ENERGY RESOURCES ENGINEERING

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Courses given in Energy Resources Engineering have the subject code ENERGY. For a complete list of subject codes, see Appendix.

Energy Resources Engineering, known as Petroleum Engineering until its name change effective in academic year 2006-07, offers a B.S., M.S., Engineer, and Ph.D. in Petroleum Engineering.

Energy resources engineers are concerned with the design of processes for energy recovery. Included in the design process are characterizing the spatial distribution of hydrocarbon reservoir properties, drilling wells, designing and operating production facilities, selecting and implementing methods for enhancing fluid recovery, examining the environmental aspects of petroleum exploration and production, monitoring reservoirs, and predicting recovery process performance. The Energy Resources Engineering curriculum provides a sound background in basic sciences and their application to practical problems to address the complex and changing nature of the field. Course work includes the fundamentals of chemistry, computer science, engineering, geology, geophysics, mathematics, and physics. Applied courses cover most aspects of energy resources engineering and some related fields like geothermal engineering and geostatistics. The curriculum emphasizes the fundamental aspects of fluid flow in the subsurface. These principles apply equally well to optimizing oil recovery from petroleum reservoirs and remediating contaminated groundwater systems. The program also has a strong interest in related energy topics such as renewable energy, global climate change, and CO_2 sequestration.

Faculty and graduate students conduct research in areas including: enhanced oil recovery by thermal means, gas injection, and the use of chemicals; flow of fluids in pipes; geostatistical reservoir characterization and mathematical modeling; geothermal engineering; natural gas engineering; carbon sequestration optimization; properties of petroleum fluids; reservoir simulation using computer models; and well test analysis. Undergraduates are encouraged to participate in research projects. Graduate programs lead to the degrees of Master of Science (M.S.), Engineer, and Doctor of Philosophy (Ph.D.) in Petroleum Engineering.

M.S., Engineer, and Ph.D. degrees may be awarded with field designations for students who follow programs of study in the fields of geostatistics, geothermal, crustal fluids, or environmental specialties.

The department is housed in the Green Earth Sciences Building and it operates laboratories for research in enhanced oil recovery processes and geothermal engineering. Students have access to a variety of computers for research and course work. Computers available for instruction and research include ten multiprocessor NT servers within the department, as well as campus-wide computer clusters. Each graduate student office has one 3 GHz Pentium 4 computer per student.

UNDERGRADUATE PROGRAMS

BACHELOR OF SCIENCE

The four-year program leading to the B.S. degree provides a foundation for careers in many facets of the energy industry. The curriculum includes basic science and engineering courses that provide sufficient depth for a wide spectrum of careers in the energy and environmental industries.

One of the goals of the program is to provide experience integrating the skills developed in individual courses to address a significant design problem. In ENERGY 180, taken in the senior year, student teams design facilities for a real petroleum reservoir to meet specific management objectives.

PROGRAM

The requirements for the B.S. degree in Petroleum Engineering are similar to those described in the "School of Engineering" section of this bulletin. Students must satisfy the University general education, writing, and language requirements. The normal Energy Resources Engineering undergraduate program automatically satisfies the University General Education Requirements (GERs) in the Disciplinary Breadth areas of Natural Sciences, Engineering and Applied Sciences, and Mathematics. Engineering fundamentals courses and Energy Resources Engineering depth and elective courses must be taken for a letter grade.

In brief, the unit and subject requirements are:

Subject	*Minimum Units*
Engineering fundamentals	25
General Education, writing, language, and electives	68-69
Mathematics	23
Energy Resources Engineering depth	39-40
Science	26
Total	181

The following courses constitute the normal program leading to a B.S. in Petroleum Engineering. The program may be modified to meet a particular student's needs and interests with the adviser's prior approval.

MATHEMATICS

Subject and Catalog Number	*Units*
MATH 41. Single Variable Calculus	5
and MATH 42. Single Variable Calculus	5
or MATH 19. Calculus	3
and MATH 20. Calculus	3
and MATH 21. Calculus	4
MATH 51. Linear Algebra &Differential Calculus of Several Variables	5
MATH 51A. Integral Calculus of Several Variables	5
Total	23

SCIENCE

CHEM 31A. Chemical Principles	4
CHEM 33. Structure and Reactivity	4
CHEM 171. Physical Chemistry	3
GES 1. Fundamentals of Geology	5
PHYSICS 29. Electricity and Magnetism	4
PHYSICS 41 (formerly 53). Mechanics	4
PHYSICS 44 (formerly 56). Electricity and Magnetism Laboratory	1
Total	25

ENGINEERING FUNDAMENTALS

CS 106A. Programming Methodology	5
or CS 106X. Programming Methodology and Abstractions	5
ENGR 14. Applied Mechanics: Statics	5
and ENGR 15. Dynamics	5
ENGR 30. Engineering Thermodynamics	3
ENGR 60. Engineering Economy	3
ME 70. Introductory Fluids Engineering	4
Total	25

ENGINEERING DEPTH

The following courses constitute the core program in Petroleum Engineering:

ENERGY 120. Reservoir Engineering	3
ENERGY 121. Fundamentals of Multiphase Flow	3
ENERGY 130. Well Log Analysis I	3
ENERGY 175. Well Test Analysis	3
ENERGY 180. Oil and Gas Production Engineering	3
ENERGY 260. Groundwater Pollution and Oil Spills	3
CHEMENG 120A. Fluid Mechanics	3
or CHEMENG 180. Chemical Engineering Plant Design	3

CHEMENG 185. Chemical Engineering Laboratory	3
GES 151. Sedimentary Geology and Petrography: Depositional Systems	4
Total	31

A list of suggested electives and sample course programs is available in the department office, room 65, Green Earth Sciences Building. It is important to start mathematics courses in the first year and engineering and geology early in the second year. Computers are used extensively in most energy resources engineering courses. Students must develop programming skills through course work and self-study and are expected to achieve fluency in the use of FORTRAN, C, or C++ by their junior year.

MINORS

To be recommended for a B.S. degree with Petroleum Engineering as a minor subject, a student must take the following courses in addition to those required by the major department or program: ENERGY 120, 121, 130, 175, 180; GES 111A and 151. In some programs, GES 111A or 151 may also satisfy major requirements.

HONORS PROGRAM

A limited number of undergraduates may be admitted to the honors program at the beginning of their senior year.

To be admitted, the student must have a grade point average (GPA) of at least 3.0 in all course work in the University. In addition to the minimum requirements for the B.S. degree, the student must complete 6 units of advanced energy resources engineering courses and at least 3 units of research (ENERGY 193).

Students who wish to be admitted to the honors program should consult with their adviser before the start of their senior year. Those who do not meet all of the formal requirements may petition the department for admission. Those completing the program receive the B.S. degree in Petroleum Engineering with Honors. An overall 3.5 GPA is required in all energy resources engineering courses for graduation with honors.

COTERMINAL B.S. AND M.S. PROGRAM

The coterminal B.S./M.S. program offers an opportunity for Stanford University students to pursue a graduate experience while completing the B.S. degree in any relevant major. Energy Resources Engineering graduate students generally come from backgrounds such as chemical, civil, or mechanical engineering; geology or other earth sciences; or physics or chemistry. Students should have a background at least through MATH 51A and CS 106 before beginning graduate work in this program.

The two types of M.S. degrees, the course work only degree and the research degree, as well as the courses required to meet degree requirements, are described below in the M.S. section. Both degrees require 45 units and may take from one to two years to complete depending on circumstances unique to each student.

Requirements to enter the program are two letters of recommendation from faculty members or job supervisors, a statement of purpose, scores from the GRE general test, and a copy of Stanford University transcripts. While the department does not require any specific GPA or GRE score, potential applicants are expected to compete favorably with graduate student applicants.

A Petroleum Engineering master's degree can be used as a terminal degree for obtaining a professional job in the petroleum or geothermal industry, or in any related industry where analyzing flow in porous media or computer simulation skills are required. It can also be a stepping stone to a Ph.D. degree, which usually leads to a professional research job or an academic position.

Students should apply to the program any time after they have completed 105 undergraduate units, and in time to take ENERGY 120, the basic introductory course in Autumn Quarter of the year they wish to begin the program. Contact the Department of Energy Resources Engineering to obtain additional information. For University coterminal degree program rules and University application forms, see http://registrar.stanford.edu/shared/publications.htm#Coterm.

GRADUATE PROGRAMS

The University's basic requirements for M.S., Engineer, and Ph.D. degrees are discussed in the "Graduate Degrees" section of this bulletin.

The following are minimum requirements for an Energy Resources Engineering student to remain in good academic standing regarding course work:

1. no more than one incomplete grade at any time
2. a cumulative grade point average (GPA) of 3.0
3. a grade point average (GPA) of 2.7 each quarter.
4. a minimum of 15 units completed within each two quarter period (excluding Summer Quarter).

Unless otherwise stated by the instructor, incomplete grades in courses within the department are changed to 'NP' (not passed) at the end of the quarter after the one in which the course was given. This one quarter limit is a different constraint from the maximum one-year limit allowed by the University.

Academic performance is reviewed each quarter by a faculty committee. At the beginning of the next quarter, any student not in good academic standing receives a letter from the committee or department chair stating criteria that must be met for the student to return to good academic standing. If the situation is not corrected by the end of the quarter, possible consequences include termination of financial support, termination of departmental privileges, and termination from the University.

Students funded by research grants or fellowships from the department are expected to spend at least half of their time (a minimum of 20 hours per week) on research. Continued funding is contingent upon satisfactory research effort and progress as determined by the student's adviser. After Autumn Quarter of the first year, students receive a letter from the department chair concerning their research performance. If problems are identified and they persist through the second quarter, a warning letter is sent. Problems persisting into a third quarter may lead to loss of departmental support including tuition and stipend. Similar procedures are applied in subsequent years.

A balanced master's degree program including engineering course work and research requires a minimum of one maximum-tuition academic year beyond the baccalaureate to meet the University residence requirements. Most full-time students spend at least one additional summer to complete the research requirement. An alternative master's degree program based only on course work is available, also requiring at least one full tuition academic year to meet University residence requirements.

M.S. students who anticipate continuing in the Ph.D. program should follow the research option. M.S. students receiving financial aid normally require two academic years to complete the degree. Such students must take the research option and are limited to an 8-10 unit course load per quarter.

The degree of Engineer requires a comprehensive maximum-tuition, two-year program of graduate study. This degree permits more extensive course work than the master's degree, with an emphasis on professional practice. All Engineer degree students receiving financial aid are limited to an 8-10 unit course load per quarter and need at least ten quarters of work to complete the degree.

The Ph.D. degree is awarded primarily on the basis of completion of significant, original research. Extensive course work and a minimum of 90 units of graduate work beyond the master's degree is required. Doctoral candidates planning theoretical work are encouraged to gain experimental research experience in the M.S. program. Ph.D. students receiving financial assistance are limited to 8-10 units per quarter and often require more than three years to complete the Ph.D.

In special cases, the M.S., Engineer, and Ph.D. degrees may be awarded with field designations for students who follow programs of study in the particular fields of (1) geostatistics, (2) geothermal, or (3) environment. For example, students may be awarded the degree Master of Science in Petroleum Engineering (Geothermal).

MASTER OF SCIENCE

The objective is to prepare the student for professional work in the energy industry through completion of fundamental courses in the major field and in related sciences as well as independent research.

Students entering the graduate program are expected to have an undergraduate-level energy resources engineering background. Competence in computer programming in a high-level language (CS 106X or the equivalent) and knowledge of energy resources engineering and geological fundamentals (ENERGY 120, 130, and GES 151) are prerequisites for taking most graduate courses.

The candidate must fulfill the following requirements:

1. Register as a graduate student for at least 45 units.
2. Submit a program proposal for the Master's degree approved by the adviser during the first quarter of enrollment.
3. Complete 45 units with at least a grade point average (GPA) of 3.0. This requirement is satisfied by taking the core sequence, selecting one of the seven elective sequences, an appropriate number of additional courses from the list of technical electives, and completing 6 units of master's level research. Students electing the course work only M.S. degree are strongly encouraged to select an additional elective sequence in place of the research requirement. Students interested in continuing for a Ph.D. are expected to choose the research option and enroll in 6 units of ENERGY 361. All courses must be taken for a letter grade.
4. Students entering without an undergraduate degree in Petroleum Engineering must make up deficiencies in previous training. Not more than 10 units of such work may be counted as part of the minimum total of 45 units toward the M.S. degree.

Research subjects include certain groundwater hydrology and environmental problems, energy industry management, flow of non-Newtonian fluids, geothermal energy, natural gas engineering, oil and gas recovery, pipeline transportation, production optimization, reservoir characterization and modeling, carbon sequestration, reservoir engineering, reservoir simulation, and transient well test analysis.

RECOMMENDED COURSES AND SEQUENCES

The following list is recommended for most students. With the prior special consent of the student's adviser, courses listed under technical electives may be substituted based on interest or background.

CORE SEQUENCE

Subject and Catalog Number	*Units*
ENERGY 175. Well Test Analysis	3
or ENERGY 130. Well Log Analysis	3
ENERGY 221. Fundamentals of Multiphase Flow	3
ENERGY 222. Reservoir Engineering*	3
ENERGY 246. Reservoir Characterization and Flow Modeling with Outcrop Data	3
ENERGY 251. Thermodynamics of Equilibria†	3
CME 200. Linear Algebra with Application to Engineering Computations	3
CME 204. Partial Differential Equations in Engineering	3
Total	21

* Students taking the Environmental sequence may substitute ENERGY 227.
† Optional for students taking the Geostatistics and Reservoir Modeling sequence.

ELECTIVE SEQUENCE

Choose one of the following:

Crustal Fluids:	
GES 230. Physical Hydrogeology	4
GES 231. Contaminant Hydrogeology	4
GEOPHYS 200. Fluids and Tectonics	3
Total	11
Environmental:	
ENERGY 227. Enhanced Oil Recovery	3
GES 231. Contaminant Hydrogeology	4
Plus two out of the following courses:	
ENERGY 240. Geostatistics	3-4
ENERGY 260. Environmental Problems in Petroleum Engineering	3
CEE 270. Movement, Fate, and Effect of Contaminants in Surface Water and Groundwater	3
CEE 273. Aquatic Chemistry	3
CEE 274A. Environmental Microbiology	3
GES 230. Physical Hydrogeology	4
Total	13-14
Enhanced Recovery:	
ENERGY 225. Theory of Gas Injection Processes	3
ENERGY 226. Thermal Recovery Methods	3
ENERGY 227. Enhanced Oil Recovery	3
Total	9
Geostatistics and Reservoir Modeling:	
ENERGY 240. Geostatistics for Spatial Phenomena	3-4
ENERGY 241. Practice of Geostatistics	3-4
GEOPHYS 182. Reflection Seismology	3
or GEOPHYS 262. Rock Physics	3
Total	9-11
Geothermal:	
ENERGY 269. Geothermal Reservoir Engineering	3
or ENERGY 102 Renewable Energy Sources	3
CHEMENG 120B. Energy and Mass Transport	4
ME 131A. Heat Transfer	3
Total	10
Reservoir Performance:	
ENERGY 223. Reservoir Simulation	3-4
ENERGY 280. Oil and Gas Production Engineering	3
GEOPHYS 202. Reservoir Geomechanics	3
Total	9-11
Simulation and Optimization:	
ENERGY 223. Reservoir Simulation	3-4
ENERGY 224. Advanced Reservoir Simulation	3
ENERGY 284. Optimization	3
Total	9-10
Renewable Energy:	
ENERGY 102. Renewable Energy Sources	3
EE 293A. Fundamentals of Energy Processes	3-4
EE 293B. Fundamentals of Energy Processes	3-4
Total	9-12

RESEARCH SEQUENCE

ENERGY 361. Master's Degree Research in Petroleum Engineering*	6
Total units required for M.S. degree	45

* Students choosing the company sponsored course-work-only for the M.S. degree may substitute an additional elective sequence in place of the research.

TECHNICAL ELECTIVES

Technical electives from the following list of advanced-level courses usually complete the M.S. program. In unique cases, when justified and approved by the adviser prior to taking the course, courses listed here may be substituted for courses listed above in the elective sequences.

ENERGY 130. Well Log Analysis	3
ENERGY 224. Advanced Reservoir Simulation	3
ENERGY 230. Advanced Topics in Well Logging	3
ENERGY 260. Environmental Aspects of Petroleum Engineering	3
ENERGY 267. Engineering Valuation and Appraisal of Oil and Gas Wells, Facilities and Properties	3
ENERGY 269. Geothermal Reservoir Engineering	3
ENERGY 273. Special Production Engineering Topics in Petroleum Engineering	1-3
ENERGY 280. Oil and Gas Production	3
ENERGY 281. Applied Mathematics in Reservoir Engineering	3
ENERGY 284. Optimization	3
CME 204. Partial Differential Equations to Engineering (formerly 300B)	3
EE 293A. Fundamentals of Energy Processes	3-4
EE 293B. Fundamentals of Energy Processes	3-4
GEOPHYS 182. Reflection Seismology	3
GEOPHYS 190. Near Surface Geophysics	3
GEOPHYS 202. Reservoir Geomechanics	3

M.S. IN INTEGRATED RESERVOIR MODELING

This M.S. degree requires a minimum of 45 units of which 39 should be course units. The following courses are suggested for this program.

MATH SEQUENCE

Subject and Catalog Number	*Units*
CME 200. Linear Algebra with Application to Engineering Computations	3
CME 204. Partial Differential Equations in Engineering	3

ENERGY RESOURCES ENGINEERING SEQUENCE

ENERGY 246. Reservoir Characterization and Flow Modeling	3
ENERGY 130. Well Logging; or	3
ENERGY 175. Well Test Analysis	3
ENERGY 221. Fundamentals of Multiphase Flow, or	3
ENERGY 222. Advanced Reservoir Engineering	3
ENERGY 223. Reservoir Simulation	3-4

GEOSTATISTICS SEQUENCE

ENERGY 240. Geostatistics for Spatial Phenomena	3-4
ENERGY 241. Practice of Geostatistics and Seismic Data Integration	3-4

GEOLOGY SEQUENCE

GES 151. Sedimentary Geology	4
GES 253. Petroleum Geology	3

GEOPHYSICS SEQUENCE

GEOPHYS 182 Reflection Seismology, or	3
GEOPHYS 183. Reflection Seismology Interpretation	1-4
GEOPHYS 262. Rock Physics	3

ENGINEER

The objective is to broaden training through additional work in engineering and the related sciences and by additional specialization.

Basic requirements include completion of 90 units of course work including 15 units of research (ENERGY 362), and including all course requirements of the department's master's degree (39 units, excluding research). If the candidate has received credit for research in the M.S. degree, this credit ordinarily would be transferable to the Engineer degree, in which case a total of 9 additional research units would be required. No more than 10 of the 90 required units can be applied to overcoming deficiencies in undergraduate training.

At least 30 units in Engineering and closely allied fields must be taken in advanced work, that is, work beyond the master's degree requirements and in addition to research (ENERGY 362). These may include courses from the Ph.D. degree list below or advanced-level courses from other departments with prior consent of the adviser. All courses must be taken for a letter grade. The student must have a grade point average (GPA) of at least 3.0 in courses taken for the degree of Engineer. A thesis based on 15 units of research must be submitted and approved by the adviser, another faculty member, and the University Committee on Graduate Studies.

DOCTOR OF PHILOSOPHY

The Ph.D. degree is conferred upon demonstration of high achievement in independent research and by presentation of the research results in a written dissertation and oral defense.

Basic requirements include a minimum of 135 units of satisfactorily completed graduate study. Students must take at least 90 units beyond the 45 units required for the master's degree. The 90 units are composed of 54 units of research and 36 units of course work. The student's record must indicate outstanding scholarship. The student must pass the department's qualifying examination, submit an approved research proposal, fulfill the requirements of the minor department if a minor is elected, and pass the University oral examination, which is a defense of the dissertation. The student must prepare a dissertation based on independent research and that makes a significant contribution to the field.

The specification of 36 units of course work is a minimum; in some cases the research adviser may specify additional requirements to strengthen the student's expertise in particular areas. The 36 units of course work does not include teaching experience (ENERGY 359), which is a requirement for the Ph.D. degree, nor any units in research seminars, which students are required to attend. All courses must be taken for a letter grade, with an average grade point average (GPA) of at least 3.25 in the 36 units of course work. Incoming Ph.D. students who earned their master's degree at another institution are required to take at least 36 units of course work. No more than four of the eight courses that make up the strategic requirements for the Ph.D. qualifying exams are included in these 36 units (ENERGY 175, 221, 222, 223, 227, 240, 251, 281). The 36 units of course work may include graduate courses in Energy Resources Engineering (numbered 200 and above) and courses selected from the following list. Other courses may be substituted with prior approval by the adviser. In general, non-technical courses are not approved.

MATH AND APPLIED MATH

Subject and Catalog Number	*Units*
AA 210A. Fundamentals of Compressible Flow	3
AA 214A. Numerical Methods in Fluid Mechanics	3
AA 214B. Numerical Computation of Compressible Flow	3
CHEMENG 300. Applied Mathematics in Chemical Engineering	3
CEE 268. Groundwater Flow	3-4
CME 108. Introduction to Scientific Computing	3-4
CME 302. Numerical Linear Algebra	3
CME 306. Numerical Solution of Partial Differential Equations	3
CS 106X. Programming Methodology and Abstractions	5
CS 193D. Professional Software Development with C++	3
MATH 106 Functions of a Complex Variable	3
MATH 113. Linear Algebra and Matrix Theory	3
MATH 114. Linear Algebra and Matrix Theory	3
MATH 115. Functions of a Real Variable	3
MATH 131. Partial Differential Equations I	3
MATH 132. Partial Differential Equations II	3
MATH 220A,B,C. Partial Differential Equations of Applied Mathematics	3 ea.
CME 200. Linear Algebra with Application to Engineering Computations	3
CME 204. Partial Differential Equations in Engineering	3
CME 206. Introduction to Numerical Methods for Engineering	3
ME 331A,B. Classical Dynamics	3 ea.
ME335A,B,C. Finite Element Analysis	3 ea.
STATS 110. Statistical Methods in Engineering and Physical Sciences	4
STATS 116. Theory of Probability	4
STATS 200. Introduction to Statistical Inference	3
STATS 202. Data Analysis	3

SCIENCE

GES 231. Contaminant Hydrogeology	4
GES 253. Petroleum Geology and Exploration	3
GEOPHYS 182. Reflection Seismology	3
GEOPHYS 190. Near Surface Geophysics	3
GEOPHYS 262. Rock Physics	3

ENGINEERING

CHEMENG 110. Equilibrium Thermodynamics	3
CHEMENG 120A. Fluid Mechanics	3
CHEMENG 120B. Energy and Mass Transport	3
CHEMENG 310A. Microscale Transport in Chemical Engineering	3
ENGR 298. Seminar in Fluid Mechanics	1

Ph.D. students are required to take the doctoral qualifying examination at the beginning of the second year of study. Students receiving a master's degree from the Department of Energy Resources Engineering and continuing on for a Ph.D. are required to take the qualifying examination at the first opportunity after the completion of the requirements for the master's degree.

The qualifying examination consists of both a written and an oral section. The written part consists of three or four three-hour examinations on different subjects. The oral part is a three-hour examination in which members of the department faculty question the student. Students are required to apply for candidacy for the Ph.D. degree after passing the department's qualifying examination.

Within a year of passing the qualifying examination, the student must prepare a short written report that contains a literature review and a research proposal. This proposal must be approved after oral examination by a committee made up of the student's adviser and two other faculty, at least one of whom must be from the department.

The dissertation must be submitted in its final form within five calendar years from the date of admission to candidacy. Candidates who fail to meet this deadline must submit an Application for Extension of Candidacy for approval by the department chair if they wish to continue in the program.

PH.D. MINOR

To be recommended for a Ph.D. degree with Petroleum Engineering as a minor subject, a student must take 20 units of selected graduate-level lecture courses in the department. These courses must include ENERGY 221 and 222. The remaining courses should be selected from ENERGY 175, 223, 224, 225, 227, 240, 241, 251, 280, 281, and 284.

COURSES

WIM indicates that the course satisfies the Writing in the Major requirements.

ENERGY 101. Energy and the Environment—(Same as EARTHSYS 101.) Energy use in modern society and the consequences of current and future energy use patterns. Case studies illustrate resource estimation, engineering analysis of energy systems, and options for managing carbon emissions. Focus is on energy definitions, use patterns, resource estimation, pollution. Recommended: MATH 21 or 42, ENGR 30. GER: DB-EngrAppSci

3 units, Win (Kovscek, A; Durlofsky, L; Gerritsen, M)

ENERGY 102. Renewable Energy Sources and Greener Energy Processes—(Same as EARTHSYS 102.) The energy sources that power society are rooted in fossil energy although energy from the core of the Earth and the sun is almost inexhaustible; but the rate at which energy can be drawn from them with today's technology is limited. The renewable energy resource base, its conversion to useful forms, and practical methods of energy storage. Geothermal, wind, solar, biomass, and tidal energies; resource extraction and its consequences. Recommended: 101, MATH 21 or 42. GER:DB-EngrAppSci

3 units, Spr (Kovscek, A; Horne, R)

ENERGY 104. Technology in the Greenhouse—Technologies that might be employed to reduce emissions of greenhouse materials, such as carbon dioxide, methane, nitrous oxide, and black soot, produced by the generation and use of energy. Sources of greenhouse materials in the current energy mix and evidence for global geochemical and climate changes. Advantages and limitations of technologies to reduce emissions. Examples include renewable sources such as wind and solar energy, more efficient use of energy, hydrogen, capture and storage of cardon dioxide, and nuclear power.

3 units, Spr (Orr, F)

ENERGY 120. Fundamentals of Petroleum Engineering—(Same as ENGR 120.) Lectures, problems, field trip. Engineering topics in petroleum recovery; origin, discovery, and development of oil and gas. Chemical, physical, and thermodynamic properties of oil and natural gas. Material balance equations and reserve estimates using volumetric calculations. Gas laws. Single phase and multiphase flow through porous media. GER:DB-EngrAppSci

3 units, Aut (Horne, R)

ENERGY 121. Fundamentals of Multiphase Flow—(Same as 221.) Multiphase flow in porous media. Wettability, capillary pressure, imbibition and drainage, Leverett J-function, transition zone, vertical equilibrium. Relative permeabilities, Darcy's law for multiphase flow, fractional flow equation, effects of gravity, Buckley-Leverett theory, recovery predictions, volumetric linear scaling, JBN and Jones-Rozelle determination of relative permeability. Frontal advance equation, Buckley-Leverett equation as frontal advance solution, tracers in multiphase flow, adsorption, three-phase relative permeabilities. GER:DB-EngrAppSci

3 units, Win (Tchelepi, H)

ENERGY 130. Well Log Analysis I—For earth scientists and engineers. Interdisciplinary, providing a practical understanding of the interpretation of well logs. Lectures, problem sets using real field examples: methods for evaluating the presence of hydrocarbons in rock formations penetrated by exploratory and development drilling. The fundamentals of all types of logs, including electric and non-electric logs.

3 units, Aut (Lindblom, R)

ENERGY 155. Undergraduate Report on Energy Industry Training—On-the-job practical training under the guidance of experienced, on-site supervisors. Required report detailing work activities, problems, assignments and key results. Prerequisite: written consent of instructor.

1-3 units, Aut, Win, Spr, Sum (Staff)

ENERGY 161. Statistical Methods for the Earth and Environmental Sciences: Geostatistics—(Same as GES 161.) Statistical analysis and graphical display of data, common distribution models, sampling, and regression. The variogram as a tool for modeling spatial correlation; variogram estimation and modeling; introduction to spatial mapping and prediction with kriging; integration of remote sensing and other ancillary information using co-kriging models; spatial uncertainty; introduction to geostatistical software applied to large environmental, climatological, and reservoir engineering databases; emphasis is on practical use of geostatistical tools. GER:DB-NatSci

3-4 units, Win (Caers, J)

ENERGY 167. Engineering Valuation and Appraisal of Oil and Gas Wells, Facilities, and Properties—(Same as 267.) Appraisal of development and remedial work on oil and gas wells; appraisal of producing properties; estimation of productive capacity, reserves; operating costs, depletion, and depreciation; value of future profits, taxation, fair market value; original or guided research problems on economic topics with report. Prerequisite: consent of instructor. GER:DB-EngrAppSci

3 units, Win (Kourt, W; Pande, K)

ENERGY 175. Well Test Analysis—Lectures, problems. Application of solutions of unsteady flow in porous media to transient pressure analysis of oil, gas, water, and geothermal wells. Pressure buildup analysis and drawdown. Design of well tests. Computer-aided interpretation.

3 units, Spr (Horne, R)

ENERGY 180. Oil and Gas Production Engineering—(Same as 280.) Design and analysis of production systems for oil and gas reservoirs. Topics: well completion, single-phase and multi-phase flow in wells and gathering systems, artificial lift and field processing, well stimulation, inflow performance. Prerequisite: 120. Recommended: 130. GER:DB-EngrAppSci, WIM

3 units, alternate years, not given this year

ENERGY 192. Undergraduate Teaching Experience—Leading field trips, preparing lecture notes, quizzes under supervision of the instructor. May be repeated for credit.

1-3 units, Aut, Win, Spr, Sum (Staff)

ENERGY 193. Undergraduate Research Problems—Original and guided research problems with comprehensive report. May be repeated for credit.

1-3 units, Aut, Win, Spr, Sum (Staff)

ENERGY 194. Special Topics in Energy and Mineral Fluids—May be repeated for credit.

1-3 units, Aut, Win, Spr, Sum (Staff)

ENERGY 211. Computer Programming in C++ for Earth Scientists and Engineers—(Same as CME 211.) Computer programming methodology emphasizing modern software engineering principles: object-oriented design, decomposition, encapsulation, abstraction, and modularity. Fundamental data structures. Time and space complexity analysis. The basic facilities of the programming language C++. Numerical problems from various science and engineering applications.

3 units, Win (Staff)

ENERGY 221. Fundamentals of Multiphase Flow—(For graduate students; see 121.)

3 units, Win (Tchelepi, H)

ENERGY 222. Advanced Reservoir Engineering—Lectures, problems. General flow equations, tensor permeabilities, steady state radial flow, skin, and succession of steady states. Injectivity during fill-up of a depleted reservoir, injectivity for liquid-filled reservoirs. Flow potential and gravity forces, coning. Displacements in layered reservoirs. Transient radial flow equation, primary drainage of a cylindrical reservoir, line source solution, pseudo-steady state. Prerequisite: 221. May be repeated for credit.

3 units, Spr (Durlofsky, L)

SCHOOL OF EARTH SCIENCES

ENERGY 223. Reservoir Simulation—Fundamentals of petroleum reservoir simulation. Equations for multicomponent, multiphase flow between gridblocks comprising a petroleum reservoir. Relationships between black-oil and compositional models. Techniques for developing black-oil, compositional, thermal, and dual-porosity models. Practical considerations in the use of simulators for predicting reservoir performance. Class project. Prerequisite: 221 and 246, or consent of instructor. Recommended: CME 206 (formerly ME 300C).
3-4 units, Win (Durlofsky, L; Gerritsen, M)

ENERGY 224. Advanced Reservoir Simulation—Topics include modeling of complex wells, coupling of surface facilities, compositional modeling, dual porosity models, treatment of full tensor permeability and grid nonorthogonality, local grid refinement, higher order methods, streamline simulation, upscaling, algebraic multigrid solvers, unstructured grid solvers, history matching, other selected topics. Prerequisite: 223 or consent of instructor. May be repeated for credit.
3 units, Aut (Durlofsky, L; Tchelepi, H)

ENERGY 225. Theory of Gas Injection Processes—Lectures, problems. Theory of multicomponent, multiphase flow in porous media. Miscible displacement: diffusion and dispersion, convection-dispersion equations and its solutions. Method of characteristic calculations of chromatographic transport of multicomponent mixtures. Development of miscibility and interaction of phase behavior with heterogeneity. May be repeated for credit. Prerequisite: CME 200 (formerly ME 300A).
3 units, Win (Orr, F)

ENERGY 226. Thermal Recovery Methods—Theory and practice of thermal recovery methods: steam drive, cyclic steam injections, and in situ combustion. Models of combined mass and energy transport. Estimates of heated reservoir volume and oil recovery performance. Wellbore heat losses, recovery production, and field examples.
3 units, Spr (Castanier)

ENERGY 227. Enhanced Oil Recovery—The physics, theories, and methods of evaluating chemical, miscible, and thermal enhanced oil recovery projects. Existing methods and screening techniques, and analytical and simulation based means of evaluating project effectiveness. Dispersion-convection-adsorption equations, coupled heat, and mass balances and phase behavior provide requisite building blocks for evaluation.
3 units, Spr (Kovscek, A) alternate years, not given next year

ENERGY 230. Advanced Topics in Well Logging—(Same as GEOPHYS 230.) State of the art tools and analyses; the technology, rock physical basis, and applications of each measurement. Hands-on computer-based analyses illustrate instructional material. Guest speakers on formation evaluation topics. Prerequisites: 130 or equivalent; basic well logging; and standard practice and application of electric well logs.
3 units, Spr (Lindblom, R)

ENERGY 240. Geostatistics for Spatial Phenomena—(Same as GES 240.) Probabilistic modeling of spatial and/or time dependent phenomena. Kriging and cokriging for gridding and spatial interpolation. Integration of heterogeneous sources of information. Multiple-point geostatistics and training image-based stochastic imaging of reservoir/field heterogeneities. Introduction to GSLIB and SGEMS software. Case studies from the oil and mining industry and environmental sciences. Prerequisites: introductory calculus and linear algebra, STATS 116, GES 161, or equivalent.
3-4 units, Win (Journel, A)

ENERGY 241. Practice of Geostatistics and Seismic Data Integration—(Same as GEOPHYS 241A.) Students build a synthetic 3D fluvial channel reservoir model with layer depths, channel geometry, and facies-specific petrophysic and seismic properties, stressing the physical significance of geophysical data. Reference data set is sparsely sampled, providing the sample data typically available for an actual reservoir assessment. Geostatistical reservoir modeling uses well and seismic data, with results checked against the reference database. Software provided (GSLIB and SRBtools). Prerequisite: 240. Recommended: experience with Unix, Matlab/C++/Fortran programming.
3-4 units, Spr (Caers, J; Mukerji, T)

ENERGY 242. Topics in Advanced Geostatistics—(Same as GES 242.) Conditional expectation theory and projections in Hilbert spaces; parametric versus non-parametric geostatistics; Boolean, Gaussian, fractal, indicator, and annealing approaches to stochastic imaging; multiple point statistics inference and reproduction; neural net geostatistics; Bayesian methods for data integration; techniques for upscaling hydrodynamic properties. May be repeated for credit. Prerequisites: 240, advanced calculus, C++/Fortran.
3-4 units, alternate years, not given this year

ENERGY 244. Modeling of 3D Geological Objects with Gocad—Accurate 3D modeling of subsurface structures as prerequisite for decision making. Concepts and methods for modeling the complex geometries and spatial distribution of geological objects. Building 3D models using the Gocad software. The definition and placement of discrete curves and surfaces. Integration of diverse types of data. Flexible volume modeling algorithms used to conform the volume objects to both the structural model and the data.
3 units, not given this year

ENERGY 245. Probability Theory—(Same as GEOPHYS 245.) Probabilistic formulations and solutions to inverse problems. Monte Carlo methods for solving inverse problems. Metropolis algorithm. Deterministic solutions using maximum likelihood, gradient methods. Dealing with prior probability and data uncertainty. Gaussian and non-Gaussian model formulations. Application to Earth Science problems. Prerequisite: introduction to probability theory course.
3 units, not given this year

ENERGY 246. Reservoir Characterization and Flow Modeling with Outcrop Data—(Same as GES 246.) Project addresses a reservoir management problem by studying an outcrop analog, constructing geostatistical reservoir models, and performing flow simulation. How to use outcrop observations in quantitative geological modeling and flow simulation. Relationships between disciplines. Weekend field trip.
3 units, Aut (Graham, S; Journel, A; Tchelepi, H)

ENERGY 247. Stochastic Simulation—Characterization and inference of statistical properties of spatial random function models; how they average over volumes, expected fluctuations, and implementation issues. Models include point processes (Cox, Poisson), random sets (Boolean, truncated Gaussian), and mixture of Gaussian random functions. Prerequisite: 240.
3 units, not given this year (Journel, A)

ENERGY 251. Thermodynamics of Equilibria—Lectures, problems. The volumetric behavior of fluids at high pressure. Equation of state representation of volumetric behavior. Thermodynamic functions and conditions of equilibrium, Gibbs and Helmholtz energy, chemical potential, fugacity. Phase diagrams for binary and multicomponent systems. Calculation of phase compositions from volumetric behavior for multicomponent mixtures. Experimental techniques for phase-equilibrium measurements. May be repeated for credit.
3 units, Aut (Kovscek, A)

ENERGY 255. Master's Report on Energy Industry Training—On-the-job training for master's degree students under the guidance of on-site supervisors. Students submit a report detailing work activities, problems, assignments, and key results. May be repeated for credit. Prerequisite: consent of adviser.
1-3 units, Sum (Staff)

ENERGY 259. Presentation Skills—For teaching assistants in Energy Resources Engineering. Five two-hour sessions in the first half of the quarter. Awareness of different learning styles, grading philosophies, fair and efficient grading, text design; presentation and teaching skills, PowerPoint slide design; presentation practice in small groups. Taught in collaboration with the Center for Teaching and Learning.
1 unit, Spr (Gerritsen, M)

ENERGY 260. Groundwater Pollution and Oil Slicks: Environmental Problems in Petroleum Engineering—Sources and types of wastes in petroleum operations. Partitioning of hydrocarbons in soil. Review of single phase flow. Multiphase flow of oil, water, and air. Movement of hydrocarbons in the vadose zone and in the groundwater. Remediation and cleanup techniques: air stripping and sparging, bioremediation, steam flooding, and solvent and surfactant injection. Drilling wastes. The physical processes affecting the spread of oil slicks at sea. Methods for containing and removing the spill and cleaning polluted beaches.

3 units, not given this year

ENERGY 267. Engineering Valuation and Appraisal of Oil and Gas Wells, Facilities, and Properties—(For graduate students; see 167.)

3 units, Win (Kourt, W; Pande, K)

ENERGY 269. Geothermal Reservoir Engineering—Conceptual models of heat and mass flows within geothermal reservoirs. The fundamentals of fluid/heat flow in porous media; convective/conductive regimes, dispersion of solutes, reactions in porous media, stability of fluid interfaces, liquid and vapor flows. Interpretation of geochemical, geological, and well data to determine reservoir properties/characteristics. Geothermal plants and the integrated geothermal system.

3 units, alternate years, not given this year

ENERGY 273. Special Topics in Petroleum Engineering

1-3 units, Aut, Win, Spr, Sum (Staff)

ENERGY 280. Oil and Gas Production Engineering—(For graduate students; see 180.)

3 units, alternate years, not given this year

ENERGY 281. Applied Mathematics in Reservoir Engineering—The philosophy of the solution of engineering problems. Methods of solution of partial differential equations: Laplace transforms, Fourier transforms, wavelet transforms, Green's functions, and boundary element methods. Prerequisites: CME 204 or MATH 131, and consent of instructor.

3 units, Spr (Staff)

ENERGY 284. Optimization: Deterministic and Stochastic Approaches—Deterministic and stochastic methods for optimization in earth sciences and engineering. Linear and nonlinear regression, classification and pattern recognition using neural networks, simulated annealing and genetic algorithms. Deterministic optimization using non-gradient-based methods (simplex) and gradient-based methods (conjugated gradient, steepest descent, Levenberg-Marquardt, Gauss-Newton), eigenvalue and singular value decomposition. Applications in petroleum engineering, geostatistics, and geophysics. Prerequisite: CME 200 or consent of instructor.

3 units, Aut (Caers, J)

ENERGY 285. Research Seminars—Focused study in research areas within the department. Graduate students may participate in advanced work in areas of particular interest prior to making a final decision on a thesis subject. May be repeated for credit. Prerequisite: consent of instructor.

ENERGY 285A. SUPRI-A Research Seminar: Enhanced Oil Recovery

1 unit, Aut, Win, Spr (Staff)

ENERGY 285B. SUPRI-B Research Seminar: Reservoir Simulation

1 unit, Aut, Win, Spr (Staff)

ENERGY 285C. SUPRI-C Research Seminar: Gas Injection Processes

1 unit, Aut, Win, Spr (Staff)

ENERGY 285D. SUPRI-D Research Seminar: Well Test Analysis

1 unit, Aut, Win, Spr (Staff)

ENERGY 285F. SCRF Research Seminar: Geostatistics and Reservoir Forecasting—Stanford Center for Reservoir Forecasting.

1 unit, Aut, Win, Spr (Staff)

ENERGY 285G. Geothermal Reservoir Engineering Research Seminar

1 unit, Aut, Win, Spr (Staff)

ENERGY 285H. SUPRI-HW Research Seminar: Horizontal Well Technology

1 unit, Aut, Win, Spr (Staff)

ENERGY 290. Numerical Modeling of Fluid Flow in Heterogeneous Porous Media—How to mathematically model and solve elliptic partial differential equations with variable and discontinuous coefficients describing flow in highly heterogeneous porous media. Topics include finite difference and finite volume approaches on structured grids, efficient solvers for the resulting system of equations, Krylov space methods, preconditioning, multi-grid solvers, grid adaptivity and adaptivity criteria, multiscale approaches, and effects of anistropy on solver efficiency and accuracy. MATLAB programming and application of commercial or public domain simulation packages. Prerequisite: CME 200, 201, and 202, or equivalents with consent of instructor.

3 units, not given this year

ENERGY 300. Earth Sciences Seminar—(Same as EARTHSYS 300, GES 300, GEOPHYS 300, IPER 300.) Required for incoming graduate students except coterms. Research questions, tools, and approaches of faculty members from all departments in the School of Earth Sciences. Goals are: to inform new graduate students about the school's range of scientific interests and expertise; and introduce them to each other across departments and research groups. Two faculty members present work at each meeting. May be repeated for credit.

1 unit, Aut (Matson, P; Graham, S)

ENERGY 355. Doctoral Report on Energy Industry Training—On-the-job training for doctoral students under the guidance of on-site supervisors. Students submit a report on work activities, problems, assignments, and results. May be repeated for credit. Prerequisite: consent of adviser.

1-3 units, Sum (Staff)

ENERGY 359. Teaching Experience in Energy Resources Engineering—For TAs in Energy Resources Engineering. Course and lecture design and preparation; lecturing practice in small groups. Classroom teaching practice in na Energy Resources Engineering course for which the participant is the TA (may be in a later quarter). Taught in collaboration with the Center for Teaching and Learning.

1 unit, Aut (Gerritsen, M)

ENERGY 360. Advanced Research Work in Petroleum Engineering—Graduate-level work in experimental, computational, or theoretical research. Special research not included in graduate degree program. May be repeated for credit.

1-10 units, Aut, Win, Spr, Sum (Staff)

ENERGY 361. Master's Degree Research in Petroleum Engineering—Experimental, computational, or theoretical research. Advanced technical report writing. Limited to 6 units total.

1-6 units, Aut, Win, Spr, Sum (Staff)

ENERGY 362. Engineer's Degree Research in Petroleum Engineering—Graduate-level work in experimental, computational, or theoretical research for Engineer students. Advanced technical report writing. Limited to 15 units total, or 9 units total if 6 units of 361 were previously credited.

1-10 units, Aut, Win, Spr, Sum (Staff)

ENERGY 363. Doctoral Degree Research in Petroleum Engineering—Graduate-level work in experimental, computational, or theoretical research for Ph.D. students. Advanced technical report writing.

1-10 units, Aut, Win, Spr, Sum (Staff)

ENERGY 365. Special Research Topics in Petroleum Engineering—Graduate-level research work not related to report, thesis, or dissertation. May be repeated for credit.

1-15 units, Aut, Win, Spr, Sum (Staff)

COGNATE COURSE

See department listing for course description.

EEES 257. Introduction to Computational Earth Sciences

2-4 units, Spr (Clapp, R; Harris, J)