governments, and/or energy companies come together to promote socially just and economically viable forms of energy production/conservation. Case studies are supplemented by the expertise of guest speakers from industry, government, NGOs, and elsewhere. 3 hours seminar; 3 semester hours.

LAIS597. SUMMER PROGRAMS

LAIS598. SPECIAL TOPICS Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Variable credit: 1 to 6 semester hours. Repeatable for credit under different titles.

LAIS599. INDEPENDENT STUDY Individual research or special problem projects supervised by a faculty member. Variable credit: 1 to 6 hours. Repeatable for credit.

LAIS601. ACADEMIC PUBLISHING Students will finish this course with increased knowledge of general and discipline-specific writing conversations as well as the ability to use that knowledge in publishing portions of theses or dissertations. Beyond the research article, students will also have

the opportunity to learn more about genres such as conference abstracts, conference presentations, literature reviews, and research funding proposals. Prerequisite: Must have completed one full year (or equivalent) of graduate school course work. Variable credit: 2 or 3 semester hours.

LAIS705. GRADUATE RESEARCH: MASTERS Research Credit hours required for completion of the MIPER with thesis degree. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

Communication (LICM)

LICM501. PROFESSIONAL ORAL COMMUNICATION A five-week course which teaches the fundamentals of effectively preparing and presenting messages. "Hands-on" course emphasizing short (5- and 10-minute) weekly presentations made in small groups to simulate professional and corporate communications. Students are encouraged to make formal presentations which relate to their academic or professional fields. Extensive instruction in the use of visuals. Presentations are rehearsed in class two days prior to the formal presentations, all of which are video-taped and carefully evaluated. 1 hour lecture/lab; 1 semester hour.

Materials Science

DAVID L. OLSON, Lead Scientist, John Henry Moore Distinguished Professor of Physical Metallurgy

Department of Chemistry and Geochemistry

DANIEL M. KNAUSS, Professor and Department Head
MARK EBERHART, Professor
KENT J. VOORHEES, Professor
STEPHEN G. BOYES, Associate Professor
SCOTT W. COWLEY, Associate Professor
RYAN RICHARDS, Associate Professor
KIM R. WILLIAMS, Associate Professor
YONGAN YANG, Assistant Professor

Department of Chemical Engineering

DAVID W.M. MARR, Professor and Department Head
JOHN R. DORGAN, Professor
COLIN WOLDEN, Professor and Weaver Distinguished Professor
DAVID T. WU, Associate Professor
SUMIT AGARWAL, Assistant Professor

Division of Engineering

KEVIN MOORE, Gerard August Dohelman Distinguished Professor, and Interim Division Director
WILLIAM A. HOFF, Associate Professor and Assistant Division Director
D. VAUGHAN GRIFFITHS, Professor
MARTE S. GUTIERREZ, James R. Paden Chair Distinguished Professor
ROBERT J. KEE, George R. Brown Distinguished Professor
ROBERT H. KING, Professor
NING LU, Professor
NIGEL T. MIDDLETON, Senior Vice President for Strategic Enterprises, Professor
GRAHAM G. W. MUSTOE, Professor
PANKAJ K. (PK) SEN, Professor
JOEL M. BACH, Associate Professor
JOHN R. BERGER, Associate Professor
CRISTIAN V. CIOBANU, Associate Professor
PANOS D. KIOUSIS, Associate Professor
MICHAEL MOONEY, Associate Professor
MARCELO GODOY SIMOES, Associate Professor
JOHN P. H. STEELE, Associate Professor
NEAL SULLIVAN, Associate Professor
TYRONE VINCENT, Associate Professor
RAY RUICHONG ZHANG, Associate Professor
ROBERT J. BRAUN, Assistant Professor
KATHRYN JOHNSON, Clare Boothe Luce Assistant Professor
ANTHONY J. PETRELLA, Assistant Professor
JASON PORTER, Assistant Professor
CAMERON TURNER, Assistant Professor
MICHAEL WAKIN, Assistant Professor
JUDITH WANG, Assistant Professor

Department of Environmental Science & Engineering

RONALD R.H. COHEN, Associate Professor
LINDA FIGUEROA, Associate Professor
JOHN R. SPEAR, Associate Professor

Department of Metallurgical and Materials Engineering

MICHAEL J. KAUFMAN, Professor and Department Head
CORBY G. ANDERSON, Professor
STEPHEN LIU, Professor

GERARD P. MARTINS, Professor
 DAVID K. MATLOCK, Charles S. Fogarty Professor
 BRAJENDRA MISHRA, Professor
 DAVID L. OLSON, John H. Moore Distinguished Professor
 IVAR E. REIMANIS, Professor
 JOHN G. SPEER, Professor, V.P. of Research and Development
 PATRICK R. TAYLOR, George S. Ansell Distinguished Professor of
 Chemical Metallurgy
 CHESTER J. VANTYNE, FIERF Professor and Associate
 Department Head
 RYAN P. O'HAYRE, Associate Professor
 STEVEN W. THOMPSON, Associate Professor
 REED AYERS, Assistant Professor
 KIP O. FINDLEY, Assistant Professor
 BRIAN GORMAN, Assistant Professor
 JEFFREY C. KING, Assistant Professor
 HONGJUN LIANG, Assistant Professor
 CORINNE E. PACKARD, Assistant Professor
 GERALD BOURNE, Teaching Associate Professor
 JOHN CHANDLER, Teaching Associate Professor
 RICHARD K. AHRENKIEL, Research Professor
 WILLIAM (GROVER) COORS, Research Professor
 ZEEV SHAYER, Research Professor
 D. (ERIK) SPILLER, Research Professor
 JAMES C. WILLIAMS, Research Professor
 CAROLE GRAAS, Research Associate Professor
 JIANHUA TONG, Research Associate Professor
 EDGAR VIDAL, Research Associate Professor
 EMMANUEL De MOOR, Research Assistant Professor
 DAVID DIERCKS, Research Assistant Professor
 JUDITH C. GOMEZ, Research Assistant Professor
 JIANLIANG LIN, Research Assistant Professor
 GEORGE S. ANSELL, President Emeritus and Professor Emeritus
 GLEN R. EDWARDS, University Professor-Emeritus
 JOHN P. HAGER, University Professor-Emeritus
 GEORGE KRAUSS, University Professor-Emeritus
 DENNIS W. READEY, University Professor Emeritus
 W. REX BULL, Professor Emeritus
 JOHN MOORE, Professor Emeritus
 GERALD L. DePOORTER, Associate Professor Emeritus
 ROBERT H. FROST, Associate Professor Emeritus

Department of Physics

THOMAS E. FURTAK, Professor and Department Head
 REUBEN T. COLLINS, Professor and Director, Center of Solar and
 Electronic Materials
 FRANK KOWALSKI, Professor
 JOHN SCALES, Professor
 JEFF SQUIER, Professor
 P. CRAIG TAYLOR, Professor and Associate Director of Colorado
 Energy Research Institute
 CHARLES DURFEE III, Associate Professor
 UWE GREIFE, Associate Professor
 TIMOTHY R. OHNO, Associate Professor
 FREDERIC SARAZIN, Associate Professor
 LAWRENCE WIENCKE, Associate Professor
 DAVID M. WOOD, Associate Professor
 LINCOLN CARR, Assistant Professor
 JAMES E. BERNARD, Research Associate Professor
 DON L. WILLIAMSON, Emeritus Professor

Department of Mining Engineering

HUGH MILLER, Associate Professor

Degrees Offered:

Master of Science (Materials Science; thesis option or
 non-thesis option)

Doctor of Philosophy (Materials Science)

Program Description:

The interdisciplinary materials science program is administered jointly by the Departments of Chemical Engineering, Chemistry and Geochemistry, Metallurgical and Materials Engineering, Physics and the Division of Engineering. Each department is represented on both the Governing Board, the Graduate Affairs Committee and the Faculty Opportunities Committee which are responsible for the operation of the program. The variety of disciplines provides for programs of study ranging from the traditional materials science program to a custom-designed program.

Program Requirements:

Master of Science (thesis option):

The Master of Science degree requires a minimum of 30 semester hours of acceptable course work and thesis research credit including:

- ◆ Minimum of 18 hours of Materials Science courses (must have completed the core courses).
- ◆ 6 to 18 hours of thesis research credits depending upon focus area requirements.
- ◆ Submit a thesis and pass the Defense of Thesis examination before the Thesis Committee.

Master of Science (non-thesis option with a case study):

The Master of Science degree requires a minimum of 30 semester hours of acceptable course work and case study credit including:

- ◆ 18 hours of Materials Sciences courses from a list of required courses and 6 hours of other materials-related courses selected by the student with guidance from the student's advisor and the mentor of the specialty area group that the student has selected and 6 hours of case study. The specialty materials-related courses can be courses that are taken in preparation for the student's PhD qualifying process examination, usually taken in the second year of graduate school. Total of at least 30 credit hours.
- ◆ 6 hours of case study credits. (Sign up for MLGN599, Case Study Materials Science, using a paper form at the Registrar's Office.) The student must successfully prepare and defend a case study report on a topic that is most likely supporting materials for the student's PhD thesis.

The decision of which type of Master degree you should pursue needs to be decided with council of your advisor. The decision will affect the number of course hours required for the Master degree and whether a thesis or a case study report is to be written and defended.

Required Curriculum:

Listed below are the required six Materials Science core courses:

MLGN500 Processing, Microstructure, and Properties of Materials

MLGN512/MTGN412 Ceramic Engineering

MLGN530/CR415/CH430 Intro to Polymer Science

MLGN501/CHGN580 Structure of Materials

MLGN504/MTGN555 Solid State Thermodynamics or
CHEN509 Advanced Chemical Engineering Thermodynamics

MLGN511 Kinetic Concerns in Materials Processing or
MTGN548 Transformations in Metals or
MTGN/MLGN506 Transport in Solids

Students who have taken the equivalent of any of the core courses listed above, may petition the Materials Science Graduate Committee for transfer credit.

MLGN531/CHGN430, Introduction to Polymer Science, also meets the requirements.

Conversion of Master Program to Doctor of Philosophy Degree Program

An M.S. or M.S. Non-thesis student who wishes to continue to the PhD program must first defend his/her thesis or present his/her engineering case study report. The quality of the defense and research will be considered when the advisor and committee discusses the student's qualifications to enter the PhD program. The advisor or Committee Chair must submit a "Promotion to the PhD Program" form to the Materials Science program office. The form should clearly state that the student has met all the requirements of the Master of Science or Master of Science Non-thesis degree program (including checkout) and is qualified to be promoted to the PhD Program. This document will be forwarded to the Graduate School with a copy to the Graduate Education Specialist. Once the Graduate School grants PhD status the student is expected to complete all the requirements expected of any PhD candidate. If a student continues on to a PhD Program, an application must be completed on the Graduate School website. A student with a scientific or engineering Master of Science degree from another program can proceed directly to the PhD Materials Science program on his/her admission.

If it is your intention to get a PhD when you first apply, it is possible to be dual listed as a MS/PhD graduate student. Until you complete your M.S. or M.S. Non Thesis, you are officially a Master degree student. Once you complete all the requirements for the M.S. (including checkout), the advisor

and your thesis committee must recommend that you are qualified to continue to the PhD program based on the quality of your research and defense. Again, your advisor or Committee Chair needs to send an email to the Lead Scientist and to the Graduate Education Specialist stating that the student has completed all the requirements of the Master of Science or Master of Science Non-thesis degree (including checkout) and is considered qualified to enter the PhD program. Once the Graduate School has process this memo, you will be listed solely as a PhD Materials Science student.

Doctor of Philosophy:

The prerequisite for acceptance into the Materials Science PhD Program is completion of a science or engineering Master degree (with or without thesis) and completion of the Materials Science Core courses with a grade of B or better (or evidence that the course content of these courses had been taken in previous courses).

The Doctor of Philosophy degree requires a minimum of 72 hours of course and research credit including:

- ◆ The fulfillment of the Materials Science core course requirements plus additional courses as required by the focus area and a minimum of 30 hours of research credit.
- ◆ An oral qualifying examination in the specialty area (depending upon focus area requirements). See the Material Science Program Guidelines for Graduate Students at <http://www.mines.edu/academic/matsci/>.
- ◆ Prepare and submit a thesis and pass a Defense of Thesis examination before the Thesis Committee.

Prerequisites:

The primary admission requirement for this interdisciplinary program is a Bachelor of Science or Master of Engineering degree in biological sciences, physical science, or engineering. Courses must be equivalent to the degree programs offered at CSM in the following departments: Chemistry and Geochemistry, Engineering (mechanical, electrical, or civil), Chemical Engineering, Metallurgical and Materials Engineering, or Physics.

Deficiency Courses:

A student admitted to this graduate program who has not taken one or all of the following courses (or equivalent) will be required (depending on their focus area) to satisfy any such deficiency early in their program of study: Mechanics, Differential Equations, Modern Physics, and Physical Chemistry/Chemical Thermodynamics.

Focus Areas:

Advanced Polymeric Materials; Ceramics; Composites; Electronic Materials; Joining Science; Mechanics of Materials; Computational Materials Science; Surfaces & Interfaces/Films & Coatings; Biomaterials; Nuclear Materials, Enviro-Material Science, Mining-Materials Science, Nondestructive Material Assess, and Materials Chemical Processing.

Thesis Committee Structure:

The M.S. student will invite at least 3 members (one of whom is the advisor) to serve on a graduate committee. At least one of these members must be from a department other than that of the advisor.

The Ph.D. student will invite 5 members (one of whom is the advisor) to serve on a graduate committee. At least one of these members must be in a department other than that of the advisor. External members may be invited to participate.

For administrative purposes, the student will be resident in the advisor's department.

The student's graduate committee will have final approval of the course of study.

Fields of Research:

Advanced polymeric materials
Alloy theory, concurrent design, theory-assisted materials engineering, and electronic structure theory
Applications of artificial intelligence techniques to materials processing and manufacturing, neural networks for process modeling and sensor data processing, manufacturing process control
Archaeometallurgy, industry and university partnerships
Bio materials
Ceramic processing, modeling of ceramic processing
Characterization, thermal stability, and thermal degradation mechanisms of polymers
Chemical and physical processing of materials, engineered materials, materials synthesis
Chemical processing of materials
Chemical vapor deposition
Coating materials and applications
Computational condensed-matter physics, semiconductor alloys, first-principles phonon calculations
Computer modeling and simulation
Control systems engineering, artificial neural systems for sensor data processing, polymer cure monitoring sensors, process monitoring and control for composites manufacturing
Crystal and molecular structure determination by X-ray crystallography
Electro deposition
Experimental condensed-matter physics, thermal and electrical properties of materials, superconductivity, photovoltaics
Extractive and process metallurgy, electrochemical corrosion, synthesis of ceramic precursor powders and metal powders
Forging, deformation modeling, high-temperature material behavior
Fuel cell materials
Fullerene synthesis, combustion chemistry
Heat and mass transfer, materials processing
Heterogeneous catalysis, reformulated and alcohol fuels, surface analysis, electrophotography

Intelligent automated systems, intelligent process control, robotics, artificial neural systems
Materials synthesis, interfaces, flocculation, fine particles
Mathematical modeling of material processes
Mechanical metallurgy, failure analysis, deformation of materials, advanced steel coatings
Molten salt processing
Mössbauer spectroscopy, ion implantation, small-angle X-ray scattering, semiconductor defects
Nano materials
Non destructive evaluation
Novel separation processes: membranes, catalytical membrane reactors, biopolymer adsorbents for heavy metal remediation of ground surface water
Numerical modeling of particulate media, thermomechanical analysis
Optical properties of materials and interfaces
Phase transformations and mechanisms of microstructural change, electron microscopy, structure-property relationships
Physical metallurgy, ferrous and nonferrous alloy systems
Physical vapor deposition, thin films, coatings
Power electronics, plasma physics, pulsed power, plasma material processing
Processing and characterization of electroceramics (ferroelectrics, piezoelectrics, pyroelectrics, and dielectrics), glass-ceramics for electronic and structural applications, thermodynamic modeling of ferroelectrics
Pyrometallurgy, corrosion, materials synthesis, coatings
Reactive metals properties and processing of ceramics and ceramic-metal composites, dielectrics and ferrimagnetics
Soft materials
Solidification and near net shape processing
Surface physics, epitaxial growth, interfacial science, adsorption
Transformations, microstructure, deformation, fracture
Transport phenomena, mathematical modeling, kinetic properties of colloidal suspensions, and diffusion with chemical reaction
Weld metallurgy, materials joining processes
Welding and joining science

Description of Courses (Interdisciplinary Program)

The following courses are considered to be part of the Materials Science Program. Some have been cross-listed between Materials Science and the participating departments/division. Other courses not included may be suitable for inclusion in a graduate program. See the participating department listings. It should be noted that the course requirement for graduate-level registration for a MLGN 500-level course which is cross-listed with a 400-level course-number will include an additional course-component above that required for 400-level credit.

MLGN500. PROCESSING, MICROSTRUCTURE, AND PROPERTIES OF MATERIALS (II) A summary of the important relationships between the processing, microstructure, and properties of materials. Topics include electronic structure and bonding, crystal structures, lattice defects and mass transport, glasses, phase transformation, important materials processes, and properties including: mechanical and rheological, electrical conductivity, magnetic, dielectric, optical, thermal, and chemical. In a given year, one of these topics will be given special emphasis. Another area of emphasis is phase equilibria. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MLGN501/CHGN580. STRUCTURE OF MATERIALS (I) Application of X-ray diffraction techniques for crystal and molecular structure determination of minerals, inorganic and organometallic compounds. Topics include the heavy atom method, data collection by moving film techniques and by diffractometers, Fourier methods, interpretation of Patterson maps, refinement methods, and direct methods. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

MLGN502/PHGN440. SOLID STATE PHYSICS (I) An elementary study of the properties of solids including crystalline structure and its determination, lattice vibrations, electrons in metals, and semiconductors. (Graduate students in physics may register only for PHGN440.) Prerequisite: PHGN320. 3 hours lecture; 3 semester hours.

MLGN503/CHGN515. CHEMICAL BONDING IN MATERIALS (I) Introduction to chemical bonding theories and calculations and their applications to solids of interest to materials science. The relationship between a material's properties and the bonding of its atoms will be examined for a variety of materials. Includes an introduction to organic polymers. Computer programs will be used for calculating bonding parameters. Prerequisite: Consent of department. 3 hours lecture; 3 semester hours.

MLGN504/MTGN555. SOLID STATE THERMODYNAMICS (I) Thermodynamics applied to solid state reactions, binary and ternary phase diagrams, point, line and planar defects, interfaces, and electrochemical concepts. Prerequisites: consent of instructor. 3 hours lecture; 3 semester hours.

MLGN505/MTGN445. MECHANICAL PROPERTIES OF MATERIALS (I) Mechanical properties and relationships. Plastic deformation of crystalline materials. Relationships of microstructures to mechanical strength. Fracture, creep, and fatigue. Laboratory sessions devoted to advanced mechanical testing techniques to illustrate the application of the fundamentals presented in the lectures. Prerequisite: MTGN348. 3 hours lecture; 3 hours lab; 3*³/₄ semester hours. * This is a 3 credit-hour graduate-course in the Materials Science Program and a 4 credit-hour undergraduate-course in the MTGN program.

MLGN506/MTGN556. TRANSPORT IN SOLIDS (II) Thermal and electrical conductivity. Solid state diffusion in metals and metal systems. Kinetics of metallurgical reactions in the solid state. Prerequisite: Consent of department. 3 hours lecture; 3 semester hours. (Spring of even years only.)

MLGN509/CHGN523. SOLID STATE CHEMISTRY (I) Dependence on properties of solids on chemical bonding and structure; principles of crystal growth, crystal imperfections, reactions and diffusion in solids, and the theory of conductors and semiconductors. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate years.

MLGN510/CHGN410 SURFACE CHEMISTRY (II) Introduction to colloid systems, capillarity, surface tension and contact angle, adsorption from solution, micelles and microemulsions, the solid/gas interface, surface analytical techniques, Van Der Waal forces, electrical properties and colloid stability, some specific colloid systems (clays, foams and emulsions). Students enrolled for graduate credit in MLGN510 must complete a special project. Prerequisite: DCGN209 or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN511. KINETIC CONCERNS IN MATERIALS PROCESSING I (I) Introduction to the kinetics of materials processing, with emphasis on the momentum, heat and mass transport. Discussion of the basic mechanism of transport in gases, liquids and solids. Prerequisite: MTGN352, MTGN361, MATH225 or equivalent. 3 hours lecture; 3 semester hours.

MLGN512/MTGN412. CERAMIC ENGINEERING (I) Application of engineering principles to nonmetallic and ceramic materials. Processing of raw materials and production of ceramic bodies, glazes, glasses, enamels, and cements. Firing processes and reactions in glass bonded as well as mechanically bonded systems. Prerequisite: MTGN348. 3 hours lecture; 3 semester hours.

MLGN513. PROBLEM SOLVING IN MATERIALS SCIENCE (I) Review the theoretical aspects of various physical phenomena of major importance to materials scientists. Develop mathematical models from these theories, and construct quantitative solution procedures based on analytical and numerical techniques. Prerequisite: MATH225. 3 hours lecture; 3 semester hours.

MLGN515/MTGN415. ELECTRICAL PROPERTIES AND APPLICATIONS OF MATERIALS (II) Survey of the electrical properties of materials, and the applications of materials as electrical circuit components. The effects of chemistry, processing, and microstructure on the electrical properties will be discussed, along with functions, performance requirements, and testing methods of materials for each type of circuit component. The general topics covered are conductors, resistors, insulators, capacitors, energy convertors, magnetic materials, and integrated circuits. Prerequisites: PHGN200; MTGN311 or MLGN501 or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN516/MTGN416. PROPERTIES OF CERAMICS (II) A survey of the properties of ceramic materials and how these properties are determined by the chemical structure (composition), crystal structure, and the microstructure of crystalline ceramics and glasses. Thermal, optical, and mechanical properties of single-phase and multi-phase ceramics, including composites, are covered. Prerequisites: PHGN200, MTGN311 or MLGN501 or consent of instructor. 3 semester hours; 3 hours lecture.

MLGN517/EGGN422. SOLID MECHANICS OF MATERIALS (I, II) Review mechanics of materials. Introduction to elastic and non-linear continua. Cartesian tensors and stresses and strains. Analytical solution of elasticity problems. Develop basic concepts of fracture mechanics. Prerequisite: EGGN320 or equivalent, MATH225 or equivalent. 3 hours lecture; 3 semester hours. Taught every semester.

MLGN518/MTGN518. PHASE EQUILIBRIA IN CERAMICS SYSTEMS (II) Application of one of four component oxide diagrams to ceramic engineering problems. Emphasis on refractories and glasses and their interaction with metallic systems. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MLGN519/MTGN419. NON-CRYSTALLINE MATERIALS (I) An introduction to the principles of glass science and engineering and non-crystalline materials in general. Glass formation, structure, crystallization and properties will be covered, along with a survey of commercial glass compositions, manufacturing processes and applications. Prerequisites: MTGN311 or MLGN501; MLGN512/MTGN412, or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN521. KINETIC CONCERNS IN MATERIAL PROCESSING II (I, II) Advanced course to address the kinetics of materials processing, with emphasis in those processes that promote phase and structural transformations. Processes that involve precipitation, sintering, oxidation, sol-gel, coating, etc., will be discussed in detail. Prerequisite: MLGN511. 3 hours lecture; 3 semester hours.

MLGN523/MTGN523. APPLIED SURFACE AND SOLUTION CHEMISTRY (II) Solution and surface chemistry of importance in mineral and metallurgical operations. Prerequisite: Consent of department. 3 semester hours. (Spring of odd years only.)

MLGN526/MTGN526. GEL SCIENCE AND TECHNOLOGY An introduction to the science and technology of particulate and polymeric gels, emphasizing inorganic systems. Interparticle forces. Aggregation, network formation, percolation, and the gel transition. Gel structure, rheology, and mechanical properties. Application to solid-liquid separation operations (filtration, centrifugation, sedimentation) and to ceramics processing. Prerequisite: Graduate level status or consent of instructor. 3 hours lecture; 3 semester hours. Spring of odd years only.

MLGN530/CHGN430. INTRODUCTION TO POLYMER SCIENCE (I) An introduction to the chemistry and physics of macromolecules. Topics include the properties and statistics of polymer solutions, measurements of molecular weights, molecular weight distributions, properties of bulk polymers, mechanisms of polymer formation, and properties of thermosets and thermoplasts including elastomers. Prerequisite: CHGN221 or permission of instructor. 3 hour lecture, 3 semester hours.

MLGN531/CHEN416 POLYMER ENGINEERING AND TECHNOLOGY (II) Polymer fluid mechanics, polymer rheological response, and polymer shape forming. Definition and measurement of material properties. Interrelationships between response functions and correlation of data and material response. Theoretical approaches for prediction of polymer properties. Processing operations for polymeric materials; melt and flow instabilities. Prerequisite: CHEN307, MATH225, or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN535/PHGN535/CHEN535/PHGN435/GHEN435. INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY (II) Application of science and engineering principles to the design, fabrication, and testing of microelectronic devices. Emphasis on specific unit operations and the interrelation among processing steps. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

MLGN536/CHGN536. ADVANCED POLYMER SYNTHESIS (II) An advanced course in the synthesis of macromolecules. Various methods of polymerization will be discussed with an emphasis on the specifics concerning the syntheses of different classes of organic and inorganic polymers. Prerequisite: CHGN430, CHEN415, MLGN530 or consent of instructor. 3 hours lecture, 3 semester hours.

MLGN544/MTGN414. PROCESSING OF CERAMICS (II) A description of the principles of ceramic processing and the relationship between processing and microstructure. Raw materials and raw material preparation, forming and fabrication, thermal processing, and finishing of ceramic materials will be covered. Principles will be illustrated by case studies on specific ceramic materials. A project to design a ceramic fabrication process is required. Field trips to local ceramic manufacturing operations are included. Prerequisites: MTGN272, MTGN311 or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN545/EGGN532 FATIGUE AND FRACTURE (I) Basic fracture mechanics as applied to engineering materials, S-N curves, the Goodman diagram, stress concentrations, residual stress effects, and effect of material properties on mechanisms of crack propagation. Prerequisite: Consent of department. 3 hours lecture; 3 semester hours. Fall semesters, odd numbered years.

MLGN550/MTGN450. STATISTICAL PROCESS CONTROL AND DESIGN OF EXPERIMENTS (I) An introduction to statistical process control, process capability analysis and experimental design techniques. Statistical process control theory and techniques will be developed and applied to control charts for variables and attributes involved in process control and evaluation. Process capability concepts will be developed and applied for the evaluation of manufacturing processes. The theory and application of designed experiments will be developed and applied for full factorial experiments, fractional factorial experiments, screening experiments, multilevel experiments and mixture experiments. Analysis of designed experiments will be carried out by graphical and statistical techniques. Computer software will be utilized for statistical process control and for the design and analysis of experiments. Prerequisite: Consent of Instructor. 3 hours lecture, 3 semester hours.

MLGN552/MTGN552. INORGANIC MATRIX COMPOSITES (I) An introduction to the processing, structure, properties and applications of metal matrix and ceramic matrix composites. Importance of structure and properties of both the matrix and the reinforcement and the types of reinforcement utilized, e.g., particulate, short fiber, continuous fiber, and laminates. Special emphasis will be placed on the development of properties such as electrical and thermal will also be examined. Prerequisite/Co-requisite: MTGN311, MTGN352, MTGN445/MLGN505 or consent of instructor. 3 hours lecture; 3 semester hours (Summer of even years only.)

MLGN561 TRANSPORT PHENOMENA IN MATERIALS PROCESSING (II) Fluid flow, heat and mass transfer applied to processing of materials. Rheology of polymers, liquid metal/particles slurries, and particulate solids. Transient flow behavior of these materials in various geometries, including infiltration of liquids in porous media. Mixing and blending. Flow behavior of jets, drainage of films and particle fluidization. Surface-tension-, electromagnetic-, and bubble-driven flows. Heat-transfer behavior in porous bodies applied to sintering and solidification of composites. Simultaneous heat-and-mass-transfer applied to spray drying and drying porous bodies. Prerequisites: ChEN307 or ChEN308 or MTGN461 or consent of instructor. 3 hours lecture; 3 semester hours

MLGN563/MTGN463. POLYMER ENGINEERING: STRUCTURE, PROPERTIES AND PROCESSING (II) An introduction to the structure and properties of polymeric materials, their deformation and failure mechanisms, and the design and fabrication of polymeric end items. The molecular and crystallographic structures of polymers will be developed and related to the elastic, viscoelastic, yield and fracture properties of polymeric solids and reinforced polymer composites. Emphasis will be placed on forming techniques for end item fabrication including: extrusion, injection molding, reaction injection molding, thermoforming, and blow molding. The design of end items will be considered in relation to: materi-

als selection, manufacturing engineering, properties, and applications. Prerequisite: MTGN311 or equivalent or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN565/MTGN565. MECHANICAL PROPERTIES OF CERAMICS AND COMPOSITES (II) Mechanical properties of ceramics and ceramic-based composites; brittle fracture of solids; toughening mechanisms in composites; fatigue, high temperature mechanical behavior, including fracture, creep deformation. Prerequisites: MTGN445 or MLGN505, or consent of instructor. 3 hours lecture; 3 semester hours. (Fall of even years only.)

MLGN569/MTGN569/EGGN569/ChEN569/MTGN469/EGGN469/CHEN469. FUEL CELL SCIENCE AND TECHNOLOGY (II) Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical thermodynamics and materials-science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. 3 credit hours. Prerequisites: EGGN371 or ChEN357 or MTGN351; and Math225 or consent of instructor.

MLGN570/MTGN570. BIOCMPATIBILITY OF MATERIALS (II) Introduction to the diversity of biomaterials and applications through examination of the physiologic environment in conjunction with compositional and structural requirements of tissues and organs. Appropriate domains and applications of metals, ceramics and polymers, including implants, sensors, drug delivery, laboratory automation, and tissue engineering are presented. Prerequisites: ESGN 301 or equivalent, or instructor consent. 3 hours lecture; 3 semester hours.

MLGN583/CHGN583. PRINCIPLES AND APPLICATIONS OF SURFACE ANALYSIS TECHNIQUES (II) Instrumental techniques for the characterization of surfaces of solid materials. Applications of such techniques to polymers, corrosion, metallurgy, adhesion science, micro-electronics. Methods of analysis discussed: X-ray photoelectron spectroscopy (XPS), auger electron spectroscopy (AES), ion scattering spectroscopy (ISS), secondary ion mass spectroscopy (SIMS), Rutherford backscattering (RBS), scanning and transmission electron microscopy (SEM, TEM), energy and wavelength dispersive X-ray analysis; principles of these methods, quantification, instrumentation, sample preparation. Prerequisite: B.S. in metallurgy, chemistry, chemical engineering, physics, or consent of instructor. 3 hours lecture; 3 semester hours. This course taught in alternate even numbered years.

MLGN598. SPECIAL TOPICS (I, II) Special topic course on a specific subject defined by instructor. Prerequisite: consent of instructor 1 to 3 hours.

MLGN599. CASE STUDY MATERIALS SCIENCE (I, II) An independent study of a selected materials processing or material characterization problem involving a thorough

analysis of the various solutions reported in the technical literature and/or a thorough industrial survey. The case study will prepare a case study report of technical merit. Prerequisite/co-requisite: MLGN501, MLGN502, MLGN503, MLGN504, and MLGN511, and MLGN517 or consent of advisor. 3 semester hours. Repeatable for credit.

MLGN 607/PHGN640. CONDENSED MATTER I (I) Principles and applications of the quantum theory of electronic in solids: structure and symmetry, electron states and excitations in metals; transport properties. Prerequisite: PHGN520 and PHGN440/MLGN502 or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN625/CHEN625/CHGN625. MOLECULAR SIMULATION METHODS (I Even Years). Principles and practice of modern computer simulation techniques used to understand solids, liquids, and gases. Review of the statistical foundation of thermodynamics followed by in-depth discussion of Monte Carlo and Molecular Dynamics techniques. Discussion of intermolecular potentials, extended ensembles, and mathematical algorithms used in molecular simulations. Prerequisites: graduate level thermodynamics (required), statistical mechanics (recommended). 3 semester hours.

MLGN634/CHEN609. ADVANCED TOPICS IN THERMODYNAMICS Advanced study of thermodynamic theory and application of thermodynamic principles. Possible topics include stability, critical phenomena, chemical thermodynamics, thermodynamics of polymer solutions and thermodynamics of aqueous and ionic solutions. Prerequisite: Consent of instructor. 1 to 3 semester hours.

MLGN635. POLYMER REACTION ENGINEERING/
CRGN618. ADVANCED TOPICS IN REACTION KINETICS This class is aimed at engineers with a firm technical background who wish to apply that background to polymerization production techniques. The class begins with a review of the fundamental concepts of reaction engineering, introduces the needed terminology and describes different reactor types. The applied kinetic models relevant to polymerization reaction engineering are then developed. Next, mixing effects are introduced; goodness of mixing and effects on reactor performance are discussed. Thermal effects are then introduced and the subjects of thermal runaway, thermal instabilities, and multiple steady states are included. Reactive processing, change in viscosity with the extent of reaction and continuous drag flow reactors are described. Polymer de-volatilization constitutes the final subject of the class. Prerequisites: CRGN518 or equivalent. 3 hours lecture; 3 semester hours.

MLGN648/PHGN641 CONDENSED MATTER II (II) Principles and applications of the quantum theory of electronic and phonons in solids; phonon states in solids; transport properties; electron states and excitation in semiconductors and insulators; magnetism; superconductivity. Prerequisite: PHGN640/MLGN607 or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN673. STRUCTURE AND PROPERTIES OF POLYMERS This course will provide an understanding of structure - properties relations in polymeric materials. The topics include: phase separation, amorphous structures, crystalline structures, liquid crystals, glass-rubber transition behavior, rubber elasticity, viscoelasticity, mechanical properties of polymers, polymer forming processes, and electrical properties of polymers. Prerequisite: MLGN563 or consent of instructor. 3 hours lecture; 3 semester hours

MLGN696/MTGN696. VAPOR DEPOSITION PROCESSES (II) Introduction to the fundamental physics and chemistry underlying the control of vapor deposition processes for the deposition of thin films for a variety of applications, e.g., corrosion/oxidation resistance, decorative coatings, electronic and magnetic thin films. Emphasis on the vapor deposition processes and the control of process variables rather than the structure and properties of the thin films. Prerequisites: MTGN351, MTGN461, or equivalent courses, or consent of instructor. 3 hours lecture; 3 semester hours.

MLGN698. ADVANCED TOPICS Advanced study of materials science theory and application of materials science principles in a specialty area of the instructor's choosing. Not part of thesis. Prerequisite: Consent of instructor. 1 to 3 semester hours. Repeatable for credit under different titles.

MLGN699. INDEPENDENT STUDY Independent study of a materials science topic with guidance of an instructor. Not part of thesis. Prerequisite: Consent of Instructor. 1 to 3 hours. Repeatable for credit.

MLGN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

MLGN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

Mathematical and Computer Sciences

TRACY CAMP, Professor and Interim Department Head

BERNARD BIALECKI, Professor

MAHADEVAN GANESH, Professor

WILLY HEREMAN, Professor

PAUL A. MARTIN, Professor

DINESH MEHTA, Professor

BARBARA M. MOSKAL, Professor

WILLIAM NAVIDI, Professor

QI HAN, Associate Professor

LUIS TENORIO, Associate Professor

CORY AHRENS, Assistant Professor

ZIZHONG (JEFFREY) CHEN, Assistant Professor

JON M. COLLIS, Assistant Professor

QI HAN, Associate Professor

AMANDA HERING, Assistant Professor

IRENE POLYCARPOU, Assistant Professor

ANDRZEJ SZYM CZAK, Assistant Professor

G. GUSTAVE GREIVEL, Teaching Professor

CYNDI RADER, Teaching Professor

TERRY BRIDGMAN, Teaching Associate Professor

HOLLY EKLUND, Teaching Associate Professor

KEITH HELLMAN, Teaching Associate Professor

JENNIFER STRONG, Teaching Associate Professor

SCOTT STRONG, Teaching Associate Professor

ROMAN TANKELEVICH, Teaching Associate Professor

WILLIAM R. ASTLE, Professor Emeritus

NORMAN BLEISTEIN, Professor Emeritus

ARDEL J. BOES, Professor Emeritus

AUSTIN R. BROWN, Professor Emeritus

JOHN DeSANTO, Professor Emeritus

RAYMOND R. GUTZMAN, Professor Emeritus

FRANK G. HAGIN, Professor Emeritus

DONALD C.B. MARSH, Professor Emeritus

STEVEN PRUESS, Professor Emeritus

ROBERT E. D. WOOLSEY, Professor Emeritus

BARBARA B. BATH, Associate Professor Emerita

RUTH MAURER, Associate Professor Emerita

ROBERT G. UNDERWOOD, Associate Professor Emeritus

Degrees Offered:

Master of Science (Mathematical and Computer Sciences)

Doctor of Philosophy (Mathematical and Computer Sciences)

Program Description:

There are three areas of concentration within the department: applied mathematics, statistics, and computer science. Since the requirements for these areas vary somewhat, they are often considered separately in this catalog. However, labeling these as distinct areas is not meant to discourage any student from pursuing research involving more than one. Work in any of these areas can lead to the degree of Master of Science or Doctor of Philosophy. Applicants to the graduate program need four items: 1. A statement of purpose (short essay) from the applicant briefly describing background, interests, goals at CSM, career intentions, etc. 2. The general

Graduate Record Examination. 3. B or better average in courses in the major field. 4. B or better overall undergraduate grade point average.

Program Requirements:

The Master of Science degree (thesis option) requires 36 credit hours of acceptable course work and research, completion of a satisfactory thesis, and successful oral defense of this thesis. The course work includes the required core curriculum. 12 of the 36 credit hours must be designated for supervised research.

The Master of Science degree (non-thesis option) requires 36 credit hours of course work. The course work includes the required core curriculum.

The Doctor of Philosophy requires 72 credit hours beyond the bachelor's degree. At least 24 of these hours are thesis hours. Doctoral students must pass the comprehensive examination (a qualifying examination and thesis proposal), complete a satisfactory thesis, and successfully defend their thesis.

The specific core curriculum requirements can be found in the Mathematical and Computer Sciences Department Graduate Handbook: Call 303 273-3860; FAX 303 273-3875, or look on the Web at mcs.mines.edu. This handbook also provides an overview of the programs, requirements and policies of the department.

Combined BS/MS Program

CSM undergraduates may apply to the Combined BS/MS Program. Students enrolled in this program may double-count 6 hours of undergraduate coursework toward their MS degree, so that the MS degree can be earned with only 30 hours of additional coursework.

Prerequisites:

Applied Mathematics:

Linear algebra

Vector calculus

Ordinary differential equations

Advanced calculus (Introduction to real analysis)

Statistics:

Linear algebra

Introduction to probability & statistics

Advanced calculus (Introduction to real analysis)

Computer Science:

Science - two semesters

Mathematics - two semesters of calculus, at least two courses from ordinary differential equations, linear algebra, statistics, discrete mathematics

Data structures

A programming language

Upper level courses in at least three of software engineering, numerical analysis, machine architecture/assembly language, comparative languages, analysis of algorithms, operating systems

Fields of Research:

Applied Mathematics:

Computational Methods and Analysis for Wave Phenomena
Classical Scattering Theory
Classical Wave Propagation
Mathematical Methods for Wave Phenomena
Nonlinear Partial Differential Equations
Numerical Analysis
Optimization Software
Symbolic Computing
Wavelets

Statistics:

Inverse Problems in Statistics
Multivariate Statistics
Spatial Statistics
Stochastic Models for Environmental Science
Survival Analysis

Computer Science:

Applied Algorithms and Data Structures
Computer Aided Geometric Design
Computer Graphics
Computer Networks
High Performance Computing
Image Processing
Mobile Computing and Networking
Parallel Computing
Scientific Visualization
Sensor Networks
VLSI Design Automation

Description of Courses

Senior Year

CSCI400. PRINCIPLES OF PROGRAMMING LANGUAGES (I, II) Study of the principles relating to design, evaluation and implementation of programming languages of historical and technical interest, considered as individual entities and with respect to their relationships to other languages. Topics discussed for each language include: history, design, structural organization, data structures, name structures, control structures, syntactic structures, and implementation of issues. The primary languages discussed are FORTRAN, PASCAL, LISP, ADA, C/C++, JAVA, PROLOG, PERL. Prerequisite: CSCI262 and CSCI306 or knowledge of JAVA. 3 hours lecture; 3 semester hours.

MATH401 INTRODUCTION TO ANALYSIS (I) This course is a first course in real analysis that lays out the context and motivation of analysis in terms of the transition from power series to those less predictable series. The course is taught from a historical perspective. It covers an introduction to the real numbers, sequences and series and their conver-

gence, real-valued functions and their continuity and differentiability, sequences of functions and their pointwise and uniform convergence, and Riemann-Stieltjes integration theory. Prerequisite: MATH213, MATH223 or MATH224, and MATH332. 3 hours lecture; 3 semester hours.

CSCI403. DATA BASE MANAGEMENT (I) Design and evaluation of information storage and retrieval systems, including defining and building a data base and producing the necessary queries for access to the stored information. Generalized data base management systems, query languages, and data storage facilities. General organization of files including lists, inverted lists and trees. System security and system recovery, and system definition. Interfacing host language to data base systems. Prerequisite: CSCI262. 3 hours lecture; 3 semester hours.

CSCI404. ARTIFICIAL INTELLIGENCE (I) General investigation of the Artificial Intelligence field. During the first part of the course a working knowledge of the LISP programming language is developed. Several methods used in artificial intelligence such as search strategies, knowledge representation, logic and probabilistic reasoning are developed and applied to problems. Learning is discussed and selected applications presented. Prerequisite: CSCI262, MATH/CSCI358. 3 hours lecture; 3 semester hours.

MATH/CSCI406. ALGORITHMS (I, II) Divide-and-conquer: splitting problems into subproblems of a finite number. Greedy: considering each problem piece one at a time for optimality. Dynamic programming: considering a sequence of decisions in problem solution. Searches and traversals: determination of the vertex in the given data set that satisfies a given property. Techniques of backtracking, branch-and-bound techniques, techniques in lower bound theory. Prerequisite: CSCI262, MATH213, MATH223 or MATH224, MATH/CSCI358. 3 hours lecture; 3 semester hours.

MATH/CSCI407. INTRODUCTION TO SCIENTIFIC COMPUTING (I, II) Round-off error in floating point arithmetic, conditioning and stability, solution techniques (Gaussian elimination, LU factorization, iterative methods) of linear algebraic systems, curve and surface fitting by the method of least-squares, zeros of nonlinear equations and systems by iterative methods, polynomial interpolation and cubic splines, numerical integration by adaptive quadrature and multivariate quadrature, numerical methods for initial value problems in ordinary differential equations. Emphasis is on problem solving using efficient numerical methods in scientific computing. Prerequisite: MATH315 or MATH325 and knowledge of computer programming. 3 hours lecture; 3 semester hours.

CSCI410. ELEMENTS OF COMPUTING SYSTEMS (II) This comprehensive course will help students consolidate their understanding of all fundamental computer science concepts. Topics include symbolic communication, Boolean logic, binary systems, logic gates, computer architecture, as-

sembly language, assembler construction, virtual machines, object-oriented programming languages, software engineering, compilers, language design, and operating systems. Using a hardware simulator and a programming language of their choice, students construct an entire modern computer from the ground up, resulting in an intimate understanding of how each component works. Prerequisites: CSCI261, CSCI341. 3 lecture hours, 3 semester hours.

MATH/CSCI411. INTRODUCTION TO EXPERT SYSTEMS (II) General investigation of the field of expert systems. The first part of the course is devoted to designing expert systems. The last half of the course is implementation of the design and construction of demonstration prototypes of expert systems. Prerequisite: CSCI262, MATH/CSCI358. 3 hours lecture; 3 semester hours.

CSCI422. USER INTERFACES (I) User Interface Design is a course for programmers who want to learn how to create more effective software. This objective will be achieved by studying principles and patterns of interaction design, critiquing existing software using criteria presented in the textbook, and researching and analyzing the capabilities of various software development tools. Students will also learn a variety of techniques to guide the software design process, including Goal-Directed Design, Cognitive Walkthrough, Talk-aloud and others. Prerequisite: CSCI262. 3 hours lecture; 3 semester hours.

MATH424. INTRODUCTION TO APPLIED STATISTICS (I) Linear regression, analysis of variance, and design of experiments, focusing on the construction of models and evaluation of their fit. Techniques covered will include stepwise and best subsets regression, variable transformations, and residual analysis. Emphasis will be placed on the analysis of data with statistical software. Prerequisites: MATH323 or MATH335. 3 hours lecture; 3 semester hours.

MATH433/BELS433 MATHEMATICAL BIOLOGY (I) This course will discuss methods for building and solving both continuous and discrete mathematical models. These methods will be applied to population dynamics, epidemic spread, pharmacokinetics and modeling of physiologic systems. Modern Control Theory will be introduced and used to model living systems. Some concepts related to self-organizing systems will be introduced. Prerequisite: MATH315 or MATH325. 3 hours lecture, 3 semester hours.

MATH436. ADVANCED STATISTICAL MODELING (II) Modern methods for constructing and evaluating statistical models. Topics include generalized linear models, generalized additive models, hierarchical Bayes methods, and resampling methods. Prerequisites: MATH335 and MATH424. 3 hours lecture; 3 semester hours.

MATH437. MULTIVARIATE ANALYSIS (II) Introduction to applied multivariate techniques for data analysis. Topics include principal components, cluster analysis, MANOVA

and other methods based on the multivariate Gaussian distribution, discriminant analysis, classification with nearest neighbors. Prerequisites: MATH335 or MATH323. 3 hours lecture; 3 semester hours.

MATH438. STOCHASTIC MODELS (II) An introduction to stochastic models applicable to problems in engineering, physical science, economics, and operations research. Markov chains in discrete and continuous time, Poisson processes, and topics in queuing, reliability, and renewal theory. Prerequisite: MATH334. 3 hours lecture, 3 semester hours.

CSCI440. PARALLEL COMPUTING FOR SCIENTISTS AND ENGINEERS (I) This course is designed to introduce the field of parallel computing to all scientists and engineers. The students will be taught how to solve scientific problems. They will be introduced to various software and hardware issues related to high performance computing. Prerequisite: Programming experience in C++, consent of instructor. 3 hours lecture; 3 semester hours.

MATH440. PARALLEL SCIENTIFIC COMPUTING (I). This course is designed to facilitate students' learning of parallel programming techniques to efficiently simulate various complex processes modeled by mathematical equations using multiple and multi-core processors. Emphasis will be placed on implementation of various scientific computing algorithms in FORTRAN 90 and its variants using MPI and OpenMP. Prerequisite: CSCI/MATH 407. 3 hours lecture; 3 semester hours.

MATH/CSCI441. COMPUTER GRAPHICS (I) Data structures suitable for the representation of structures, maps, three-dimensional plots. Algorithms required for windowing, color plots, hidden surface and line, perspective drawings. Survey of graphics software and hardware systems. Prerequisite: CSCI262. 3 hours lecture, 3 semester hours.

CSCI442. OPERATING SYSTEMS (I, II) Covers the basic concepts and functionality of batch, timesharing and single-user operating system components, file systems, processes, protection and scheduling. Representative operating systems are studied in detail. Actual operating system components are programmed on a representative processor. This course provides insight into the internal structure of operating systems; emphasis is on concepts and techniques which are valid for all computers. Prerequisite: CSCI262, CSCI341. 3 hours lecture; 3 semester hours.

CSCI443. ADVANCED PROGRAMMING CONCEPTS USING JAVA. (I, II) This course will quickly review programming constructs using the syntax and semantics of the Java programming language. It will compare the constructs of Java with other languages and discuss program design and implementation. Object oriented programming concepts will be reviewed and applications, applets, servlets, graphical user interfaces, threading, exception handling, JDBC, and net-

working as implemented in Java will be discussed. The basics of the Java Virtual Machine will be presented. Prerequisites: CSCI261, CSCI262. 3 hours lecture, 3 semester hours.

MATH/CSCI444. ADVANCED COMPUTER GRAPHICS (I) This is an advanced computer graphics course, focusing on modern rendering and geometric modeling techniques. Students will learn a variety of mathematical and algorithmic techniques that can be used to develop high-quality computer graphics software. In particular, the course will cover global illumination, GPU programming, geometry acquisition and processing, point based graphics and non-photorealistic rendering. Basic understanding of computer graphics and prior exposure to graphics-related programming required. Prerequisite: MATH441. 3 lecture hours, 3 semester hours.

CSCI445. WEB PROGRAMMING (II) Web Programming is a course for programmers who want to develop Web-based applications. It covers basic web site design extended by client-side and server-side programming. Students should know the elements of HTML and Web architecture and be able to program in a high level language such as C++ or Java. The course builds on this knowledge by presenting topics such as Cascading Style Sheets, JavaScript, PERL and database connectivity that will allow the students to develop dynamic Web applications. Prerequisites: Fluency in a high level computer language/consent of instructor. 3 hours lecture, 3 semester hours.

CSCI446. WEB APPLICATIONS (I) Web Applications is a course for programmers who want to learn how to create effective, dynamic web pages. At the completion of this course, students should know Hypertext Markup Language (HTML), Cascading Style Sheets (CSS), JavaScript and JavaScript Object Notation (JSON), Ajax, Ruby and Flash. Additionally students should have considered a variety of issues related to web site design, including but not limited to web security, web server performance and content management. Prerequisites: CSCI262. 3 hours lecture, 3 semester hours.

MATH/CSCI447. SCIENTIFIC VISUALIZATION (I) Scientific visualization uses computer graphics to create visual images which aid in understanding of complex, often massive numerical representation of scientific concepts or results. The main focus of this course is on modern visualization techniques applicable to spatial data such as scalar, vector and tensor fields. In particular, the course will cover volume rendering, texture based methods for vector and tensor field visualization, and scalar and vector field topology. Basic understanding of computer graphics and analysis of algorithms required. Prerequisites: CSCI262 and MATH441. 3 lecture hours, 3 semester hours.

MATH454. COMPLEX ANALYSIS (II) The complex plane. Analytic functions, harmonic functions. Mapping by elementary functions. Complex integration, power series, calculus of

residues. Conformal mapping. Prerequisite: MATH315 or MATH325. 3 hours lecture, 3 semester hours.

MATH455. PARTIAL DIFFERENTIAL EQUATIONS (I) Linear partial differential equations, with emphasis on the classical second-order equations: wave equation, heat equation, Laplace's equation. Separation of variables, Fourier methods, Sturm-Liouville problems. Prerequisite: MATH315 or MATH325. 3 hours lecture; 3 semester hours.

MATH458. ABSTRACT ALGEBRA (II) This course is an introduction to the concepts of contemporary abstract algebra and applications of those concepts in areas such as physics and chemistry. Topics include groups, subgroups, isomorphisms and homomorphisms, rings integral domains and fields. Prerequisites: MATH213 and MATH223 or MATH224, and MATH300 or consent of the instructor. 3 hours lecture; 3 semester hours.

CSCI471. COMPUTER NETWORKS I (I) This introduction to computer networks covers the fundamentals of computer communications, using TCP/IP standardized protocols as the main case study. The application layer and transport layer of communication protocols will be covered in depth. Detailed topics include application layer protocols (HTTP, FTP, SMTP, and DNS), reliable data transfer, connection management, and congestion control. In addition, students will build a computer network from scratch and program client/server network applications. Prerequisite: CSCI442 or consent of instructor. 3 hours lecture, 3 semester hours.

MATH/CSCI474. INTRODUCTION TO CRYPTOGRAPHY This course is primarily oriented towards the mathematical aspects of cryptography, but is also closely related to practical and theoretical issues of computer security. The course provides mathematical background required for cryptography including relevant aspects of number theory and mathematical statistics. The following aspects of cryptography will be covered: symmetric and asymmetric encryption, computational number theory, quantum encryption, RSA and discrete log systems, SHA, steganography, chaotic and pseudo-random sequences, message authentication, digital signatures, key distribution and key management, and block ciphers. Many practical approaches and most commonly used techniques will be considered and illustrated with real-life examples. Prerequisites: CSCI262, MATH334/335, MATH358. 3 credit hours.

CSCI475. INFORMATION SECURITY AND PRIVACY (I) Information Security and Privacy provides a hands-on introduction to the principles and best practices in information and computer security. Lecture topics will include basic components of information security including threat assessment and mitigation, policy development, and the legal and political dimensions of information security. Prerequisite: CSCI 442 or consent of instructor. 3 hours lecture; 3 semester hours.

MATH 482 STATISTICS PRACTICUM (II) This is the capstone course in the Statistics Option. Students will apply statistical principles to data analysis through advanced work, leading to a written report and an oral presentation. Choice of project is arranged between the student and the individual faculty member who will serve as advisor. Prerequisites: MATH335 and MATH424. 3 hours lecture; 3 semester hours.

MATH484. MATHEMATICAL AND COMPUTATIONAL MODELING (CAPSTONE) (II) This is the capstone course in the Computational and Applied Mathematics option. Students will apply computational and applied mathematics modeling techniques to solve complex problems in biological, engineering and physical systems. Mathematical methods and algorithms will be studied within both theoretical and computational contexts. The emphasis is on how to formulate, analyze and use nonlinear modeling to solve typical modern problems. Prerequisites: MACS407, MACS433 and MACS455. 3 hours lecture; 3 semester hours.

MATH/CSCI491. UNDERGRADUATE RESEARCH (I) (WI) Individual investigation under the direction of a department faculty member. Written report required for credit. Prerequisite: Consent of Department Head. 1 to 3 semester hours, no more than 6 in a degree program.

MATH/CSCI492. UNDERGRADUATE RESEARCH (II) (WI) Individual investigation under the direction of a department faculty member. Written report required for credit. Prerequisite: Consent of Department Head. 1 to 3 semester hours, no more than 6 in a degree program.

MATH/CSCI498. SPECIAL TOPICS (I, II, S) Selected topics chosen from special interests of instructor and students. Prerequisite: Consent of Department Head. Variable: 1 to 3 semester hours. Repeatable for credit under different titles.

MATH/CSCI499. INDEPENDENT STUDY (I, II, S) Individual research or special problem projects supervised by a faculty member; also, given agreement on a subject matter, content, and credit hours. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable Credit: 1 to 6 credit hours. Repeatable for credit.

Graduate Courses

500-level and 700-level courses are open to qualified seniors with the permission of the department and Dean of Graduate School.

MATH500. LINEAR VECTOR SPACES (I) Finite dimensional vector spaces and subspaces: dimension, dual bases, annihilators. Linear transformations, matrices, projections, change of basis, similarity. Determinants, eigenvalues, multiplicity. Jordan form. Inner products and inner product spaces with orthogonality and completeness. Prerequisite: MATH401. 3 hours lecture; 3 semester hours.

MATH502. REAL AND ABSTRACT ANALYSIS (I) Introduction to metric and topological spaces. Lebesgue measure and measurable functions and sets. Types of convergence, Lebesgue integration and its relation to other integrals. Integral convergence theorems. Absolute continuity and related concepts. Prerequisite: MATH401. 3 hours lecture; 3 semester hours.

MATH503. FUNCTIONAL ANALYSIS (I) Normed linear spaces, linear operators on normed linear spaces, Banach spaces, inner product and Hilbert spaces, orthonormal bases, duality, orthogonality, adjoint of a linear operator, spectral analysis of linear operators. Prerequisite: MATH502. 3 hours lecture; 3 semester hours.

MATH506. COMPLEX ANALYSIS II (II) Analytic functions. Conformal mapping and applications. Analytic continuation. Schlicht functions. Approximation theorems in the complex domain. Prerequisite: MATH454. 3 hours lecture; 3 semester hours.

MATH510. ORDINARY DIFFERENTIAL EQUATIONS AND DYNAMICAL SYSTEMS (I) Topics to be covered: basic existence and uniqueness theory, systems of equations, stability, differential inequalities, Poincare-Bendixon theory, linearization. Other topics from: Hamiltonian systems, periodic and almost periodic systems, integral manifolds, Lyapunov functions, bifurcations, homoclinic points and chaos theory. Prerequisite: MATH315 and MATH332 or equivalent. 3 hours lecture; 3 semester hours.

MATH514. APPLIED MATHEMATICS I (I) The major theme in this course is various non-numerical techniques for dealing with partial differential equations which arise in science and engineering problems. Topics include transform techniques, Green's functions and partial differential equations. Stress is on applications to boundary value problems and wave theory. Prerequisite: MATH455 or equivalent. 3 hours lecture; 3 semester hours.

MATH515. APPLIED MATHEMATICS II (II) Topics include integral equations, applied complex variables, an introduction to asymptotics, linear spaces and the calculus of variations. Stress is on applications to boundary value problems and wave theory, with additional applications to engineering and physical problems. Prerequisite: MATH514. 3 hours lecture; 3 semester hours.

CSCI522. USER INTERFACE DESIGN (I) An introduction to the field of Human-Computer Interaction (HCI). Students will review current literature from prominent researchers in HCI and will discuss how the researchers' results may be applied to the students' own software design efforts. The course textbook and supplementary materials will provide a number of practical techniques and guidelines for developing software to better meet users' needs, such as Goal-Directed Design, Cognitive Walk Through and Talk-aloud

testing methodologies, and interaction design patterns. Prerequisite: CSCI261 or equivalent. 3 hours lecture, 3 semester hours.

MATH530. STATISTICAL METHODS I (I) Introduction to probability, random variables, and discrete and continuous probability models. Elementary simulation. Data summarization and analysis. Confidence intervals and hypothesis testing for means and variances. Chi square tests. Distribution-free techniques and regression analysis. Prerequisite: MATH213 or equivalent. 3 hours lecture; 3 semester hours.

MATH531. STATISTICAL METHODS II (II) Continuation of MATH530. Multiple regression and trend surface analysis. Analysis of variance. Experimental design (Latin squares, factorial designs, confounding, fractional replication, etc.) Nonparametric analysis of variance. Topics selected from multivariate analysis, sequential analysis or time series analysis. Prerequisite: MATH323 or MATH530 or MATH535. 3 hours lecture; 3 semester hours.

MATH534. MATHEMATICAL STATISTICS I (I) The basics of probability, discrete and continuous probability distributions, sampling distributions, order statistics, convergence in probability and in distribution, and basic limit theorems, including the central limit theorem, are covered. Prerequisite: Consent of department. 3 hours lecture; 3 semester hours.

MATH535. MATHEMATICAL STATISTICS II (II) The basics of hypothesis testing using likelihood ratios, point and interval estimation, consistency, efficiency, sufficient statistics, and some nonparametric methods are presented. Prerequisite: MATH534 or equivalent. 3 hours lecture; 3 semester hours.

MATH/CSCI542. SIMULATION (I) Advanced study of simulation techniques, random number, and variate generation. Monte Carlo techniques, simulation languages, simulation experimental design, variance reduction, and other methods of increasing efficiency, practice on actual problems. Offered every other year. Prerequisite: CSCI262 (or equivalent), CSCI323 (or CSCI530 or equivalent), or permission of instructor. 3 hours lecture; 3 semester hours.

MATH540. PARALLEL SCIENTIFIC COMPUTING (I) This course is designed to facilitate students' learning of parallel programming techniques to efficiently simulate various complex processes modeled by mathematical equations using multiple and multi-core processors. Emphasis will be placed on the implementation of various scientific computing algorithms in FORTRAN/C/C++ using MPI and OpenMP. Prerequisite: MATH407, CSCI407, or consent of instructor. 3 hours lecture, 3 semester hours.

MATH/CSCI544. ADVANCED COMPUTER GRAPHICS (II) This is an advanced computer graphics course in which students will learn a variety of mathematical and algorithmic techniques that can be used to solve fundamental problems in

computer graphics. Topics include global illumination, GPU programming, geometry acquisition and processing, point based graphics and non-photorealistic rendering. Students will learn about modern rendering and geometric modeling techniques by reading and discussing research papers and implementing one or more of the algorithms described in the literature.

CSCI546. WEB PROGRAMMING II (I) This course covers methods for creating effective and dynamic web pages, and using those sites as part of a research agenda related to Humanitarian Engineering. Students will review current literature from the International Symposium on Technology and Society (ISTAS), American Society for Engineering Education (ASEE), and other sources to develop a research agenda for the semester. Following a brief survey of web programming languages, including HTML, CSS, JavaScript and Flash, students will design and implement a website to meet their research agenda. The final product will be a research paper which documents the students' efforts and research results. Prerequisite: CSCI 262. 3 hours lecture, 3 semester hours.

MATH/CSCI547. SCIENTIFIC VISUALIZATION (I) Scientific visualization uses computer graphics to create visual images which aid in understanding of complex, often massive numerical representation of scientific concepts or results. The main focus of this course is on techniques applicable to spatial data such as scalar, vector and tensor fields. Topics include volume rendering, texture based methods for vector and tensor field visualization, and scalar and vector field topology. Students will learn about modern visualization techniques by reading and discussing research papers and implementing one of the algorithms described in the literature.

MATH550. NUMERICAL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS (II) Numerical methods for solving partial differential equations. Explicit and implicit finite difference methods; stability, convergence, and consistency. Alternating direction implicit (ADI) methods. Weighted residual and finite element methods. Prerequisite: MATH315, MATH332, or consent of instructor. 3 hours lecture; 3 semester hours.

MATH551. COMPUTATIONAL LINEAR ALGEBRA (II) Numerical analysis of algorithms for solving linear systems of equations, least squares methods, the symmetric eigenproblem, singular value decomposition, conjugate gradient iteration. Modification of algorithms to fit the architecture. Error analysis, existing software packages. Prerequisites: MATH332, MATH/CSCI407, or consent of instructor. 3 hours lecture; 3 semester hours.

MATH556. MODELING WITH SYMBOLIC SOFTWARE (I) Case studies of various models from mathematics, the sciences and engineering through the use of the symbolic software package MATHEMATICA. Based on hands-on projects

dealing with contemporary topics such as number theory, discrete mathematics, complex analysis, special functions, classical and quantum mechanics, relativity, dynamical systems, chaos and fractals, solitons, wavelets, chemical reactions, population dynamics, pollution models, electrical circuits, signal processing, optimization, control theory, and industrial mathematics. The course is designed for graduate students and scientists interested in modeling and using symbolic software as a programming language and a research tool. It is taught in a computer laboratory. Prerequisites: Senior undergraduates need consent of instructor. 3 hours lecture; 3 semester hours.

CSCI561. THEORY OF COMPUTATION (I) An introduction to abstract models of computation and computability theory; including finite automata (finite state machines), pushdown automata, and Turing machines. Language models, including formal languages, regular expressions, and grammars. Decidability and undecidability of computational problems. Prerequisite: CSCI/MATH358. 3 hours lecture; 3 semester hours.

CSCI562 APPLIED ALGORITHMS AND DATA STRUCTURES (II) Industry competitiveness in certain areas is often based on the use of better algorithms and data structures. The objective of this class is to survey some interesting application areas and to understand the core algorithms and data structures that support these applications. Application areas could change with each offering of the class, but would include some of the following: VLSI design automation, computational biology, mobile computing, computer security, data compression, web search engines, geographical information systems. Prerequisite: MATH/CSCI406, or consent of instructor. 3 hours lecture; 3 semester hours.

CSCI563. PARALLEL COMPUTING FOR SCIENTISTS AND ENGINEERS (I) Students are taught how to use parallel computing to solve complex scientific problems. They learn how to develop parallel programs, how to analyze their performance, and how to optimize program performance. The course covers the classification of parallel computers, shared memory versus distributed memory machines, software issues, and hardware issues in parallel computing. Students write programs for state of the art high performance supercomputers, which are accessed over the network. Prerequisite: Programming experience in C, consent of instructor. 3 hours lecture; 3 semester hours

CSCI564 ADVANCED COMPUTER ARCHITECTURE (I) The objective of this class is to gain a detailed understanding about the options available to a computer architect when designing a computer system along with quantitative justifications for the options. All aspects of modern computer architectures including instruction sets, processor design, memory system design, storage system design, multiprocessors, and software approaches will be discussed. Prerequisite: CSCI341, or consent of instructor. 3 hours lecture; 3 semester hours.

CSCI565. DISTRIBUTED COMPUTING SYSTEMS (II) Introduction to the design and use of distributed computer systems based on networks of workstations and server computers. Topics include theory, applications, systems and case studies describing current approaches. Prerequisites: Undergraduate machine architecture or consent of instructor. 3 hours lecture; 3 semester hours.

CSCI566. ADVANCED DATABASE MANAGEMENT (II) Advanced issues in database management, with emphasis on their application to scientific data. Topics to be covered include: object-oriented database management, database rules, distributed databases, database design, transaction management, query optimization, concurrency control, and management of scientific data. Each student develops a course project, as a vehicle for exploring and applying a database research issue. Prerequisite: CSCI403 or equivalent. 3 hours lecture; 3 semester hours.

CSCI567. ADVANCED OBJECT ORIENTED SOFTWARE ENGINEERING (II) Advanced software engineering concepts, with emphasis on how to develop object-oriented application programs. The entire software lifecycle is discussed: requirements analysis, program design, implementation, debugging and testing. Seamless program development is emphasized, in which the development process is an incremental refinement of a computer model of real-world objects. Examples in the course are from scientific application programs. The object-oriented use of the C++ language is taught and used in assignments. Prerequisite: Knowledge of C or C++. 3 hours lecture; 3 semester hours.

CSCI568. DATA MINING (II) This course is an introductory course in data mining. It covers fundamentals of data mining theories and techniques. We will discuss association rule mining and its applications, overview of classification and clustering, data preprocessing, and several application-specific data mining tasks. We will also discuss practical data mining using a data mining software. Project assignments include implementation of existing data mining algorithms, data mining with or without data mining software, and study of data mining-related research issues. Prerequisite: CSCI262 or permission of instructor. 3 hours lecture; 3 semester hours.

CSCI569. NETWORKED MULTIMEDIA SYSTEMS Advances in computation, storage and communication technologies are initiating the large scale deployment of multimedia services and applications such as distance learning, video-on-demand, multimedia conferencing, video phones and multiparty games. This course covers the design and implementation of the technologies for interactive distributed multimedia applications. Fundamentals of human perception, digital media representations, compression and synchronization are covered. Implementation technologies including operating systems support, multimedia systems services, and network architectures and protocols are also discussed. In addition, the latest development and open research issues in multimedia networking and operating systems are intro-

duced. Prerequisite: CSCI446, CSCI471, or consent of instructor. 3 hours lecture; 3 semester hours.

CSCI570. NEURAL NETWORKS (I) This course explores the theory behind neural networks, and focuses on the application of this technology to real problems in areas as diverse as DNA pattern recognition, robot control, hazardous waste remediation, and forensics. For the prepared student, this course also facilitates a transition from doing coursework to producing publishable research. Skills required to understand, critique, and extend existing research are emphasized. An introductory series of lectures is followed by more in-depth study of current research topics. Depending on a student's background, the course project is either a literature survey or application or exploration of a neural network method of the student's choice. Prerequisite: CSCI404. 3 hours lecture; 3 semester hours.

CSCI571. ARTIFICIAL INTELLIGENCE (I) Artificial Intelligence (AI) is the subfield of computer science that studies how to automate tasks for which people currently exhibit superior performance over computers. Historically, AI has studied problems such as machine learning, language understanding, game playing, planning, robotics, and machine vision. AI techniques include those for uncertainty management, automated theorem proving, heuristic search, neural networks, and simulation of expert performance in specialized domains like medical diagnosis. This course provides an overview of the field of Artificial Intelligence. Particular attention will be paid to learning the LISP language for AI programming. Prerequisite: CSCI262. 3 hours lecture; 3 semester hours.

CSCI572. COMPUTER NETWORKS II (II) This introduction to computer networks covers the fundamentals of computer communications, using TCP/IP standardized protocols as the main case study. This second course on computer networks covers the network layer, data link layer, and physical layer of communication protocols in depth. Detailed topics include routing (unicast, multicast, and broadcast), one hop error detection and correction, and physical topologies. Other topics include the history of computer communications and protocols for emerging networks (e.g., ad hoc networks and sensor networks). In addition, students will program client/server network applications and simulate a network protocol in a network simulator. Prerequisite: CSCI471. 3 hours lecture; 3 semester hours.

MATH/CSCI574. THEORY OF CRYPTOGRAPHY Students will draw upon current research results to design, implement and analyze their own computer security or other related cryptography projects. The requisite mathematical background, including relevant aspects of number theory and mathematical statistics, will be covered in lecture. Students will be expected to review current literature from prominent researchers in cryptography and to present their findings to the class. Particular focus will be given to the application of various techniques to real-life situations. The course will also

cover the following aspects of cryptography: symmetric and asymmetric encryption, computational number theory, quantum encryption, RSA and discrete log systems, SHA, steganography, chaotic and pseudo-random sequences, message authentication, digital signatures, key distribution and key management, and block ciphers. Prerequisites: CSCI 262 plus undergraduate-level knowledge of statistics and discrete mathematics. 3 hours lecture, 3 semester hours.

CSCI575. MACHINE LEARNING (II) The goal of machine learning research is to build computer systems that learn from experience and that adapt to their environments. Machine learning systems do not have to be programmed by humans to solve a problem; instead, they essentially program themselves based on examples of how they should behave, or based on trial and error experience trying to solve the problem. This course will focus on the methods that have proven valuable and successful in practical applications. The course will also contrast the various methods, with the aim of explaining the situations in which each is most appropriate. Prerequisites: CSCI262 and MATH323, or consent of instructor. 3 hours lecture; 3 semester hours.

CSCI576. WIRELESS SENSOR SYSTEMS With the advances in computational, communication, and sensing capabilities, large scale sensor-based distributed environments are becoming a reality. Sensor enriched communication and information infrastructures have the potential to revolutionize almost every aspect of human life benefitting application domains such as transportation, medicine, surveillance, security, defense, science and engineering. Such a distributed infrastructure must integrate networking, embedded systems, distributed computing and data management technologies to ensure seamless access to data dispersed across a hierarchy of storage, communication, and processing units, from sensor devices where data originates to large databases where the data generated is stored and/or analyzed. Prerequisite: CSCI406, CSCI446, CSCI471, or consent of instructor. 3 hours lecture; 3 semester hours.

CSCI580. ADVANCED HIGH PERFORMANCE COMPUTING This course provides students with knowledge of the fundamental concepts of high performance computing as well as hands-on experience with the core technology in the field. The objective of this class is to understand how to achieve high performance on a wide range of computational platforms. Topics will include sequential computers including memory hierarchies, shared memory computers and multicore, distributed memory computers, graphical processing units (GPUs), cloud and grid computing, threads, OpenMP, message passing (MPI), CUDA (for GPUs), parallel file systems, and scientific applications. 3 hours lecture; 3 semester hours.

CSCI586. FAULT TOLERANT COMPUTING. This course provides a comprehensive overview of fault tolerant computing including uniprocessor fault tolerance, distributed fault tolerance, failure model, fault detection, checkpoint, message

log, algorithm-based fault tolerance, error correction codes, and fault tolerance in large storage systems. 3 hours lecture; 3 semester hours.

MATH/CSCI597. SUMMER PROGRAMS

MATH/CSCI598. SPECIAL TOPICS (I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

MATH/CSCI599. INDEPENDENT STUDY (I, II, S) Individual research or special problem projects supervised by a faculty member, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

MATH610. ADVANCED TOPICS IN DIFFERENTIAL EQUATIONS (II) Topics from current research in ordinary and/or partial differential equations; for example, dynamical systems, advanced asymptotic analysis, nonlinear wave propagation, solitons. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

MATH614. ADVANCED TOPICS IN APPLIED MATHEMATICS (I) Topics from current literature in applied mathematics; for example, wavelets and their applications, calculus of variations, advanced applied functional analysis, control theory. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

MATH616. INTRODUCTION TO MULTI-DIMENSIONAL SEISMIC INVERSION (II) Introduction to high frequency inversion techniques. Emphasis on the application of this theory to produce a reflector map of the earth's interior and estimates of changes in earth parameters across those reflectors from data gathered in response to sources at the surface or in the interior of the earth. Extensions to elastic media are discussed, as well. Includes high frequency modeling of the propagation of acoustic and elastic waves. Prerequisites: partial differential equations, wave equation in the time or frequency domain, complex function theory, contour integration. Some knowledge of wave propagation: reflection, refraction, diffraction. 3 hours lecture; 3 semester hours.

MATH650. ADVANCED TOPICS IN NUMERICAL ANALYSIS (II) Topics from the current literature in numerical analysis and/or computational mathematics; for example, advanced finite element method, sparse matrix algorithms, applications of approximation theory, software for initial value ODE's, numerical methods for integral equations. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

CSCI660. ADVANCED TOPICS IN COMPUTER SYSTEMS (II) Topics from the current literature in hardware and software computer systems; for example, user interfaces, object oriented software engineering, database

management, computer architectures, supercomputing, parallel processing, distributed processing, and algorithms. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

MATH/CSCI691. GRADUATE SEMINAR (I) Presentation of latest research results by guest lecturers, staff, and advanced students. Prerequisite: Consent of department. 1 hour seminar; 1 semester hour. Repeatable for credit to a maximum of 12 hours.

MATH/CSCI692. GRADUATE SEMINAR (II) Presentation of latest research results by guest lecturers, staff, and advanced students. Prerequisite: Consent of department. 1 hour seminar; 1 semester hour. Repeatable for credit to a maximum of 12 hours.

MATH693/GPGN551. WAVE PHENOMENA SEMINAR (I, II) Students will probe a range of current methodologies and issues in seismic data processing, with emphasis on underlying assumptions, implications of these assumptions, and implications that would follow from use of alternative assumptions. Such analysis should provide seed topics for ongoing and subsequent research. Topic areas include: Statistics estimation and compensation, deconvolution, multiple suppression, suppression of other noises, wavelet estimation, imaging and inversion, extraction of stratigraphic and lithologic information, and correlation of surface and borehole seismic data with well log data. Prerequisite: Consent of department. 1 hour seminar; 1 semester hour.

MATH/CSCI698. SPECIAL TOPICS (I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

MATH/CSCI699. INDEPENDENT STUDY (I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

MATH/CSCI705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE (I, II, S) Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

MATH/CSCI706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY (I, II, S) Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

Metallurgical and Materials Engineering

MICHAEL J. KAUFMAN, Professor and Department Head
CORBY G. ANDERSON, Professor
STEPHEN LIU, Professor
GERARD P. MARTINS, Professor
DAVID K. MATLOCK, Charles S. Fogarty Professor
BRAJENDRA MISHRA, Professor
DAVID L. OLSON, John H. Moore Distinguished Professor
IVAR E. REIMANIS, Professor
JOHN G. SPEER, Professor
PATRICK R. TAYLOR, George S. Ansell Distinguished Professor of Chemical Metallurgy
CHESTER J. VANTYNE, FIERF Professor and Associate Department Head
BRIAN GORMAN, Associate Professor
RYAN P. O'HAYRE, Associate Professor
STEVEN W. THOMPSON, Associate Professor
REED AYERS, Assistant Professor
KIP O. FINDLEY, Assistant Professor
JEFFREY C. KING, Assistant Professor
HONGJUN LIANG, Assistant Professor
CORINNE E. PACKARD, Assistant Professor
GERALD BOURNE, Teaching Associate Professor
JOHN P. CHANDLER, Teaching Associate Professor
RICHARD K. AHRENKIEL, Research Professor
WILLIAM (GROVER) COORS, Research Professor
ZEEV SHAYER, Research Professor
D. (ERIK) SPILLER, Research Professor
JAMES C. WILLIAMS, Research Professor
CAROLE GRAAS, Research Associate Professor
JIANHUA TONG, Research Associate Professor
EDGAR VIDAL, Research Associate Professor
EMMANUEL De MOOR, Research Assistant Professor
DAVID DIERCKS, Research Assistant Professor
JUDITH C. GOMEZ, Research Assistant Professor
JIANLIANG LIN, Research Assistant Professor
YONG-WOOK SIN, Research Assistant Professor
GEORGE S. ANSELL, President Emeritus and Professor Emeritus
GLEN R. EDWARDS, University Professor Emeritus
JOHN P. HAGER, University Professor Emeritus
GEORGE KRAUSS, University Professor Emeritus
DENNIS W. READEY, University Professor Emeritus
W. REX BULL, Professor Emeritus
JOHN J. MOORE, Professor Emeritus
GERALD L. DePOORTER, Associate Professor Emeritus
ROBERT H. FROST, Associate Professor Emeritus

Degrees Offered:

- Master of Engineering (Metallurgical and Materials Engineering)
- Master of Science (Metallurgical and Materials Engineering)
- Doctor of Philosophy (Metallurgical and Materials Engineering)

Program Description:

The program of study for the Master or Doctor of Philosophy degrees in Metallurgical and Materials Engineering is selected by the student in consultation with her or his advisor, and with the approval of the Thesis Committee. The program can be tailored within the framework of the regulations of the Graduate School to match the student's interests while maintaining the main theme of materials engineering and processing. There are three Areas of Specialization within the Department: Physical and Mechanical Metallurgy; Physico-chemical Processing of Materials; and, Ceramic Engineering.

The Department is home to five research centers: the Advanced Coatings and Surface Engineering Laboratory (ACSEL); the Advanced Steel Processing and Products Research Center (ASPPRC); the Colorado Center for Advanced Ceramics (CCAC); the Center for Welding Joining, and Coatings Research (CWJCR); and, the Kroll Institute for Extractive Metallurgy (KIEM). The Nuclear Science and Engineering Center (NuSEC) also operates closely with the Department.

A Graduate Certificate is offered by each Department Center – the requirements for the Graduate Certificate are: 1) Be admitted to MME Graduate Certificate Program upon the recommendation of the MME Department. 2) Complete a total of 12 hours of course credits of which only 3 credit hours can be at the 400 level. The specific courses to be taken are determined by the Graduate Advisor in the Department Center selected by the candidate. A cumulative grade point average of B or better must be maintained while completing these requirements.

Degree Program Requirements:

The program requirements for the three graduate degrees offered by the Department are listed below:

Master of Engineering degree: Two tracks are available as follows:

- I. Undergraduate/graduate program*: i) a minimum of 30 total semester hours of acceptable course work; ii) case independent study course work component cannot exceed 6 semester hours; and iii) submittal and presentation, and subsequent acceptance by the Graduate Advisor, of a report which presents the results of a case study or an engineering development. (*See Combined Undergraduate/Graduate Programs in the Graduate Degrees and Requirements Section of the Bulletin.)
- II. Graduate Program: i) a minimum of 30 total semester hours of acceptable course work; ii) case-/independent study course work cannot exceed 6 semester hours; and iii) submittal and presentation, and subsequent acceptance by the Graduate Advisor, of a report which presents the results of a case study or an engineering development.

Master of Science degree: i) a minimum of 24 semester hours of acceptable course work and 6 semester hours of research credit; and, ii) submittal and successful oral-defense of a thesis, before their Thesis Committee, which presents the results of original scientific research or development.

Doctor of Philosophy degree: i) a minimum of 42 semester hours of acceptable course work, which may include course credits (to be approved by the Thesis Committee) presented for the Master's degree, provided that the degree was in Metallurgical and Materials Engineering or a similar field. However, at least 21 hours of acceptable course work must be taken at the Colorado School of Mines; ii) 30 semester hours of research credit; iii) 9 to 12 semester hours of course work to compliment the research program of the student as determined by the Advisor/Thesis-Committee; iv) presentation of a Proposal on their Thesis-Research Project to their Thesis Committee; v) a passing grade on written and oral Qualifying-Process (Q.P.) Examinations, for the purpose of determining that adequate preparation and the ability to conduct high-quality, independent research have been achieved; vi) presentation (usually 6 months after successfully completing their Q.P. Examinations) of a Progress Report on their Research Project to their Thesis Committee and, vii) submittal and successful defense of a thesis, which presents the results of original scientific research or development (See Graduate Degrees and Requirements Section of the Bulletin), before their Thesis Committee.

Notes: The examinations under v) are specific to the student's declared Area of Specialization (currently a total of three), and consist of a written and oral component. The written examinations consist of a general topics examination and an area or specialization examination. The oral examination consists of responses by the student to questions on the fundamentals related to the student's proposed research. A Q.P. Oral-Examination Document consisting of: a) an Extended Abstract of the student's Thesis-Research Proposal, and b) associated Fundamental Topics on which the student expects to be examined, is presented to the Examining Committee (different from the Thesis Committee) prior to this event. The student delivers a 10 minutes oral-presentation, reviewing the document at the start of the (oral) examination. There is a standing schedule to offer the examinations during the last four to five weeks of the Spring and Fall semesters. However, intent to take the examinations must be declared within the first month of the intended semester.

Although there is no formal seminar-course requirement, graduate students, both Master and Doctoral candidates, as part of their professional development, are required to attend the Department seminars scheduled on Thursdays during the Fall and Spring semesters.

Prerequisites:

The entering graduate-student in the Department of Metallurgical and Materials Engineering must have completed an

undergraduate program equivalent to that required for the B.S. degree in: Metallurgical and Materials Engineering, Materials Science or a related field. This undergraduate program should have included a background in science fundamentals and engineering principles. A student, who possesses this background but has not taken specific undergraduate courses in Metallurgical and Materials Engineering, will be allowed to rectify these course deficiencies at the beginning of their program of study.

Fields of Research:

- Synthesis, processing, and characterization of photovoltaic materials
- Optical phenomena of interfaces and composites
- High- T_c superconductors
- Dielectrics and piezoelectrics
- Glasses and crystallizable glasses for electronics
- Ferroelectrics and ferroelectric thin films
- Porous ceramics and ceramic fibers
- Combustion synthesis of advanced materials
- Nuclear engineering
- Welding and joining of metals and dissimilar materials including ceramics and composites
- Laser processing of materials
- Physical metallurgy
- Mechanical metallurgy
- Processing microstructure, and properties of advanced steels
- Oxidation and corrosion of metals and ceramics
- Interfacial phenomena
- Surface characterization of materials
- Biomaterials
- Composite materials
- Preparation of ceramic powders
- Pyro-, hydro-, and electro-metallurgy
- Processing of industrial wastes
- Plasma synthesis and processing
- Computer simulation techniques for design of new high performance materials
- Thin film/coating, processing, and characterization
- Environmentally benign materials processes
- Semiconductor materials
- Powder metallurgy
- Aerospace structural materials
- Failure analysis and fracture mechanics of materials
- Forming of metals and other materials
- Fatigue of materials

Description of Courses

Undergraduate Courses

A maximum of nine hours of 400-level credits, with the approval of the Thesis Committee, may be applied towards the course-work requirement for a Master's degree.

MTGN412/MLGN512.CERAMIC ENGINEERING (I) Application of engineering principles to nonmetallic and ceramic materials. Processing of raw materials and produc-

tion of ceramic bodies, glazes, glasses, enamels, and cermets. Firing processes and reactions in glass bonded as well as mechanically bonded systems. Prerequisite: MTGN348. 3 hours lecture; 3 semester hours.

MTGN414/MLGN544. PROCESSING OF CERAMICS (II) Principles of ceramic processing and the relationship between processing and microstructure. Raw materials and raw materials preparation, forming and fabrication, thermal processing, and finishing of ceramic materials will be covered. Principles will be illustrated by case studies on specific ceramic materials. A project to design a ceramic fabrication process is required. Field trips to local ceramic manufacturing operations are included. Prerequisites: MTGN272, MTGN311 or consent of the Instructor. 3 hours lecture; 3 semester hours.

MTGN415/MLGN515. ELECTRICAL PROPERTIES AND APPLICATIONS OF MATERIALS (II) Survey of the electrical properties of materials, and the applications of materials as electrical circuit components. The effects of chemistry, processing, and microstructure on the electrical properties. Functions, performance requirements, and testing methods of materials for each type of circuit component. The general topics covered are conductors, resistors, insulators, capacitors, energy convertors, magnetic materials, and integrated circuits. Prerequisite: PHGN200, MTGN311 or MLGN501 or consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN416/MLGN516. PROPERTIES OF CERAMICS (II) Survey of the properties of ceramic materials and how these properties are determined by the chemical structure (composition), crystal structure, and the microstructure of crystalline ceramics and glasses. Thermal, optical, and mechanical properties of single-phase and multiphase ceramics, including composites, are covered. Prerequisites: PHGN200, MTGN311 or MLGN501 or consent of Instructor. 3 hours lecture, 3 semester hours.

MTGN417. REFRACTORY MATERIALS (I) Refractory materials in metallurgical construction. Oxide phase diagrams for analyzing the behavior of metallurgical slags in contact with materials of construction. Prerequisite: consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN419/MLGN519. NON-CRYSTALLINE MATERIALS (II) Introduction to the principles of glass science-and-engineering and non-crystalline materials in general. Glass formation, structure, crystallization, and properties will be covered, along with a survey of commercial glass compositions, manufacturing processes, and applications. Prerequisites: MTGN311 or MLGN501, MTGN412/MLGN512, or consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN422. PROCESS ANALYSIS AND DEVELOPMENT (II) Aspects of process development, plant design, and management. Prerequisite: MTGN334. Co-requisite: MTGN424 or consent of Instructor. 2 hours lecture; 2 semester hours.

MTGN424. PROCESS ANALYSIS AND DEVELOPMENT LABORATORY (II) Projects designed to supplement the lectures in MTGN422. Co-requisite: MTGN422 or consent of Instructor. 3 hours lab; 1 semester hour.

MTGN429. METALLURGICAL ENVIRONMENT (I) Examination of the interface between metallurgical process engineering and environmental engineering. Wastes, effluents and their point sources in metallurgical processes such as mineral concentration, value extraction and process metallurgy are studied in context. Fundamentals of metallurgical unit operations and unit processes with those applicable to waste and effluent control, disposal and materials recycling are covered. Engineering design and engineering cost components are also included for selected examples. Fundamentals and applications receive equal coverage. Prerequisites: MTGN334 or consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN430. PHYSICAL CHEMISTRY OF IRON AND STEELMAKING (I) Physical chemistry principles of blast furnace and direct reduction production of iron and refining of iron to steel. Discussion of raw materials, productivity, impurity removal, deoxidation, alloy additions, and ladle metallurgy. Prerequisite: MTGN334. 3 hours lecture; 3 semester hours.

MTGN431. HYDRO- AND ELECTROMETALLURGY (I) Physicochemical principles associated with the extraction and refining of metals by hydro- and electrometallurgical techniques. Discussion of unit processes in hydrometallurgy, electrowinning, and electrorefining. Analysis of integrated flowsheets for the recovery of nonferrous metals. Prerequisite: MTGN334, MTGN351, and MTGN352. Co-requisite: MTGN461 or consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN432. PYROMETALLURGY (II) Extraction and refining of metals including emergent practices. Modifications driven by environmental regulations and by energy minimization. Analysis and design of processes and the impact of economic considerations. Prerequisite: MTGN334. 3 hours lecture; 3 semester hours.

MTGN434. DESIGN AND ECONOMICS OF METALLURGICAL PLANTS (II) Design of metallurgical processing systems. Methods for estimating process costs and profitability. Performance, selection, and design of process equipment. Integration of process units into a working plant and its economics, construction, and operation. Market research and surveys. Prerequisites: DCGN209, MTGN351 or consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN436. CONTROL AND INSTRUMENTATION OF METALLURGICAL PROCESSES (II) Analysis of processes for metal extraction and refining using classical and direct-search optimization methods and classical process control with the aid of chemical functions and thermody-

namic transfer operations. Examples from physicochemical and physical metallurgy processes. Co-requisite: MTGN438 or consent of Instructor. 2 hours lecture; 2 semester hours.

MTGN438. CONTROL AND INSTRUMENTATION OF METALLURGICAL PROCESSES LABORATORY (II) Experiments designed to supplement the lectures in MTGN436. Co-requisite: MTGN436 or consent of Instructor. 3 hours lab; 1 semester hour.

MTGN442. ENGINEERING ALLOYS (II) This course is intended to be an important component of the physical metallurgy sequence, to reinforce and integrate principles from earlier courses, and enhance the breadth and depth of understanding of concepts in a wide variety of alloy systems. Metallic systems considered include iron and steels, copper, aluminum, titanium, superalloys, etc. Phase stability, microstructural evolution and structure/property relationships are emphasized. Prerequisite: MTGN348 or consent of instructor. 3 hours lecture; 3 semester hours.

MTGN445/MLGN505*. MECHANICAL PROPERTIES OF MATERIALS (I) Mechanical properties and relationships. Plastic deformation of crystalline materials. Relationships of microstructures to mechanical strength. Fracture, creep, and fatigue. Laboratory sessions devoted to advanced mechanical testing techniques to illustrate the application of the fundamentals presented in the lectures. Prerequisite: MTGN348. 3 hours lecture, 3 hours lab; 4/3* semester hours. *A 3 semester-hour graduate-course in the Materials Science Program (ML) and a 4 semester-hour undergraduate-course in the MTGN program.

MTGN450/MLGN550. STATISTICAL PROCESS CONTROL AND DESIGN OF EXPERIMENTS (I) Introduction to statistical process control, process capability analysis and experimental design techniques. Statistical process control theory and techniques developed and applied to control charts for variables and attributes involved in process control and evaluation. Process capability concepts developed and applied to the evaluation of manufacturing processes. Theory of designed experiments developed and applied to full factorial experiments, fractional factorial experiments, screening experiments, multilevel experiments and mixture experiments. Analysis of designed experiments by graphical and statistical techniques. Introduction to computer software for statistical process control and for the design and analysis of experiments. Prerequisite: Consent of Instructor. 3 hours lecture, 3 semester hours

MTGN451. CORROSION ENGINEERING (II) Principles of electrochemistry. Corrosion mechanisms. Methods of corrosion protection including cathodic and anodic protection and coatings. Examples, from various industries, of corrosion problems and solutions. Prerequisite: MTGN351. 3 hours lecture; 3 semester hours

MTGN452. CERAMIC AND METAL MATRIX COMPOSITES (I) Introduction to the synthesis, processing, structure, properties and performance of ceramic and metal matrix composites. Survey of various types of composites, and correlation between processing, structural architecture and properties. Prerequisites: MTGN272, MTGN311, MTGN348, MTGN351. 3 hours lecture; 3 semester hours

MTGN453. PRINCIPLES OF INTEGRATED CIRCUIT PROCESSING (I) Introduction to the electrical conductivity of semiconductor materials; qualitative discussion of active semiconductor devices; discussion of the steps in integrated circuit fabrication; detailed investigation of the materials science and engineering principles involved in the various steps of VLSI device fabrication; a presentation of device packaging techniques and the processes and principles involved. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN456. ELECTRON MICROSCOPY (II) Introduction to electron optics and the design and application of transmission and scanning electron microscopes. Interpretation of images produced by various contrast mechanisms. Electron diffraction analysis and the indexing of electron diffraction patterns. Prerequisite: MTGN311 or consent of instructor. Co-requisite: MTGN458. 2 hours lecture; 2 semester hours.

MTGN458. ELECTRON MICROSCOPY LABORATORY (II) Laboratory exercises to illustrate specimen preparation techniques, microscope operation, and the interpretation of images produced from a variety of specimens, and to supplement the lectures in MTGN456. Co-requisite: MTGN456. 3 hours lab; 1 semester hour.

MTGN461. TRANSPORT PHENOMENA AND REACTOR DESIGN FOR METALLURGICAL-AND-MATERIALS ENGINEERS (I) Introduction to the conserved-quantities: momentum, heat, and mass transfer, and application of chemical kinetics to elementary reactor-design. Examples from materials processing and process metallurgy. Molecular transport properties: viscosity, thermal conductivity, and mass diffusivity of materials encountered during processing operations. Uni-directional transport: problem formulation based on the required balance of the conserved-quantity applied to a control-volume. Prediction of velocity, temperature and concentration profiles. Equations of change: continuity, motion, and energy. Transport with two independent variables (unsteady-state behavior). Interphase transport: dimensionless correlations - friction factor, heat, and mass transfer coefficients. Elementary concepts of radiation heat-transfer. Flow behavior in packed beds. Design equations for: Continuous-Flow/Batch Reactors with Uniform Dispersion and Plug Flow Reactors. Digital computer methods for the design of metallurgical systems. Laboratory sessions devoted to: Tutorials/Demonstrations to facilitate the understanding of concepts related to selected topics; and, Projects with the primary focus on the operating principles and use of modern electronic instrumentation for measurements on lab-scale

systems in conjunction with correlation and prediction strategies for analysis of results. Prerequisites: MATH225, MTGN351 and MTGN352. 2 hours lecture, 3 hours lab; 3 semester hours.

MTGN462/ESGN462. SOLID WASTE MINIMIZATION AND RECYCLING (I) This course will examine, using case studies, how industry applies engineering principles to minimize waste formation and to meet solid waste recycling challenges. Both proven and emerging solutions to solid waste environmental problems, especially those associated with metals, will be discussed. Prerequisites: EGGN/ESGN353, EGGN/ESGN354, and ESGN302/CHGN403 or consent of instructor. 3 hours lecture; 3 semester hours.

MTGN463. POLYMER ENGINEERING (I) Introduction to the structure and properties of polymeric materials, their deformation and failure mechanisms, and the design and fabrication of polymeric end items. Molecular and crystallographic structures of polymers will be developed and related to the elastic, viscoelastic, yield and fracture properties of polymeric solids and reinforced polymer composites. Emphasis on forming and joining techniques for end item fabrication including: extrusion, injection molding, reaction injection molding, thermoforming, and blow molding. The design of end items will be considered in relation to: materials selection, manufacturing engineering, properties, and applications. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN464/MTGN564. FORGING AND FORMING (II) Introduction to plasticity. Survey and analysis of working operations of forging, extrusion, rolling, wire drawing and sheet metal forming. Metallurgical structure evolution during working. Prerequisites: EGGN320 and MTGN348 or EGGN390. 2 hours lecture; 3 hours lab, 3 semester hours.

MTGN465. MECHANICAL PROPERTIES OF CERAMICS (II) Mechanical properties of ceramics and ceramic-based composites; brittle fracture of solids; toughening mechanisms in composites; fatigue, high temperature mechanical behavior, including fracture, creep deformation. Prerequisites: MTGN445, MTGN412 or consent of instructor. 3 hours lecture; 3 semester hours.

MTGN466. MATERIALS DESIGN: SYNTHESIS, CHARACTERIZATION AND SELECTION (II) Selection of alloys for specific applications, designing for corrosion resistant service, concept of passivity, designing for wear resistant service, designing for high temperature service and designing for high strength/weight applications. Introduction to the aluminum, copper, nickel, cobalt, stainless steel, cast irons, titanium and refractory metal alloy-systems. Coating science and selection. Prerequisite: MTGN348. 1 hour lecture, 6 hours lab; 3 semester hours.

MTGN475. METALLURGY OF WELDING (I) Introduction to welding processes; thermal aspects; metallurgical evaluation of resulting microstructures; attendant phase

transformations; selection of filler metals; stresses; stress relief and annealing; preheating and post heating; distortion and defects; welding ferrous and nonferrous alloys; and, welding tests. Prerequisite: MTGN348. Co-requisite: MTGN477. 2 hours lecture; 2 semester hours.

MTGN477. METALLURGY OF WELDING LABORATORY (I) Experiments designed to supplement the lectures in MTGN475. Co-requisite: MTGN475. 3 hours lab; 1 semester hour.

MTGN498. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING (I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). The course topic is generally offered only once. Prerequisite: Consent of Instructor. 1 to 3 semester hours. Repeatable for credit under different titles.

MTGN499. INDEPENDENT STUDY (I, II, S) Independent advanced-work leading to a comprehensive report. This work may take the form of conferences, library, and laboratory work. Choice of problem is arranged between student and a specific Department faculty member. Prerequisite: Selection of topic with consent of faculty supervisor; "Independent Study Form" must be completed and submitted to Registrar. 1 to 3 semester hours. Repeatable for credit to a maximum of 6 hours.

Graduate Courses

Most courses are offered once every two years. However, those courses offered for which fewer than five students have registered may be cancelled that semester. Courses at the 500-level are open to qualified seniors with approval of the Department and the Dean of the Graduate School. Courses at the 600-level are open only to graduate students in good standing. A two-year course-schedule is available in the Department office.

MTGN505 CRYSTALLOGRAPHY AND DIFFRACTION (I) Introduction to point symmetry operations, crystal systems, Bravais lattices, point groups, space groups, Laue classes, stereographic projections, reciprocal lattice and Ewald sphere constructions, the new International Tables for Crystallography, and, finally, how certain properties correlate with symmetry. Subsequent to the crystallography portion, the course will move into the area of diffraction and will consider the primary diffraction techniques (x-rays, electrons and neutrons) used to determine the crystal structure of materials. Other applications of diffraction such as texture and residual stress will also be considered. Prerequisites: Graduate or Senior in good standing or consent of instructor. 3 hours lecture, 3 semester hours.

MTGN511. SPECIAL METALLURGICAL AND MATERIALS ENGINEERING PROBLEMS (I) Independent advanced work, not leading to a thesis. This may take the form of conferences, library, and laboratory work. Selection of assignment is arranged between student and a specific Department faculty-member. Prerequisite: Selection of topic

with consent of faculty supervisor. 1 to 3 semester hours. Repeatable for credit under different titles.

MTGN512. SPECIAL METALLURGICAL AND MATERIALS ENGINEERING PROBLEMS (II) Continuation of MTGN511. Prerequisite: Selection of topic with consent of faculty supervisor. 1 to 3 semester hours. Repeatable for credit under different titles.

MTGN514. DEFECT CHEMISTRY AND TRANSPORT PROCESSES IN CERAMIC SYSTEMS (I) Ceramic materials science in the area of structural imperfections, their chemistry, and their relation to mass and charge transport; defects and diffusion, sintering, and grain growth with particular emphasis on the relation of fundamental transport phenomena to sintering and microstructure development and control. Prerequisites: DCGN209 or MTGN351; MT311 or Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN516. MICROSTRUCTURE OF CERAMIC SYSTEMS (II) Analysis of the chemical and physical processes controlling microstructure development in ceramic systems. Development of the glassy phase in ceramic systems and the resulting properties. Relationship of microstructure to chemical, electrical, and mechanical properties of ceramics. Application to strengthening and toughening in ceramic composite system. Prerequisite: Graduate status or Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of even years only.)

MTGN517. REFRACTORIES (I) The manufacture, testing, and use of basic, neutral, acid, and specialty refractories are presented. Special emphasis is placed on the relationship between physical properties of the various refractories and their uses in the metallurgical industry. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN518/MLGN518. PHASE EQUILIBRIA IN CERAMIC SYSTEMS (II) Application of one to four component oxide diagrams to ceramic engineering problems. Emphasis on refractories and glasses and their interaction with metallic systems. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN523/MLGN523. APPLIED SURFACE AND SOLUTION CHEMISTRY (II) Solution and surface chemistry of importance in mineral and metallurgical operations. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN526/MLGN526. GEL SCIENCE AND TECHNOLOGY An introduction to the science and technology of particulate and polymeric gels, emphasizing inorganic systems. Interparticle forces. Aggregation, network formation, percolation, and the gel transition. Gel structure, rheology, and mechanical properties. Application to solid-liquid separation operations (filtration, centrifugation, sedimentation) and to ceramics processing. Prerequisite: Graduate Status or Consent of

Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN527/ESGN562. SOLID WASTE MINIMIZATION AND RECYCLING (II) Industrial case-studies, on the application of engineering principles to minimize waste formation and to meet solid waste recycling challenges. Proven and emerging solutions to solid waste environmental problems, especially those associated with metals. Prerequisites: ESGN500 and ESGN504 or Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN528. EXTRACTIVE METALLURGY OF COPPER, GOLD AND SILVER. Practical applications of fundamentals of chemical-processing-of-materials to the extraction of gold, silver and copper. Topics covered include: History; Ore deposits and mineralogy; Process Selection; Hydrometallurgy and leaching; Oxidation pretreatment; Purification and recovery; Refinement; Waste treatment; and Industrial examples. Prerequisites: Graduate or Senior in good-standing or consent of instructor. 3 hours lecture, 3 semester hours.

MTGN529. METALLURGICAL ENVIRONMENT (I) Effluents, wastes, and their point sources associated with metallurgical processes, such as mineral concentration and values extraction—providing for an interface between metallurgical process engineering and the environmental engineering areas. Fundamentals of metallurgical unit operations and unit processes, applied to waste and effluents control, recycling, and waste disposal. Examples which incorporate engineering design and cost components are included. Prerequisites: MTGN334 or Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN530. ADVANCED IRON AND STEELMAKING (I) Physicochemical principles of gas-slag-metal reactions applied to the reduction of iron ore concentrates and to the refining of liquid iron to steel. The role of these reactions in reactor design—blast furnace and direct iron smelting furnace, pneumatic steelmaking furnace, refining slags, deoxidation and degassing, ladle metallurgy, alloying, and continuous casting of steel. Prerequisite: DCGN209 or MTGN351 or Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of even years only.)

MTGN531. THERMODYNAMICS OF METALLURGICAL AND MATERIALS PROCESSING (I) Application of thermodynamics to the processing of metals and materials, with emphasis on the use of thermodynamics in the development and optimization of processing systems. Focus areas will include entropy and enthalpy, reaction equilibrium, solution thermodynamics, methods for analysis and correlation of thermodynamics data, thermodynamic analysis of phase diagrams, thermodynamics of surfaces, thermodynamics of defect structures, and irreversible thermodynamics. Attention will be given to experimental methods for the measurement of thermodynamic quantities. Prerequisite: MTGN351 or Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN 532 PARTICULATE MATERIAL PROCESSING I - COMMINATION AND PHYSICAL SEPARATIONS. An introduction to the fundamental principles and design criteria for the selection and use of standard mineral processing unit operations in comminution and physical separation. Topics covered include: crushing (jaw, cone, gyratory), grinding (ball, pebble, rod, SAG, HPGR), screening, thickening, sedimentation, filtration and hydrocyclones. Two standard mineral processing plant-design simulation software (MinOCad and JK SimMet) are used in the course. Prerequisites: Graduate or Senior in good-standing or consent of instructor. 3 hours lecture, 3 semester hours.

MTGN 533 PARTICULATE MATERIAL PROCESSING II - APPLIED SEPARATIONS. An introduction to the fundamental principles and design criteria for the selection and use of standard mineral processing unit operations in applied separations. Topics covered include: photometric ore sorting, magnetic separation, dense media separation, gravity separation, electrostatic separation and flotation (surface chemistry, reagents selection, laboratory testing procedures, design and simulation). Two standard mineral processing plant-design simulation software (MinOCad and JK SimMet) are used in the course. Graduate or Senior in good-standing or consent of instructor. 3 hours lecture, 3 semester hours.

MTGN534. CASE STUDIES IN PROCESS DEVELOPMENT A study of the steps required for development of a mineral recovery process. Technical, economic, and human factors involved in bringing a process concept into commercial production. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

MTGN535. PYROMETALLURGICAL PROCESSES (II) Detailed study of a selected few processes, illustrating the application of the principles of physical chemistry (both thermodynamics and kinetics) and chemical engineering (heat and mass transfer, fluid flow, plant design, fuel technology, etc.) to process development. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN536. OPTIMIZATION AND CONTROL OF METALLURGICAL SYSTEMS Application of modern optimization and control theory to the analysis of specific systems in extractive metallurgy and mineral processing. Mathematical modeling, linear control analysis, dynamic response, and indirect optimum seeking techniques applied to the process analysis of grinding, screening, filtration, leaching, precipitation of metals from solution, and blast furnace reduction of metals. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN537. ELECTROMETALLURGY (II) Electrochemical nature of metallurgical processes. Kinetics of electrode reactions. Electrochemical oxidation and reduction. Complex electrode reactions. Mixed potential systems. Cell design and optimization of electrometallurgical processes. Batteries and fuel cells. Some aspects of corrosion. Prerequisite: Consent

of Instructor. 3 hours lecture; 3 semester hours. (Spring of even years only.)

MTGN538. HYDROMETALLURGY (II) Kinetics of liquid-solid reactions. Theory of uniformly accessible surfaces. Hydrometallurgy of sulfide and oxides. Cementation and hydrogen reduction. Ion exchange and solvent extraction. Physicochemical phenomena at high pressures. Microbiological metallurgy. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN539. PRINCIPLES OF MATERIALS PROCESSING REACTOR DESIGN (II) Review of reactor types and idealized design equations for isothermal conditions. Residence time functions for nonreacting and reacting species and its relevance to process control. Selection of reactor type for a given application. Reversible and irreversible reactions in CSTR's under nonisothermal conditions. Heat and mass transfer considerations and kinetics of gas-solid reactions applied to fluo-solids type reactors. Reactions in packed beds. Scale up and design of experiments. Brief introduction into drying, crystallization, and bacterial processes. Examples will be taken from current metallurgical practice. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN541. INTRODUCTORY PHYSICS OF METALS (I) Electron theory of metals. Classical and quantum-mechanical free electron theory. Electrical and thermal conductivity, thermoelectric effects, theory of magnetism, specific heat, diffusion, and reaction rates. Prerequisite: MTGN445. 3 hours lecture; 3 semester hours.

MTGN542. ALLOYING THEORY, STRUCTURE, AND PHASE STABILITY (II) Empirical rules and theories relating to alloy formation. Various alloy phases and constituents which result when metals are alloyed and examined in detail. Current information on solid solutions, intermetallic compounds, eutectics, liquid immiscibility. Prerequisite: MTGN445 or Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN543. THEORY OF DISLOCATIONS (I) Stress field around dislocation, forces on dislocations, dislocation reactions, dislocation multiplication, image forces, interaction with point defects, interpretation of macroscopic behavior in light of dislocation mechanisms. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN544. FORGING AND DEFORMATION MODELING (I) Examination of the forging process for the fabrication of metal components. Techniques used to model deformation processes including slab equilibrium, slip line, upper bound and finite element methods. Application of these techniques to specific aspects of forging and metal forming processes. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN545/EGGN532. FATIGUE AND FRACTURE (I) Basic fracture mechanics as applied to engineering materials, S-N curves, the Goodman diagram, stress concentrations, residual stress effects, effect of material properties on mechanisms of crack propagation. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN546. CREEP AND HIGH TEMPERATURE MATERIALS (II) Mathematical description of creep process. Mathematical methods of extrapolation of creep data. Micromechanisms of creep deformation, including dislocation glide and grain boundary sliding. Study of various high temperature materials, including iron, nickel, and cobalt base alloys and refractory metals, and ceramics. Emphasis on phase transformations and microstructure-property relationships. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN547. PHASE EQUILIBRIA IN MATERIALS SYSTEMS (I) Phase equilibria of unary, binary, ternary, and multicomponent systems, microstructure interpretation, pressure-temperature diagrams, determination of phase diagrams. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN548. TRANSFORMATIONS IN METALS (I) Surface and interfacial phenomena, order of transformation, grain growth, recovery, recrystallization, solidification, phase transformation in solids, precipitation hardening, spinoidal decomposition, martensitic transformation, gas metal reactions. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN549. CURRENT DEVELOPMENTS IN FERROUS ALLOYS (I) Development and review of solid state transformations and strengthening mechanisms in ferrous alloys. Application of these principles to the development of new alloys and processes such as high strength low alloy steels, high temperature alloys, maraging steels, and case hardening processes. Prerequisite: MTGN348. 3 hours lecture; 3 semester hours.

MTGN551. ADVANCED CORROSION ENGINEERING (I) Advanced topics in corrosion engineering. Case studies and industrial application. Special forms of corrosion. Advanced measurement techniques. Prerequisite: MTGN451. 3 hours lecture; 3 semester hours. (Fall of even years only.)

MTGN552/MLGN552. INORGANIC MATRIX COMPOSITES Introduction to the processing, structure, properties and applications of metal matrix and ceramic matrix composites. Importance of structure and properties of both the matrix and the reinforcement and the types of reinforcement utilized—particulate, short fiber, continuous fiber, and laminates. Emphasis on the development of mechanical properties through control of synthesis and processing parameters. Other physical properties such as electrical and thermal will also be ex-

amined. Prerequisite/Co-requisite*: MTGN352, MTGN445/MLGN505*; or, Consent of Instructor. 3 hours lecture; 3 semester hours. (Summer of even years only.)

MTGN553. STRENGTHENING MECHANISMS (II) Strain hardening in polycrystalline materials, dislocation interactions, effect of grain boundaries on strength, solid solution hardening, martensitic transformations, precipitation hardening, point defects. Prerequisite: MTGN543 or concurrent enrollment. 3 hours lecture; 3 semester hours. (Spring of even years only.)

MTGN554. OXIDATION OF METALS (II) Kinetics of oxidation. The nature of the oxide film. Transport in oxides. Mechanisms of oxidation. The Oxidation protection of high-temperature metal systems. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of even years only.)

MTGN555/MLGN504. SOLID STATE THERMODYNAMICS (I) Thermodynamics applied to solid state reactions, binary and ternary phase diagrams, point, line and planar defects, interfaces, and electrochemical concepts. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN556/MLGN506. TRANSPORT IN SOLIDS (I) Thermal and electrical conductivity. Solid state diffusion in metals and metal systems. Kinetics of metallurgical reactions in the solid state. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of even years only.)

MTGN557. SOLIDIFICATION (I) Heat flow and fluid flow in solidification, thermodynamics of solidification, nucleation and interface kinetics, grain refining, crystal and grain growth, constitutional supercooling, eutectic growth, solidification of castings and ingots, segregation, and porosity. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN560. ANALYSIS OF METALLURGICAL FAILURES (II) Applications of the principles of physical and mechanical metallurgy to the analysis of metallurgical failures. Nondestructive testing. Fractography. Case study analysis. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN561. PHYSICAL METALLURGY OF ALLOYS FOR AEROSPACE (I) Review of current developments in aerospace materials with particular attention paid to titanium alloys, aluminum alloys, and metal-matrix composites. Emphasis is on phase equilibria, phase transformations, and microstructure-property relationships. Concepts of innovative processing and microstructural alloy design are included where appropriate. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of even years only.)

MTGN564. ADVANCED FORGING AND FORMING (II) Overview of plasticity. Examination and Analysis of working operations of forging, extrusion, rolling, wire drawing

and sheet metal forming. Metallurgical structure evolution during working. Laboratory experiments involving metal forming processes. Prerequisites: MTGN445/MLGN505 or Consent of Instructor, 2 hours lecture; 3 hours lab, 3 semester hours.

MTGN565/MLGN565. MECHANICAL PROPERTIES OF CERAMICS AND COMPOSITES (I) Mechanical properties of ceramics and ceramic-based composites; brittle fracture of solids; toughening mechanisms in composites; fatigue, high temperature mechanical behavior, including fracture, creep deformation. Prerequisites: MTGN445 or MLGN505, or Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of even years only.)

MTGN569/MLGN569/EGGN569/ChEN569. FUEL CELL SCIENCE AND TECHNOLOGY (II) Fundamentals of fuel-cell operation and electrochemistry from a chemical thermodynamics and materials-science perspective. Review of types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Current topics in fuel-cell science and technology. Fabrication and testing of operational fuel cells in the Colorado Fuel Cell Center. 3 credit hours. Prerequisites: EGGN371 or ChEN357 or MTGN351; and MATH225 or consent of instructor.

MTGN570/MLGN570. BIOCOMPATIBILITY OF MATERIALS Introduction to the diversity of biomaterials and applications through examination of the physiologic environment in conjunction with compositional and structural requirements of tissues and organs. Appropriate domains and applications of metals, ceramics and polymers, including implants, sensors, drug delivery, laboratory automation, and tissue engineering are presented. Prerequisites: ESGN301 or equivalent, or Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN571. METALLURGICAL AND MATERIALS ENGINEERING LABORATORY Basic instruction in advanced equipment and techniques in the field of extraction, mechanical or physical metallurgy. Prerequisite: Selection and Consent of Instructor. 3 to 9 hours lab ; 1 to 3 semester hours.

MTGN580. ADVANCED WELDING METALLURGY (II) Weldability of high strength steels, high alloys, and light metals; Welding defects; Phase transformations in weldments; Thermal experience in weldments; Pre- and Post-weld heat treatment; Heat affected zone formation, microstructure, and properties; Consumables development.. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN581. WELDING HEAT SOURCES AND INTERACTIVE CONTROLS (I) The science of welding heat sources including gas tungsten arc, gas metal arc, electron beam and laser. The interaction of the heat source with the workpiece will be explored and special emphasis will be given to using this knowledge for automatic control of the

welding process. Prerequisite: Graduate Status or Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN582. MECHANICAL PROPERTIES OF WELDED JOINTS (II) Mechanical metallurgy of heterogeneous systems, shrinkage, distortion, cracking, residual stresses, mechanical testing of joints, size effects, joint design, transition temperature, fracture. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

MTGN583. PRINCIPLES OF NON-DESTRUCTIVE TESTING AND EVALUATION (I) Introduction to testing methods; basic physical principles of acoustics, radiography, and electromagnetism; statistical and risk analysis; fracture mechanics concepts; design decision making, limitations and applications of processes; fitness-for- service evaluations. Prerequisite: Graduate Status or Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN584. NON-FUSION JOINING PROCESSES (II) Joining processes for which the base materials are not melted. Brazing, soldering, diffusion bonding, explosive bonding, and adhesive bonding processes. Theoretical aspects of these processes, as well as the influence of process parameters. Special emphasis to the joining of dissimilar materials using these processes. Prerequisite: Consent of Instructor. 3 hours lecture; 3 semester hours. (Spring of even years only.)

MTGN586. DESIGN OF WELDED STRUCTURES AND ASSEMBLIES Introduction to the concepts and analytical practice of designing weldments. Designing for impact, fatigue, and torsional loading. Designing of weldments using overmatching and undermatching criteria. Analysis of combined stresses. Designing of compression members, column bases and splices. Designing of built-up columns, welded plate cylinders, beam-to-column connections, and trusses. Designing for tubular construction. Weld distortion and residual stresses. Joint design. Process consideration in weld design. Welding codes and specifications. Estimation of welding costs. Prerequisite/Co-requisite: MATH225 or equivalent, EGGN320 or equivalent, MTGN475 or Consent of Instructor. 3 hours lecture; 3 semester hours. (Summer of odd years only.)

MTGN587. PHYSICAL PHENOMENA OF WELDING AND JOINING PROCESSES (I) Introduction to arc physics, fluid flow in the plasma, behavior of high pressure plasma, cathodic and anodic phenomena, energy generation and temperature distribution in the plasma, arc stability, metal transfer across arc, electron beam welding processes, keyhole phenomena. Ohmic welding processes, high frequency welding, weld pool phenomena. Development of relationships between physics concepts and the behavior of specific welding and joining processes. Prerequisite/Co-requisite: PHGN300, MATH225, MTGN475, or Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of even years only.)

MTGN591. PHYSICAL PHENOMENA OF COATING PROCESSES (I) Introduction to plasma physics, behavior of low pressure plasma, cathodic and anodic phenomena, glow discharge phenomena, glow discharge sputtering, magnetron plasma deposition, ion beam deposition, cathodic arc evaporation, electron beam and laser coating processes. Development of relationships between physics concepts and the behavior of specific coating processes. Prerequisite/Co-requisite: PHGN300, MATH225, or Consent of Instructor. 3 hours lecture; 3 semester hours. (Fall of odd years only.)

MTGN593. NUCLEAR MATERIALS SCIENCE AND ENGINEERING (I) Introduction to the physical metallurgy of nuclear materials, including the nuclear, physical, thermal, and mechanical properties for nuclear materials, the physical and mechanical processing of nuclear alloys, the effect of nuclear and thermal environments on structural reactor materials and the selection of nuclear and reactor structural materials are described. Selected topics include ceramic science of ceramic nuclear material, ceramic processing of ceramic fuel, nuclear reaction with structural materials, radiation interactions with materials, the aging of nuclear materials, cladding, corrosion and the manufacturing of fuels elements. Relevant issues in the modern fuel cycle will also be introduced including nuclear safety, reactor decommissioning, and environmental impacts. Prerequisites: Graduate or Senior in good-standing or consent of instructor. 3 hours lecture, 3 semester hours. (Fall of even years only.)

MTGN597. SUMMER PROGRAMS

MTGN598. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING (I, II) Pilot course or special topics course. Topics chosen according to special interests of instructor(s) and student(s). The course topic is generally offered only once. Prerequisite: Consent of Instructor. Variable hours lecture/lab; 1 to 6 semester hours. Repeatable for credit under different titles.

MTGN599. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member. Student and instructor to agree on subject matter, content, and credit hours. Prerequisite: "Independent Study" Form must be completed and submitted to the Registrar. 1 to 3 semester hours. Repeatable for credit to a maximum of 6 hours.

MTGN 605 ADVANCED TRANSMISSION ELECTRON MICROSCOPY Introduction to transmission electron microscopy techniques and their application to materials characterization. Topics include electron optics, electron-specimen interactions, imaging, diffraction, contrast mechanisms, defect analyses, compositional measurements using energy dispersive x-ray spectroscopy and energy loss spectroscopy, scanning transmission electron microscopy, high angle annular dark field imaging, energy filtered TEM and high resolution phase contrast imaging. Prerequisite:

MTGN 505 or consent of instructor. Co-requisite; MTGN 605L. 2 hours lecture, 2 semester hours.

MTGN 605L ADVANCED TRANSMISSION ELECTRON MICROSCOPY LABORATORY Specimen preparation techniques and their application to materials characterization. Topics include electron optics, electron-specimen interactions, imaging, diffraction, contrast mechanisms, defect analyses, compositional measurements using energy dispersive x-ray spectroscopy and energy loss spectroscopy, scanning transmission electron microscopy, high angle annular dark field imaging, energy filtered TEM and high resolution phase contrast imaging. Prerequisite: Concurrent enrollment in MTGN 605 or consent of instructor. 3 hours lab, 1 semester hour.

MTGN631. TRANSPORT PHENOMENA IN METALLURGICAL AND MATERIALS SYSTEMS Physical principles of mass, momentum, and energy transport. Application to the analysis of extraction metallurgy and other physicochemical processes. Prerequisite: MATH225 and MTGN461 or equivalent, or Consent of Instructor. 3 hours lecture; 3 semester hours.

MTGN671 ADVANCED MATERIALS LABORATORY (I) Experimental and analytical research in the fields of production, mechanical, chemical, and/or physical metallurgy. Prerequisite: Consent of Instructor. 1 to 3 semester hours; 3 semester hours.

MTGN672. ADVANCED MATERIALS LABORATORY (II) Continuation of MTGN671. 1 to 3 semester hours.

MTGN696/MLGN696. VAPOR DEPOSITION PROCESSES (II) Introduction to the fundamental physics and chemistry underlying the control of deposition processes for thin films for a variety of applications—wear resistance, corrosion/oxidation resistance, decorative coatings, electronic and magnetic. Emphasis on the vapor deposition process variables rather than the structure and properties of the deposited film. Prerequisites: MTGN351, MTGN461, or equivalent courses or Consent of Instructor. 3 hours lecture; 3 semester hours. (Summer of odd years only.)

MTGN697. MICROSTRUCTURAL EVOLUTION OF COATINGS AND THIN FILMS (I) Introduction to aqueous and non-aqueous chemistry for the preparation of an effective electrolyte; for interpretation of electrochemical principles associated with electrodeposition; surface science to describe surface structure and transport; interfacial structure including space charge and double layer concepts; nucleation concepts applied to electrodeposition; electrocrystallization including growth concepts; factors affecting morphology and kinetics; co-deposition of non-Brownian particles; pulse electrodeposition; electrodeposition parameters and control; physical metallurgy of electrodeposits; and, principles associated with vacuum evaporation and sputter deposition. Factors affecting microstructural evolution of vacuum and sputtered deposits; nucleation of vapor and sputtered deposits;

modeling of matter-energy interactions during co-deposition; and, Thornton's model for coating growth. Prerequisite/co-requisite: MATH225, MTGN351, MTGN352, or Consent of Instructor. 3 hours lecture; 3 semester hours. (Summer of even years only.)

MTGN698. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING (I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). The course topic is generally offered only once. Prerequisite: Consent of instructor. 1 to 3 semester hours per semester. Repeatable for credit under different titles.

MTGN699. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member. Student and instructor to agree on subject matter, content, and credit hours. Prerequisite: "Independent Study" Form must be completed and submitted to the Registrar. 1 to 3 semester hours. Repeatable for credit up to a maximum of 6 hours.

MTGN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science. Research under the direct supervision of the faculty advisor. Repeatable for credit.

MTGN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research under the direct supervision of the faculty advisor. Repeatable for credit.

Mining Engineering

KADRI DAGDELEN, Professor and Department Head
UGUR OZBAY, Professor
MARK KUCHTA, Associate Professor
HUGH B. MILLER, Associate Professor
MASAMI NAKAGAWA, Associate Professor
CHRISTIAN FRENZEL, Associate Professor
MANOHAR ARORA, Teaching Professor
VILEM PETR, Research Associate Professor

Degrees Offered:

Master of Engineering (Engineer of Mines)
Master of Science (Mining and Earth Systems Engineering)
Doctor of Philosophy (Mining and Earth Systems Engineering)

Program Description:

The program has two distinctive, but inherently interwoven specialties.

The **Mining Engineering** area or specialty is predominantly for mining engineers and it is directed towards the traditional mining engineering fields. Graduate work is normally centered around subject areas such as mine planning and development, computer aided mine design, rock mechanics, operations research applied to the mineral industry, environment and sustainability considerations, mine mechanization, mine evaluation, finance and management and similar mining engineering topics.

The **Earth Systems Engineering** area or specialty is designed to be distinctly interdisciplinary by merging the mining engineering fundamentals with civil, geotechnical, environmental or other engineering into advanced study tracks in earth systems, rock mechanics and earth structural systems, underground excavation, and construction systems. This specialty is open for engineers with different sub-disciplinary backgrounds, but interested in working and/or considering performing research in mining, tunneling, excavation and underground construction areas.

Graduate work is normally centered around subject areas such as site characterization, environmental aspects, underground construction and tunneling (including microtunneling), excavation methods and equipment, mechanization of mines and underground construction, environmental and management aspects, modeling and design in geoen지니어ing.

Program Requirements:

The Master of Science degree in Mining and Earth Systems Engineering has two options available. Master of Science - Thesis and Master of Science - Non-Thesis. Thesis Option requires a minimum of 21 semester credit hours of course work and 9 semester credits of research, approved by student's graduate committee, plus a master's thesis. The Master of Science - Non-Thesis option must complete a minimum of 30 credit hours of course work of which 6 credit hours may be applied towards the analytical report writing, if required.

The Master of Engineering degree (Engineer of Mines) in Mining Engineering includes all the requirements for the M.S. degree, with the sole exception that an “engineering report” is required rather than a Master’s Thesis.

The Doctor of Philosophy degree in Mining and Earth Systems Engineering requires a total of 72 credit hours, beyond the bachelor’s degree. A maximum of 48 credit hours of course work, and a minimum of 24 hours of research credit is required. Those with an MSc in an appropriate field may transfer a maximum of 30 credit hours of course work towards the 48 credit hour requirement upon the approval of the advisor and thesis committee. The thesis must be successfully defended before a doctoral committee.

Prerequisites:

Students entering a graduate program for the master’s or doctor’s degree are expected to have had much the same undergraduate training as that required at Colorado School of Mines in mining, if they are interested in the traditional mining specialty. Students interested in the Earth Systems engineering specialty with different engineering sub-disciplinary background may also require special mining engineering subjects depending upon their graduate program. Deficiencies if any, will be determined by the Department of Mining Engineering on the basis of students’ education, experience, and graduate study.

For specific information on prerequisites, students are encouraged to refer to a copy of the Mining Engineering Department’s Departmental Guidelines and Regulations for Graduate Students, available from the Mining Engineering Department.

Required Curriculum:

Graduate students, depending upon their specialty and background may be required to complete two of the three core courses listed below during their program of study at CSM.

These courses are:

- MNGN508. Advanced Rock Mechanics
- MNGN512 - Surface Mine Design
- MNGN516 - Underground Mine Design

In addition, all full-time graduate students are required to register for and attend MNGN625 - Graduate Mining Seminar each semester while in residence, except in the case of extreme circumstances. For these circumstances, consideration will be given on a case-by-case basis by the coordinator or the Department Head. It is expected that part time students participate in MNGN625 as determined by the course coordinator or the Department Head. Although it is mandatory to enroll in MNGN625 each semester, this course will only count as one credit hour for the total program.

Fields of Research:

The Mining Engineering Department focuses on the following fundamental areas:

Geomechanics, Rock Mechanics and Stability of Underground and Surface Excavations

Computerized Mine Design and Related Applications (including Geostatistical Modeling)
Advanced Integrated Mining Systems Incorporating Mine Mechanization and Mechanical Mining Systems
Underground Excavation (Tunneling) and Construction
Site Characterization and Geotechnical Investigations, Modeling and Design in Geoen지니어ing.
Rock Fragmentation
Mineral Processing, Communiton, Separation Technology
Bulk Material Handling

Description of Courses

MNGN404. TUNNELING (I) Modern tunneling techniques. Emphasis on evaluation of ground conditions, estimation of support requirements, methods of tunnel driving and boring, design systems and equipment, and safety. Prerequisite: none. 3 hours lecture; 3 semester hours.

MNGN405. ROCK MECHANICS IN MINING (I) The course deals with the rock mechanics aspect of design of mine layouts developed in both underground and surface. Underground mining sections include design of coal and hard rock pillars, mine layout design for tabular and massive ore bodies, assessment of caving characteristics or ore bodies, performance and application of backfill, and phenomenon of rock burst and its alleviation. Surface mining portion covers rock mass characterization, failure modes of slopes excavated in rock masses, probabilistic and deterministic approaches to design of slopes, and remedial measures for slope stability problems. Prerequisite: MN321 or equivalent. 3 hours lecture; 3 semester hours

MNGN406. DESIGN AND SUPPORT OF UNDERGROUND EXCAVATIONS Design of underground excavations and support. Analysis of stress and rock mass deformations around excavations using analytical and numerical methods. Collections, preparation, and evaluation of in situ and laboratory data for excavation design. Use of rock mass rating systems for site characterization and excavation design. Study of support types and selection of support for underground excavations. Use of numerical models for design of shafts, tunnels and large chambers. Prerequisite: Instructor’s consent. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN407. ROCK FRAGMENTATION (II) Theory and application of rock drilling, rock boring, explosives, blasting, and mechanical rock breakage. Design of blasting rounds, applications to surface and underground excavation. Prerequisite: DCGN241, concurrent enrollment or Instructor’s consent. 3 hours lecture; 3 semester hours.

MNGN408. UNDERGROUND DESIGN AND CONSTRUCTION Soil and rock engineering applied to underground civil works. Tunneling and the construction of underground openings for power facilities, water conveyance, transportation, and waste disposal; design, excavation and support of

underground openings. Emphasis on consulting practice, case studies, geotechnical design, and construction methods. Prerequisite: EGGN361 OR MNGN321, or Instructor's consent. 2 hours of lecture; 2 semester hours.

MNGN410. EXCAVATION PROJECT MANAGEMENT. Successful implementation and management of surface and underground construction projects, preparation of contract documents, project bidding and estimating, contract awarding and notice to proceed, value engineering, risk management, construction management and dispute resolution, evaluation of differing site conditions claims. Prerequisite: MNGN 210 or Instructor's consent, 2-hour lecture, 2 semester hours.

MNGN414. MINE PLANT DESIGN Analysis of mine plant elements with emphasis on design. Materials handling, dewatering, hoisting, belt conveyor and other material handling systems for underground mines. Prerequisite: MNGN312, MNGN314 or Instructor's consent. 3 hours lecture, 3 hours lab; 3 semester hours.

MNGN418. ADVANCED ROCK MECHANICS Analytical and numerical modeling analysis of stresses and displacements induced around engineering excavations in rock. In-situ stress. Rock failure criteria. Complete load deformation behavior of rocks. Measurement and monitoring techniques in rock mechanics. Principles of design of excavation in rocks. Analytical, numerical modeling and empirical design methods. Probabilistic and deterministic approaches to rock engineering designs. Excavation design examples for shafts, tunnels, large chambers and mine pillars. Seismic loading of structures in rock. Phenomenon of rock burst and its alleviation. Prerequisite: MNGN321 or Instructor's consent. 3 hours lecture; 3 semester hours.

MNGN421. DESIGN OF UNDERGROUND EXCAVATIONS (II) Design of underground openings in competent and broken ground using rock mechanics principles. Rock bolting design and other ground support methods. Coal, evaporite, metallic and nonmetallic deposits included. Prerequisite: MNGN321, concurrent enrollment or Instructor's consent. 3 hours lecture; 3 semester hours.

MNGN422/522. FLOTATION Science and engineering governing the practice of mineral concentration by flotation. Interfacial phenomena, flotation reagents, mineral-reagent interactions, and zeta-potential are covered. Flotation circuit design and evaluation as well as tailings handling are also covered. The course also includes laboratory demonstrations of some fundamental concepts. 3 hours lecture; 3 semester hours.

MNGN423. FLOTATION LABORATORY (I) Experiments to accompany the lectures in MNGN422. Corequisite: MNGN421 or Instructor's consent. 3 hours lab; 1 semester hour

MNGN424. MINE VENTILATION (II) Fundamentals of mine ventilation, including control of gas, dust, temperature, and humidity; ventilation network analysis and design of systems. Prerequisite: EGGN351, 371 and MNGN314 or Instructor's consent. 2 hours lecture, 3 hours lab; 3 semester hours.

MNGN427. MINE VALUATION (II) Course emphasis is on the business aspects of mining. Topics include time valuation of money and interest formulas, cash flow, investment criteria, tax considerations, risk and sensitivity analysis, escalation and inflation and cost of capital. Calculation procedures are illustrated by case studies. Computer programs are used. Prerequisite: Senior in Mining, graduate status or Instructor's consent. 2 hours lecture; 2 semester hours.

MNGN431. MINING AND METALLURGICAL ENVIRONMENT This course covers studies of the interface between mining and metallurgical process engineering and environmental engineering areas. Wastes, effluents and their point sources in mining and metallurgical processes such as mineral concentration, value extraction and process metallurgy are studied in context. Fundamentals of unit operations and unit processes with those applicable to waste and effluent control, disposal and materials recycling are covered. Engineering design and engineering cost components are also included for some examples chosen. The ratio of fundamentals to applications coverage is about 1:1. Prerequisite: Instructor's consent. 3 hours lecture; 3 semester hours.

MNGN433. MINE SYSTEMS ANALYSIS I (II) Application of statistics, systems analysis, and operations research techniques to mineral industry problems. Laboratory work using computer techniques to improve efficiency of mining operations. Prerequisite: senior or graduate status. 2 hours lecture, 3 hours lab; 3 semester hours.

MNGN434. PROCESS ANALYSIS Projects to accompany the lectures in MNGN422. Prerequisite: MNGN422 or Instructor's consent. 3 hours lab; 1 semester hour.

MNGN436. UNDERGROUND COAL MINE DESIGN (II) Design of an underground coal mine based on an actual coal reserve. This course shall utilize all previous course material in the actual design of an underground coal mine. Ventilation, materials handling, electrical transmission and distribution, fluid mechanics, equipment selection and application, mine plant design. Information from all basic mining survey courses will be used. Prerequisite: MNGN316, 321, 414, EGGN329 and DCGN381 or EGGN384. Concurrent enrollment with the Instructor's consent permitted. 3 hours lecture, 3 hours lab; 3 semester hours.

MNGN438. GEOSTATISTICS (I) Introduction to elementary probability theory and its applications in engineering and sciences; discrete and continuous probability distributions; parameter estimation; hypothesis testing; linear regression; spatial correlations and geostatistics with emphasis on applications in earth sciences and engineering. Prerequisites: MATH112. 2 hours of lecture and 3 hours of lab. 3 semester hours.

MNGN440. EQUIPMENT REPLACEMENT ANALYSIS (I) Introduction to the fundamentals of classical equipment replacement theory. Emphasis on new, practical approaches to equipment replacement decision making. Topics include: operating and maintenance costs, obsolescence factors, tech-

nological changes, salvage, capital investments, minimal average annual costs, optimum economic life, infinite and finite planning horizons, replacement cycles, replacement vs. expansion, maximization of returns from equipment replacement expenditures. Prerequisite: MNGN427, senior or graduate status. 2 hours lecture; 2 semester hours.

MNGN444. EXPLOSIVES ENGINEERING II This course gives students in engineering and applied sciences the opportunity to acquire the fundamental concepts of explosives engineering and science applications as they apply to industry and real life examples. Students will expand upon their MNGN 333 knowledge and develop a more advanced knowledge base including an understanding of the subject as it applies to their specific project interests. Assignments, quizzes, concept modeling and their project development and presentation will demonstrate student's progress. Prerequisite: none. 3 hours lecture, 3 semester hours.

MNGN445/545. ROCK SLOPE ENGINEERING Introduction to the analysis and design of slopes excavated in rock. Rock mass classification and strength determination, geological structural parameters, properties of fracture sets, data collection techniques, hydrological factors, methods of analysis of slope stability, wedge intersections, monitoring and maintenance of final pit slopes, classification of slides. Deterministic and probabilistic approaches in slope design. Remedial measures. Laboratory and field exercise in slope design. Collection of data and specimens in the field for determining physical properties required for slope design. Application of numerical modeling and analytical techniques to slope stability determinations for hard rock and soft rock environments. Prerequisite: Instructor's consent. 3 hours lecture. 3 hours semester hours.

MNGN460 INDUSTRIAL MINERALS PRODUCTION (II) This course describes the engineering principles and practices associated with quarry mining operations related to the cement and aggregate industries. The course will cover resource definition, quarry planning and design, extraction, and processing of minerals for cement and aggregate production. Permitting issues and reclamation, particle sizing and environmental practices, will be studied in depth. Prerequisite: MNGN312, MNGN318, MNGN322, MNGN323, or Instructor's consent. 3 hours lecture; 3 semester hours.

MNGN482. MINE MANAGEMENT (II) Basic principles of successful mine management including supervision skills, administrative policies, industrial and human relations, improvement engineering, risk management, conflict resolution and external affairs. Prerequisite: Senior or graduate status or Instructor's consent. 2 hours lecture and 1 hour case study presentation/discussion per week; 3 semester hours.

MNGN498. SPECIAL TOPICS IN MINING ENGINEERING (I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually

the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

MNGN499. INDEPENDENT STUDY (I, II) (WI) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

Graduate Courses

500-level courses are open to qualified seniors with permission of the department and Dean of the Graduate School. 600-level courses are open only to students enrolled in the Graduate School.

MNGN501. REGULATORY MINING LAWS AND CONTRACTS (I) Basic fundamentals of engineering law, regulations of federal and state laws pertaining to the mineral industry and environment control. Basic concepts of mining contracts. Offered in even numbered years. Prerequisite: Senior or graduate status. 3 hours lecture; 3 semester hours. Offered in even years.

MNGN503. MINING TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT (I, II) The primary focus of this course is to provide students an understanding of the fundamental principles of sustainability and how they influence the technical components of a mine's life cycle, beginning during project feasibility and extending through operations to closure and site reclamation. Course discussions will address a wide range of traditional engineering topics that have specific relevance and impact to local and regional communities, such as mining methods and systems, mine plant design and layout, mine operations and supervision, resource utilization and cutoff grades, and labor. The course will emphasize the importance of integrating social, political, and economic considerations into technical decision-making and problem solving. 3 hours lecture; 3 semester hours

MNGN505. ROCK MECHANICS IN MINING (I) The course deals with the rock mechanics aspect of design of mine layouts developed in both underground and surface. Underground mining sections include design of coal and hard rock pillars, mine layout design for tabular and massive ore bodies, assessment of caving characteristics or ore bodies, performance and application of backfill, and phenomenon of rock burst and its alleviation. Surface mining portion covers rock mass characterization, failure modes of slopes excavated in rock masses, probabilistic and deterministic approaches to design of slopes, and remedial measures for slope stability problems. Prerequisite: MN321 or equivalent. 3 hours lecture; 3 semester hours

MNGN506. DESIGN AND SUPPORT OF UNDERGROUND EXCAVATIONS Design of underground excavations and support. Analysis of stress and rock mass deformations around excavations using analytical and numerical methods. Collections, preparation, and evaluation of in situ and laboratory data for excavation design. Use of rock mass rating systems for site characterization and excavation design. Study of support types and selection of support for underground excavations. Use of numerical models for design of shafts, tunnels and large chambers. Prerequisite: Instructor's consent. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN507. ADVANCED DRILLING AND BLASTING (I) An advanced study of the theories of rock penetration including percussion, rotary, and rotary percussion drilling. Rock fragmentation including explosives and the theories of blasting rock. Application of theory to drilling and blasting practice at mines, pits, and quarries. Prerequisite: MNGN407. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN508. ADVANCED ROCK MECHANICS Analytical and numerical modeling analysis of stresses and displacements induced around engineering excavations in rock. In-situ stress. Rock failure criteria. Complete load deformation behavior of rocks. Measurement and monitoring techniques in rock mechanics. Principles of design of excavation in rocks. Analytical, numerical modeling and empirical design methods. Probabilistic and deterministic approaches to rock engineering designs. Excavation design examples for shafts, tunnels, large chambers and mine pillars. Seismic loading of structures in rock. Phenomenon of rock burst and its alleviation. Prerequisite: MNGN321 or professor's consent. 3 hours lecture; 3 semester hours.

MNGN510. FUNDAMENTALS OF MINING AND MINERAL RESOURCE DEVELOPMENT Specifically designed for non-majors, the primary focus of this course is to provide students with a fundamental understanding of how mineral resources are found, developed, mined, and ultimately reclaimed. The course will present a wide range of traditional engineering and economic topics related to: exploration and resource characterization, project feasibility, mining methods and systems, mine plant design and layout, mine operations and scheduling, labor, and environmental and safety considerations. The course will emphasize the importance of integrating social (human), political, and environmental issues into technical decision-making and design. 3 hours lecture; 3 semester hours.

MNGN511. MINING INVESTIGATIONS (I, II) Investigational problems associated with any important aspect of mining. Choice of problem is arranged between student and instructor. Prerequisite: Consent of instructor. Lecture, consultation, lab, and assigned reading; 2 to 4 semester hours.

MNGN512. SURFACE MINE DESIGN Analysis of elements of surface mine operation and design of surface mining system components with emphasis on minimization of adverse environmental impact and maximization of efficient use of mineral resources. Ore estimates, unit operations, equipment selection, final pit determinations, short- and long-range planning, road layouts, dump planning, and cost estimation. Prerequisite: MNGN210. 3 hours lecture; 3 semester hours.

MNGN513 ADVANCED SURFACE MINE DESIGN (II) This course introduces students to alternative open pit planning and design concepts. Course emphasis is on optimization aspects of open pit mine design. Topics include 3-D ultimate pit limit algorithms and their applications; computer aided haul road and dump designs; heuristic long- and short-term pit scheduling techniques; parametrization concepts; mathematical optimization for sequencing and scheduling; ore control and truck dispatching. Design procedures are illustrated by case studies using various computer programs. Prerequisite: MNGN308, MNGN312, or consent of instructor. 3 hours lecture; 3 semester hours.

MNGN514/EGGN514. MINING ROBOTICS (I) Fundamentals of robotics as applied to the mining industry. The focus is on mobile robotic vehicles. Topics covered are mining applications, introduction and history of mobile robotics, sensors, including vision, problems of sensing variations in rock properties, problems of representing human knowledge in control systems, machine condition diagnostics, kinematics, and path finding. Prerequisite: CSC1404 or consent of instructor. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN515. MINE MECHANIZATION AND AUTOMATION This course will provide an in-depth study of the current state of the art and future trends in mine mechanization and mine automation systems for both surface and underground mining, review the infrastructure required to support mine automation, and analyze the potential economic and health and safety benefits. Prerequisite: MNGN312, MNGN314, MNGN316, or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours. Fall of odd years.

MNGN516. UNDERGROUND MINE DESIGN Selection, design, and development of most suitable underground mining methods based upon the physical and the geological properties of mineral deposits (metallics and nonmetallics), conservation considerations, and associated environmental impacts. Reserve estimates, development and production planning, engineering drawings for development and extraction, underground haulage systems, and cost estimates. Prerequisite: MNGN210. 2 hours lecture, 3 hours lab; 3 semester hours.

MNGN517. ADVANCED UNDERGROUND MINING (II) Review and evaluation of new developments in advanced underground mining systems to achieve improved productivity and reduced costs. The major topics covered include: mechanical excavation techniques for mine development and production, new haulage and vertical conveyance systems, advanced ground support and roof control methods, mine automation and monitoring, new mining systems and future trends in automated, high productivity mining schemes. Prerequisite: Underground Mine Design (e.g., MNGN314). 3 hours lecture; 3 semester hours.

MNGN518. ADVANCED BULK UNDERGROUND MINING TECHNIQUES This course will provide advanced knowledge and understanding of the current state-of-the-art in design, development, and production in underground hard rock mining using bulk-mining methods. Design and layout of sublevel caving, block caving, open stoping and blasthole stoping systems. Equipment selection, production scheduling, ventilation design, and mining costs. Prerequisites: MNGN314, MNGN516, or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours. Spring of odd years.

MNGN519. ADVANCED SURFACE COAL MINE DESIGN (II) Review of current manual and computer methods of reserve estimation, mine design, equipment selection, and mine planning and scheduling. Course includes design of a surface coal mine for a given case study and comparison of manual and computer results. Prerequisite: MNGN312, 316, 427. 2 hours lecture, 3 hours lab; 3 semester hours. Offered in odd years.

MNGN520. ROCK MECHANICS IN UNDERGROUND COAL MINING (I) Rock mechanics consideration in the design of room-and-pillar, longwall, and shortwall coal mining systems. Evaluation of bump and outburst conditions and remedial measures. Methane drainage systems. Surface subsidence evaluation. Prerequisite: MNGN321. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN522/422. FLOTATION Science and engineering governing the practice of mineral concentration by flotation. Interfacial phenomena, flotation reagents, mineral-reagent interactions, and zeta-potential are covered. Flotation circuit design and evaluation as well as tailings handling are also covered. The course also includes laboratory demonstrations of some fundamental concepts. 3 hours lecture; 3 semester hours.

MNGN523. SELECTED TOPICS (I, II) Special topics in mining engineering, incorporating lectures, laboratory work or independent study, depending on needs. This course may be repeated for additional credit only if subject material is different. Prerequisite: Consent of instructor. 2 to 4 semester hours. Repeatable for credit under different titles.

MNGN525. INTRODUCTION TO NUMERICAL TECHNIQUES IN ROCK MECHANICS (I) Principles of stress and infinitesimal strain analysis are summarized, linear constitutive laws and energy methods are reviewed. Continu-

ous and laminated models of stratified rock masses are introduced. The general concepts of the boundary element and finite element methods are discussed. Emphasis is placed on the boundary element approach with displacement discontinuities, because of its relevance to the modeling of the extraction of tabular mineral bodies and to the mobilization of faults, joints, etc. Several practical problems, selected from rock mechanics and subsidence engineering practices, are treated to demonstrate applications of the techniques. Prerequisite: MNGN321, EGGN320, or equivalent courses, MATH455 or consent of instructor. 3 hours lecture; 3 semester hours. Offered in even years.

MNGN526. MODELING AND MEASURING IN GEOMECHANICS (II) Introduction to instruments and instrumentation systems used for making field measurements (stress, convergence, deformation, load, etc.) in geomechanics. Techniques for determining rock mass strength and deformability. Design of field measurement programs. Interpretation of field data. Development of predictive models using field data. Introduction to various numerical techniques (boundary element, finite element, FLAC, etc.) for modeling the behavior of rock structures. Demonstration of concepts using various case studies. Prerequisite: Graduate standing or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours. Offered in odd years.

MNGN527. THEORY OF PLATES AND SHELLS Classical methods for the analysis of stresses in plate type structure are presented first. The stiffness matrices for plate element will be developed and used in the finite element method of analysis. Membrane and bending stresses in shells are derived. Application of the theory to tunnels, pipes, pressure vessels, and domes, etc., will be included. Prerequisites: EGGN320 or instructor's consent. 3 hours lecture; 3 credit hours.

MNGN528/GEGN528. MINING GEOLOGY (I) Role of geology and the geologist in the development and production stages of a mining operation. Topics addressed: mining operation sequence, mine mapping, drilling, sampling, reserve estimation, economic evaluation, permitting, support functions. Field trips, mine mapping, data evaluation, exercises and term project. Prerequisite: GEGN401 or GEGN405 or permission of instructors. 2 hours lecture/seminar, 3 hours laboratory; 3 semester hours. Offered in even years.

MNGN530. INTRODUCTION TO MICRO COMPUTERS IN MINING (I) General overview of the use of PC based micro computers and software applications in the mining industry. Topics include the use of: database, CAD, spreadsheets, computer graphics, data acquisition, and remote communications as applied in the mining industry. Prerequisite: Any course in computer programming. 2 hours lecture, 3 hours lab; 3 semester hours.

MNGN536. OPERATIONS RESEARCH TECHNIQUES IN THE MINERAL INDUSTRY Analysis of exploration, mining, and metallurgy systems using statistical analysis. Monte Carlo methods, simulation, linear programming, and computer methods. Prerequisite: MNGN433 or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours. Offered in even years.

MNGN538. GEOSTATISTICAL ORE RESERVE ESTIMATION (I) Introduction to the application and theory of geostatistics in the mining industry. Review of elementary statistics and traditional ore reserve calculation techniques. Presentation of fundamental geostatistical concepts, including: variogram, estimation variance, block variance, kriging, geostatistical simulation. Emphasis on the practical aspects of geostatistical modeling in mining. Prerequisite: MATH323 or equivalent course in statistics; graduate or senior status. 3 hours lecture; 3 semester hours.

MNGN539. ADVANCED MINING GEOSTATISTICS (II) Advanced study of the theory and application of geostatistics in mining engineering. Presentation of state-of-the-art geostatistical concepts, including: robust estimation, nonlinear geostatistics, disjunctive kriging, geostatistical simulation, computational aspects. This course includes presentations by many guest lecturers from the mining industry. Emphasis on the development and application of advanced geostatistical techniques to difficult problems in the mining industry today. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN545/445 ROCK SLOPE ENGINEERING Introduction to the analysis and design of slopes excavated in rock. Rock mass classification and strength determinations, geological structural parameters, properties of fracture sets, data collection techniques, hydrological factors, methods of analysis of slope stability, wedge intersections, monitoring and maintenance of final pit slopes, classification of slides. Deterministic and probabilistic approaches in slope design. Remedial measures. Laboratory and field exercise in slope design. Collection of data and specimens in the field for determining physical properties required for slope design. Application of numerical modeling and analytical techniques to slope stability determinations for hard rock and soft rock environments. Prerequisite: Instructor's consent. 3 hours lecture. 3 hours semester hours.

MNGN549/EGGN549. MARINE MINING SYSTEMS (I) Define interdisciplinary marine mining systems and operational requirements for the exploration survey, sea floor mining, hoisting, and transport. Describe and design components of deep-ocean, manganese-nodule mining systems and other marine mineral extraction methods. Analyze dynamics and remote control of the marine mining systems interactions and system components. Describe the current state-of-the-art technology, operational practice, trade-offs of the system design and risk. Prerequisite: EGGN351, EGGN320, GEOC408 or consent of instructor. 3 hours lecture; 3 semester hours. Offered alternate even years.

MNGN550. NEW TECHNIQUES IN MINING (II) Review of various experimental mining procedures, including a critical evaluation of their potential applications. Mining methods covered include deep sea nodule mining, in situ gassification of coal, in situ retorting of oil shale, solution mining of soluble minerals, in situ leaching of metals, geothermal power generation, oil mining, nuclear fragmentation, slope caving, electro-thermal rock penetration and fragmentation. Prerequisite: Graduate standing or consent of instructor. 3 hours lecture; 3 semester hours. Offered in even years.

MNGN552/MNGN452. SOLUTION MINING AND PROCESSING OF ORES Theory and application of advanced methods of extracting and processing of minerals, underground or in situ, to recover solutions and concentrates of value-materials, by minimization of the traditional surface processing and disposal of tailings to minimize environmental impacts. Prerequisites: Senior or graduate status; instructor's consent 3 hours lecture; 3 semester hours. Offered in spring.

MNGN559/EGGN559. MECHANICS OF PARTICULATE MEDIA (I) This course allows students to establish fundamental knowledge of quasi-static and dynamic particle behavior that is beneficial to interdisciplinary material handling processes in the chemical, civil, materials, metallurgy, geophysics, physics, and mining engineering. Issues of interest are the definition of particle size and size distribution, particle shape, nature of packing, quasi-static behavior under different external loading, particle collisions, kinetic theoretical modeling of particulate flows, molecular dynamic simulations, and a brief introduction of solid-fluid two-phase flows. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Fall semesters, every other year.

MNGN585. MINING ECONOMICS (I) Advanced study in mine valuation with emphasis on revenue and cost aspects. Topics include price and contract consideration in coal, metal and other commodities; mine capital and operating cost estimation and indexing; and other topics of current interest. Prerequisite: MNGN427 or EBGN504 or equivalent. 3 hours lecture; 3 semester hours. Offered in even years.

MNGN590. MECHANICAL EXCAVATION IN MINING (II) This course provides a comprehensive review of the existing and emerging mechanical excavation technologies for mine development and production in surface and underground mining. The major topics covered in the course include: history and development of mechanical excavators, theory and principles of mechanical rock fragmentation, design and performance of rock cutting tools, design and operational characteristics of mechanical excavators (e.g. continuous miners, roadheaders, tunnel boring machines, raise drills, shaft borers, impact miners, slotters), applications to mine development and production, performance prediction and geotechnical investigations, costs versus conventional methods, new mine designs for applying mechanical excavators, case histories, future trends and anticipated developments and novel rock fragmentation methods including water

jets, lasers, microwaves, electron beams, penetrators, electrical discharge and sonic rock breakers. Prerequisite: Senior or graduate status. 3 hours lecture; 3 semester hours. Offered in odd years.

MNGN597. SUMMER PROGRAMS

MNGN598. SPECIAL TOPICS IN MINING ENGINEERING (I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

MNGN599. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

MNGN625. GRADUATE MINING SEMINAR (I, II) Discussions presented by graduate students, staff, and visiting lecturers on research and development topics of general interest. Required of all graduate students in mining engineering every semester during residence. 1 semester hour upon completion of thesis or residence.

MNGN698. SPECIAL TOPICS IN MINING ENGINEERING (I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

MNGN699. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

MNGN700. GRADUATE ENGINEERING REPORT-MASTER OF ENGINEERING (I, II) Laboratory, field, and library work for the Master of Engineering report under supervision of the student's advisory committee. Required of candidates for the degree of Master of Engineering. Variable 1 to 6 hours. Repeatable for credit to a maximum of 6 hours.

MNGN705 GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

MNGN706 GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

GOGN501. SITE INVESTIGATION AND CHARACTERIZATION An applications oriented course covering: geological data collection, geophysical methods for site investigation; hydrological data collection; materials properties determination; and various engineering classification systems. Presentation of data in a format suitable for subsequent engineering design will be emphasized. Prerequisite: Introductory courses in geology, rock mechanics, and soil mechanics. 3 hours lecture; 3 semester hours.

GOGN502. SOLID MECHANICS APPLIED TO ROCKS An introduction to the deformation and failure of rocks and rock masses and to the flow of groundwater. Principles of displacement, strain and stress, together with the equations of equilibrium are discussed. Elastic and plastic constitutive laws, with and without time dependence, are introduced. Concepts of strain hardening and softening are summarized. Energy principles, energy changes caused by underground excavations, stable and unstable equilibria are defined. Failure criteria for intact rock and rock masses are explained. Principles of numerical techniques are discussed and illustrated. Basic laws and modeling of groundwater flows are introduced. Prerequisite: Introductory Rock Mechanics. 3 hours lecture; 3 semester hours.

GOGN503. CHARACTERIZATION AND MODELING LABORATORY An applications oriented course covering: Advanced rock testing procedures; dynamic rock properties determination; on-site measurements; and various rock mass modeling approaches. Presentation of data in a format suitable for subsequent engineering design will be emphasized. Prerequisite: Introductory courses in geology, rock mechanics, and soil mechanics. 3 hours lecture; 3 semester hours.

GOGN504. SURFACE STRUCTURES IN EARTH MATERIALS Principles involved in the design and construction of surface structures involving earth materials. Slopes and cuts. Retaining walls. Tailing dams. Leach dumps. Foundations. Piles and piers. Extensive use of case examples. Prerequisites: GOGN501, GOGN502, GOGN503. 3 hours lecture; 3 semester hours.

GOGN505. UNDERGROUND EXCAVATION IN ROCK Components of stress, stress distributions, underground excavation failure mechanisms, optimum orientation and shape of excavations, excavation stability, excavation support design, ground treatment and rock pre-reinforcement, drill and blast excavations, mechanical excavation, material haulage, ventilation and power supply, labor requirements and training, scheduling and costing of underground excavations, and case histories. Prerequisites: GOGN501, GOGN502, GOGN503. 3 hours lecture; 3 semester hours.

GOGN506. EXCAVATION PROJECT MANAGEMENT

Normal project initiation, design procedures, project financing, permitting and environmental impacts, preparation of plans and specifications, contract award, notice to proceed and legal requirements. Construction alternatives, contract types, standard contract language, bidding and estimating and contract awarding procedures. Construction inspection and control methods and completion procedures. Conflict resolution, administrative redress, arbitration and litigation. Time and tonnage based incentive programs. The role of experts. Prerequisite: College-level in Microeconomics or Engineering Economy. Degree in Engineering. 2 hours lecture; 2 semester hours.

GOGN625. GEO-ENGINEERING SEMINAR Discussions presented by graduate students, staff, and visiting lectures on research and development topics of general interest. Required of all graduate students in Geo-Engineering every semester, during residence. Prerequisite: Enrollment in Geo-Engineering Program. 1 semester hour upon completion of thesis or residence.

Nuclear Engineering

Department of Chemistry

JAMES F. RANVILLE, Associate Professor

Department of Engineering

KEVIN L. MOORE, Gerard August Dobelman Chair and Professor

RAY R. ZHANG, Associate Professor

Department of Environmental Science and Engineering

LINDA A. FIGUEROA, Associate Professor

JOHN R. SPEAR, Associate Professor

Department of Geology and Geological Engineering

JOHN D. HUMPHREY, Associate Professor and Interim Department Head

SAMUEL B. ROMBERGER, Professor

Department of Liberal Arts and International Studies

CARL MITCHAM, Professor

JENNIFER SCHNEIDER, Assistant Professor

Department of Mathematical and Computer Sciences

CORY AHRENS, Assistant Professor

Department of Metallurgical and Materials Engineering

JOHN J. MOORE, Trustees Professor

STEPHEN LIU, Professor

DAVID K. MATLOCK, Charles S. Fogarty Professor

BRAJENDRA MISHRA, Professor

DAVID L. OLSON, John H. Moore Distinguished Professor

IVAR E. REIMANIS, Professor

JOHN G. SPEER, Professor

JEFFREY C. KING, Assistant Professor and Interim Nuclear Science and Engineering Program Director

FRANK E. GIBBS, Research Associate Professor

BRIAN P. GORMAN, Assistant Professor

Department of Mining Engineering

MARK KUCHTA, Associate Professor

Department of Physics

UWE GREIFE, Professor

JAMES A. McNEIL, Professor

MARK T. LUSK, Professor

F. EDWARD CECIL, University Professor Emeritus

FREDERIC SARAZIN, Associate Professor

ZEEV SHAYER, Research Professor

Degrees Offered:

Master of Science (Nuclear Engineering), Thesis option

Master of Science (Nuclear Engineering), Non-thesis option

Doctor of Philosophy (Nuclear Engineering)

In addition, students majoring in allied fields may complete a minor degree program, consisting of 12 credit hours of coursework, through the Nuclear Science and Engineering Program. Minor programs are designed to allow students in allied fields to acquire and then indicate, in a formal way, specialization in a nuclear-related area of expertise.

Program Description:

The Nuclear Science and Engineering program at the Colorado School of Mines is interdisciplinary in nature and draws substantial contributions from the Department of

Chemistry, Division of Engineering, the Division of Environmental Science and Engineering, the Department of Geology and Geological Engineering, the Division of Liberal Arts and International Studies, the Department of Mathematical and Computer Sciences, the Department of Metallurgical and Materials Engineering, the Department of Mining Engineering, and the Department of Physics. While delivering a traditional Nuclear Engineering course core, the School of Mines program in Nuclear Science and Engineering emphasizes the nuclear fuel life cycle. Faculty bring to the program expertise in all aspects of the nuclear fuel life cycle; fuel exploration and processing, nuclear power systems production, design and operation, fuel recycling, storage and waste remediation, radiation detection and radiation damage as well as the policy issues surrounding each of these activities. Related research is conducted in CSM's Nuclear Science and Engineering Center.

Students in all three Nuclear Engineering degrees are exposed to a broad systems overview of the complete nuclear fuel cycle as well as having detailed expertise in a particular component of the cycle. Breadth is assured by requiring all students to complete a rigorous set of core courses. The core consists of a 21 credit-hour course sequence. The remainder of the course and research work is obtained from the multiple participating departments, as approved for each student by the student's advisor and the student's thesis committee (as appropriate).

The Master of Science (Non-Thesis) is a non-thesis graduate degree intended to supplement the student's undergraduate degree by providing the core knowledge needed to prepare the student to pursue a career in the nuclear engineering field. The Master of Science and Doctor of Philosophy degrees are thesis-based degrees that emphasize research.

Nuclear Engineering Combined Degree Program Option:

CSM undergraduate students have the opportunity to begin work on an M.S. degree in Nuclear Engineering while completing their Bachelor's degree. The Nuclear Engineering Combined Degree Program provides the vehicle for students to use up to 6 credit hours of undergraduate coursework as part of their Nuclear Engineering Graduate Degree curriculum, as well as the opportunity to take additional graduate courses while completing their undergraduate degree. Students in the Nuclear Engineering Combined Degree Program are generally expected to apply for admission to the graduate program by the beginning of their Senior Year. For more information please contact the Nuclear Science and Engineering program director.

Program Requirements:

Master of Science (Non-Thesis): 36 total credit hours, consisting of required core coursework (13 h), elective core coursework (12 h), additional elective courses (9 h), and Nuclear Science and Engineering Seminar (2 h).

Master of Science: 36 total credit hours, including required core coursework (13 h), elective core coursework (6 h), Nuclear Science and Engineering Seminar (2 h) and graduate research (at least 12 h). M.S. students must complete and defend a research thesis. An M.S. thesis proposal must be presented to and accepted by the thesis committee in accordance with the Nuclear Science and Engineering Program Guidelines at least one semester before the student defends his or her M.S. thesis.

Doctor of Philosophy: 72 total credit hours, including required core coursework (13 h), elective core coursework (9 h), additional elective courses (12 h), Nuclear Science and Engineering Seminar (4 h) and graduate research (at least 24 h). Ph.D. students must successfully complete the program's quality control process. The Ph.D. quality control process includes the following:

- Prior to admission to candidacy, the student must complete all seven of his or her Nuclear Engineering required and elective core classes;

- Prior to admission to candidacy, the student must pass a separate oral examination for any of his or her seven core classes in which he or she did not receive a grade of B or better;

- A Ph.D. thesis proposal, including an oral qualifying examination on the topical areas directly relevant to the student's proposed research, must be presented to, and accepted by, the student's thesis committee in accordance with the Nuclear Science and Engineering Program Guidelines at least one year before the student defends his or her Ph.D. thesis; and the student must complete and defend a Ph.D. thesis in accordance with this Graduate Bulletin and the Nuclear Science and Engineering Program Guidelines.

Thesis Committee Requirements: The student's thesis committee must meet the general requirements listed in the Graduate Bulletin section on Graduate Degrees and Requirements. In addition, the student's advisor or co-advisor must be an active faculty member of CSM's Nuclear Science and Engineering Program. For M.S. students, at least two, and for Ph.D. students, at least three committee members must be faculty members of the Nuclear Science and Engineering Program. At least one member of the Ph.D. committee must be a faculty member from outside the Nuclear Science and Engineering Program.

Graduate Seminar: Full-time graduate students in the Nuclear Science and Engineering Program are expected to maintain continuous enrollment in Nuclear Science and Engineering Seminar (NUGN505). Students who are concurrently enrolled in a different degree program that also requires seminar attendance may have this requirement waived at the discretion of the Program Director.

General: In order to be admitted to the Nuclear Science and Engineering Graduate Degree Program, students must meet the following minimum requirements:

- baccalaureate degree in a science or engineering discipline from an accredited program
- mathematics coursework up to and including differential equations
- physics coursework up to and including courses in modern physics and introductory nuclear physics
- coursework in engineering thermodynamics, heat transfer, and fluid flow (or equivalent)

Students who do not meet all of these pre-requisites may be admitted provisionally, with specified coursework to be completed in the first semesters of the graduate program after consultation with the student's advisor. Students planning to pursue a Nuclear Engineering graduate degree are also strongly advised to take an undergraduate Introduction to Nuclear Engineering course such as ENGY 340.

Doctor of Philosophy: Students seeking a Ph.D in Nuclear Engineering are also generally expected to complete a thesis-based Master's degree in Nuclear Engineering or a related field prior to their admission to candidacy.

Required Curriculum:

All degree offerings within the Nuclear Science and Engineering program are based on a set of required and elective core courses. The required core classes are:

- Introduction to Nuclear Reactor Physics (NUGN510)
- Introduction to Nuclear Reactor Thermal-Hydraulics
- Nuclear Reactor Laboratory (NUGN580 - taught in collaboration with the USGS)
- Nuclear Reactor Design (NUGN585 and NUGN586)

Additionally, students pursuing a Nuclear Engineering graduate degree must take a certain number of courses from the elective core (all four for an M.S. (Non-Thesis), two for an M.S. and three for a Ph.D.). The core electives consist of the following:

- Radiation Detection and Measurement (PHGN504)
- Nuclear Materials Science and Engineering (MTGN593)
- Environmental Stewardship of Nuclear Resources (ESGN511)
- Nuclear Power and Public Policy (LAIS589)

Students will select additional coursework in consultation with their graduate advisor and their thesis committee (where applicable). This additional coursework may include offerings from all of the academic units participating in the degree program: Engineering, Environmental Sciences and Engineering, Geology and Geological Engineering, Liberal Arts and International Studies, Metallurgical and Materials Engineering, Mining Engineering and Physics. Through these ad-

ditional courses, students gain breadth and depth in their knowledge the Nuclear Engineering industry.

Students seeking M.S. (Thesis) and Ph.D. degrees are required to complete the minimum research credit hour requirements ultimately leading to the completion and defense of a thesis. Research is conducted under the direction of a member of CSM's Nuclear Science and Engineering faculty and could be tied to a research opportunity provided by industry partners.

Minor Degree Programs

Students majoring in allied fields may choose to complete minor degree programs through the Nuclear Science and Engineering Program indicating specialization in a nuclear-related area of expertise. Minor programs require completion of 12 credit hours of approved coursework. Existing minors and their requirements are as follows:

Nuclear Engineering

"Introduction to Nuclear Reactor Physics (NUGN510)

"Nuclear Reactor Laboratory (NUGN580)

"Reactor Design (NUGN585)

"Either Nuclear Power and Public Policy (LAIS589) or Environmental Stewardship of Nuclear Resources (ESGN511)

Nuclear Materials Processing

"Introduction to Nuclear Reactor Physics (NUGN510)

"Nuclear Materials Science and Engineering (MTGN593)

"Chemical Processing of Nuclear Materials (MTGN591)

"Environmental Stewardship of Nuclear Resources (ESGN511)

Nuclear Detection

"Nuclear Physics (PHGN422)

"Introduction to Nuclear Reactor Physics (NUGN510)

"Radiation Detection and Measurement (PHGN504)

"Nuclear Reactor Laboratory (NUGN580)

Nuclear Geoscience and Geoenvironmental Engineering

"Nuclear Physics (PHGN422), plus three of the following five courses

"Nuclear and Isotope Geochemistry

"In-situ Mining

"Uranium Mining

"Uranium Geology and Geochemistry (GEGN520)

"Design of Geologic Radioactive Waste Repositories (MNGN543)

Description of Courses

NUGN505. NUCLEAR SCIENCE AND ENGINEERING SEMINAR (I, II) The nuclear Science and Engineering Seminar provides a forum for Nuclear Engineering graduate students to present their research projects, participate in seminars given by Nuclear Science and Engineering professionals, and develop an enhanced understanding of the breadth of the nuclear engineering discipline. Prerequisite: graduate standing. 1 hour seminar; 1 semester hour. Repeatable; maximum 2 hours granted towards M.S. Degree requirements and 4 hours maximum granted towards Ph.D. Requirements.

NUGN510. INTRODUCTION TO NUCLEAR REACTOR PHYSICS (II) Bridges the gap between courses in fundamental nuclear physics and the neutronic design and analysis of nuclear reactors. Review of neutron energetics and reactions; nuclear cross sections; neutron induced fission; neutron life cycle, multiplication, and criticality; nuclear reactor kinetics and control; the diffusion approximation for neutron transport; simple reactor geometries and compositions; modeling and simulation of reactors. Prerequisite: PHGN422 or consent of instructor. 3 hours lecture; 3 semester hours.

NUGN580. NUCLEAR REACTOR LABORATORY (I) Provides hands-on experience with a number of nuclear reactor operations topics. Reactor power calibration; gamma spectroscopy; neutron activation analysis; reactor flux and power profiles; reactor criticality; control rod worth; xenon transients and burnout; reactor pulsing. Taught at the USGS TRIGA reactor. Prerequisite: NUGN510. 3 hours laboratory; 3 semester hours.

NUGN585. NUCLEAR REACTOR DESIGN I (I) Provides a basic understanding of the nuclear reactor design process, including: key features of nuclear reactors; nuclear reactor design principals; identification of design drivers; neutronic and thermal-hydraulic design of nuclear reactors; reactor safety considerations; relevant nuclear engineering computer codes. Prerequisite: NUGN510. 2 hours lecture. 2 semester hours.

NUGN586. NUCLEAR REACTOR DESIGN II (II) Builds on the design experience obtained in NUGN586 to provide an in-depth understanding of the nuclear reactor design process. Prerequisites: NUGN585 (taken in the same academic year). 2 hours lecture. 2 semester hours.

NUGN599/699. INDEPENDENT STUDY IN NUCLEAR ENGINEERING (I, II) Individual special studies, laboratory or case study in nuclear engineering. Prerequisite: Approval of instructor and program director. Variable credit: 1-6 semester hours. Repeatable for credit.

NUGN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

NUGN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

In addition to the core courses listed above and in the respective departments, elective courses need to be approved by the student's Nuclear Science and Engineering faculty advisor.

Petroleum Engineering

RAMONA M. GRAVES, Professor and Department Head
HOSSEIN KAZEMI, Chesebro' Distinguished Professor
ERDAL OZKAN, Professor
AZRA TUTUNCU, Harry D. Campbell Chair and Professor
YU-SHU WU, CMG Chair and Professor
ALFRED W. EUSTES III, Associate Professor
JENNIFER L. MISKIMINS, Associate Professor
MANIKA PRASAD, Associate Professor
TODD HOFFMAN, Assistant Professor
XIAOLONG YIN, Assistant Professor
LINDA BATTALORA, Teaching Associate Professor
MARK G. MILLER, Teaching Associate Professor
M.W. SCOGGINS, Research Professor and CSM President
BILLY J. MITCHELL, Professor Emeritus
CRAIG W. VAN KIRK, Professor Emeritus
RICHARD CHRISTIANSEN, Associate Professor Emeritus

Degrees Offered:

- Professional Masters in Petroleum Reservoir Systems
- Master of Engineering (Petroleum Engineering)
- Master of Science (Petroleum Engineering)
- Doctor of Philosophy (Petroleum Engineering)

Program Description:

The Petroleum Engineering Department offers students a choice of a Master of Science (MS) degree or a Master of Engineering (ME) degree. For the MS degree, a thesis is required in addition to course work. For the ME degree, no thesis is required, but the course work requirement is greater than that for the MS degree. The Petroleum Engineering Department also offers CSM undergraduate students the option of a Combined Undergraduate/Graduate Program. This is an accelerated program that provides the opportunity to CSM students to have a head start on their graduate education.

Applications from students having a MS in Petroleum Engineering, or in another complimentary discipline, will be considered for admission to the Doctor of Philosophy (Ph.D.) program. To obtain the Ph.D. degree, a student must demonstrate unusual competence, creativity, and dedication in the degree field. In addition to extensive course work, a dissertation is required for the Ph.D. degree.

Program Requirements:

Professional Masters in Petroleum Reservoir Systems

Minimum 36 hours of course credit

Master of Engineering

Minimum 36 hours of course credit

Master of Science

Minimum 36 hours, of which no less than 12 credit hours earned by research and 24 credit hours by course work

Combined Undergraduate/Graduate Program

The same requirements as Master of Engineering or Master of Science after the student is granted full graduate status. Students in the Combined Undergraduate/Graduate Program

may fulfill part of the requirements of their graduate degree by including up to 6 credit hours of undergraduate course credits upon approval of the department.

Doctor of Philosophy

Minimum 90 credit hours beyond the bachelor's degree of which no less than 30 credit hours earned by research, or minimum 54 credit hours beyond the Master's degree of which no less than 30 credit hours earned by research.

The Petroleum Engineering, Geology and Geological Engineering, and the Geophysics Departments share oversight for the **Professional Masters in Petroleum Reservoir Systems** program through a committee consisting of one faculty member from each department. Students gain admission to the program by application to any of the three sponsoring departments. Students are administered by that department into which they first matriculate. A minimum of 36 credit hours of course credit is required to complete the Professional Masters in Petroleum Reservoir Systems program. Up to 9 credits may be earned by 400 level courses. All other credits toward the degree must be 500 level or above. At least 9 hours must consist of:

1 course selected from the following:

GEGN439/GPGN439/PEGN439 Multidisciplinary
Petroleum Design

1 course selected from the following:

GPGN419/ PEGN419 Well Log Analysis and Formation
Evaluation or
GPGN519/PEGN519 Advanced Formation Evaluation

1 courses selected from the following:

GEGN503/GPGN503/PEGN503 Integrated Exploration
and Development or
GEGN504/GPGN504/PEGN504 Integrated Exploration
and Development

Also 9 additional hours must consist of one course each from the 3 participating departments. The remaining 18 hours may consist of graduate courses from any of the 3 participating departments, or other courses approved by the committee. Up to 6 hours may consist of independent study, including an industry project.

Candidates for the non-thesis **Master of Engineering** degree must complete a minimum of 36 hours of graduate course credit. At least 18 of the credit hours must be from the Petroleum Engineering Department. Up to 12 graduate credit hours can be transferred from another institution, and up to 9 credit hours of senior-level courses may be applied to the degree. All courses must be approved by the student's advisor and the department head. No graduate committee is required. No more than six credit hours can be earned through independent study.

Candidates for the **Master of Science** degree must complete at least 24 graduate credit hours of course work, approved by the candidate's graduate committee, and a minimum of 12

hours of research credit. At least 12 of the course credit hours must be from the Petroleum Engineering Department. Up to 9 credit hours may be transferred from another institution. Up to 9 credit hours of senior-level courses may be applied to the degree. For the MS degree, the student must demonstrate ability to observe, analyze, and report original scientific research. For other requirements, refer to the general instructions of the Graduate School in this bulletin.

The requirements for the **Combined Undergraduate/Graduate Program** are defined in the section of this Bulletin titled "Graduate Degrees and Requirements—V. Combined Undergraduate/Graduate Programs." After the student is granted full graduate status, the requirements are the same as those for the non-thesis Master of Engineering or thesis-based Master of Science degree, depending to which program the student was accepted. The Combined Undergraduate/Graduate Program allows students to fulfill part of the requirements of their graduate degree by including up to 6 credit hours of their undergraduate course credits upon approval of the department. The student must apply for the program by submitting an application through the Graduate School before the first semester of their Senior year. For other requirements, refer to the general directions of the Graduate School in this bulletin.

A candidate for the **Ph.D.** must complete at least 60 hours of course credit and a minimum of 30 credit hours of research beyond the Bachelor's degree or at least 24 hours of course credit and a minimum of 30 credit hours of research beyond the Master's degree. The credit hours to be counted toward a Ph.D. are dependent upon approval of the student's thesis committee. Students who enter the Ph.D. program with a Bachelor's degree may transfer up to 33 graduate credit hours from another institution with the approval of the graduate advisor. Students who enter the Ph.D. program with a master's degree may transfer up to 45 credit hours of course and research work from another institution upon approval by the graduate advisor. Ph.D. students must complete a minimum of 12 credit hours of their required course credit in a minor program of study. The student's faculty advisor, thesis committee, and the department head must approve the course selection. Full-time Ph.D. students must satisfy the following requirements for admission to candidacy within the first two calendar years after enrolling in the program:

- i) have a thesis committee appointment form on file,
- ii) complete all prerequisite courses successfully,
- iii) demonstrate adequate preparation for and satisfactory ability to conduct doctoral research by successfully completing a series of written and/or oral examinations and fulfilling the other requirements of their graduate committees as outlined in the department's graduate handbook.

Failure to fulfill these requirements within the time limits specified above may result in immediate mandatory dis-

missal from the Ph.D. program according to the procedure outlined in the section of this Bulletin titled "General Regulations—Unsatisfactory Academic Performance—Unsatisfactory Academic Progress Resulting in Probation or Discretionary Dismissal." For other requirements, refer to the general directions of the Graduate School in this bulletin and/or the Department's Graduate Student Handbook.

Applying for Admission:

All graduate applicants must have taken core engineering, math and science courses before applying to graduate school. For the Colorado School of Mines this would be 3 units of Calculus, 2 units of Chemistry with Quantitative Lab, 2 units of Physics, Differential Equations, Statics, Fluid Mechanics, Thermodynamics and Mechanics of Materials. To apply for admission, follow the procedure outlined in the general section of this bulletin. Three letters of recommendation must accompany the application. The Petroleum Engineering Department requires the general test of the Graduate Record Examination (GRE) for applicants to all degree levels.

Applicants for the Master of Science, Master of Engineering, and Professional Masters in Petroleum Reservoir Systems programs should have a minimum score of 700 or better and applicants for the Ph.D. program are expected to have 750 or better on the quantitative section of the GRE exam, in addition to acceptable scores in the verbal and analytical sections. The GPA of the applicant must be 3.0 or higher. The graduate application review committee determines minimum requirements accordingly, and these requirements may change depending on the application pool for the particular semester. The applicants whose native language is not English are also expected to provide satisfactory scores on the TOEFL (Test of English as a Foreign Language) exam as specified in the general section of this bulletin.

Required Curriculum:

A student in the graduate program selects course work by consultation with the Faculty Advisor and with the approval of the graduate committee. Course work is tailored to the needs and interests of the student. Students who do not have a BS degree in petroleum engineering must take deficiency courses as required by the department as soon as possible in their graduate programs. Depending on the applicant's undergraduate degree, various basic undergraduate petroleum engineering and geology courses will be required. These deficiency courses are not counted towards the graduate degree; none-the-less, the student is expected to pass the required courses and the grades received in these courses are included in the GPA. Not passing these courses can jeopardize the student's continuance in the graduate program. It is desirable for students with deficiencies to complete the deficiencies or course work within the first two semesters of arrival to the program or as soon as possible with the approval of their advisor.

All PE graduate students are required to complete 3 credit hours of course work in writing, research, or presentation intensive classes, such as PEGN681, LICM501, SYGN501, and SYGN600, as agreed to by their graduate advisor.

Fields of Research:

Current research topics include

- Rock and fluid properties, phase behavior, and rock mechanics
- Analytical and numerical modeling of fluid flow in porous media
- Formation evaluation, well test analysis, and reservoir characterization
- Geomechanics
- Oil recovery processes
- Unconventional oil and gas
- Shale gas and shale oil
- Natural gas engineering, coalbed methane, and geothermal energy
- Completion and stimulation of wells
- Horizontal and multilateral wells
- Drilling management and rig automation
- Fluid flow in wellbores and artificial lift
- External fluid flow on offshore structures
- Drilling mechanics, directional drilling, extraterrestrial drilling, ice coring and drilling
- Bit vibration analysis, tubular buckling and stability, wave propagation in drilling tubulars
- Laser technology in penetrating rocks

Research projects may involve professors and graduate students from other disciplines. Projects often include off-campus laboratories, institutes, and other resources.

The Petroleum Engineering Department houses a research institute, two research centers, and one consortia.

Research Institute

Unconventional Natural Gas Institute (UNGI)

Research Centers

- Marathon Center of Excellence for Reservoir Studies (MCERS)
- Center for Earth Mechanics, Materials, and Characterization (CEMMC)

Research Consortia

Fracturing, Acidizing, Stimulation Technology (FAST) Consortium.

Special Features:

In the exchange programs with the Petroleum Engineering Departments of the Mining University of Leoben, Austria, Technical University in Delft, Holland, and the University of Adelaide, Australia, a student may spend one semester abroad during graduate studies and receive full transfer of credit

back to CSM with prior approval of the Petroleum Engineering Department at CSM.

The Petroleum Engineering Department is located in the foothills west of Denver. The laboratory wing has 20,000 square feet of space, with about \$2 million of equipment acquired in recent years.

The Petroleum Engineering Department enjoys strong collaboration with the Geology and Geological Engineering Department and Geophysics Department at CSM. Courses that integrate the faculty and interests of the three departments are taught at the undergraduate and graduate levels.

The department is close to oil and gas field operations, oil companies and laboratories, and geologic outcrops of producing formations. There are many opportunities for summer and part-time employment in the oil and gas industry in the Denver metropolitan region.

Each summer, several graduate students assist with the field sessions designed for undergraduate students. The field sessions in the past several years have included visits to oil and gas operations in Europe, Alaska, Canada, Southern California, the Gulf Coast, the Northeast US, the Rocky Mountain regions, and western Colorado.

The Petroleum Engineering Department encourages student involvement with the Society of Petroleum Engineers, the American Association of Drilling Engineers and the American Rock Mechanics Association. The department provides some financial support for students attending the annual technical conferences for these professional societies.

Description of Courses

Undergraduate Courses

Students in Professional Masters in Petroleum Reservoir Systems, Master of Engineering, Master of Science, and Combined Undergraduate/Graduate Degree programs may take up to 9 credit hours of 400-level courses provided that these courses are not required for the BS PE program at CSM. The department should approve all such courses. The following 400-level courses in the Petroleum Engineering Department are not required for BS PE degree and may be considered for graduate degree credit. Other 400-level courses may be available in the other departments.

PEGN450. ENERGY ENGINEERING (I or II) Energy Engineering is an overview of energy sources that will be available for use in the 21st century. After discussing the history of energy and its contribution to society, we survey the science and technology of energy, including geothermal energy, fossil energy, solar energy, nuclear energy, wind energy, hydro energy, bio energy, energy and the environment, energy and economics, the hydrogen economy, and energy forecasts. This broad background will give you additional flexibility during your career and help you thrive in an energy industry that is evolving from an industry dominated

by fossil fuels to an industry working with many energy sources. Prerequisites: MATH213 and PHGN200. 3 hours lecture; 3 semester hours.

PEGN498. SPECIAL TOPICS IN PETROLEUM ENGINEERING (I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and students(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit, 1 to 6 semester hours. Repeatable for credit under different titles.

Graduate Courses

The 500-level courses are open to qualified seniors with permission of the department and the Dean of the Graduate School. The 600-level courses are open only to students enrolled in Graduate School. Certain courses may vary from year to year, depending upon the number of students and their particular needs.

PEGN501. APPLICATIONS OF NUMERICAL METHODS TO PETROLEUM ENGINEERING The course will solve problems of interest in Petroleum Engineering through the use of spreadsheets on personal computers and structured FORTRAN programming on PCs or mainframes. Numerical techniques will include methods for numerical quadrature, differentiation, interpolation, solution of linear and non-linear ordinary differential equations, curve fitting and direct or iterative methods for solving simultaneous equations. Prerequisites: PEGN414 and PEGN424 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN502. ADVANCED DRILLING FLUIDS The physical properties and purpose of drilling fluids are investigated. Emphasis is placed on drilling fluid design, clay chemistry, testing, and solids control. Prerequisite: PEGN311 or consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

PEGN503/GEGN503/GPGN503. INTEGRATED EXPLORATION AND DEVELOPMENT Students work alone and in teams to study reservoirs from fluvial-deltaic and valley fill depositional environments. This is a multidisciplinary course that shows students how to characterize and model subsurface reservoir performance by integrating data, methods and concepts from geology, geophysics and petroleum engineering. Activities and topics include field trips to surface outcrops, well logs, borehole cores, seismograms, reservoir modeling of field performance, written exercises and oral team presentations. Prerequisite: Consent of instructor. 2 hours lecture, 3 hours lab; 3 semester hours.

PEGN504/GEGN504/GPGN504. INTEGRATED EXPLORATION AND DEVELOPMENT Students work in multidisciplinary teams to study practical problems and case studies in integrated subsurface exploration and development. The course addresses emerging technologies and timely topics. Activities include field trips, 3D computer modeling, written exercises and oral team presentations. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

PEGN505. HORIZONTAL WELLS: RESERVOIR AND PRODUCTION ASPECTS This course covers the fundamental concepts of horizontal well reservoir and production engineering with special emphasis on the new developments. Each topic covered highlights the concepts that are generic to horizontal wells and draws attention to the pitfalls of applying conventional concepts to horizontal wells without critical evaluation. There is no set prerequisite for the course but basic knowledge on general reservoir engineering concepts is useful. 3 hours lecture; 3 semester hours.

PEGN506. ENHANCED OIL RECOVERY METHODS Enhanced oil recovery (EOR) methods are reviewed from both the qualitative and quantitative standpoint. Recovery mechanisms and design procedures for the various EOR processes are discussed. In addition to lectures, problems on actual field design procedures will be covered. Field case histories will be reviewed. Prerequisite: PEGN424 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN507. INTEGRATED FIELD PROCESSING Integrated design of production facilities covering multistage separation of oil, gas, and water, multiphase flow, oil skimmers, natural gas dehydration, compression, crude stabilization, petroleum fluid storage, and vapor recovery. Prerequisite: PEGN411 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN508. ADVANCED ROCK PROPERTIES Application of rock mechanics and rock properties to reservoir engineering, well logging, well completion and well stimulation. Topics covered include: capillary pressure, relative permeability, velocity effects on Darcy's Law, elastic/mechanical rock properties, subsidence, reservoir compaction, and sand control. Prerequisites: PEGN423 and PEGN426 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN511. ADVANCED THERMODYNAMICS AND PETROLEUM FLUIDS PHASE BEHAVIOR Essentials of thermodynamics for understanding the phase behavior of petroleum fluids such as natural gas and oil. Modeling of phase behavior of single and multi-component systems with equations of states with a brief introduction to PVT laboratory studies, commercial PVT software, asphaltenes, gas hydrates, mineral deposition, and statistical thermodynamics. Prerequisites: PEGN310 and PEGN305 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN512. ADVANCED GAS ENGINEERING The physical properties and phase behavior of gas and gas condensates will be discussed. Flow through tubing and pipelines as well as through porous media is covered. Reserve calculations for normally pressured, abnormally pressured and water drive reservoirs are presented. Both stabilized and isochronal deliverability testing of gas wells will be illustrated. Prerequisite: PEGN423 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN513 - RESERVOIR SIMULATION I The course provides the rudiments of reservoir simulation, which include flow equations, solution methods, and data requirement. Specifically, the course covers: equations of conservation of mass, conservation of momentum, and energy balance; numerical solution of flow in petroleum reservoirs by finite difference (FD) and control volume FD; permeability tensor and directional permeability; non-Darcy flow; convective flow and numerical dispersion; grid orientation problems; introduction to finite element and mixed finite-element methods; introduction to hybrid analytical/numerical solutions; introduction to multi-phase flow models; relative permeability, capillary pressure and wettability issues; linear equation solvers; streamline simulation; and multi-scale simulation concept. Prerequisite: PEGN424 or equivalent, strong reservoir engineering background, and basic computer programming knowledge. 3 credit hours. 3 hours of lecture per week.

PEGN514. PETROLEUM TESTING TECHNIQUES Investigation of basic physical properties of petroleum reservoir rocks and fluids. Review of recommended practices for testing drilling fluids and oil well cements. Emphasis is placed on the accuracy and calibration of test equipment. Quality report writing is stressed. Prerequisite: Graduate status. 2 hours lecture, 1 hour lab; 3 semester hours. Required for students who do not have a BS in PE.

PEGN515. RESERVOIR ENGINEERING PRINCIPLES Reservoir Engineering overview. Predicting hydrocarbon in place; volumetric method, deterministic and probabilistic approaches, material balance, water influx, graphical techniques. Fluid flow in porous media; continuity and diffusivity equations. Well performance; productivity index for vertical, perforated, fractured, restricted, slanted, and horizontal wells, inflow performance relationship under multiphase flow conditions. Combining material balance and well performance equations. Future reservoir performance prediction; Muskat, Tarner, Carter and Tracy methods. Fetkovich decline curves. Reservoir simulation; fundamentals and formulation, streamline simulation, integrated reservoir studies. 3 hours lecture, 3 semester hours.

PEGN516. PRODUCTION ENGINEERING PRINCIPLES Production Engineering Overview. Course provides a broad introduction to the practice of production engineering. Covers petroleum system analysis, well stimulation (fracturing and acidizing), artificial lift (gas lift, sucker rod, ESP, and others), and surface facilities. 3 hours lecture, 3 semester hours.

PEGN 517. DRILLING ENGINEERING PRINCIPLES Drilling Engineering overview. Subjects to be covered include overall drilling organization, contracting, and reporting; basic drilling engineering principles and equipment; drilling fluids, hydraulics, and cuttings transport; drillstring design; drill bits; drilling optimization; fishing operations; well control; pore pressure and fracture gradients, casing

points and design; cementing; directional drilling and horizontal drilling. 3 hours lecture, 3 semester hours.

PEGN519. ADVANCED FORMATION EVALUATION A detailed review of wireline well logging and evaluation methods stressing the capability of the measurements to determine normal and special reservoir rock parameters related to reservoir and production problems. Computers for log processing of single and multiple wells. Utilization of well logs and geology in evaluating well performance before, during, and after production of hydrocarbons. The sensitivity of formation evaluation parameters in the volumetric determination of petroleum in reservoirs. Prerequisite: PEGN419 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN522. ADVANCED WELL STIMULATION Basic applications of rock mechanics to petroleum engineering problems. Hydraulic fracturing; acid fracturing, fracturing simulators; fracturing diagnostics; sandstone acidizing; sand control, and well bore stability. Different theories of formation failure, measurement of mechanical properties. Review of recent advances and research areas. Prerequisite: PEGN426 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN523. ADVANCED ECONOMIC ANALYSIS OF OIL AND GAS PROJECTS Determination of present value of oil properties. Determination of severance, ad valorem, windfall profit, and federal income taxes. Analysis of profitability indicators. Application of decision tree theory and Monte Carlo methods to oil and gas properties. Economic criteria for equipment selection. Prerequisite: PEGN422 or EBG504 or ChEN504 or MNGN427 or ChEN421 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN524. PETROLEUM ECONOMICS AND MANAGEMENT Business applications in the petroleum industry are the central focus. Topics covered are: fundamentals of accounting, oil and gas accounting, strategic planning, oil and gas taxation, oil field deals, negotiations, and the formation of secondary units. The concepts are covered by forming companies that prepare proforma financial statements, make deals, drill for oil and gas, keep accounting records, and negotiate the participation formula for a secondary unit. Prerequisite: PEGN422 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN530/ESGN502. ENVIRONMENTAL LAW -- Designed for engineers, geoscientists, managers, consultants and citizens, this course covers the basics of environmental, energy and natural resources law. Topics include: an introduction to U.S. Environmental Law, Policy and Practice; the administrative process; enforcement and liability; a survey of U.S. laws and compliance programs addressing pollution, toxic substances, endangered species, pesticides, minerals, oil & gas, land uses and others including the National Environmental Protection Act (NEPA), Resource Conservation and Recovery Act (RCRA), Underground Storage Tanks

(UST), Clean Air Act (CAA), Clean Water Act (CWA), Oil Pollution Act (OPA); Safe Drinking Water Act (SDWA); Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); Toxic Substances Control Act (TSCA) and others; an introduction to international environmental law; ethics; and case studies. 3 hours lecture; 3 semester hours.

PEGN541. APPLIED RESERVOIR SIMULATION Concepts of reservoir simulation within the context of reservoir management will be discussed. Course participants will learn how to use available flow simulators to achieve reservoir management objectives. They will apply the concepts to an open-ended engineering design problem. Prerequisites: PEGN424 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN542. INTEGRATED RESERVOIR CHARACTERIZATION The course introduces integrated reservoir characterization from a petroleum engineering perspective. Reservoir characterization helps quantify properties that influence flow characteristics. Students will learn to assess and integrate data sources into a comprehensive reservoir model. Prerequisites: PEGN424 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN550. MODERN RESERVOIR SIMULATORS Students will learn to run reservoir simulation software using a variety of reservoir engineering examples. The course will focus on the capabilities and operational features of simulators. Students will learn to use pre- and post-processors, fluid property analysis software, black oil and gas reservoir models, and compositional models. 3 hours lecture; 3 semester hours.

PEGN577. WORKOVER DESIGN AND PRACTICE Workover Engineering overview. Subjects to be covered include Workover Economics, Completion Types, Workover Design Considerations, Wellbore Cleanout (Fishing), Workover Well Control, Tubing and Workstring Design, Slickline Operations, Coiled Tubing Operations, Packer Selection, Remedial Cementing Design and Execution, Completion Fluids, Gravel Packing, and Acidizing. 3 hours lecture, 3 semester hours.

PEGN590. RESERVOIR GEOMECHANICS The course provides an introduction to fundamental rock mechanics and aims to emphasize their role in exploration, drilling, completion and production engineering operations. Deformation as a function of stress, elastic moduli, in situ stress, stress magnitude and orientation, pore pressure, strength and fracture gradient, rock characteristic from field data (seismic, logging, drilling, production), integrated wellbore stability analysis, depletion and drilling induced fractures, compaction and associated changes in rock properties, hydraulic fracturing and fracture stability are among the topics are covered. 3 hours lecture; 3 semester hours.

PEGN592. GEOMECHANICS FOR UNCONVENTIONAL RESOURCES A wide spectrum of topics related to the challenges and solutions for the exploration, drilling, completion, production and hydraulic fracturing of unconventional resources including gas and oil shale, heavy oil sand and carbonate reservoirs, their seal formations is explored. The students acquire skills in integrating and visualizing multidiscipline data in Petrel (a short tutorial is offered) as well as assignments regarding case studies using field and core datasets. The role of integrating geomechanics data in execution of the exploration, drilling, completion, production, hydraulic fracturing and monitoring of pilots as well as commercial applications in unlocking the unconventional resources are pointed out using examples. Prerequisite: PEGN590. 3 hours lecture; 3 semester hours.

PEGN593. ADVANCED WELL INTEGRITY -- Fundamentals of wellbore stability, sand production, how to keep wellbore intact are covered in this course. The stress alterations in near wellbore region and associated consequences in the form of well failures are covered in detail theoretically and with examples from deepwater conventional wells and on-shore unconventional well operations. Assignments are given to expose the students to the real field data to interpret and evaluate cases to determine practical solutions to drilling and production related challenges. Fluid pressure and composition sensitivity of various formations are studied. 3 hours lecture; 3 semester hours.

PEGN594. ADVANCED DIRECTIONAL DRILLING Application of directional control and planning to drilling. Major topics covered include: Review of procedures for the drilling of directional wells. Section and horizontal view preparation. Two and three dimensional directional planning. Collision diagrams. Surveying and trajectory calculations. Surface and down hole equipment. Common rig operating procedures, and horizontal drilling techniques. Prerequisite: PEGN311 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN595. DRILLING OPERATIONS Lectures, seminars, and technical problems with emphasis on well planning, rotary rig supervision, and field practices for execution of the plan. This course makes extensive use of the drilling rig simulator. Prerequisite: PEGN311, or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN596. ADVANCED WELL CONTROL Principles and procedures of pressure control are taught with the aid of a full-scale drilling simulator. Specifications and design of blowout control equipment for onshore and offshore drilling operations, gaining control of kicks, abnormal pressure detection, well planning for wells containing abnormal pressures, and kick circulation removal methods are taught. Students receive hands-on training with the simulator and its peripheral equipment. Prerequisite: PEGN311 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN597. TUBULAR DESIGN Fundamentals of tubulars (casing, tubing, and drill pipe) design applied to drilling. Major topics covered include: Dogleg running loads. Directional hole considerations. Design criteria development. Effects of formation pressures. Stability loads after cementing. Effects of temperature, pressure, mud weights, and cement. Helical bending of tubing. Fishing loads. Micro-annulus problem. Strengths of API tubulars. Abrasive wear while rotating drill pipe. How to design for hydrogen sulfide and fatigue corrosion. Connection selection. Common rig operating procedures. Prerequisites: PEGN311 and PEGN361 or equivalent, or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN598. SPECIAL TOPICS IN PETROLEUM ENGINEERING Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

PEGN599. INDEPENDENT STUDY Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

PEGN601. APPLIED MATHEMATICS OF FLUID FLOW IN POROUS MEDIA This course is intended to expose petroleum-engineering students to the special mathematical techniques used to solve transient flow problems in porous media. Bessel's equation and functions, Laplace and Fourier transformations, the method of sources and sinks, Green's functions, and boundary integral techniques are covered. Numerical evaluation of various reservoir engineering solutions, numerical Laplace transformation and inverse transformation are also discussed. 3 hours lecture; 3 semester hours.

PEGN603. DRILLING MODELS Analytical models of physical phenomena encountered in drilling. Casing and drilling failure from bending, fatigue, doglegs, temperature, stretch; mud filtration; corrosion; wellhead loads; and buoyancy of tubular goods. Bit weight and rotary speed optimization. Prerequisites: PEGN311 and PEGN361, or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN604. INTEGRATED FLOW MODELING Students will study the formulation, development and application of a reservoir flow simulator that includes traditional fluid flow equations and a petrophysical model. The course will discuss properties of porous media within the context of reservoir modeling, and present the mathematics needed to understand and apply the simulator. Simulator applications will be interspersed throughout the course. 3 hours lecture; 3 semester hours.

PEGN605. WELL TESTING AND EVALUATION Various well testing procedures and interpretation techniques for individual wells or groups of wells. Application of these techniques to field development, analysis of well problems, secondary recovery, and reservoir studies. Productivity, gas well testing, pressure buildup and drawdown, well interference, fractured wells, type curve matching, and short-term testing. Prerequisite: PEGN426 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN606. ADVANCED RESERVOIR ENGINEERING A review of depletion type, gas-cap, and volatile oil reservoirs. Lectures and supervised studies on gravity segregation, moving gas-oil front, individual well performance analysis, history matching, performance prediction, and development planning. Prerequisite: PEGN423 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN607. PARTIAL WATER DRIVE RESERVOIRS The hydrodynamic factors which influence underground water movement, particularly with respect to petroleum reservoirs. Evaluation of oil and gas reservoirs in major water containing formations. Prerequisite: PEGN424 or consent of instructor. 3 hours lecture; 3 semester hours.

PEGN608. MULTIPHASE FLUID FLOW IN POROUS MEDIA: The factors involved in multiphase fluid flow in porous and fractured media. Physical processes and mathematical models for micro- and macroscopic movement of multiphase fluids in reservoirs. Performance evaluation of various displacement processes in the laboratory as well as in the petroleum field during the secondary and EOR/IOR operations. Prerequisite: PEGN 424, or consent of instructor, 3 hours lecture; 3 semester hours.

PEGN614. RESERVOIR SIMULATION II: The course reviews the rudiments of reservoir simulation and flow equations, solution methods, and data requirement. The course emphasizes multi-phase flow and solution techniques; teaches the difference between conventional reservoir simulation, compositional modeling and multi-porosity modeling; teaches how to construct three-phase relative permeability from water-oil and gas-oil relative permeability data set; the importance of capillary pressure measurements and wettability issues; discusses the significance of gas diffusion and interphase mass transfer. Finally, the course develops solution techniques to include time tested implicit-pressure-explicit-saturation, sequential and fully implicit methods. Prerequisite: PEGN513 or equivalent, strong reservoir engineering background, and basic computer programming knowledge. 3 credit hours. 3 hours of lecture per week.

PEGN615. SHALE RESERVOIR ENGINEERING Fundamentals of shale-reservoir engineering and special topics of production from shale reservoirs are covered. The question of what makes shale a producing reservoir is explored. The pitfalls of conventional measurements and interpretations for unconventional reservoirs are discussed. Geological, geome-

chanical, and engineering aspects of shale reservoirs are explained. Well completions with emphasis on hydraulic fracturing and fractured horizontal wells are discussed from the view-point of reservoir engineering. Darcy flow, diffusive flow, and desorption in shale matrix are covered. Contributions of hydraulic and natural fractures and their interactions are discussed and the stimulated reservoir volume concept is introduced. Applications of pressure-transient, rate-transient, decline-curve and transient-productivity analyses are covered. 3 hours lecture; 3 semester hours.

PEGN619. **GEOMECHANICALLY AND PHYSICO-CHEMICALLY COUPLED FLUID FLOW IN POROUS MEDIA** The role of physico-chemistry and geomechanics on fluid flow in porous media will be included in addition to conventional fluid flow modeling and measurements in porous media. The conventional as well as unconventional reservoirs are studied with the coupling of physicochemical effects and geomechanics stresses. Assignments are given to expose the students to the real field data in interpretation and evaluation of filed cases to determine practical solutions to drilling and production related modeling challenges. Prerequisite: PEGN590. 3 hours lecture; 3 semester hours.

PEGN620. **NATURALLY FRACTURED RESERVOIRS--ENGINEERING AND RESERVOIR SIMULATION** The course covers reservoir engineering, well testing, and simulation aspects of naturally fractured reservoirs. Specifics include: fracture description, connectivity and network; fracture properties; physical principles underlying reservoir engineering and modeling naturally fractured reservoirs; local and global effects of viscous, capillary, gravity and molecular diffusion flow; dual-porosity/dual-permeability models; multi-scale fracture model; dual-mesh model; streamline model; transient testing with non-Darcy flow effects; tracer injection and breakthrough analysis; geomechanics and fractures; compositional model; coal-bed gas model; oil and gas from fractured shale; improved and enhanced oil recovery in naturally fracture reservoirs. Prerequisite: PEGN513 or equivalent, strong reservoir engineering background, and basic computer programming knowledge. 3 hours lecture; 3 semester hours.

PEGN624. **COMPOSITIONAL MODELING - APPLICATION TO ENHANCED OIL RECOVERY** Efficient production of rich and volatile oils as well as enhanced oil recovery by gas injection (lean and rich natural gas, CO₂, N₂, air, and steam) is of great interest in the light of greater demand for hydrocarbons and the need for CO₂ sequestration. This course is intended to provide technical support for engineers dealing with such issues. The course begins with a review of the primary and secondary recovery methods, and will analyze the latest worldwide enhanced oil recovery production statistics. This will be followed by presenting a simple and practical solvent flooding model to introduce the student to

data preparation and code writing. Next, fundamentals of phase behavior, ternary phase diagram, and the Peng-Robinson equation of state will be presented. Finally, a detailed set of flow and thermodynamic equations for a full-fledged compositional model, using molar balance, equation of motion and the afore-mentioned equation of state, will be developed and solution strategy will be presented. Prerequisite: PEGN513 or equivalent, strong reservoir engineering background, and basic computer programming knowledge. 3 hours lecture; 3 semester hours.

PEGN681. **PETROLEUM ENGINEERING SEMINAR** Comprehensive reviews of current petroleum engineering literature, ethics, and selected topics as related to research and professionalism. 2 hours seminar; 3 semester hour.

PEGN698. **SPECIAL TOPICS IN PETROLEUM ENGINEERING** Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: Instructor consent. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

PEGN699. **INDEPENDENT STUDY** Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. An "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

PEGN705. **GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE** Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor. Repeatable for credit.

PEGN706. **GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY** Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor. Repeatable for credit.

Physics

THOMAS E. FURTAK, Professor and Department Head
REUBEN T. COLLINS, Professor
UWE GREIFE, Professor
FRANK V. KOWALSKI, Professor
MARK T. LUSK, Professor
JOHN A. SCALES, Professor
JEFF A. SQUIER, Professor
P. CRAIG TAYLOR, Professor
LINCOLN D. CARR, Associate Professor
CHARLES G. DURFEE III, Associate Professor
TIMOTHY R. OHNO, Associate Professor
FREDERIC SARAZIN, Associate Professor
ERIC S. TOBERER, Assistant Professor
LAWRENCE R. WIENCKE, Associate Professor
DAVID M. WOOD, Associate Professor
ZHIGANG WU, Assistant Professor
TODD G. RUSKELL, Teaching Professor
CHARLES A. STONE, Teaching Professor
MATTHEW M. YOUNG, Teaching Professor
ALEX T. FLOURNOY, Teaching Associate Professor
PATRICK B. KOHL, Teaching Associate Professor
H. VINCENT KUO, Teaching Associate Professor
JOHN U. TREFNY, Professor Emeritus and President Emeritus
F. EDWARD CECIL, University Professor Emeritus
JAMES T. BROWN, Professor Emeritus
JOHN A. DESANTO, Professor Emeritus
JAMES A. McNEIL, University Professor Emeritus
FRANKLIN D. SCHOWENGERDT, Professor Emeritus
DON L. WILLIAMSON, Professor Emeritus
F. RICHARD YEATTS, Professor Emeritus
WILLIAM B. LAW, Associate Professor Emeritus
ARTHUR Y. SAKAKURA, Associate Professor Emeritus
JOSEPH D. BEACH, Research Associate Professor
JAMES E. BERNARD, Research Associate Professor
M. SCOTT BRADLEY, Research Assistant Professor
MARK W. COFFEY, Research Professor
P. DAVID FLAMMER, Research Assistant Professor
ALBERTO FRANCESCHETTI, Research Professor
DAVID S. GINLEY, Research Professor
FREDRICK E. GRAY, Research Assistant Professor
RUSSELL E. HOLLINGSWORTH, Research Professor
G. MARTIN HUDSON, Research Professor
JONATHAN L. MACE, Research Professor
DANA C. OLSON, Research Assistant Professor
VOICU A. POPESCU, Research Assistant Professor
ZEEV SHAYER, Research Professor
STEVE J. SMITH, Research Assistant Professor
PAULS STRADINS, Research Professor
ADELE C. TAMBOLI, Research Assistant Professor
QI WANG, Research Professor
JOHN M. YARBROUGH, Research Assistant Professor
XIUWEN ZHANG, Research Assistant Professor

Degrees Offered:

- Master of Science (Applied Physics)
- Doctor of Philosophy (Applied Physics)

Program Description:

The Physics Department at CSM offers a full program of instruction and research leading to the M.S. or Ph.D. in applied physics.

Graduate students are given a solid background in the fundamentals of classical and modern physics at an advanced level and are encouraged early in their studies to learn about the research interests of the faculty so that a thesis topic can be identified.

Program Requirements:

Students entering graduate programs in Applied Physics will select an initial program in consultation with the departmental graduate student advising committee until such time as a research field has been chosen and a thesis committee appointed. The following are requirements for the M.S. and Ph.D. degrees:

Master's: 20 semester hours of course work in an approved program plus 16 semester hours of research credit, with a satisfactory thesis. Doctorate: 34 semester hours of course work in an approved program plus 38 semester hours of research credit, with a satisfactory thesis. 12 semester hours of course work will be in a specialty topic area defined in consultation with the thesis advisor. Possible specialty topic areas within the physics department exist in Optical Science and Engineering, Condensed Matter Physics, Theoretical Physics, Renewable Energy Physics, and Nuclear/Particle Physics and Astrophysics.

To demonstrate adequate preparation for the Ph.D. degree in Applied Physics, each student must pass the physics graduate core courses with a grade point average of 3.0 or better. Students not achieving this standard must pass oral examinations covering the areas of weakness identified in the core courses or retake the respective course with a grade of 3.0 or better within one year. This process is part of the requirement for admission to candidacy, which full time Ph.D. students must complete within two calendar years of admission, as described in the campus-wide graduate degree requirements section of this bulletin. Other degree requirements, time limits, and procedural details can be found in the Physics Department Graduate Student Advising Brochure.

All full-time physics graduate students must attend the Physics Colloquium, which is represented in the curriculum by the Graduate Seminar courses. Students must take one of these courses every semester that they are enrolled at CSM. Those students who are in the M.S. Program, or those in the Ph.D. program who have not yet been admitted to candidacy should sign up for PHGN501 (fall) and PHGN502 (spring), while Ph.D. students who have been admitted to candidacy should sign up for PHGN601 (fall) and PHGN602 (spring). All semester attendance grades will be combined to yield final grades for these courses at the end of the student's final semester. Students who have official part-time status, and who have already taken at least one semester of 501 and 502

for the M.S. degree, or 501, 502, 601, and 602 for the Ph.D. degree, are not required to sign up for additional graduate seminar credits.

Prerequisites:

The Graduate School of the Colorado School of Mines is open to graduates from four-year programs at accredited colleges or universities. Admission to the Physics Department M.S. and Ph.D. programs is competitive and is based on an evaluation of undergraduate performance, standardized test scores, and references. The undergraduate course of study of each applicant is evaluated according to the requirements of the Physics Department.

Required Curriculum:

Master of Science, Applied Physics

Core Courses

PHGN511 Mathematical Physics I

PHGN520 Quantum Mechanics I

One additional course selected from:

PHGN505 Classical Mechanics I

PHGN507 Electromagnetic Theory I

PHGN521 Quantum Mechanics II

PHGN530 Statistical Mechanics

Electives - 9 hours.

Graduate Seminar* - 2 hours: PHGN501 and PHGN502

Master's Thesis

Doctor of Philosophy, Applied Physics

Core Courses

PHGN505 Classical Mechanics I

PHGN507 Electromagnetic Theory I

PHGN511 Mathematical Physics I

PHGN520 Quantum Mechanics I

PHGN521 Quantum Mechanics II

PHGN530 Statistical Mechanics

Graduate Seminar* - 4 hours: PHGN 501, PHGN502, PHGN601 and PHGN602

12 hours special topic area electives.

Doctoral Thesis.

*Graduate Seminar: Each full-time graduate student (M.S. and Ph.D.) will register for Graduate Seminar each semester for a total of 2 semester hours credit for the M.S. and 4 semester hours credit for the Ph.D.

Fields of Research:

Applied Optics: lasers, ultrafast optics and x-ray generation, spectroscopy, near-field and multi-photon microscopy, non-linear optics, quasi-optics and millimeter waves.

Ultrasonics: laser ultrasonics, resonant ultrasound spectroscopy, wave propagation in random media.

Subatomic: low energy nuclear physics, nuclear astrophysics, cosmic ray physics, nuclear theory, fusion plasma diagnostics.

Materials Physics: photovoltaics, nanostructures and quantum dots, thin film semiconductors, transparent conductors, amorphous materials, thermoelectric materials, plasmonics, first principles materials theory.

Condensed Matter: x-ray diffraction, Raman spectroscopy, self assembled systems, soft condensed matter, condensed matter theory, quantum chaos, quantum information and quantum many body theory.

Surface and Interfaces: x-ray photoelectron spectroscopy, Auger spectroscopy, scanning probe microscopies, second harmonic generation.

Description of Courses

Senior Level

PHGN401. THEORETICAL PHYSICS SEMINAR (I,II).

Students will attend the weekly theoretical physics seminar.

Students will be responsible for presentation and discussion.

Corequisite: PHGN300/310. 1 hour lecture; 1 semester hour.

PHGN412. MATHEMATICAL PHYSICS Mathematical techniques applied to the equations of physics; complex variables, partial differential equations, special functions, finite and infinite-dimensional vector spaces. Green's functions. Transforms; computer algebra. Prerequisite: PHGN311. 3 hours lecture; 3 semester hours.

PHGN419. PRINCIPLES OF SOLAR ENERGY SYSTEMS Review of the solar resource and components of solar irradiance; principles of photovoltaic devices and photovoltaic system design; photovoltaic electrical energy production and cost analysis of photovoltaic systems relative to fossil fuel alternatives; introduction to concentrated photovoltaic systems and manufacturing methods for wafer-based and thin film photovoltaic panels. Prerequisite: PHGN200 and MATH225. 3 hours lecture; 3 semester hours.

PHGN422. NUCLEAR PHYSICS Introduction to subatomic (particle and nuclear) phenomena. Characterization and systematics of particle and nuclear states; symmetries; introduction and systematics of the electromagnetic, weak, and strong interactions; systematics of radioactivity; liquid drop and shell models; nuclear technology. Prerequisite: PHGN300/310. 3 hours lecture; 3 semester hours.

PHGN424. ASTROPHYSICS A survey of fundamental aspects of astrophysical phenomena, concentrating on measurements of basic stellar properties such as distance, luminosity, spectral classification, mass, and radii. Simple models of stellar structure evolution and the associated nuclear processes as sources of energy and nucleosynthesis. Introduction to cosmology and physics of standard big-bang models. Prerequisite: PHGN320. 3 hours lecture; 3 semester hours.

PHGN435/ChEN435/ChEN535/PHGN535/MLGN535. INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY Application of science and engineering principles to the design, fabrication, and testing of microelectronic devices. Emphasis on specific unit operations and the interrelation among processing steps. Prerequisites: Senior standing in PHGN, ChEN, MTGN, or EGGN; consent of instructor. 1.5 hours lecture, 4 hours lab; 3 semester hours.

PHGN440/MLGN502. SOLID STATE PHYSICS An elementary study of the properties of solids including crystalline structure and its determination, lattice vibrations, electrons in metals, and semiconductors. (Graduate students in physics may register only for PHGN440.) Prerequisite: PHGN320. 3 hours lecture; 3 semester hours.

PHGN441/MLGN522. SOLID STATE PHYSICS APPLICATION AND PHENOMENA Continuation of PHGN440/MLGN502 with an emphasis on applications of the principles of solid state physics to practical properties of materials including: optical properties, superconductivity, dielectric properties, magnetism, noncrystalline structure, and interfaces. (Graduate students in physics may register only for PHGN441.) Prerequisite: PHGN440/MLGN501 or equivalent by instructor's permission. 3 hours lecture; 3 semester hours.

PHGN450. COMPUTATIONAL PHYSICS Introduction to numerical methods for analyzing advanced physics problems. Topics covered include finite element methods, analysis of scaling, efficiency, errors, and stability, as well as a survey of numerical algorithms and packages for analyzing algebraic, differential, and matrix systems. The numerical methods are introduced and developed in the analysis of advanced physics problems taken from classical physics, astrophysics, electromagnetism, solid state, and nuclear physics. Prerequisites: Introductory-level knowledge of C, Fortran or Basic; PHGN311. 3 hours lecture; 3 semester hours.

PHGN462. ELECTROMAGNETIC WAVES AND OPTICAL PHYSICS (I) Solutions to the electromagnetic wave equation and polarization; applications in optics: imaging, lasers, resonators and wavelengths. Prerequisite: PHGN361. 3 hours lecture; 3 semester hours.

PHGN466. MODERN OPTICAL ENGINEERING Provides students with a comprehensive working knowledge of optical system design that is sufficient to address optical problems found in their respective disciplines. Topics include paraxial optics, imaging, aberration analysis, use of commercial ray-tracing and optimization, diffraction, linear systems and optical transfer functions, detectors and optical systems examples. Prerequisite: PHGN462 or consent of the instructor. 3 hours lecture; 3 semester hours.

PHGN471. SENIOR DESIGN PRINCIPLES (I) (WI) The first of a two semester sequence covering the principles of project design. Class sessions cover effective team organiza-

tion, project planning, time management, literature research methods, record keeping, fundamentals of technical writing, professional ethics, project funding and intellectual property. Prerequisite: PHGN384 and PHGN326. Corequisite: PHGN481. 1 hour lecture in 7 class sessions; 0.5 semester hours.

PHGN472. SENIOR DESIGN PRINCIPLES (II) (WI) Continuation of PHGN471. Prerequisite: PHGN384 and PHGN326. Corequisite: PHGN482. 1 hour lecture in 7 class sessions; 0.5 semester hours.

PHGN480. LASER PHYSICS (I) Theory and application of the following: Gaussian beams, optical cavities and wave guides, atomic radiation, detection of radiation, laser oscillation, nonlinear optics and ultrafast pulses. Prerequisite: PHGN320. Corequisite: PHGN462. 3 hours lecture; 3 semester hours.

PHGN481. SENIOR DESIGN PRACTICE (I) (WI) The first of a two semester program covering the full spectrum of project design, drawing on all of the student's previous course work. At the beginning of the first semester, the student selects a research project in consultation with the Senior Design Oversight Committee (SDOC) and the Project Mentor. The objectives of the project are given to the student in broad outline form. The student then designs the entire project, including any or all of the following elements as appropriate: literature search, specialized apparatus or algorithms, block-diagram electronics, computer data acquisition and/or analysis, sample materials, and measurement and/or analysis sequences. The course culminates in a formal interim written report. Prerequisite: PHGN384 and PHGN326. Corequisite: PHGN471. 7.5 hour lab; 2.5 semester hours.

PHGN482. SENIOR DESIGN PRACTICE (II) (WI) Continuation of PHGN481. The course culminates in a formal written report and poster. Prerequisite: PHGN384 and PHGN326. Corequisite: PHGN472. 7.5 hour lab; 2.5 semester hours.

PHGN491. HONORS SENIOR DESIGN PRACTICE (I) (WI) Individual work on an advanced research topic that involves more challenging demands than a regular senior design project. Honors students will devote more time to their project, and will produce an intermediate report in a more advanced format. Prerequisite: PHGN384 and PHGN326. Corequisite: PHGN471. 7.5 hour lab; 2.5 semester hours.

PHGN492. HONORS SENIOR DESIGN PRACTICE (II) (WI) Continuation of PHGN481 or PHGN491. The course culminates in a formal written report and poster. The report may be in the form of a manuscript suitable for submission to a professional journal. Prerequisite: PHGN481 or PHGN491. Corequisite: PHGN472. 7.5 hour lab; 2.5 semester hours.

PHGN498. SPECIAL TOPICS (I, II) Pilot course or special topics course. Prerequisites: Consent of instructor. Credit to be determined by instructor, maximum of 6 credit hours.

PHGN499. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member; student and instructor agree on a subject matter, content, deliverables, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours.

Graduate Courses

500-level courses are open to qualified seniors with the permission of the department and the Dean of the Graduate School.

PHGN501. GRADUATE SEMINAR (I) M.S. students and Ph.D. students who have not been admitted to candidacy will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. See additional course registration instructions under Program Requirements above. 1 hour seminar; 1 semester hour.

PHGN502. GRADUATE SEMINAR (II) M.S. students and Ph.D. students who have not been admitted to candidacy will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. See additional course registration instructions under Program Requirements above. 1 hour seminar; 1 semester hour.

PHGN504. RADIATION DETECTION AND MEASUREMENT Physical principles and methodology of the instrumentation used in the detection and measurement of ionizing radiation. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours.

PHGN505. CLASSICAL MECHANICS I (I) Review of Lagrangian and Hamiltonian formulations in the dynamics of particles and rigid bodies; kinetic theory; coupled oscillations and continuum mechanics; fluid mechanics. Prerequisite: PHGN350 or equivalent. 3 hours lecture; 3 semester hours.

PHGN507. ELECTROMAGNETIC THEORY I (II) To provide a strong background in electromagnetic theory. Electrostatics, magnetostatics, dynamical Maxwell equations, wave phenomena. Prerequisite: PHGN462 or equivalent and PHGN511. 3 hours lecture; 3 semester hours.

PHGN511. MATHEMATICAL PHYSICS (I) Review of complex variable and finite and infinite-dimensional linear vector spaces. Sturm-Liouville problem, integral equations, computer algebra. Prerequisite: PHGN311 or equivalent. 3 hours lecture; 3 semester hours.

PHGN520. QUANTUM MECHANICS I (II) Schroedinger equation, uncertainty, change of representation, one-dimensional problems, axioms for state vectors and operators, matrix mechanics, uncertainty relations, time-independent perturbation theory, time-dependent perturbations, harmonic oscillator, angular momentum; semiclassical methods, variational methods, two-level system, sudden and adiabatic

changes, applications. Prerequisite: PHGN511 and PHGN320 or equivalent. 3 hours lecture; 3 semester hours.

PHGN521. QUANTUM MECHANICS II (I) Review of angular momentum, central potentials and applications. Spin; rotations in quantum mechanics. Formal scattering theory, Born series, partial wave analysis. Addition of angular momenta, Wigner-Eckart theorem, selection rules, identical particles. Prerequisite: PHGN520. 3 hours lecture; 3 semester hours.

PHGN530. STATISTICAL MECHANICS (I) Review of thermodynamics; equilibrium and stability; statistical operator and ensembles; ideal systems; phase transitions; non-equilibrium systems. Prerequisite: PHGN341 or equivalent and PHGN520. Co-requisite: PHGN521. 3 hours lecture; 3 semester hours.

PHGN535/ChEN535/MLGN535/ChEN435/PHEN435. INTERDISCIPLINARY SILICON PROCESSING LABORATORY (II) Explores the application of science and engineering principles to the fabrication and testing of micro-electronic devices with emphasis on specific unit operations and interrelation among processing steps. Teams work together to fabricate, test, and optimize simple devices. Prerequisite: Consent of instructor. 1 hour lecture, 4 hours lab; 3 semester hours.

PHGN542. SOLID STATE DEVICES AND PHOTO-VOLTAIC APPLICATIONS (II) An overview of the physical principles involved in the characterization, and operation of solid state devices. Topics will include: semiconductor physics, electronic transport, recombination and generation, intrinsic and extrinsic semiconductors, electrical contacts, p-n junction devices (e.g., LEDs, solar cells, lasers, particle detectors); other semiconductor devices (e.g., bipolar junction transistors and field effect transistors and capacitors). There will be emphasis on optical interactions and application to photovoltaic devices. Prerequisite: PHGN440 or equivalent or consent of instructor. 3 hours lecture; 3 semester hours.

PHGN550 NANOSCALE PHYSICS AND TECHNOLOGY An introduction to the basic physics concepts involved in nanoscale phenomena, processing methods resulting in engineered nanostructures, and the design and operation of novel structures and devices which take advantage of nanoscale effects. Students will become familiar with interdisciplinary aspects of nanotechnology, as well as with current nanoscience developments described in the literature. Prerequisites: PHGN 320, PHGN 341, co-requisite: PHGN462, or permission of instructor. 3 hours lecture; 3 semester hours.

PHGN566. MODERN OPTICAL ENGINEERING Provides students with a comprehensive working knowledge of optical system design that is sufficient to address optical problems found in their respective disciplines. Topics include paraxial optics, imaging, aberration analysis, use of commercial ray tracing and optimization, diffraction, linear systems and optical transfer functions, detectors, and optical system exam-

ples. Prerequisite: PHGN462 or consent of instructor. 3 hours lecture; 3 semester hours.

PHGN 570. FOURIER AND PHYSICAL OPTICS This course addresses the propagation of light through optical systems. Diffraction theory is developed to show how 2D Fourier transforms and linear systems theory can be applied to imaging systems. Analytic and numerical Fourier and Fresnel transform techniques are applied to systems such as microscopes, spectrometers and holographic imaging. They are also applied to temporal propagation in ultrafast optics. Prerequisite: PHGN 462 or equivalent, or permission of instructor. 3 hours lecture; 3 semester hours.

PHGN 585. NONLINEAR OPTICS An exploration of the nonlinear response of a medium (semiclassical and quantum descriptions) and nonlinear wave mixing and propagation. Analytic and numeric techniques to treat nonlinear dynamics are developed. Applications to devices and modern research areas are discussed, including harmonic and parametric wave generation and phase matching, self-focusing, self-phase modulation, phase conjugation, electro-optic modulation. Prerequisite: PHGN 462 or equivalent, PHGN 520, or by permission of instructor. 3 hours lecture; 3 semester hours.

PHGN590. NUCLEAR REACTOR PHYSICS. Bridges the gap between courses in fundamental nuclear physics and the practice of electrical power production using nuclear reactors. Review of nuclear constituents, forces, structure, energetics, decay and reactions; interaction of radiation with matter, detection of radiation; nuclear cross sections, neutron induced reactions including scattering, absorption, and fission; neutron diffusion, multiplication, criticality; simple reactor geometries and compositions; nuclear reactor kinetics and control; modeling and simulation of reactors. Prerequisites: PHGN422 or consent of instructor.

PHGN597. SUMMER PROGRAMS

PHGN598. SPECIAL TOPICS (I, II) Pilot course or special topics course. Prerequisites: Consent of department. Credit to be determined by instructor, maximum of 6 credit hours.

PHGN599. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member; student and instructor agree on a subject matter, content, deliverables, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours.

PHGN601. ADVANCED GRADUATE SEMINAR (I) Ph.D. students who have been admitted to candidacy will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. Prerequisite: credit in PHGN501 and PHGN502. See additional course registration instructions under Program Requirements above. 1 hour seminar; 1 semester hour.

PHGN602. ADVANCED GRADUATE SEMINAR (II) Ph.D. students who have been admitted to candidacy will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. See additional course registration instructions under Program Requirements above. Prerequisite: credit in PHGN501 and PHGN502. 1 hour seminar; 1 semester hour.

PHGN608. ELECTROMAGNETIC THEORY II Spherical, cylindrical, and guided waves; relativistic 4-dimensional formulation of electromagnetic theory. Prerequisite: PHGN507. 3 hours lecture; 3 semester hours. Offered on demand.

PHGN612. MATHEMATICAL PHYSICS II Continuation of PHGN511. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered on demand.

PHGN623. NUCLEAR STRUCTURE AND REACTIONS The fundamental physics principles and quantum mechanical models and methods underlying nuclear structure, transitions, and scattering reactions. Prerequisite: PHGN521 or consent of instructor. 3 hours lecture; 3 semester hours. Offered on demand.

PHGN624. NUCLEAR ASTROPHYSICS The physical principles and research methods used to understand nucleosynthesis and energy generation in the universe. Prerequisite: Consent of instructor. 3 hours lecture; 3 semester hours. Offered on demand.

PHGN641. ADVANCED CONDENSED MATTER PHYSICS (II) Provides working graduate-level knowledge of applications of solid state physics and important models to crystalline and non-crystalline systems in two and three dimensions. Prerequisite: PHGN440 or equivalent, PHGN520, PHGN530. 3 hours lecture; 3 semester hours.

PHGN698. SPECIAL TOPICS (I, II) Pilot course or special topics course. Prerequisites: Consent of department. Credit to be determined by instructor, maximum of 6 credit hours.

PHGN699. INDEPENDENT STUDY (I, II) Individual research or special problem projects supervised by a faculty member; student and instructor agree on a subject matter, content, deliverables, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours.

PHGN705. GRADUATE RESEARCH CREDIT: MASTER OF SCIENCE Research credit hours required for completion of the degree Master of Science - thesis. Research must be carried out under the direct supervision of the graduate student's faculty advisor.

PHGN706. GRADUATE RESEARCH CREDIT: DOCTOR OF PHILOSOPHY Research credit hours required for completion of the degree Doctor of Philosophy. Research must be carried out under direct supervision of the graduate student's faculty advisor.

Systems

Description of Courses

Graduate Courses

SYGN501. THE ART OF SCIENCE This course consists of class sessions and practical exercises. The content of the course is aimed at helping students acquire the skills needed for a career in research. The class sessions cover topics such as the choice of a research topic, making a work plan and executing that plan effectively, what to do when you are stuck, how to write a publication and choose a journal for publication, how to write proposals, the ethics of research, the academic career versus a career in industry, time-management, and a variety of other topics. The course is open to students with very different backgrounds; this ensures a rich and diverse intellectual environment. Prerequisite: Consent of instructor. 1 hour lecture; 1 semester hour.

SYGN502. INTRODUCTION TO RESEARCH ETHICS A five-week course that introduces students to the various components of responsible and research practices. Topics covered move from issues related to the planning of research through the conducting of research to the dissemination of research results. The course culminates with students writing and defending their ethics statements. 1 hour lecture/lab; 1 semester hour.

SYGN555. SMARTGEO SEMINAR Geosystems are natural or engineered earth structures, e.g. earth dams or levees, groundwater systems, underground construction sites, and contaminated aquifers. An intelligent geosystem is one that can sense its environment, diagnose its condition/state, and provide decision support to improve the management, operation, or objective of the geosystem. The goal of this course is to introduce students to topics that are needed for them to be successful working in a multi-disciplinary field. The course will include training in leadership, multidisciplinary teams, policy and ethical issues, and a monthly technical seminar. Prerequisite/Corequisite: SYGN 550. 1 hour lecture; 1 semester hour credit.

SYGN600. COLLEGE TEACHING This course is designed for graduate students planning careers in academia and focuses on principles of learning and teaching in a college setting; methods to foster and assess higher order thinking; and effective design, delivery and assessment of college courses. Prerequisite: Permission of the instructor. 2 hours lecture; 2 semester hours.

Research Centers and Institutes

8th Continent Project

The 8th Continent Project is a comprehensive effort to integrate space technology and resources into the global economy. It includes a chamber of commerce, business incubator, funding network and research center. The Project is organizing "Space 2.0" - the emerging generation of entrepreneurial space-related business ventures - to apply space technology to a variety of multidisciplinary challenges, from global warming to resource and energy development to biotechnology.

Advanced Coatings and Surface Engineering Laboratory

The Advanced Coating and Surface Engineering Laboratory (ACSEL) is a multi-disciplinary laboratory that serves as a focal point for industry-driven research and education in advanced thin films and coating systems, surface engineering, tribology, electronic, optical and magnetic thin films and devices. The laboratory is supported by a combination of government funding agencies (NSF, DOE, DOD) and an industrial consortium that holds annual workshops designed to maximize interaction between participants, evaluate the research conducted by graduate students and faculty, and provide direction and guidance for future activities. ACSEL provides opportunities for CSM faculty and graduate students to visit and work in sponsor facilities, participate in technical meetings with sponsors, and for CSM graduates to gain employment with sponsors.

Advanced Control of Energy and Power Systems

The Advanced Control of Energy and Power Systems Center (ACEPS), based in the Engineering Division, features a unique partnership consisting of industry, the Department of Energy (DOE), the Electric Power Research Institute (EPRI), Colorado School of Mines (CSM) and twelve other universities. The mission of ACEPS is to conduct fundamental and applied research supporting the technical advancement of the electric utility industry, their customers, and component suppliers in the field of electric power systems and power electronics. Special emphasis is placed on advanced/intelligent control and power quality in the generation, transmission, distribution, and utilization.

Center research projects focus on the development of an intelligent energy system that will employ advanced power electronics, enhanced computer and communications systems, renewable energy applications and distributed generation. Examples include development of intelligent substations, impact of highly varying loads, power quality, electrical equipment life assessment, and intelligent automatic generation control for transient loads.

Advanced Mineralogy Research Center

The Advanced Mineralogy Research Center (AMRC), is an Independent Center dedicated to the characterization of a broad array of materials in mining, energy, environmental, and planetary applications. The focus of the Center is to provide improved understanding of geological and mineralogical materials in order to better predict their management, development, and the effective recovery of resources. The AMRC utilizes scanning-electron-microscopy-based quantitative mineralogy techniques with high-speed, image-analysis capabilities. Particles and solid materials from the micron-scale to hand sample size are analyzed to determine the distribution of minerals, ores, fabrics, textures, porosity, fracture distribution, alteration, and other attributes critical to understanding the material properties and behavior. The AMRC encourages interdisciplinary research, particularly in new and developing areas such as geomet, oil shale and unconventional energy resources, environmental materials characterization, medical geology, and lunar materials science. The Center includes two sample preparation laboratories, an analytical laboratory, and work stations and hot-seats for visiting researchers. Short courses in applications and data management using image analysis and quantification software are given at the beginning of each semester, and further training is available onsite. Students, faculty, university and government researchers, and commercial partners provide projects in a range of applications with the common goal of solving problems related to mineral characterization.

Advanced Steel Processing and Products Research Center

The Advanced Steel Processing and Products Research Center (ASPPRC) at Colorado School of Mines was established in 1984. The Center is a unique partnership between industry, the National Science Foundation (NSF), and Colorado School of Mines, and is devoted to building excellence in research and education in the ferrous metallurgy branch of materials science and engineering. Objectives of ASPPRC are to perform research of direct benefit to the users and producers of steels, to educate graduate students within the context of research programs of major theoretical and practical interest to the steel-using and steel-producing industries, to stimulate undergraduate education in ferrous metallurgy, and to develop a forum to stimulate advances in the processing, quality and application of steel.

Research programs consist of several projects, each of which is a graduate student thesis. Small groups of students and faculty are involved in each of the research programs. Sponsor representatives are encouraged to participate on the graduate student committees.

The Center was established with a five-year grant of \$575,000 from the National Science Foundation, and is now self-sufficient, primarily as a result of industry support.

Advanced Water Technology Center

The Advanced Water Technology Center (AQWATEC) was established in 2006 to support the advancement of the campus' thrust areas of water and renewable energy. Research activities at AQWATEC are directed to advance research and development of novel water treatment processes and hybrid systems to enable sustainable and energy efficient utilization of impaired water sources to provide potable and non-potable water supplies. Our focus areas include:

- ◆ To conduct world-class research on teaching and learning in engineering and science.
- ◆ Advanced natural systems for elimination of emerging contaminants from the environment
- ◆ Traditional and novel membrane separation processes for water purification, reuse and desalination including zero-liquid discharge
- ◆ Development of multiple-barrier hybrid processes to provide more efficient water treatment systems
- ◆ Predictive tools for process performance/reliability and water quality assessments
- ◆ Advanced concepts in decentralized water treatment facilities
- ◆ Development of more efficient water treatment systems for the industrial and renewable energy sector
- ◆ Treatment and management strategies for produced water from unconventional gas resources

AQWATEC operates two major on-campus facilities, a state-of-the-art water quality analysis laboratory and a high-bay facility for laboratory- and pilot-scale research. The center also jointly operates a state-of-the-art surface water pilot plant at Golden's Water Treatment Plant and supports the Rocky Mountain Onsite & Small Flow Program by operating advanced pilot-scale system for onsite wastewater treatment. AQWATEC faculty currently sustain a research funding base of over \$6.6M via active grants and contracts from AwwaRF, WERF, WRF, NSF, Cal DWR, U.S. Bureau of Reclamation, U.S. Department of Energy, NREL, and private industry.

Center for Assessment in Science, Technology, Engineering and Mathematics (CA:STEM)

The mission of the Center for Assessment (CA) in Science, Technology, Engineering and Mathematics (STEM) at the Colorado School of Mines (CSM) is to improve the methodologies used in the assessment of educational interventions in the STEM disciplines. CA:STEM's role is to bring together experts in quantitative research, qualitative research, and STEM content with the purpose of improving the evaluation of educational research projects and the validity of the interpretations made based on the results of those projects. CA:STEM also provides a training ground for undergraduate students, graduate students and researchers who are interested in assessment and evaluation. The primary goals of CA:STEM are:

- ◆ To conduct research in the assessment of STEM disciplines at all levels, kindergarten through graduate education.
- ◆ To provide evaluation experts for educational research projects (kindergarten through graduate education) conducted both in CSM and across the nation.
- ◆ To train undergraduate and graduate students in both qualitative and quantitative research techniques for the evaluation of educational research projects in the STEM disciplines.

Center for Automation, Robotics and Distributed Intelligence

The mission of the Center for Automation, Robotics and Distributed Intelligence (CARDI) is to engage in interdisciplinary research encompassing the fields of control systems, robotics and automation, and distributed systems and networking. Focus areas include the theory of adaptive and non-linear control, intelligent and learning control systems, system identification and fault detection, computer vision and image processing, wireless communication networks, intelligent autonomous robotic systems, machine learning and artificial intelligence, network communication protocols and simulation and modeling of computer networks. Applications of CARDI research can be found in renewable energy and power systems, materials processing, sensor and control networks, bio-engineering and medicine, data mining and activity recognition, defense and homeland security, smart structures, intelligent geo-systems, and environmental monitoring. CARDI research concentrates on problems which are not amenable to traditional solutions within a single discipline, but rather require a multi-disciplinary systems approach to integrate technologies.

Established in 1994, CARDI includes faculty from the Division of Engineering and the Department of Mathematical and Computer Science. Research is sponsored by industry, federal agencies, state agencies, and joint government-indus-

try initiatives. Interaction with industry enables CARDI to identify technical needs that require research, to cooperatively develop solutions, and to generate innovative mechanisms for the technology transfer. Enthusiastic and motivated students are encouraged to join CARDI for education and research in the area of automation, robotics, and distributed systems.

Center for Earth Materials, Mechanics, and Characterization

CEMMC is a multidisciplinary research center intended to promote research in a variety of areas including rock mechanics, earth systems, and nontraditional characterization. The Center does not limit its focus to either "hard" or "soft" rock applications but instead fosters research in both arenas and encourages interdisciplinary communication between the associated disciplines. The Colorado School of Mines is a world leader in multidisciplinary integration and therefore presents a unique atmosphere to promote the success of such research. Faculty and students from the Departments of Petroleum Engineering, Geophysical Engineering, Geology and Geological Engineering, Physics, Engineering, and Mining Engineering are involved in CEMMC. In addition to traditional topics in these disciplines, the center cultivates research in nontraditional characterization such as arctic ice coring, extraterrestrial space boring, and laser/rock destruction for multiple applications. CEMMC was established in 2003.

Center for Engineering Education

The Center serves as a focal point for engineering and science education research conducted by CSM faculty. Successfully educating tomorrow's engineers and scientists requires that we look at student learning as a system. The principles of cognitive psychology and educational psychology provide the best explanation of how this learning system works. Education will be most effective when education research, informed by the principles of cognitive and educational psychology are applied to design and application of classroom teaching techniques and curricular materials.

The primary goals of the Center for Engineering Education are:

- ◆ To conduct world-class research on teaching and learning in engineering and science.
- ◆ To use the results of that research by continually improving instruction at the Colorado School of Mines to better support the learning process of our students.
- ◆ To support the educational needs of science and engineering instructors at the pre-college, college, graduate and professional development levels.

Center for Environmental Risk Assessment

The mission of the Center for Environmental Risk Assessment (CERA) at CSM is to unify and enhance environmental risk assessment research and educational activities at CSM. By bringing diverse, inter-disciplinary expertise to bear on problems in environmental risk assessment, CERA facilitates the development of significantly improved, scientifically based approaches for estimating human and ecological risks and for using the results of such assessments. Education and research programs within CERA integrate faculty and students from the departments of Chemical Engineering, Environmental Sciences and Engineering, Chemistry and Geochemistry, Mathematics and Computer Science, and Geology and Geological Engineering.

Center for Experimental Study of Subsurface Environmental Processes

The Center for Experimental Study of Subsurface Environmental Processes (CESEP) emphasizes the multi-disciplinary nature of subsurface remediation technologies by integrating the fundamental sciences of chemistry, biology, geology, hydrology and physics with applied geotechnical, civil and environmental engineering. With this emphasis, the focus for CESEP is to enhance environmental quality through innovative research of subsurface remediation techniques for the clean-up of environmental contaminants leading to improved methodology and decision-making.

Center for Intelligent Biomedical Devices and Musculoskeletal Systems

The multi-institutional Center for Intelligent Biomedical Devices and Musculoskeletal systems (IBDMS) integrates programs and expertise from CSM and the University of Colorado at Denver and Health Sciences Center. Established at CSM as a National Science Foundation (NSF) Industry/University Cooperative Research Center, IBDMS is also supported by industry, State, and Federal organizations.

IBDMS has become an international center for the development of Computer Assisted Surgery, Advanced Orthopaedic Applications, Sports Medicine, Occupational Biomechanics, and Biomaterials. Through the efforts of this center, new major and minor programs in bioengineering and biotechnology have been established at both the CSM graduate and undergraduate levels.

IBDMS seeks to establish educational programs in addition to short- and long-term basic and applied research efforts that would enhance the competitive position of Colorado and U.S. bio-industry in the international markets. IBDMS focuses the work of diverse engineering, materials and medicine disciplines. Its graduates are a new generation of students with an integrated engineering and medicine systems view, with increasing opportunities available in the biosciences.

Center for Research on Hydrates and Other Solids

Since 1975, the Center for Research on Hydrates and Other Solids has performed both fundamental and applied research on natural gas hydrates, curious ice-like compounds composed of water and hydrocarbon gases. Gas hydrates, which generally form at cold temperatures and high pressures, present both a major challenge and major opportunity in energy production. Gas hydrates can plug deep sea and arctic gas and oil pipelines, and preventing hydrate formation is a major design and operational challenge. On the other hand, naturally occurring gas hydrates could potentially provide the world's largest resource of natural gas. Recently, researchers at the center have also found that hydrates can be used as a hydrogen storage material for potential use in fuel cell applications.

With active participation of faculty, graduate, and undergraduate students, the center provides a unique combination of expertise that has enabled CSM to achieve international prominence in gas hydrate research. CSM participants interact on an on-going basis with sponsors and other collaborators, including frequent visits to their facilities both in the US and abroad. For students, this interaction often continues beyond graduation, with opportunities for employment at sponsoring industries. More information can be found at the center website, <http://hydrates.mines.edu/>.

Center for Solar and Electronic Materials

The Center for Solar and Electronic Materials (CSEM) was established in 1995 to focus, support, and extend growing activity in electronic materials for solar applications, in electronic and microelectronic technologies, and in related optical technologies. In addition to photovoltaics, CSEM supports research into advanced optics, novel optical devices, thin film materials, polymeric devices, micro fluidic devices, nanoscale science and nanofabrication, novel characterization, electronic materials processing, process simulation, and systems issues associated with electronic materials and devices. Alternative energy technologies and sustainability are also areas of interest. CSEM facilitates interdisciplinary collaborations across the CSM campus, fosters interactions with national laboratories, industries, public utilities, local state and federal government, and other universities, and operates in close coordination with the National Science Foundation sponsored Renewable Energy Materials Research Science and Engineering Center. The Center coordinates grant applications by its members to collective funding opportunities, manages a joint-use laboratory with a broad range of characterization and processing tools, purchases joint-use tools based on member needs and maintains a virtual computational lab. In fulfilling its research and educa-

tional mission, CSEM draws from expertise in the departments of Physics, Chemical Engineering, Metallurgical and Materials Engineering, Chemistry and Geochemistry, and from the Division of Engineering.

CSEM also serves to guide and strengthen the curriculum in electronic materials and related areas. CSEM members develop and teach relevant courses. CSEM also emphasizes training through research experiences for both graduate and undergraduate students. Graduate students in the above-mentioned departments as well as the materials science program can pursue research on center-related projects. Undergraduates are involved through engineering design courses and summer research experiences. Close proximity to the National Renewable Energy Lab and several local photovoltaic companies provides a unique opportunity for students to work with industry and government labs as they solve real world problems. External contacts also provide guidance in targeting the educational curriculum toward the needs of the electronic materials industry.

Center for Space Resources (CSR)

The Center for Space Resources is dedicated to the human and robotic exploration of space and to the utilization of what we learn to the improvement of our society. These objectives are pursued by developing technologies for space resource prospecting, drilling, excavation, extraction, materials processing and manufacturing in space, and life-support systems on spacecraft and planetary habitats. While there are several practical applications of space exploration on Earth, the greatest achievement bringing benefits to humankind would be to develop commercial applications of space technology, including space and planetary resources, in space.

These applications will one day form the basis for new space industries that include the harvesting of solar energy outside Earth's atmosphere, the development of an in-space reusable transportation infrastructure carrying payloads from Earth to geostationary orbits, the Moon or Mars and back, servicing of satellites to extend their useful lifetimes and reduce the costs of space operations, processing of value-added materials in Earth orbit based on lunar material resources, and utilization of resources for in-situ planetary applications, such as energy, propellants, manufacturing, and habitat development.

These goals are pursued by a Consortium involving faculty and students from several departments, NASA and other government agencies, and industrial partners working together on space-related projects.

Center for Wave Phenomena

With sponsorship for its research by 25 companies in the worldwide oil exploration industry and several government agencies, this program, which includes faculty and students from the Departments of Geophysics, is engaged in a coordinated and integrated program of research in wave propagation, inverse problems and seismic data processing. Its methods have applications to seismic exploration and reservoir monitoring, global seismology, nondestructive testing and evaluation, and land-mine detection, among other areas. Extensive use is made of analytical methods as well as computational techniques. Methodology is developed through computer implementation, based on the philosophy that the ultimate test of an inverse method is its application to experimental data. Thus, the group starts from a physical problem, develops a mathematical model that adequately represents the physics, derives an approximate solution, generates a computer code to implement the method, performs tests on synthetic data, and finally, on field data.

Center for Welding, Joining and Coatings Research

The Center for Welding, Joining and Coatings Research (CWJCR) is an interdisciplinary organization with researchers and faculty from the Metallurgical and Materials Engineering Department, the Engineering Division, and the Mining Engineering Department. The goal of CWJCR is to promote graduate-level education and research, and to advance understanding of the metallurgical and processing aspects of welding, joining and coating processes. CWJCR has in average around 20 graduate students per year conducting research under the supervision of Center faculty researchers in the areas of microstructural characterization, process optimization and modeling. Current center activities include: education, research, conferences, short courses, seminars, information source and transfer, and industrial consortia. The Center receives significant support from industry, national laboratories and government entities.

The Center for Welding, Joining and Coatings Research strives to provide numerous opportunities that directly contribute to the student's professional growth. Some of the opportunities include:

- ◆ Direct involvement of graduate students in projects that constitute the Center's research program.
- ◆ Interaction with internationally renowned visiting scholars.
- ◆ Industrial collaborations that provide equipment, materials and services.
- ◆ Research experience at industrial plants or national laboratories.
- ◆ Professional experience and exposure before nationally recognized organizations through student presentations of university research.

- ◆ Direct involvement in national welding, materials, and engineering professional societies.

Chevron Center of Research Excellence

The Chevron Center of Research Excellence (CoRE) is an industry-academic partnership between the Colorado School of Mines and Chevron that promotes the research, education, training, and recruiting objectives of both organizations. The current research focus is quantitative outcrop characterization using outcrops to document how sedimentary systems evolve through time and space in a variety of settings.

Colorado Center for Advanced Ceramics

The Colorado Center for Advanced Ceramics (CCAC) is developing the fundamental knowledge that is leading to important technological developments in advanced ceramics and composite materials. Established at CSM in April 1988 as a joint effort between CSM and the Coors Ceramics Company (now CoorsTek); the Center is dedicated to excellence in research and graduate education in high technology ceramic and composite materials. The goal of the Center is to translate advances in materials science into new and improved ceramic fabrication processes and ceramic and composite materials. Current research projects cover a broad spectrum of materials and phenomena including fuel cell, solar cell and battery materials; nano-scale powder preparation and mechanics; ceramic-metal composites; layered materials for ballistic applications; and mechanical behavior. Current projects are supported by both industry and government and several students are performing their research through collaboration with the National Renewable Energy Laboratory located in Golden. Each project involves research leading to a graduate thesis of a student. Significant international collaboration exists leading to student experiences abroad.

Colorado Energy Research Institute

Originally established in 1974 and reestablished in 2004, the Colorado Energy Research Institute (CERI) promotes research and educational activities through networking among all constituencies in Colorado, including government agencies, energy industries, and universities. CERI's mission is to serve as a state and regional resource on energy and energy-related minerals issues, provide energy status reports, sponsorship of symposia, demonstration programs, and reports on research results. CERI's activities enhance the development and promotion of energy and energy-related minerals education programs in the areas of energy development, utilization, and conservation, and provide a basis for informed energy-related state policies and actions. Currently CERI has started a sub center for oil shale research.

Colorado Fuel Cell Center

The Colorado Fuel Cell Center (CFCC) seeks to advance fuel-cell research, development, and commercialization and to promote business opportunities in Colorado. The CFCC was created in 2005 with funding from the Governor's Energy Office and co-funding from four partnering organizations. In July 2006 the CFCC was granted status as a Colorado School of Mines research center. The CFCC is managed by a faculty panel consisting of CSM faculty members using the facilities to perform research. The various scopes of the center are solid-oxide fuel cell (SOFC) development and testing, polymer-electrolyte membrane (PEM) development, fuel processing, modeling and simulation, advanced materials processing and evaluation, manufacturing technology development, and systems integration.

Colorado Institute for Energy, Materials and Computational Science

The Colorado Institute for Energy, Materials and Computational Science (CIEMACS) is an interdisciplinary research institute involving research active faculty and students from several academic departments at the Colorado School of Mines. These faculty and students have expertise in the chemistry, physics and engineering of energy conversion processes, including solid oxide and PEMS fuel cells, clean fuels, combustion experimentation and modeling, materials synthesis in flames, atomistic materials modeling and the development of optical measurement techniques for combustion systems and reactive flows.

Colorado Institute for Macromolecular Science and Engineering

The Colorado Institute for Macromolecular Science and Engineering (CIMSE) was established in 1999 by an interdisciplinary team of faculty from several CSM departments. It is sponsored by the National Science Foundation, the Environmental Protection Agency, and the Department of Energy.

The mission of the Institute is to enhance the training and research capabilities of CSM in the area of polymeric and other complex materials as well as to promote education in the areas of materials, energy, and the environment.

Fourteen CSM faculty members from eight departments are involved with the Institute's research. The research volume is more than \$1 million and supports around 15 full-time graduate students in polymers, colloids and complex fluids. Current research projects include plastics from renewable resources, computer simulation of polymers, novel synthetic methods, and the development of new processing strategies from polymer materials.

CIMSE works to improve the educational experience of undergraduate and graduate students in polymers and complex fluids as well as maintain state-of-the-art lab facilities.

Currently CSM has the largest polymeric materials effort in the State of Colorado. Materials are a dominant theme at CSM, and CIMSE will play an important role in ensuring that our students remain competitive in the workforce.

Colorado Renewable Energy Collaboratory

The Colorado Renewable Energy Collaboratory was created by the State of Colorado to advance multidisciplinary science, technology development and technology transfer on challenges related to renewable, reliable, secure, clean, and economically viable energy resources and technologies ("renewable energy"). Currently five centers have been created to explore initiatives in renewable energy:

- ◆ Colorado Center for Biorefining and Biofuels (C2B2)
- ◆ Center for Revolutionary Solar Photoconversion (CRSP)
- ◆ Collaborative Research and Education in Wind (CREW)
- ◆ Solar Technology Acceleration Center - Research Partnership (SolarTAC)
- ◆ Carbon Management Center (CMC)

Energy and Minerals Field Institute

The Energy and Minerals Field Institute is an educational activity serving Colorado School of Mines students and external audiences. The goal of the Institute is to provide better understanding of complex regional issues surrounding development of western energy and mineral resources by providing firsthand experience that cannot be duplicated in the classroom. The Institute conducts field programs for educators, the media, government officials, industry, and the financial community. The Institute also hosts conferences and seminars throughout the year dealing with issues specific to western resources development. Students involved in Institute programs are afforded a unique opportunity to learn about the technological, economic, environmental, and policy aspects of resource development.

Excavation Engineering and Earth Mechanics Institute

The Excavation Engineering and Earth Mechanics Institute (EMI), established in 1974, combines education and research for the development of improved excavation technology. By emphasizing a joint effort among research, academic, and industrial concerns, EMI contributes to the research, development and testing of new methods and equipment, thus facilitating the rapid application of economically feasible new technologies.

Current research projects are being conducted throughout the world in the areas of tunnel, raise and shaft boring, rock mechanics, micro-seismic detection, machine instrumenta-

tion and robotics, rock fragmentation and drilling, materials handling systems, innovative mining methods, and mine design and economics analysis relating to energy and non-fuel minerals development and production. EMI has been a pioneer in the development of special applications software and hardware systems and has amassed extensive databases and specialized computer programs. Outreach activities for the Institute include the offering of short courses to the industry, and sponsorship and participation in major international conferences in tunneling, shaft drilling, raise boring and mine mechanization.

The full-time team at EMI consists of scientists, engineers, and support staff. Graduate students pursue their thesis work on Institute projects, while undergraduate students are employed in research.

Golden Energy Computing Organization

The Golden Energy Computing Organization (GECO) is a partnership between Mines, the National Renewable Energy Laboratory, the National Center for Atmospheric Research and the National Science Foundation. It is dedicated to the use of high performance computing to advance research in the energy sciences. GECO has four main priority areas: pursuing renewable sources, locating and developing existing resources, advancing environmental stewardship, and designing new energy related materials. The center has acquired and maintains a Linux supercomputer, named Ra, which has 2144 computing cores and a peak performance of 23 teraflops. This is one of the most powerful computer resources in academe. It can do three-thousand calculations per second for each of the 6.6 billion people on the planet. A staff of full-time specialists works with researchers to install and optimize computing codes. The facility is open to all CSM faculty and students pursuing energy-related research.

International Ground Water Modeling Center

The International Ground Water Modeling Center (IGWMC) is an information, education, and research center for ground-water modeling established at Holcomb Research Institute in 1978, and relocated to the Colorado School of Mines in 1991. Its mission is to provide an international focal point for ground-water professionals, managers, and educators in advancing the use of computer models in ground-water resource protection and management. IGWMC operates a clearinghouse for ground-water modeling software; organizes conferences, short courses and seminars; and provides technical advice and assistance related to ground water modeling. In support of its information and training activities, IGWMC conducts a program of applied research and development in ground-water modeling.

Kroll Institute for Extractive Metallurgy

The Kroll Institute for Extractive Metallurgy (KIEM), a Center for Excellence in Extractive Metallurgy, was established at the Colorado School of Mines in 1974 using a bequest from William J. Kroll. Over the years, the Kroll Institute has provided support for a significant number of undergraduate and graduate students who have gone on to make important contributions to the mining, minerals and metals industries. The initial endowment has provided a great foundation for the development of a more comprehensive program to support industry needs.

The primary objectives of the Kroll Institute are to provide research expertise, well-trained engineers to industry, and research and educational opportunities to students, in the areas of minerals, metals and materials processing; extractive and chemical metallurgy; chemical processing of materials; and recycling and waste treatment and minimization.

Marathon Center of Excellence for Reservoir Studies

Marathon Center of Excellence for Reservoir Studies conducts collaborative research on timely topics of interest to the upstream segment of the petroleum industry and provides relevant technical service support, technology transfer, and training to the Center's sponsors. Research includes sponsorship of M.S. and Ph.D. graduate students, while technology transfer and training involve one-on-one training of practicing engineers and students from the sponsoring companies. The Center is a multi-disciplinary organization housed in the Petroleum Engineering Department. The Center activities call for the collaboration of the CSM faculty and graduate students in various engineering and earth sciences disciplines together with local world-class experts. The Center was initiated with a grant from Marathon Oil Company, in 2003 and has been serving the oil industry around the world. The current research topics include: modeling and evaluation of unconventional oil and gas resources, reservoir engineering aspects of horizontal and deviated wells, Non-Darcy flow effects in hydraulic fractures and naturally fractured reservoirs, streamline modeling in dual-porosity reservoirs, multi-scale simulation methods to capture the fine-scale heterogeneity effects in displacement processes, modeling of transient flow in hydraulically fractured horizontal wells, naturally fractured reservoirs containing multiple sets of intersecting fractures, numerical modeling of reservoirs containing sparse naturally fractured regions, improved modeling of matrix vertical flow in dual-porosity reservoirs, steam assisted gravity drainage (SAGD) for medium gravity foamy oil reservoirs.

Micromicrointegrated Optics for Advanced Bioimaging and Control

Micromicrointegrated Optics for Advanced Bioimaging and Control (MOABC) focuses on the integration of optics into microscale and microfluidics systems by reducing macroscale optics and electronics to an "optical lab-on-a-chip" compatible with the fluidics lab-on-a-chip paradigm. The center develops new fabrication techniques and new methods of biological measurement and manipulation based on microintegrated optics. Technology at the center is organized around three cores that tie strongly together with one another: spectroscopy, microscopy and manipulation. Our unique facilities enable the center to work closely with both academic and industrial collaborators to employ the developed technologies in useful and relevant applications.

The Nuclear Science and Engineering Center

The Nuclear Science and Engineering Center (NuSEC) is a new interdisciplinary research center whose main objective is to conduct research across all aspects of the nuclear fuel life cycle that includes: mineral exploration, extraction and processing; synthesis and processing of metal, oxide and ceramic fuels; nuclear power systems production, design and operation; fuel recycling, storage and waste remediation; and radiation damage, and the policy issues surrounding each of these activities.

NuSEC draws on substantial contributions from faculty across the Institution, which includes the Division of Engineering, the Division of Environmental Science and Engineering, the Department of Chemistry and Geochemistry, the Department of Geology and Geological Engineering, the Department of Mining Engineering, the Department of Physics, and the Department of Metallurgical and Materials Engineering. Faculty from the Division of Liberal Arts and International Studies provide key support in the areas of social license, policy and ethics.

Center for Oil Shale Technology and Research

The Center for Oil Shale Technology and Research (COSTAR) conducts investigations to advance the development of oil shale resources in the United States and around the world. Center projects include:

- ◆ Studies of rock physics and rock mechanics to understand how oil shale properties vary with temperature and how fractures will occur with heating
- ◆ Studies of geology, stratigraphy and climatology, to understand the conditions of formation of oil shale and provide the integrating framework for the Center's work

- ◆ Studies of geochemistry, to understand how best to characterize the productive potential of the resource, and to enhance geologic understanding of the formation of oil shale
- ◆ Development of a global database of oil shale information and support of the annual Oil Shale Symposium.

The founding Members of COSTAR include Total E&P USA, Shell E&P, and ExxonMobil Upstream Research Company.

Petroleum Exploration and Production Center

The Petroleum Exploration and Production Center (PEPC) is an interdisciplinary educational and research organization specializing in applied studies of petroleum reservoirs. The center integrates disciplines from within the Departments of Geology and Geological Engineering, Geophysics and Petroleum Engineering.

PEPC offers students and faculty the opportunity to participate in research areas including: improved techniques for exploration, drilling, completion, stimulation and reservoir evaluation techniques; characterization of stratigraphic architecture and flow behavior of petroleum reservoirs at multiple scales; evaluation of petroleum reserves and resources on a national and worldwide basis; and development and application of educational techniques to integrate the petroleum disciplines.

Renewable Energy Materials Research Science and Engineering Center

Meeting world energy needs is one of the most significant challenges we face in the coming century. The National Science Foundation sponsored Renewable Energy Materials Research Science and Engineering Center (REMSEC) is focused on transformative materials advances and educational directions that greatly impact emerging renewable energy technologies. Established in 2008, the Center is organized around two research thrust areas. The first concentrates on harnessing unique properties of nanostructured materials to significantly enhance the performance of photovoltaic devices. The second explores ion transport in advanced composite membranes for renewable energy applications. The Center includes a seed grant program designed to stimulate innovative directions and to integrate into the center research portfolio those approaches that show promise. Center educational and outreach activities directly expose students to renewable energy concepts at a young age and prepare them, throughout their K-12 education and into college, for potential careers in this field. Activities include a Research Experience for Undergraduates (REU) summer program in renewable energy outreach to K-12 teachers to address renewable concepts, and renewable energy curricu-

lum development. A diversity initiative seeks to broaden the participation of under represented groups in mathematics, science and engineering at all levels. The center also maintains a broad array of shared-use computational, characterization, deposition, and processing-related facilities. A strategic partnership with scientists and engineers at the National Renewable Energy Laboratory allows sharing of students, research associates, equipment and facilities between the two organizations. In addition, more than a dozen companies actively involved in alternative energy partner with the center. The REMRSEC collaborates with and integrates activities of other Centers active on the Colorado School of Mines campus including the Center for Solar and Electronic Materials (CSEM), the Colorado Fuel Cell Center (CFCC), the Colorado Renewable Energy Collaboratory (CREC) and the Golden Energy Computing Organization (GECO). It also collaborates internationally with leading universities and laboratories in the renewable energy field.

Reservoir Characterization Project

The Reservoir Characterization Project (RCP), established in 1985 at Colorado School of Mines, is an industry-sponsored research consortium. Its mission is to develop and apply 4-D, 9-C seismology and associated technologies for enhanced reservoir recovery. Each multi-year research phase focuses on a consortium partner's unique field location, where multicomponent seismic data are recorded, processed, and interpreted to define reservoir heterogeneity and architecture. Each field study has resulted in the development and advancement of new 3- and 4-D multicomponent acquisition, processing, and interpretation technology, which has led to additional hydrocarbon recovery. Research currently focuses on dynamic reservoir characterization, which enables monitoring of the reservoir production process.

The Reservoir Characterization Project promotes interdisciplinary research and education among industry and students in the fields of geophysics, geology and geological engineering, and petroleum engineering.

Unconventional Natural Gas Institute (UNGI)

The Colorado School of Mines has established the Unconventional Natural Gas Institute (UNGI) to support unconventional natural gas research and to partner with industry and government organizations in enhancing existing Mines in-house expertise and communication between departments in Colorado School of Mines. Fourteen current CSM research centers, along with faculty from nine of the thirteen degree-granting departments are affiliated with UNGI.

Directory of the School

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Policies and Procedures

Affirmative Action

Colorado School of Mines has instituted an affirmative action plan, which is available for perusal in numerous CSM offices including the Library, the Dean of Students' Office, and the Office of Human Resources.

Any person feeling that a violation of the following policies has occurred should promptly refer the matter to the Office of Human Resources, located in Guggenheim Hall (1st floor), for investigation.

The institution's Statement of Equal Opportunity and Equal Access to Educational Programs, and associated staff contacts, can be found on page 9 of this Bulletin as well as the following website: <http://inside.mines.edu/Policies>.

Colorado School of Mines Unlawful Discrimination Policy and Complaint Procedure

As of June 2011, this policy is under revision. For a complete policy statement please see http://inside.mines.edu/Board_Policies.

Promulgated by the CSM Board of Trustees on March 13, 1992. Amended by the CSM Board of Trustees on June 10, 1999. Amended by the CSM Board of Trustees on June 22, 2000.

Colorado School Of Mines Sexual Harassment Policy and Complaint Procedure

As of June 2011, this policy is under revision. For a complete policy statement please see http://inside.mines.edu/Board_Policies.

Promulgated by the CSM Board of Trustees on March 13, 1992. Amended by the CSM Board of Trustees on March 26, 1998. Amended by the CSM Board of Trustees on June 10, 1999. Amended by the CSM Board of Trustees on June 22, 2000.

Colorado School of Mines Personal Relationships Policy

I. Statement of Authority and Purpose

This policy is promulgated by the Board of Trustees pursuant to the authority conferred upon it by §23-41-104(1), C.R.S. (1988 Repl. Vol.) in order to set forth a policy concerning certain personal relationships at CSM as addressed herein. This policy shall supersede any previously promulgated CSM policy which is in conflict herewith.

II. Preface

Certain amorous, romantic, or sexual relationships in which the parties appear to have consented, but where a definite power differential exists between them, are of serious concern to CSM. Personal relationships which might be ap-

propriate in other circumstances always pose inherent dangers when they occur between an Instructor and a Student, between a Person in a Position of Trust and a Student, and between a Supervisor and a Subordinate Employee. Although both parties to the relationship may have consented at the outset, such relationships are fundamentally asymmetric in nature. It is incumbent upon those with authority not to abuse, nor appear to abuse, the power with which they are entrusted. Accordingly, codes of ethics promulgated by most professional regulatory associations forbid professional-client amorous, romantic, or sexual relationships. The relationships prohibited by this policy shall be viewed in this context, and Instructors, Persons in Positions of Trust, and Supervisors should be aware that any violation of this policy shall result in formal disciplinary action against them.

III. Definitions

For the purposes of this policy, the following definitions shall apply:

A. Person in a Position of Trust: Any person occupying a position of trust with respect to one or more students at CSM such that engaging in an amorous, romantic, or sexual relationship with any student would compromise the ability of the employee to perform his or her duties. Examples of Persons in Positions of Trust at CSM are those employed in the Office of the Registrar, those employed in the Student Life Office, those employed in the Student Development Office, those employed in Public Safety, resident assistants, and paper graders. The above examples are provided for illustrative purposes only and are not intended to be exhaustive listings or to limit the illustrated category in any manner.

B. Instructor: Any person who teaches at CSM, including academic faculty members, instructional staff, and graduate students with teaching or tutorial responsibilities.

C. Student: Any person who is pursuing a course of study at CSM.

D. Subordinate Employee: Any person employed by CSM who is supervised by another employee.

E. Supervisor: Any person employed by CSM who occupies a position of authority over another employee with regard to hiring, administering discipline, conducting evaluations, granting salary adjustments, or overseeing task performance.

IV. Policy

A. Personal Relations Between Instructors and Students in the Instructional Context

No Instructor shall engage in an amorous, romantic, or sexual relationship, consensual or otherwise, with a Student who is enrolled in a course being taught by the Instructor, or whose academic work is being supervised by the Instructor.

B. Personal Relationships Between Instructors and Students Outside the Instructional Context

In a personal relationship between an Instructor and a Student for whom the Instructor has no current professional responsibility, the Instructor should be sensitive to the constant possibility that he or she may unexpectedly be placed in a position of responsibility for the instruction or evaluation of the Student. This could entail a request to write a letter of recommendation for the Student or to serve on an admissions or selection committee involving the Student. In addition, an awareness should be maintained that others may speculate that a specific power relationship exists even when none is present, giving rise to assumptions of inequitable academic or professional advantage of the Student. Even if potential conflict of interest issues can be resolved, charges of sexual harassment may arise. In such situations, it is the Instructor who, by virtue of his or her special responsibility, shall be held accountable for unprofessional behavior.

C. Personal Relationships Between Supervisors and Subordinate Employees

No Supervisor shall engage in an amorous, romantic, or sexual relationship, consensual or otherwise, with a Subordinate Employee who reports, either directly or indirectly, to the Supervisor or is under the Supervisor's direct or indirect authority.

D. Personal Relationships Between Persons in Positions of Trust and Students

No Person in a Position of Trust shall engage in an amorous, romantic, or sexual relationship, consensual or otherwise, with a Student.

(Promulgated by the CSM Board of Trustees on February 14, 1992)

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