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 Engineering contributes to the engineering science needed to maintain and diversify energy supply while finding the least impactful and most rapid pathways toward greater energy sustainability. Energy Resources Engineering is concerned with the production, transformation, and impacts of energy resources including renewables and fossil fuels. Crude oil and natural gas are especially important components of the current energy system due to their widespread use, economic importance, and contributions to climate change. As such, the flow of water, oil, and gas in the subsurface are important to quantify accurately for energy recovery, energy storage, environmental assessment, and carbon storage.

The program also has a strong interest in related energy topics such as renewable energy, global climate change, carbon capture and sequestration, 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 geostatistics. The curriculum emphasizes the fundamental aspects of fluid flow in the subsurface. These principles apply to optimizing energy recovery from petroleum reservoirs, geothermal energy systems, energy storage, and remediating contaminated groundwater systems.

Faculty and graduate students conduct research in areas including: enhanced oil recovery; geostatistical reservoir characterization and mathematical modeling; geothermal engineering; natural gas engineering; production optimization; data assimilation and uncertainty quantification; properties of petroleum fluids; power production from wind and wave energy; well test analysis; carbon sequestration; multi-scale physics; 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, 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, that 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 independent research as well as fundamental courses in the major field and in related sciences. 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, engineering, 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 Thinking Matters, Ways of Thinking/Ways of Doing (Ways), writing and rhetoric, and language requirements. The normal Energy Resources Engineering undergraduate program automatically satisfies the University Ways requirement in the Disciplinary Breadth areas of Natural Sciences, Engineering and Applied Sciences, and Mathematics.

Courses taken to fulfill the requirements for the major (energy resources core and depth; mathematics; engineering fundamentals; science; and technology in society) must be taken for a letter grade if the option is offered.

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: Ways, Writing, Language	60-70
Total Units	170-190

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 adviser'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	Uncertainty Quantification in Data-Centric Simulations	3
ENERGY 199	Senior Project and Seminar in Energy Resources (WIM)	3-4
Mathematics		10
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, Multivariable Calculus, and Modern Applications	
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 of Organic Molecules	5
PHYSICS 41	Mechanics	4
PHYSICS 43	Electricity and Magnetism	4
PHYSICS 45	Light and Heat	4
PHYSICS 46	Light and Heat Laboratory	1
GEOLSCI 1	Introduction to Geology	5
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	3
ME 30	Engineering Thermodynamics (Previously ENGR 30)	3
ENERGY 110	Engineering Economics	3
ME 70	Introductory Fluids Engineering	3
Technology in Society, 1 course		

Earth and Energy Depth

Complete at least 5 courses from either the Renewable and Clean Energy or Petroleum Engineering emphasis lists below. Complete at least one course form the other emphasis. Units must total to at least 18 units.

		Units
Renewable and Clean Energy		
ENERGY 102	Fundamentals of Renewable Power	3
ENERGY 153	Carbon Capture and Sequestration	3-4
ENERGY 191	Optimization of Energy Systems	3-4
ENERGY 293	Energy storage and conversion: Solar Cells, Fuel Cells, Batteries and Supercapacitors	3-4
ENERGY 293B	Fundamentals of Energy Processes	3
ENERGY 293C	Energy from Wind and Water Currents	3
or ENERGY 262	Physics of Wind Energy	
CEE 70	Environmental Science and Technology	3
CEE 176A	Energy Efficient Buildings	3-4
CEE 176B	100% Clean, Renewable Energy and Storage for Everything	3-4
Petroleum Engineering		
ENERGY 112	Exploring Geosciences with MATLAB	1-3
ENERGY 121	Fundamentals of Multiphase Flow	3
ENERGY 130	Well Log Analysis I	3
ENERGY 141	Seismic Reservoir Characterization	3-4
ENERGY 153	Carbon Capture and Sequestration	3-4
ENERGY 175	Well Test Analysis	3
ENERGY 180	Oil and Gas Production Engineering	3
ENERGY 191	Optimization of Energy Systems	3-4
GEOLSCI 106	Sedimentary Geology and Depositional Systems	4
GEOPHYS 182	Reflection Seismology	3

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 serves as the research adviser.

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 adviser 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 adviser 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 adviser. Appropriate substitutions are allowed with the consent of the adviser.

Required courses

		Units
ENERGY 101	Energy and the Environment	3
ENERGY 120	Fundamentals of Petroleum Engineering	3
ENERGY 160	Uncertainty Quantification in Data-Centric Simulations	3

Elective courses

		Units
Select at least three of the following:		
ENERGY 102	Fundamentals of Renewable Power	
ENERGY 104	Sustainable Energy for 9 Billion	
ENERGY 112	Exploring Geosciences with MATLAB	
ENERGY 121	Fundamentals of Multiphase Flow	
ENERGY 130	Well Log Analysis I	
ENERGY 141	Seismic Reservoir Characterization	
ENERGY 153	Carbon Capture and Sequestration	
ENERGY 175	Well Test Analysis	
ENERGY 180	Oil and Gas Production Engineering	
ENERGY 269	Geothermal Reservoir Engineering	
GEOLSCI 106	Sedimentary Geology and Depositional Systems	
GEOPHYS 182	Reflection Seismology	

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 GEOLSCI 106 Sedimentary Geology and 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. Complete 3 units of ENERGY 351 ERE Master's Graduate Seminar. These units do not count toward the 45 units of course work required for the M.S. degree.
5. 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 (12 units)

		Units
ENERGY 221	Fundamentals of Multiphase Flow	3
ENERGY 222	Advanced Reservoir Engineering	3
ENERGY 251	Thermodynamics of Equilibria	3
ENERGY 297	Fluid Mechanics and Heat Transfer	3

Mathematics and Analysis Fundamentals (12 units)

		Units
CME 200	Linear Algebra with Application to Engineering Computations	3
And select one of the following (3 units):		
CME 204	Partial Differential Equations in Engineering	3
CME 206	Introduction to Numerical Methods for Engineering	3
ENERGY 281	Applied Mathematics in Reservoir Engineering	3
And select two of the following (6 units):		
ENERGY 240	Data science for geoscience	3
ENERGY 260	Uncertainty Quantification in Data-Centric Simulations	3
ENERGY 281	Applied Mathematics in Reservoir Engineering	3
ENERGY 291	Optimization of Energy Systems	3-4
CME 204	Partial Differential Equations in Engineering	3
CME 206	Introduction to Numerical Methods for Engineering	3

Technical Elective Sequence (15 units)

		Units
Select three courses from one of the following sequences and additional technical courses to obtain 15 total elective units:		15
Environmental:		
Select three of the following:		
ENERGY 227	Enhanced Oil Recovery	
ESS 221	Contaminant Hydrogeology and Reactive Transport	
CEE 270	Movement and Fate of Organic Contaminants in Waters	
CEE 273	Aquatic Chemistry	
Enhanced Recovery:		
Select three of the following:		
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	Data science for geoscience	
ENERGY 241	Seismic Reservoir Characterization	
GEOPHYS 182	Reflection Seismology	
or GEOPHYS 262	Rock Physics	
Geothermal:		
ENERGY 269	Geothermal Reservoir Engineering	
CHEMENG 120B	Energy and Mass Transport	
ME 131A	Heat Transfer	
Reservoir Performance:		
Select three of the following:		
ENERGY 130	Well Log Analysis I	
ENERGY 175	Well Test Analysis	
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		
Renewable Energy:		
ENERGY 293	Energy storage and conversion: Solar Cells, Fuel Cells, Batteries and Supercapacitors	
ENERGY 293B	Fundamentals of Energy Processes	
ENERGY 269	Geothermal Reservoir Engineering	
or ENERGY 262	Physics of Wind Energy	

Research Sequence (6 units)

		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.

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, with a minimum of 39 units of course work, and the remainder consisting of no more than 6 research units.
2. Complete 3 units of ENERGY 351 ERE Master's Graduate Seminar. These units do not count toward the 45 units of course work required for the M.S. degree.
3. 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.
4. All courses must be taken for a letter grade.
5. The program of study must be approved by the academic adviser and the department graduate program committee.
6. 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 (12 units)

		Units
ENERGY 253	Carbon Capture and Sequestration	3-4
ENERGY 293	Energy storage and conversion: Solar Cells, Fuel Cells, Batteries and Supercapacitors	3-4
ENERGY 293B	Fundamentals of Energy Processes	3
ENERGY 297	Fluid Mechanics and Heat Transfer	3

Mathematics and Analysis Fundamentals (12 units)

		Units
CME 200	Linear Algebra with Application to Engineering Computations	3
And select one of the following (3 units):		
CME 204	Partial Differential Equations in Engineering	3
CME 206	Introduction to Numerical Methods for Engineering	3
ENERGY 281	Applied Mathematics in Reservoir Engineering	3
And select two of the following (6 units):		
ENERGY 240	Data science for geoscience	3
ENERGY 260	Uncertainty Quantification in Data-Centric Simulations	3
ENERGY 281	Applied Mathematics in Reservoir Engineering	3
ENERGY 291	Optimization of Energy Systems	3-4
CME 204	Partial Differential Equations in Engineering	3
CME 206	Introduction to Numerical Methods for Engineering	3

Technical Elective Sequence (15 units)

		Units
Select three courses from one of the following sequences and additional technical courses to obtain 15 total elective units:		15
Geothermal:		
Select three of the following:		
ENERGY 223	Reservoir Simulation	
ENERGY 269	Geothermal Reservoir Engineering	
CHEMENG 120B	Energy and Mass Transport	
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 269	Geothermal Reservoir Engineering	
ENERGY 291	Optimization of Energy Systems	
CHEMENG 130	Separation Processes	
ME 370A	Energy Systems I: Thermodynamics	
ME 370B	Energy Systems II: Modeling and Advanced Concepts	
Modeling Natural Resources:		
Select three of the following:		
ENERGY 240	Data science for geoscience	
ENERGY 241	Seismic Reservoir Characterization	
ENERGY 284		
GEOPHYS 262	Rock Physics	
Oil and Gas:		
Select three of the following:		
ENERGY 104	Sustainable Energy for 9 Billion	
ENERGY 130	Well Log Analysis I	
ENERGY 175	Well Test Analysis	
ENERGY 221	Fundamentals of Multiphase Flow	
ENERGY 222	Advanced Reservoir Engineering	
ENERGY 223	Reservoir Simulation	
ENERGY 240	Data science for geoscience	
ENERGY 251	Thermodynamics of Equilibria	
Total Units		15

Research Sequence (6 units)

		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.

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 above 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 engineering or energy industries, or in any related industry where application of physical principles or computer simulation skills are required. It can also be a stepping stone to a Ph.D. degree, that 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.

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 Data science for geoscience, 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.
5. Complete 4 units of ENERGY 352 ERE PhD Graduate Seminar. These units do not count toward the 36 units of course work required for the Ph.D. degree.

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 M.S. 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 take the exam consistent with their Ph.D. degree objective (i.e., ERE or PE).

Students continuing within the department take the written exam at the beginning of their first quarter as Ph.D. students. Students who completed their M.S. outside of the department take the written exam at the beginning of their fourth quarter as Ph.D. 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 is 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 M.S. in the department prepare and defend their proposal in their third quarter (not counting Summer) as a Ph.D. student. Their adviser 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 M.S. outside of the department complete the proposal in their fourth quarter (not counting summer) of study.

Students who have passed the qualification procedure and later wish to change their degree objective from PE to ERE, or vice versa, may petition the graduate standing committee. A switch of degree objective is not automatically granted. Petitions are made in writing and include a brief explanation of the request for a change in degree objective and a plan to make up subject matter deficiencies. At the minimum, students who petition are expected to complete ultimately all courses listed as contributing subject matter to the written exam in the area of their degree objective with a minimum grade of 'B'. The graduate standing committee decides whether petitions have merit and if additional steps are needed to address deficiencies. Such switches in degree objective are considered provisional until all conditions have been met.

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 293 Energy storage and conversion: Solar Cells, Fuel Cells, Batteries and Supercapacitors and ENERGY 293B Fundamentals of Energy Processes or their equivalent during the M.S., then these courses must be taken during the Ph.D. (they satisfy 6 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 269	Geothermal Reservoir Engineering	3
ENERGY 291	Optimization of Energy Systems	3-4
ENERGY 293	Energy storage and conversion: Solar Cells, Fuel Cells, Batteries and Supercapacitors	3-4
ENERGY 293B	Fundamentals of Energy Processes	3
ENERGY 301	The Energy Seminar	1

CEE 176A	Energy Efficient Buildings	3-4
CEE 176B	100% Clean, Renewable Energy and Storage for Everything	3-4
CEE 268		
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	3
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
GEOLSCI 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
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	3
ME 370A	Energy Systems I: Thermodynamics	3
ME 370B	Energy Systems II: Modeling and Advanced Concepts	4
MATSCI 156	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 293 Energy storage and conversion: Solar Cells, Fuel Cells, Batteries and Supercapacitors and ENERGY 293B Fundamentals of Energy Processes 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	Data science for geoscience	3
ENERGY 241	Seismic Reservoir Characterization	3-4
ENERGY 251	Thermodynamics of Equilibria	3
ENERGY 253	Carbon Capture and Sequestration	3-4
ENERGY 269	Geothermal Reservoir Engineering	3
ENERGY 280	Oil and Gas Production Engineering	3
ENERGY 281	Applied Mathematics in Reservoir Engineering	3
ENERGY 284		

For a statement of University policy on graduate advising, see the "Graduate Advising (http://exploredegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext)" section of this bulletin.

Master's Student Advising

The Department of Energy Resources Engineering is committed to providing academic advising in support of our M.S. students' education and professional development. When most effective, this advising relationship entails collaborative engagement by both the adviser and the advisee. As a best practice, advising expectations should be discussed and reviewed to ensure mutual understanding. Both the adviser and the advisee are expected to maintain professionalism and integrity.

At or before the start of graduate study, normally at the beginning of Autumn Quarter, each student is assigned an adviser: a member of our faculty who provides research advice and guidance in course selection and in exploring academic opportunities and professional pathways. A significant advising milestone is the M.S. Program Proposal that each student completes at the end of their first quarter.

The department's graduate handbook provides information and suggested timelines for advising meetings. Typically, research M.S. students meet with their adviser on a twice weekly basis, once individually and once as part of the research group meeting. If a meeting is not possible, the student should send the adviser a brief email highlighting his/her activities for the week. Usually, the same faculty member serves as program adviser for the duration of master's study, but the handbook does describe a process for formal adviser changes.

In addition, the Chair of the Graduate Committee meets with all the master's students at the start of the first year and is available during the academic year by email and during office hours.

Students are expected to have a discussion with their adviser during or before the first week of each quarter to agree upon the courses that the student plans to take that quarter. Advisers formally approve the study list in person or by email.

The department's student services office is also an important part of the master's advising team. It informs students and advisers about University and department requirements, procedures, and opportunities, and it maintains the official records of advising assignments and approvals.

Finally, graduate students are active contributors to the advising relationship, proactively seeking academic and professional guidance and taking responsibility for informing themselves of policies and degree requirements for their graduate program.

Ph.D. Student Advising

The Department of Energy Resources Engineering is committed to providing academic advising in support of doctoral student scholarly and professional development. When most effective, this advising relationship entails collaborative and sustained engagement by both the adviser and the advisee. As a best practice, advising expectations should be periodically discussed and reviewed to ensure mutual understanding. Both the adviser and the advisee are expected to maintain professionalism and integrity.

Faculty advisers guide students in key areas such as selecting courses, designing and conducting research, developing teaching pedagogy, navigating policies and degree requirements, and exploring academic opportunities and professional pathways. The department's graduate handbook provides information and suggested timelines for advising meetings in the different stages of the doctoral program. If a meeting is not possible, the student should send the adviser a brief email highlighting his/her activities for the week. Typically, Ph.D. students meet with their adviser on a twice weekly basis, once individually and once as part of the research group meeting.

At least once per year, either formally or informally, students and advisers are expected to review the student's progress towards completion of their research and their degree. Such discussions may include other members of the student's research committee, either together or individually. A formal meeting of the full committee, which may be useful if the student and adviser differ in their assessment of research progress and goals, can be called by either the student or the adviser.

Ph.D. students are initially assigned a research adviser prior to or on arrival at Stanford. This faculty member provides initial guidance in course selection, in exploring academic opportunities and professional pathways, and in identifying doctoral research opportunities. Ultimately the adviser directs the student's dissertation. Usually, the same faculty member serves as adviser for the duration of Ph.D. study, but the handbook does describe a process for formal adviser changes.

Most students have an adviser from among the primary faculty members of the department. However, the research adviser may be a faculty member from another Stanford department who is familiar with supervising doctoral students and able to provide both advising and funding for the duration of the doctoral program. When the research adviser is from outside the department, the student must also identify a program adviser from the department's primary faculty to provide guidance on departmental requirements and opportunities.

Students are expected to have a discussion with their adviser during or before the first week of each quarter, to agree upon the courses that the student plans to take that quarter. Advisers formally approve the study list in person or by email.

The Chair of the Graduate Committee (CGC) meets with all doctoral students at the start of the first year, and is available during the academic year by email and during office hours. The department's student services office is also an important part of the doctoral advising team: it informs students and advisers about University and department requirements, procedures, and opportunities, and it maintains the official records of advising assignments and approvals. Students are encouraged to talk with the CGC and the student services office for guidance in working with their adviser(s).

The department's doctoral students are active contributors to the advising relationship, proactively seeking academic and professional guidance and taking responsibility for informing themselves of policies and degree requirements for their graduate program.

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

Chair: Hamdi Tchelepi

Professors: Sally M. Benson, Louis J. Durlofsky, Margot Gerritsen, Roland N. Horne, Anthony R. Kovscek, Daniel M. Tartakovsky, Hamdi Tchelepi

Associate Professors: Tapan Mukerji

Assistant Professors: Ilenia Battiato, Adam Brandt, Simona Onori

Courtesy Professors: Stephan A. Graham, Mark Jacobson

Professors of Practice: Richard Sears

Adjunct Faculty: Alan Burnham, Louis M. Castanier, Kurt House, Warren K. Kourt, Jonathan Lilien, Robert G. Lindblom, Stuart MacMillan, Kiran Pande, Marco R. Thiele, Denis V. Voskov

Visiting Professor: Kozo Sato

* Joint appointment with Geological Sciences