# ENERGY RESOURCES ENGINEERING

Courses offered by the Department of Energy Resources Engineering are listed under the subject code ENERGY on the Stanford Bulletin's ExploreCourses web site.

The Department of Energy Resources Engineering (ERE) awards the following degrees: the Bachelor of Science, Master of Science, Engineer, and Doctor of Philosophy in Energy Resources Engineering. The department also awards the Master of Science, Engineer, and Doctor of Philosophy in Petroleum Engineering. Consult the ERE student services office to determine the relevant program.

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 and geothermal reservoir properties, drilling wells, designing and operating production facilities, selecting and implementing methods for enhancing fluid recovery, examining the environmental aspects of petroleum and geothermal exploration and production, monitoring reservoirs, and predicting recovery process performance.

The program also has a strong interest in related energy topics such as renewable energy, global climate change, carbon capture and sequestration, clean energy conversions (e.g., "clean coal"), and energy systems. 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 such as 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, geothermal energy production and remediating contaminated groundwater systems.

Faculty and graduate students conduct research in areas including: enhanced oil recovery by thermal means, gas injection, and the use of chemicals; geostatistical reservoir characterization and mathematical modeling; geothermal engineering; natural gas engineering; production optimization; data assimilation and uncertainty modeling; properties of petroleum fluids; well test analysis; carbon sequestration; clean energy conversions; and energy system modeling and optimization. Undergraduates are encouraged to participate in research projects.

The department is housed in the Green Earth Sciences Building. It operates laboratories for research in enhanced oil recovery processes, geological carbon storage operations, clean energy conversions, and geothermal engineering. Students have access to a variety of computers, computing platforms and software for research and course work.

## Mission of the Undergraduate Program in Energy Resources Engineering

The mission of the Energy Resources Engineering major is to provide students with the engineering skills and foundational knowledge needed to flourish as technical leaders within the energy industry. Such skills and knowledge include resource assessment, choices among energy alternatives, and carbon management, as well as the basic scientific background and technical skills common to engineers. The curriculum is designed to prepare students for immediate participation in many aspects of the energy industry and graduate school.

## Learning Outcomes (Undergraduate)

The department expects undergraduate majors in the program to be able to demonstrate the following learning outcomes. These learning outcomes are used in evaluating students and the department's undergraduate program. Students are expected to:

1. apply skills developed in fundamental courses to engineering problems.
2. research, analyze, and synthesize solutions to an original and contemporary energy problem.
3. work independently and as part of a team to develop and improve engineering solutions.
4. apply written, visual, and oral presentation skills to communicate scientific knowledge.

## Graduate Programs in Energy Resources Engineering

The Energy Resources Engineering department offers two distinct degree programs at both the M.S and Ph.D. levels. One program leads to the degrees of M.S. or Ph.D. in Petroleum Engineering, and the other leads to the degrees of M.S. or Ph.D. in Energy Resources Engineering. The Engineer degree, which is offered in either Petroleum Engineering or Energy Resources Engineering, is an extended form of the M.S. degree with additional course work and research.

## Learning Outcomes (Graduate)

The objective is to prepare students to be technical leaders in the energy industry, academia and research organizations through completion of fundamental courses in the major field and in related sciences, as well as through independent research. Students are expected to:

1. apply skills developed in fundamental courses to engineering problems.
2. research, analyze, and synthesize solutions to an original and contemporary energy problem.
3. work independently and as part of a team to develop and improve engineering solutions.
4. apply written, visual, and oral presentation skills to communicate scientific knowledge.
5. MS students are expected to develop in-depth technical understanding of energy problems at an advanced level.
6. Ph.D. students are expected to complete a scientific investigation that is significant, challenging and original.

## Bachelor of Science in Energy Resources Engineering

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 fields.

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 199 Senior Project and Seminar in Energy Resources, taken in the senior year, student teams identify and propose technical solutions for an energy-resource related problem of current interest.

### Program

The requirements for the B.S. degree in Energy Resources Engineering are similar, but not identical, 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.

The Energy Resources Engineering undergraduate curriculum is designed to prepare students for participation in the energy industry or for graduate studies, while providing requisite skills to evolve as the energy landscape shifts over the next half century. The program provides a background in mathematics, basic sciences, and engineering fundamentals such as multiphase fluid flow in the subsurface. In addition, the curriculum is structured with flexibility that allows students to explore energy topics of particular individual interest and to study abroad.

In brief, the unit and subject requirements are:

| | Units |
|---|---|
| Energy Resources Core | 15-16 |
| Energy Resources Depth | 18 |
| Mathematics | 25 |
| Engineering Fundamentals and Depth | 20-24 |
| Science | 29-32 |
| Technology in Society | 3-5 |
| University Requirements: IHUM, GERs, Writing, Language | 60-70 |
| Total Units | 170-19 |

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

## Required Core in Energy Resources Engineering

| | | Units |
|---|---|---|
| **The following courses constitute the core program in Energy Resources Engineering** | | |
| ENERGY 101 | Energy and the Environment | 3 |
| ENERGY 104 | Sustainable Energy for 9 Billion | 3 |
| ENERGY 120 | Fundamentals of Petroleum Engineering | 3 |
| ENERGY 160 | Modeling Uncertainty in the Earth Sciences | 3 |
| ENERGY 199 | Senior Project and Seminar in Energy Resources (WIM) | 3-4 |
| **Mathematics** | | |
| Select one of the following Series (A or B): | | 10 |
| Series A | | |
| MATH 41 | Calculus | |
| MATH 42 | Calculus | |
| Series B | | |
| MATH 19 | Calculus | |
| MATH 20 | Calculus | |
| MATH 21 | Calculus | |
| And the following (CME series recommended): | | |
| CME 100 | Vector Calculus for Engineers | 5 |
| or MATH 51 | Linear Algebra and Differential Calculus of Several Variables | |
| CME 102 | Ordinary Differential Equations for Engineers | 5 |
| or MATH 53 | Ordinary Differential Equations with Linear Algebra | |
| CME 104 | Linear Algebra and Partial Differential Equations for Engineers | 5 |
| or MATH 52 | Integral Calculus of Several Variables | |
| **Science** | | |
| CHEM 31A | Chemical Principles I | 5 |
| or CHEM 31X | Chemical Principles Accelerated | |
| CHEM 31B | Chemical Principles II | 5 |
| or CHEM 31X | Chemical Principles Accelerated | |
| CHEM 33 | Structure and Reactivity | 5 |
| PHYSICS 41 | Mechanics | 4 |
| PHYSICS 43 | Electricity and Magnetism | 4 |
| PHYSICS 45 | Light and Heat | 4 |
| PHYSICS 46 | Light and Heat Laboratory | 1 |
| GS 1A | Introduction to Geology: The Physical Science of the Earth | 5 |
| or GS 1C | Introduction to Geology: Dynamic Earth | |
| **Engineering Fundamentals** | | |
| CS 106A | Programming Methodology | 3-5 |
| or CS 106X | Programming Abstractions (Accelerated) | |
| CS 106B | Programming Abstractions | 3-5 |
| or CS 106X | Programming Abstractions (Accelerated) | |
| ENGR 14 | Intro to Solid Mechanics | 4 |
| ENGR 30 | Engineering Thermodynamics | 3 |
| ENERGY 110 | Engineering Economics | 3 |
| or ECON 155 | Environmental Economics and Policy | |
| or ECON 250 | Environmental Economics | |
| or ECON 251 | Natural Resource and Energy Economics | |
| or CEE 146A | Engineering Economy | |
| ME 70 | Introductory Fluids Engineering | 4 |
| Technology in Society, 1 course | | |

## Earth and Energy Depth Concentration

Choose courses from the list below for a total of at least 18 units. At least one course must be completed in each category. Courses must be planned in consultation with the student's academic advisor. Appropriate substitutions are allowed with the consent of the advisor.

| | | Units |
|---|---|---|
| **Fluid Flow and the Subsurface** | | |
| ENERGY 120A | Flow Through Porous Media Laboratory | 1 |
| 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 |
| ENGR 62 | Introduction to Optimization | 4 |
| GEOPHYS 181 | Fluids and Flow in the Earth: Computational Methods | 3 |
| **3D Modeling of Subsurface Structures** | | |
| ENERGY 125 | Modeling and Simulation for Geoscientists and Engineers | 3 |
| ENERGY 141 | Seismic Reservoir Characterization | 3-4 |
| ENERGY 146 | Reservoir Characterization and Flow Modeling with Outcrop Data | 3 |
| GEOPHYS 112 | Exploring Geosciences with MATLAB | 1-3 |
| GEOPHYS 182 | Reflection Seismology | 3 |
| GS 151 | Sedimentary Geology and Petrography: Depositional Systems | 4 |
| GEOPHYS 183 | Reflection Seismology Interpretation | 1-4 |
| GEOPHYS 185 | Rock Physics for Reservoir Characterization | 3 |
| GEOPHYS 186 | Tectonophysics | 3 |
| **Earth and Energy Systems** | | |

| | | |
|---|---|---|
| ENERGY 102 | Renewable Energy Sources and Greener Energy Processes | 3 |
| ENERGY 153 | Carbon Capture and Sequestration | 3-4 |
| ENERGY 269 | Geothermal Reservoir Engineering | 3 |
| ENERGY 191 | Optimization of Energy Systems | 3-4 |
| ENERGY 301 | The Energy Seminar | 1 |
| CEE 64 | Air Pollution and Global Warming: History, Science, and Solutions | 3 |
| CEE 70 | Environmental Science and Technology | 3 |
| CEE 176B | Electric Power: Renewables and Efficiency | 3-4 |
| GEOPHYS 150 | Geodynamics: Our Dynamic Earth | 3 |
| MATSCI 156/ ENERGY 293A | Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution | 3-4 |
| GEOPHYS 120 | Ice, Water, Fire | 3-5 |
| GEOPHYS 150 | Geodynamics: Our Dynamic Earth | 3 |
| ENERGY 293A | Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution | 3-4 |
| ENERGY 293B | Fundamentals of Energy Processes | 3 |
| ENERGY 293C | Energy from Wind and Water Currents | 3 |
| MSE 211 | Linear and Nonlinear Optimization | 3-4 |

### Honors Program

The program in Energy Resources Engineering leading to the Bachelor of Science with Honors provides an opportunity for independent study and research on a topic of special interest and culminates in a written report and oral presentation.

The Honors Program is open to students with a grade point average (GPA) of at least 3.5 in all courses required for the ERE major and minimum of 3.0 in all University course work. Qualified students intending to pursue honors must submit an Honors Program Application to the Undergraduate Program Director no later than the eighth week of their ninth quarter, but students are encouraged to apply to the program during Winter Quarter of their junior year. The application includes a short form, an unofficial transcript, and a 2-3 page research proposal prepared by the student and endorsed by a faculty member who will serve as the research advisor.

Upon approval, students enroll in the Honors Program via Axess. Students must enroll in a total of 9 units of ENERGY 193 Undergraduate Research Problems; these units may be spread out over the course of the senior year, and may include previous enrollment units for the same research project. Research undertaken for the Honors Program cannot be used as a substitute for regularly required courses. A formal written report must be submitted to the student's research advisor no later than the fourth week of the student's final quarter, and the report must be read, approved, and signed by the student's faculty advisor and a second member of the faculty. Each honors candidate must make an oral presentation of his or her research results.

## Minor in Energy Resources Engineering

The minor in Energy Resources Engineering requires the following three courses plus three additional electives. Courses must be planned in consultation with an ERE advisor. Appropriate substitutions are allowed with the consent of the advisor.

### Required courses

| | | Units |
|---|---|---|
| ENERGY 101 | Energy and the Environment | 3 |
| ENERGY 120 | Fundamentals of Petroleum Engineering | 3 |
| ENERGY 160 | Modeling Uncertainty in the Earth Sciences | 3 |

### Elective courses

| | | Units |
|---|---|---|
| Select at least three of the following: | | |
| ENERGY 102 | Renewable Energy Sources and Greener Energy Processes | |
| ENERGY 104 | Sustainable Energy for 9 Billion | |
| ENERGY 121 | Fundamentals of Multiphase Flow | |
| ENERGY 125 | Modeling and Simulation for Geoscientists and Engineers | |
| ENERGY 130 | Well Log Analysis I | |
| ENERGY 141 | Seismic Reservoir Characterization | |
| ENERGY 146 | Reservoir Characterization and Flow Modeling with Outcrop Data | |
| ENERGY 153 | Carbon Capture and Sequestration | |
| ENERGY 269 | Geothermal Reservoir Engineering | |
| ENERGY 175 | Well Test Analysis | |
| ENERGY 180 | Oil and Gas Production Engineering | |
| GEOPHYS 182 | Reflection Seismology | |
| GS 151 | Sedimentary Geology and Petrography: Depositional Systems | |
| GEOPHYS 112 | Exploring Geosciences with MATLAB | |

## Master of Science in Petroleum Engineering

The objective is to prepare the student for professional work in the energy industry, or for doctoral studies, 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 engineering or physical science background. Competence in computer programming in a high-level language (CS 106X Programming Abstractions (Accelerated) or the equivalent) and knowledge of engineering and geological fundamentals (ENERGY 120 Fundamentals of Petroleum Engineering, ENERGY 130 Well Log Analysis I, and GS 151 Sedimentary Geology and Petrography: Depositional Systems) are prerequisites for taking most graduate courses.

The following are minimum requirements for a student in the Department of Energy Resources Engineering 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.

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 a grade point average (GPA) of at least 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 Master's Degree Research in Energy Resources Engineering. 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

| | | Units |
|---|---|---|
| ENERGY 175 | Well Test Analysis | 3 |
| or ENERGY 130 | Well Log Analysis I | |
| ENERGY 221 | Fundamentals of Multiphase Flow | 3 |
| ENERGY 222 | Advanced 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 Units | | 21 |

### Elective Sequence

| | | Units |
|---|---|---|
| Select one of the following Series: | | 9-14 |
| Crustal Fluids: | | |
| GEOPHYS 200 | | |
| ESS 220 | Physical Hydrogeology | |
| ESS 221 | Contaminant Hydrogeology and Reactive Transport | |
| Environmental: | | |
| ENERGY 227 | Enhanced Oil Recovery | |
| ESS 221 | Contaminant Hydrogeology and Reactive Transport | |
| And two of the following: | | |
| ENERGY 240 | Geostatistics | |
| CEE 270 | Movement and Fate of Organic Contaminants in Waters | |
| CEE 273 | Aquatic Chemistry | |
| CEE 274A | Environmental Microbiology I | |
| Enhanced Recovery: | | |
| ESS 220 | Physical Hydrogeology | |
| ENERGY 225 | Theory of Gas Injection Processes | |
| ENERGY 226 | Thermal Recovery Methods | |
| ENERGY 227 | Enhanced Oil Recovery | |
| Geostatistics and Reservoir Modeling: | | |
| ENERGY 240 | Geostatistics | |
| ENERGY 241 | Seismic Reservoir Characterization | |
| GEOPHYS 182 | Reflection Seismology | |
| or GEOPHYS 2( | Rock Physics | |
| Geothermal: | | |
| ENERGY 269 | Geothermal Reservoir Engineering | |
| or ENERGY 293 | Fundamentals of Energy Processes | |
| CHEMENG 120E | Energy and Mass Transport | |
| ME 131A | Heat Transfer | |
| Reservoir Performance: | | |
| ENERGY 223 | Reservoir Simulation | |
| ENERGY 280 | Oil and Gas Production Engineering | |
| GEOPHYS 202 | Reservoir Geomechanics | |
| Simulation and Optimization: | | |
| ENERGY 223 | Reservoir Simulation | |
| ENERGY 224 | Advanced Reservoir Simulation | |
| ENERGY 284 | Optimization and Inverse Modeling | |
| Renewable Energy: | | |
| ENERGY 293A | Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution | |
| ENERGY 293B | Fundamentals of Energy Processes | |
| ENERGY 293C | Energy from Wind and Water Currents | |
| ESS 221 | Contaminant Hydrogeology and Reactive Transport | 4 |
| Total Units | | 13-18 |

### Research Sequence

| | | Units |
|---|---|---|
| ENERGY 361 | Master's Degree Research in Energy Resources Engineering [1] | 1-6 |
| Total Units | | 1-6 |

[1] 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.

| | | Units |
|---|---|---|
| ENERGY 130 | Well Log Analysis I | 3 |
| ENERGY 224 | Advanced Reservoir Simulation | 3 |
| ENERGY 230 | Advanced Topics in Well Logging | 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 Topics in Energy Resources Engineering | 1-3 |
| ENERGY 280 | Oil and Gas Production Engineering | 3 |
| ENERGY 281 | Applied Mathematics in Reservoir Engineering | 3 |
| ENERGY 284 | Optimization and Inverse Modeling | 3 |
| ENERGY 301 | The Energy Seminar | 1 |
| CME 204 | Partial Differential Equations in Engineering | 3 |
| ENERGY 293A | Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution | 3-4 |
| ENERGY 293B | Fundamentals of Energy Processes | 3 |
| ENERGY 293C | Energy from Wind and Water Currents | 3 |
| GEOPHYS 182 | Reflection Seismology | 3 |
| GEOPHYS 190 | Near-Surface Geophysics | 3 |
| GEOPHYS 202 | Reservoir Geomechanics | 3 |
| CME 206 | Introduction to Numerical Methods for Engineering | 3 |
| CME 211 | Software Development for Scientists and Engineers | 3 |

# Master of Science in Energy Resources Engineering

The objective of the M.S. degree in Energy Resources Engineering is to prepare the student either for a professional career or for doctoral studies. Students in the M.S. degree program must fulfill the following:

1. Complete a 45-unit program of study. The degree has two options:
   a. a course work degree, requiring 45 units of course work
   b. a research degree, of which a minimum of 39 units must be course work, with the remainder consisting of no more than 6 research units.
2. Course work units must be divided among two or more scientific and/or engineering disciplines and can include the core courses required for the Ph.D. degree.
3. All courses must be taken for a letter grade.
4. The program of study must be approved by the academic adviser and the department graduate program committee.
5. Students taking the research-option degree are required to complete an M.S. thesis, approved by the student's thesis committee.

## Recommended Courses and Sequences

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

### Core Sequence

| | | Units |
|---|---|---|
| ENERGY 221 | Fundamentals of Multiphase Flow | 3 |
| ENERGY 246 | Reservoir Characterization and Flow Modeling with Outcrop Data | 3 |
| CME 200 | Linear Algebra with Application to Engineering Computations | 3 |
| CME 204 | Partial Differential Equations in Engineering | 3 |
| ENERGY 293A | Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution | 3-4 |
| ENERGY 293B | Fundamentals of Energy Processes | 3 |
| ENERGY 293C | Energy from Wind and Water Currents | 3 |
| Total Units | | 21-22 |

### Subject Sequence Alternatives

| | | Units |
|---|---|---|
| Select one of the following Series: | | 15 |
| Geothermal: | | |
| ENERGY 223 | Reservoir Simulation | |
| ENERGY 269 | Geothermal Reservoir Engineering | |
| CHEMENG 120B | Energy and Mass Transport | |
| GS 217 | | |
| ME 131A | Heat Transfer | |
| ME 370A | Energy Systems I: Thermodynamics | |
| Low Carbon Energy: | | |
| Select three of the following: | | |
| ENERGY 104 | Sustainable Energy for 9 Billion | |
| ENERGY 223 | Reservoir Simulation | |
| ENERGY 251 | Thermodynamics of Equilibria | |
| ENERGY 256 | Electronic Structure Theory and Applications to Chemical Kinetics (formerly ENERGY 252) | |
| ENERGY 269 | Geothermal Reservoir Engineering | |
| ENERGY 291 | Optimization of Energy Systems | |
| CHEMENG 130 | Separation Processes | |
| GS 170 | Environmental Geochemistry | |
| GS 171 | Geochemical Thermodynamics | |
| ME 370A | Energy Systems I: Thermodynamics | |
| ME 370B | Energy Systems II: Modeling and Advanced Concepts | |
| MATSCI 156/ ENERGY 293A | Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution | |
| Modeling Natural Resources: | | |
| Select three of the following: | | |
| ENERGY 240 | Geostatistics | |
| ENERGY 241 | Seismic Reservoir Characterization | |
| ENERGY 284 | Optimization and Inverse Modeling | |
| GEOPHYS 200 | | |
| GEOPHYS 262 | Rock Physics | |
| Oil and Gas: | | |
| ENERGY 104 | Sustainable Energy for 9 Billion | |
| ENERGY 222 | Advanced Reservoir Engineering | |
| ENERGY 223 | Reservoir Simulation | |
| ENERGY 240 | Geostatistics | |

| | | |
|---|---|---|
| ENERGY 251 | Thermodynamics of Equilibria | |
| Total Units | | 15 |

### Technical Electives

| | | Units |
|---|---|---|
| ENERGY 104 | Sustainable Energy for 9 Billion | 3 |
| ENERGY 120 | Fundamentals of Petroleum Engineering | 3 |
| ENERGY 130 | Well Log Analysis I | 3 |
| Any 200-level ENERGY course | | |
| ENERGY 301 | The Energy Seminar | 1 |
| CEE 176A | Energy Efficient Buildings | 3-4 |
| CEE 176B | Electric Power: Renewables and Efficiency | 3-4 |
| CME 206 | Introduction to Numerical Methods for Engineering | 3 |
| CME 212 | Advanced Programming for Scientists and Engineers | 3 |
| ECON 250 | Environmental Economics | 2-5 |
| ECON 251 | Natural Resource and Energy Economics | 2-5 |
| GS 217 | | |
| MATSCI 316 | Nanoscale Science, Engineering, and Technology | 3 |
| ME 131A | Heat Transfer | 3-5 |
| ME 260 | Fuel Cell Science and Technology | 3 |
| ME 370A | Energy Systems I: Thermodynamics | 3 |
| ME 370B | Energy Systems II: Modeling and Advanced Concepts | 4 |

## Coterminal B.S. and M.S. Program in Energy Resources Engineering

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.

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: three 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.

### University Coterminal Requirements

Coterminal master's degree candidates are expected to complete all master's degree requirements as described in this bulletin. University requirements for the coterminal master's degree are described in the "Coterminal Master's Program (http://exploredegrees.stanford.edu/cotermdegrees)" section. University requirements for the master's degree are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/#masterstext)" section of this bulletin.

After accepting admission to this coterminal master's degree program, students may request transfer of courses from the undergraduate to the graduate career to satisfy requirements for the master's degree. Transfer of courses to the graduate career requires review and approval of both the undergraduate and graduate programs on a case by case basis.

In this master's program, courses taken during or after the first quarter of the sophomore year are eligible for consideration for transfer to the graduate career; the timing of the first graduate quarter is not a factor. No courses taken prior to the first quarter of the sophomore year may be used to meet master's degree requirements.

Course transfers are not possible after the bachelor's degree has been conferred.

The University requires that the graduate adviser be assigned in the student's first graduate quarter even though the undergraduate career may still be open. The University also requires that the Master's Degree Program Proposal be completed by the student and approved by the department by the end of the student's first graduate quarter.

A Petroleum Engineering or Energy Resources Engineering master's degree can be used as a terminal degree for obtaining a professional job in the petroleum or energy industries, 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 120 undergraduate units, and in time to take ENERGY 120 Fundamentals of Petroleum Engineering, 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. Students should have a background at least through MATH 53 (http://exploredegrees.stanford.edu/schoolofearthsciences/energyresourcesengineering/js/fckeditor/editor/fckeditor.html?InstanceName=attr_text&Toolbar=PageWizard) Ordinary Differential Equations with Linear Algebra and CS 106AB (http://exploredegrees.stanford.edu/schoolofearthsciences/energyresourcesengineering/js/fckeditor/editor/fckeditor.html?InstanceName=attr_text&Toolbar=PageWizard) Programming Methodology before beginning graduate work in this program.

University requirements for the coterminal M.A. are described in the "Coterminal Bachelor's and Master's Degrees (http://exploredegrees.stanford.edu/cotermdegrees)" section of this bulletin. For University coterminal master's degree application forms, see the Registrar's Publications page (https://studentaffairs.stanford.edu/registrar/publications/#Coterm).

## Doctor of Philosophy in Petroleum Engineering or Energy Resources Engineering

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.

The following are minimum requirements for a student in the Department of Energy Resources Engineering 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 3.25
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.

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 are 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 10 units per quarter and often require more than three years to complete the Ph.D. beyond the M.S. degree.

In addition to University and the Department of Energy Resources Engineering basic requirements for the doctorate, the Petroleum Engineering Ph.D. and Energy Resources Engineering Ph.D. degrees have the following requirements:

1. Complete 135 units of total graduate work (90 units beyond the master's degree). The 90 units are composed of a minimum of 36 units of research and a minimum of 36 units of course work. At least half of the classes must be at a 200 level or higher and all must be taken for a letter grade. Students with an M.S. degree or other specialized training from outside ERE are generally expected to include ENERGY 221 Fundamentals of Multiphase Flow, and ENERGY 240 Geostatistics, or their equivalents. The number and distribution of courses to be taken is determined with input from the research advisers and department graduate program committee.
2. To achieve candidacy (usually during or at the end of the first year of enrollment), the student must complete 24 units of letter-graded course work beyond the M.S. degree, pass a written exam, develop a written Ph.D. research proposal, and choose a dissertation committee.
3. The research adviser(s) and two other faculty members comprise the dissertation reading committee. Upon completion of the dissertation, the student must pass a University oral examination in defense of the dissertation.
4. Act as a teaching assistant at least once, and enroll in ENERGY 359 Teaching Experience in Energy Resources Engineering.

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 required teaching experience (ENERGY 359 Teaching Experience in Energy Resources Engineering) nor required research seminars.

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. students entering the department are required to hold an M.S. degree in a relevant science or engineering discipline. Students wishing to follow the Ph.D. program in Petroleum Engineering must hold an M.S. degree (or equivalent) in Petroleum Engineering. Students following the Ph.D. program in Energy Resources Engineering must hold an M.S. degree (or equivalent), although it need not be in Energy Resources Engineering.

After the second quarter at Stanford, a faculty committee evaluates the student's progress. If a student is found to be deficient in course work and/or research, a written warning is issued. After the third quarter, the faculty committee decides whether or not funding should be continued for the student. Students denied funding after the third quarter are advised against proceeding with the Ph.D. proposal, though the student may choose to proceed under personal funding.

### Ph.D. Degree Qualification

The procedure for Ph.D. qualification is identical for individuals who entered the department as an M.S. or a Ph.D. student. For students completing an MS in the department, the student formally applies to the Ph.D. program in the second year of the M.S. degree program. The student is considered for admission to the Ph.D. program along with external applicants. The admission decision is based primarily upon research progress and course work.

There are two steps to the qualification procedure. Students first take a preliminary written exam that is offered at the beginning of Autumn Quarter. The exam focuses upon synthesis of knowledge acquired from core courses in ERE or PE. Exams are different for ERE and PE Ph.D. students, but share a goal of having students exhibit capability to solve an engineering problem. Students continuing within the department take the exam at the beginning of their first quarter as Ph.D. students. Students who completed their M.S outside of the department take the exam at the beginning of their fourth quarter as PhD students. A student who does not pass the exam may not be allowed to take the exam a second time.

Any student who does not pass the written exam is considered to have failed the qualifying exam. Any student who is deemed to have not made sufficient research progress may not be allowed to take the preliminary exam and research progress shall be taken into account for pass, fail, and retake decisions.

A written Ph.D. proposal and oral defense are the main components of the second step. The written proposals are reviewed by three faculty members. Students are provided a template of what constitutes an acceptable proposal. Students subsequently make an oral presentation of their proposal to three faculty members including material such as a literature review, identification of key unanswered research questions, proposed work outline, and an oral presentation.

Following the presentation, the student is questioned on the research topic and general field of study. The student can pass, pass with qualifications requiring more classes or teaching assistantships, or fail. Students who completed their MS in the department prepare and defend their proposal in their third quarter (not counting summer) as a Ph.D. student. Their advisor may request an additional quarter given extenuating circumstances such as a major change in research focus between M.S. and Ph.D. programs. Students who completed their MS outside of the department complete the proposal in their fourth quarter (not counting summer) of study.

## Course Work

The 36 units of course work may include graduate courses in Energy Resources Engineering (numbered 200 and above) and courses chosen from the following list. Other courses may be substituted with prior approval of the adviser. In general, non-technical courses are not approved.

Students who enter directly into the Ph.D. program after receiving an M.S. degree from another university are expected to show expertise in the core courses required for Stanford's M.S. degree in Energy Resources Engineering, either by including those courses in their Ph.D. degree or by showing that they have taken equivalent courses during their M.S. degree.

For a Ph.D. in Energy Resources Engineering, 12 of the 36 required course units must be completed from the following list of courses. If the student has not taken ENERGY 293A Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution,ENERGY 293B Fundamentals of Energy Processes, ENERGY 293C Energy from Wind and Water Currents or their equivalent during the M.S., then these courses must be taken during the Ph.D. (they will satisfy 9 of the required 12 units).

| | | Units |
|---|---|---|
| Required to take 12 units from the following list: | | |
| ENERGY 104 | Sustainable Energy for 9 Billion | 3 |
| ENERGY 253 | Carbon Capture and Sequestration | 3-4 |
| ENERGY 256 | Electronic Structure Theory and Applications to Chemical Kinetics (formerly ENERGY 252) | 3 |
| ENERGY 269 | Geothermal Reservoir Engineering | 3 |
| ENERGY 291 | Optimization of Energy Systems | 3-4 |
| ENERGY 293A | Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution | 3-4 |
| ENERGY 293B | Fundamentals of Energy Processes | 3 |
| ENERGY 293C | Energy from Wind and Water Currents | 3 |
| ENERGY 301 | The Energy Seminar | 1 |
| CEE 176A | Energy Efficient Buildings | 3-4 |
| CEE 176B | Electric Power: Renewables and Efficiency | 3-4 |
| CEE 268 | Groundwater Flow | 3-4 |
| CME 206 | Introduction to Numerical Methods for Engineering | 3 |
| CME 302 | Numerical Linear Algebra | 3 |
| CME 306 | Numerical Solution of Partial Differential Equations | 3 |
| ESS 221/ CEE 260C | Contaminant Hydrogeology and Reactive Transport | 4 |
| CHEMENG 130 | Separation Processes | 3 |
| CHEMENG 340 | Molecular Thermodynamics | 3 |
| ECON 250 | Environmental Economics | 2-5 |
| ECON 251 | Natural Resource and Energy Economics | 2-5 |
| GS 170 | Environmental Geochemistry | 4 |
| GS 171 | Geochemical Thermodynamics | 3 |
| GS 217 | | |
| GS 253 | Petroleum Geology and Exploration | 3 |
| GEOPHYS 182 | Reflection Seismology | 3 |
| GEOPHYS 202 | Reservoir Geomechanics | 3 |
| GEOPHYS 262 | Rock Physics | 3 |
| ME 131A | Heat Transfer | 3-5 |
| ME 250 | Internal Combustion Engines | 3 |
| ME 260 | Fuel Cell Science and Technology | 3 |
| ME 335A | Finite Element Analysis | 3 |
| ME 335B | Finite Element Analysis | 3 |
| ME 335C | Finite Element Analysis | 0 |
| ME 370A | Energy Systems I: Thermodynamics | 3 |
| ME 370B | Energy Systems II: Modeling and Advanced Concepts | 4 |
| MATSCI 156/ ENERGY 293A | Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution | 3-4 |
| MATSCI 316 | Nanoscale Science, Engineering, and Technology | 3 |

# Ph.D. Minor in Petroleum Engineering or Energy Resources Engineering

To be recommended for a Ph.D. degree with Petroleum Engineering or Energy Resources Engineering as a minor subject, a student must take 20 units of graduate-level lecture courses in the department. These courses must include ENERGY 221 Fundamentals of Multiphase Flow and ENERGY 222 Advanced Reservoir Engineering for the Petroleum Engineering minor, or ENERGY 293A Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution and ENERGY 293B Fundamentals of Energy Processes and ENERGY 293C Energy from Wind and Water Currents for the Energy Resources Engineering minor. The remaining courses should be selected from:

| | | Units |
|---|---|---|
| ENERGY 175 | Well Test Analysis | 3 |
| ENERGY 223 | Reservoir Simulation | 3-4 |
| ENERGY 224 | Advanced Reservoir Simulation | 3 |
| ENERGY 225 | Theory of Gas Injection Processes | 3 |
| ENERGY 227 | Enhanced Oil Recovery | 3 |
| ENERGY 240 | Geostatistics | 2-3 |
| ENERGY 241 | Seismic Reservoir Characterization | 3-4 |
| ENERGY 251 | Thermodynamics of Equilibria | 3 |
| ENERGY 253 | Carbon Capture and Sequestration | 3-4 |
| ENERGY 256 | Electronic Structure Theory and Applications to Chemical Kinetics (formerly ENERGY 252) | 3 |
| ENERGY 269 | Geothermal Reservoir Engineering | 3 |
| ENERGY 280 | Oil and Gas Production Engineering | 3 |
| ENERGY 281 | Applied Mathematics in Reservoir Engineering | 3 |
| ENERGY 284 | Optimization and Inverse Modeling | 3 |

*Emeriti: (Professors)* Khalid Aziz, John W. Harbaugh, André Journel*, Franklin M. Orr, Jr.

*Chair:* Anthony Kovscek

*Professors:* Sally M. Benson, Louis J. Durlofsky, Roland N. Horne, Anthony R. Kovscek, Hamdi Tchelepi

*Associate Professors:* Margot Gerritsen, Tapan Mukerji**

*Assistant Professors:* Adam Brandt, Jennifer Wilcox

*Courtesy Professors:* Stephan A. Graham, Mark Jacobson

*Lecturers:* Louis M. Castanier, Denis V. Voskov, Anne Macfarlane, Eric Stoutenburg

*Consulting Professors:*Warren K. Kourt, Robert G. Lindblom, Kiran Pande, Victor Pereyra, Marco R. Thiele, Birol Dindoruk, Stuart MacMillan, Richard Sears

* Joint appointment with Geological and Sciences

** Joint appointment with Geophysics