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 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. 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. As such, the flow of water, oil, and gas in the subsurface are important to quantify accurately for energy recovery, energy storage, and environmental assessment.

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 modeling; properties of petroleum fluids; power production from wind and wave energy; well test analysis; carbon sequestration; 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, 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:

Energy Resources Core
Energy Resources Depth
Mathematics
Engineering Fundamentals and Depth
Science
Technology in Society
University Requirements: IHUM, GERs, Writing, Language
Total Units

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

The following courses constitute the core program in Energy Resources Engineering

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY 101</td>
<td>Energy and the Environment</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 104</td>
<td>Sustainable Energy for 9 Billion</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 120</td>
<td>Fundamentals of Petroleum Engineering</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 160</td>
<td>Modeling Uncertainty in the Earth Sciences</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 199</td>
<td>Senior Project and Seminar in Energy Resources (WIM)</td>
<td>3-4</td>
</tr>
</tbody>
</table>

Mathematics

Select one of the following Series (A or B):

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
- or MATH 51 Linear Algebra and Differential Calculus of Several Variables
- CME 102  Ordinary Differential Equations for Engineers

Science

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 31A</td>
<td>Chemical Principles I</td>
<td>5</td>
</tr>
<tr>
<td>or CHEM 31X</td>
<td>Chemical Principles Accelerated</td>
<td>5</td>
</tr>
<tr>
<td>CHEM 31B</td>
<td>Chemical Principles II</td>
<td>5</td>
</tr>
<tr>
<td>or CHEM 31X</td>
<td>Chemical Principles Accelerated</td>
<td>5</td>
</tr>
<tr>
<td>CHEM 33</td>
<td>Structure and Reactivity</td>
<td>5</td>
</tr>
<tr>
<td>PHYSICS 41</td>
<td>Mechanics</td>
<td>4</td>
</tr>
<tr>
<td>PHYSICS 43</td>
<td>Electricity and Magnetism</td>
<td>4</td>
</tr>
<tr>
<td>PHYSICS 45</td>
<td>Light and Heat</td>
<td>4</td>
</tr>
<tr>
<td>PHYSICS 46</td>
<td>Light and Heat Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>GS 1</td>
<td>Introduction to Geology</td>
<td>5</td>
</tr>
</tbody>
</table>

Engineering Fundamentals

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>CS 106A</td>
<td>Programming Methodology</td>
<td>3-5</td>
</tr>
<tr>
<td>or CS 106X</td>
<td>Programming Abstractions (Accelerated)</td>
<td>3-5</td>
</tr>
<tr>
<td>CS 106B</td>
<td>Programming Abstractions</td>
<td>3-5</td>
</tr>
<tr>
<td>or CS 106X</td>
<td>Programming Abstractions (Accelerated)</td>
<td>3-5</td>
</tr>
<tr>
<td>ENGR 14</td>
<td>Intro to Solid Mechanics</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 30</td>
<td>Engineering Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 110</td>
<td>Engineering Economics</td>
<td>3</td>
</tr>
<tr>
<td>ME 70</td>
<td>Introductory Fluids Engineering</td>
<td>4</td>
</tr>
</tbody>
</table>

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.

Renewable and Clean Energy

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY 102</td>
<td>Fundamentals of Renewable Power</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 153</td>
<td>Carbon Capture and Sequestration</td>
<td>3-4</td>
</tr>
<tr>
<td>ENERGY 191</td>
<td>Optimization of Energy Systems</td>
<td>3-4</td>
</tr>
<tr>
<td>ENERGY 293A</td>
<td>Solar Cells, Fuel Cells, and Batteries: Materials for</td>
<td>3-4</td>
</tr>
<tr>
<td></td>
<td>the Energy Solution</td>
<td></td>
</tr>
<tr>
<td>ENERGY 293B</td>
<td>Fundamentals of Energy Processes</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 293C</td>
<td>Energy from Wind and Water Currents</td>
<td>3</td>
</tr>
<tr>
<td>CEE 70</td>
<td>Environmental Science and Technology</td>
<td>3</td>
</tr>
<tr>
<td>CEE 176A</td>
<td>Energy Efficient Buildings</td>
<td>3-4</td>
</tr>
<tr>
<td>CEE 176B</td>
<td>Electric Power: Renewables and Efficiency</td>
<td>3-4</td>
</tr>
</tbody>
</table>

Petroleum Engineering

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY 121</td>
<td>Fundamentals of Multiphase Flow</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 130</td>
<td>Well Log Analysis I</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 141</td>
<td>Seismic Reservoir Characterization</td>
<td>3-4</td>
</tr>
<tr>
<td>ENERGY 146</td>
<td>Reservoir Characterization and Flow Modeling with</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Outcrop Data</td>
<td></td>
</tr>
<tr>
<td>ENERGY 153</td>
<td>Carbon Capture and Sequestration</td>
<td>3-4</td>
</tr>
<tr>
<td>ENERGY 175</td>
<td>Well Test Analysis</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 180</td>
<td>Oil and Gas Production Engineering</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 191</td>
<td>Optimization of Energy Systems</td>
<td>3-4</td>
</tr>
<tr>
<td>GEOPHYS 112</td>
<td>Exploring Geosciences with MATLAB</td>
<td>1-3</td>
</tr>
<tr>
<td>GEOPHYS 182</td>
<td>Reflection Seismology</td>
<td>3</td>
</tr>
<tr>
<td>GS 106</td>
<td>Sedimentary Geology and Depositional Systems</td>
<td>4</td>
</tr>
</tbody>
</table>
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 advisor. Appropriate substitutions are allowed with the consent of the advisor.

Required courses

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY 101</td>
<td>Energy and the Environment</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 120</td>
<td>Fundamentals of Petroleum Engineering</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 160</td>
<td>Modeling Uncertainty in the Earth Sciences</td>
<td>3</td>
</tr>
</tbody>
</table>

Elective courses

Select at least three of the following:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY 102</td>
<td>Fundamentals of Renewable Power</td>
<td></td>
</tr>
<tr>
<td>ENERGY 104</td>
<td>Sustainable Energy for 9 Billion</td>
<td></td>
</tr>
<tr>
<td>ENERGY 121</td>
<td>Fundamentals of Multiphase Flow</td>
<td></td>
</tr>
<tr>
<td>ENERGY 125</td>
<td>Modeling and Simulation for Geoscientists and Engineers</td>
<td></td>
</tr>
<tr>
<td>ENERGY 130</td>
<td>Well Log Analysis I</td>
<td></td>
</tr>
<tr>
<td>ENERGY 141</td>
<td>Seismic Reservoir Characterization</td>
<td></td>
</tr>
<tr>
<td>ENERGY 146</td>
<td>Reservoir Characterization and Flow Modeling with Outcrop Data</td>
<td></td>
</tr>
<tr>
<td>ENERGY 153</td>
<td>Carbon Capture and Sequestration</td>
<td></td>
</tr>
<tr>
<td>ENERGY 269</td>
<td>Geothermal Reservoir Engineering</td>
<td></td>
</tr>
<tr>
<td>ENERGY 175</td>
<td>Well Test Analysis</td>
<td></td>
</tr>
<tr>
<td>ENERGY 180</td>
<td>Oil and Gas Production Engineering</td>
<td></td>
</tr>
<tr>
<td>GEOPHYS 182</td>
<td>Reflection Seismology</td>
<td></td>
</tr>
<tr>
<td>GS 106</td>
<td>Sedimentary Geology and Depositional Systems</td>
<td></td>
</tr>
<tr>
<td>GEOPHYS 112</td>
<td>Exploring Geosciences with MATLAB</td>
<td></td>
</tr>
</tbody>
</table>

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 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. 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

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY 175 or ENERGY 130</td>
<td>3</td>
<td>Well Test Analysis</td>
</tr>
<tr>
<td>ENERGY 221</td>
<td>3</td>
<td>Fundamentals of Multiphase Flow</td>
</tr>
<tr>
<td>ENERGY 222</td>
<td>3</td>
<td>Advanced Reservoir Engineering</td>
</tr>
<tr>
<td>ENERGY 246</td>
<td>3</td>
<td>Reservoir Characterization and Flow Modeling with Outcrop Data</td>
</tr>
<tr>
<td>ENERGY 251</td>
<td>3</td>
<td>Thermodynamics of Equilibria</td>
</tr>
<tr>
<td>CME 200</td>
<td>3</td>
<td>Linear Algebra with Application to Engineering Computations</td>
</tr>
<tr>
<td>CME 204</td>
<td>3</td>
<td>Partial Differential Equations in Engineering</td>
</tr>
</tbody>
</table>

Total Units: 21

### Elective Sequence

Select one of the following Series:

**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

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENR 200</td>
<td>9-14</td>
<td></td>
</tr>
</tbody>
</table>

### Research Sequence

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY 361</td>
<td>1-6</td>
<td>Master's Degree Research in Energy Resources Engineering</td>
</tr>
</tbody>
</table>

Total Units: 1-6

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.

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY 130</td>
<td>3</td>
<td>Well Log Analysis I</td>
</tr>
<tr>
<td>ENERGY 224</td>
<td>3</td>
<td>Advanced Reservoir Simulation</td>
</tr>
<tr>
<td>ENERGY 230</td>
<td>3</td>
<td>Advanced Topics in Well Logging</td>
</tr>
<tr>
<td>ENERGY 267</td>
<td>3</td>
<td>Engineering Valuation and Appraisal of Oil and Gas Wells, Facilities, and Properties</td>
</tr>
<tr>
<td>ENERGY 269</td>
<td>3</td>
<td>Geothermal Reservoir Engineering</td>
</tr>
<tr>
<td>ENERGY 273</td>
<td>1-3</td>
<td>Special Topics in Energy Resources Engineering</td>
</tr>
<tr>
<td>ENERGY 280</td>
<td>3</td>
<td>Oil and Gas Production Engineering</td>
</tr>
<tr>
<td>ENERGY 281</td>
<td>3</td>
<td>Applied Mathematics in Reservoir Engineering</td>
</tr>
</tbody>
</table>
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

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

Subject Sequence Alternatives

Select one of the following Series:

1. Geothermal:
   - ENERGY 223 Reservoir Simulation
   - ENERGY 269 Geothermal Reservoir Engineering
   - CHEMENG 120 Energy and Mass Transport

2. Low Carbon Energy:
   - Select three of the following:
     - ENERGY 217 Heat Transfer
     - ME 131A Heat Transfer
     - ME 370A Energy Systems I: Thermodynamics

3. Oil and Gas:
   - ENERGY 251 Geochemical Thermodynamics
   - ME 370A Energy Systems I: Thermodynamics
   - ME 370B Energy Systems II: Modeling and Advanced Concepts

4. 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

Technical Electives

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY 104</td>
<td>Sustainable Energy for 9 Billion</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 120</td>
<td>Fundamentals of Petroleum Engineering</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 130</td>
<td>Well Log Analysis I</td>
<td>3</td>
</tr>
<tr>
<td>Any 200-level ENERGY course</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENERGY 301</td>
<td>The Energy Seminar</td>
<td>1</td>
</tr>
<tr>
<td>CEE 176A</td>
<td>Energy Efficient Buildings</td>
<td>3-4</td>
</tr>
<tr>
<td>CEE 176B</td>
<td>Electric Power: Renewables and Efficiency</td>
<td>3-4</td>
</tr>
<tr>
<td>CME 206</td>
<td>Introduction to Numerical Methods for Engineering</td>
<td>3</td>
</tr>
<tr>
<td>CME 212</td>
<td>Advanced Software Development for Scientists and Engineers</td>
<td>3</td>
</tr>
<tr>
<td>ECON 250</td>
<td>Environmental Economics</td>
<td>2-5</td>
</tr>
<tr>
<td>ECON 251</td>
<td>Natural Resource and Energy Economics</td>
<td>2-5</td>
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<tr>
<td>GS 217</td>
<td></td>
<td></td>
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<td>MATSCI 316</td>
<td>Nanoscale Science, Engineering, and Technology</td>
<td>3</td>
</tr>
<tr>
<td>ME 131A</td>
<td>Heat Transfer</td>
<td>3-5</td>
</tr>
<tr>
<td>ME 260</td>
<td>Fuel Cell Science and Technology</td>
<td>3</td>
</tr>
<tr>
<td>ME 370A</td>
<td>Energy Systems I: Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>ME 370B</td>
<td>Energy Systems II: Modeling and Advanced Concepts</td>
<td>4</td>
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</table>
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 research job or an academic position. The B.S. degree in any relevant major. Energy Resources Engineering graduate students generally come from backgrounds such as chemical, civil, or mechanical engineering; geology or other earth sciences; or physics or chemistry.

Students should 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/energeresourcesengineering/js/fckeditor/index.html?InstanceName=attr_text&Toolbar=PageWizard)

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 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 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 satisfy 9 of the required 12 units).

Required to take 12 units from the following list:

Units
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:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
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<tbody>
<tr>
<td>ENERGY 175</td>
<td>Well Test Analysis</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 223</td>
<td>Reservoir Simulation</td>
<td>3-4</td>
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<tr>
<td>ENERGY 224</td>
<td>Advanced Reservoir Simulation</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 225</td>
<td>Theory of Gas Injection Processes</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 227</td>
<td>Enhanced Oil Recovery</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 240</td>
<td>Geostatistics</td>
<td>2-3</td>
</tr>
<tr>
<td>ENERGY 241</td>
<td>Seismic Reservoir Characterization</td>
<td>3-4</td>
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<tr>
<td>ENERGY 251</td>
<td>Thermodynamics of Equilibria</td>
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<td>ENERGY 253</td>
<td>Carbon Capture and Sequestration</td>
<td>3-4</td>
</tr>
<tr>
<td>ENERGY 259</td>
<td>Geothermal Reservoir Engineering</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 280</td>
<td>Oil and Gas Production Engineering</td>
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</tr>
<tr>
<td>ENERGY 281</td>
<td>Applied Mathematics in Reservoir Engineering</td>
<td>3</td>
</tr>
<tr>
<td>ENERGY 284</td>
<td>Optimization and Inverse Modeling</td>
<td>3</td>
</tr>
</tbody>
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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

Courtsy Professors: Stephan A. Graham, Mark Jacobson

Lecturers: Louis M. Castanier, Denis V. Voskov, Anne Macfarlane, Kurt House, Mark McClure, Charlotte Garing, Celine Scheidt

Adjunct Faculty: Warren K. Kourt, Robert G. Lindblom, Kiran Pande, Victor Pereyra, Marco R. Thiele, Birol Dindoruk, Stuart MacMillan, Richard Sears, Alan Burnham,

Visiting Professor: Kozo Sato

* Joint appointment with Geological and Sciences

** Joint appointment with Geophysics

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### 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:

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<td>Theory of Gas Injection Processes</td>
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Visiting Professor: Kozo Sato

* Joint appointment with Geological and Sciences

** Joint appointment with Geophysics
Courses

ENERGY 12SC. Water and Power in the Pacific Northwest: The Columbia River. 2 Units.
This seminar will explore the nature of and coupling between water and energy resources in the Pacific Northwest, using the Columbia River as our case study. We will explore the hydrologic, meteorologic, and geologic basis of water and energy resources, and the practical, social, environmental, economic, and political issues surrounding their development in the West. The Columbia River and its watershed provide a revealing prototype for examining these issues. A transnational, multi-state river with the largest residual populations of anadromous salmonids in the continental US, it provides a substantial fraction of the electrical energy produced in the Northwest (the Grand Coulee dam powerhouse on the Columbia is the largest-capacity hydropower facility in the US), it is a major bulk commodity transportation link to the interior West via its barge navigation system, it provides the water diversions supporting a large area of irrigated agriculture in Washington and Idaho, and its watershed is home to significant sources of solar and wind energy. We will use the Columbia to study water and energy resources, and especially their coupling, in the context of rapid climate change, ecosystem impacts, economics, and public policy.<br><br>ENERGY 102. Fundamentals of Renewable Power. 3 Units.
Do you want a much better understanding of renewable power technologies? Did you know that wind and solar are the fastest growing forms of electricity generation? Are you interested in hearing about tidal and wave power technologies. We welcome all student, from non-majors to MBAs and grad students. If you are potentially interested in an energy or environmental related major, this course is particularly useful. Recommended: Math 21 or 42.

ENERGY 101. Energy and the Environment. 3 Units.
Energy use in modern society and the consequences of current and future energy use patterns. Case studies illustrate resource estimation, engineering analysis of energy systems, and options for managing carbon emissions. Focus is on energy definitions, use patterns, resource estimation, pollution. Recommended: MATH 21 or 42.

ENERGY 101A. Energizing California. 1 Unit.
A weekend field trip featuring renewable and nonrenewable energy installations in Northern California. Tour geothermal, bioenergy, and natural gas field sites with expert guides from the Department of Energy Resources Engineering. Requirements: One campus meeting and weekend field trip. Enrollment limited to 25. Freshman have first choice.

ENERGY 102. Fundamentals of Renewable Power. 3 Units.
Do you want a much better understanding of renewable power technologies? Did you know that wind and solar are the fastest growing forms of electricity generation? Are you interested in hearing about the most recent, and future, designs for green power? Do you want to understand what limits power extraction from renewable resources and how current designs could be improved? This course dives deep into these and related issues for wind, solar, biomass, geothermal, tidal and wave power technologies. We welcome all student, from non-majors to MBAs and grad students. If you are potentially interested in an energy or environmental related major, this course is particularly useful. Recommended: Math 21 or 42.

ENERGY 104. Sustainable Energy for 9 Billion. 3 Units.
This course explores the transition to a sustainable energy system at large scales (national and global), and over long time periods (decades). Explores the drivers of global energy demand and the fundamentals of technologies that can meet this demand sustainably. Focuses on constraints affecting large-scale deployment of technologies, as well as inertial factors affecting this transition. Problems will involve modeling global energy demand, deployment rates for sustainable technologies, technological learning and economics of technical change. Recommended: ENERGY 101, 102.

ENERGY 110. Engineering Economics. 3 Units.
The success of energy projects and companies is judged by technical, economic and financial criteria. This course will introduce concepts of engineering economy, e.g., time value of money, life cycle costs and financial metrics, and explore their application to the business of energy. We will use case studies, business school cases and possibly industry guest lecturers. Examples from the hydrocarbon businesses that dominate energy today will provide the framework for the analysis of both conventional and renewable energy.

ENERGY 120. Fundamentals of Petroleum Engineering. 3 Units.
Lectures, problems, field trip. Engineering topics in petroleum recovery; origin, discovery, and development of oil and gas. Chemical, physical, and thermodynamic properties of oil and natural gas. Material balance equations and reserve estimates using volumetric calculations. Gas laws. Single phase and multiphase flow through porous media. Same as: ENGR 120

ENERGY 120A. Flow Through Porous Media Laboratory. 1 Unit.
Laboratory measurements of permeability and porosity in rocks. Applications to subsurface fluid mechanics. Course is intended as an accompaniment to Energy 120.

ENERGY 121. Fundamentals of Multiphase Flow. 3 Units.
Multiphase flow in porous media. Wettability, capillary pressure, imbibition and drainage, Leverett J-function, transition zone, vertical equilibrium. Relative permeabilities, Darcy's law for multiphase flow, fractional flow equation, effects of gravity, Buckley-Leverett theory, recovery predictions, volumetric linear scaling, JBN and Jones-Rozelle determination of relative permeability. Frontal advance equation, Buckley-Leverett equation as frontal advance solution, tracers in multiphase flow, adsorption, three-phase relative permeabilities. Same as: ENERGY 221

ENERGY 122. Lunch with Numerics. 1 Unit.
This course provides students hands-on experience in the design and implementation of numerical methods for challenging fluid flow problems in the earth sciences. The base software used it the public domain code MRST. Students will explore common pitfalls of well-known numerical approaches, assess effectiveness of numerical methods for heterogeneous and strongly nonlinear problems and gain more insight into numerical accuracy and stability concepts.

ENERGY 123. When Technology Meets Reality; An In-depth Look at the Deepwater Horizon Blowout and Oil Spill. 1 Unit.
The Deepwater Horizon blowout and spill in April 2010 occurred on one of the most advanced deepwater drilling rigs in the world operated by one of the most experienced companies. In this course we will look at and discuss the technologies and management practices involved in deepwater drilling and discuss how an accident like this happens and what could have been done differently to avoid it. We will focus on the Horizon and also look briefly at other high profile industrial and technological accidents.

ENERGY 125. Modeling and Simulation for Geoscientists and Engineers. 3 Units.
Hands-on. Topics include deterministic and statistical modeling applied to problems such as flow in the subsurface, atmospheric pollution, biological populations, wave propagation, and crustal deformation. Student teams define and present a modeling problem.
ENERGY 130. Well Log Analysis I. 3 Units.
For earth scientists and engineers. Interdisciplinary, providing a practical understanding of the interpretation of well logs. Lectures, problem sets using real field examples: methods for evaluating the presence of hydrocarbons in rock formations penetrated by exploratory and development drilling. The fundamentals of all types of logs, including electric and non-electric logs.

ENERGY 141. Seismic Reservoir Characterization. 3-4 Units.
( Same as GP241) Practical methods for quantitative characterization and uncertainty assessment of subsurface reservoir models integrating well-log and seismic data. Multidisciplinary combination of rock-physics, seismic attributes, sedimentological information and spatial statistical modeling techniques. Student teams build reservoir models using limited well data and seismic attributes typically available in practice, comparing alternative approaches. Software provided (SGEMS, Petrel, Matlab). Offered every other year. Recommended: ERE240/260, or GP222/223, or GP260/262 or GES253/257, ERE246, GP112.
Same as: ENERGY 241, GEOPHYS 241A

ENERGY 146. Reservoir Characterization and Flow Modeling with Outcrop Data. 3 Units.
Project addressing a reservoir management problem by studying an outcrop analog, constructing geostatistical reservoir models, and performing flow simulation. How to use outcrop observations in quantitative geological modeling and flow simulation. Relationships between disciplines. Weekend field trip.
Same as: ENERGY 246, GE 246

ENERGY 153. Carbon Capture and Sequestration. 3-4 Units.
CO2 separation from syngas and flue gas for gasification and combustion processes. Transportation of CO2 in pipelines and sequestration in deep underground geological formations. Pipeline specifications, monitoring, safety engineering, and costs for long distance transport of CO2. Comparison of options for geological sequestration in oil and gas reservoirs, deep unmineable coal beds, and saline aquifers. Life cycle analysis.
Same as: ENERGY 253

On-the-job practical training under the guidance of on-site supervisors. Required report detailing work activities, problems, assignments and key results. Prerequisite: written consent of instructor.

ENERGY 158. Bringing New Energy Technologies to Market: Optimizing Technology Push and Market Pull. 3 Units.
This research-based seminar will evaluate the impact of market interventions in commercializing four segments of our energy mix: wind, photovoltaics, lighting, and batteries. To accelerate the development of new technologies to reduce greenhouse gas emissions and improve national security, governments use policies like direct R&D funding, financial incentives or penalties, mandatory targets or caps, and performance standards to create market conditions that favor emerging technologies. Findings outlining the most effective mix of interventions over time will be submitted for publication. Enrollment limited to 12 graduate and co-term students. Those interested please email a paragraph to cathyzo@stanford.edu by September 16, 2013 expressing why you want to take part and research experience you can bring to the seminar.

ENERGY 160. Modeling Uncertainty in the Earth Sciences. 3 Units.
Whether Earth Science modeling is performed on a local, regional or global scale, for scientific or engineering purposes, uncertainty is inherently present due to lack of data and lack of understanding of the underlying phenomena. This course highlights the various issues, techniques and practical tools available for modeling uncertainty of complex Earth systems as well as the impact uncertainty has on practical decisions for geo-engineering problems. The course focuses on practical breadth rather than theoretical depth. Topics covered are: the process of building models, sources of uncertainty, probabilistic techniques, spatial data analysis and geostatistics, grid and scale, spatio-temporal uncertainty, visualizing uncertainty in large dimensions, Monte Carlo simulation, sensitivity analysis, reducing uncertainty with data, value of information. Applications to both local (reservoir, aquifer) and global (climate) are covered through literature study. Extensive software use with SGEMS. Prerequisites: algebra (CME 104 or equivalent), introductory statistics course (CME 106 or equivalent).

ENERGY 167. Engineering Valuation and Appraisal of Oil and Gas Wells, Facilities, and Properties. 3 Units.
Appraisal of development and remedial work on oil and gas wells; appraisal of producing properties; estimation of productive capacity, reserves; operating costs, depletion, and depreciation; value of future profits, taxation, fair market value; original or guided research problems on economic topics with report. Prerequisite: consent of instructor.
Same as: ENERGY 267

ENERGY 171. Energy Infrastructure, Technology and Economics. 3 Units.
Oil and gas represents more than 50% of global primary energy. In delivering energy at scale, the industry has developed global infrastructure with supporting technology that gives it enormous advantages in energy markets; this course explores how the oil and gas industry operates. From the perspective of these established systems and technologies, we will look at the complexity of energy systems, and will consider how installed infrastructure enables technology development and deployment, impacts energy supply, and how existing infrastructure and capital invested in fossil energy impacts renewable energy development. Prerequisites: Energy 101 and 102 or permission of instructor.
Same as: ENERGY 271

ENERGY 175. Well Test Analysis. 3 Units.

ENERGY 180. Oil and Gas Production Engineering. 3 Units.
Design and analysis of production systems for oil and gas reservoirs. Topics: well completion, single-phase and multi-phase flow in wells and gathering systems, artificial lift and field processing, well stimulation, inflow performance. Prerequisite: 120.
Same as: ENERGY 280

ENERGY 191. Optimization of Energy Systems. 3-4 Units.
Introductory mathematical programming and optimization using examples from energy industries. Emphasis on problem formulation and solving, secondary coverage of algorithms. Problem topics include optimization of energy investment, production, and transportation; uncertain and intermittent energy resources; energy storage; efficient energy production and conversion. Methods include linear and nonlinear optimization, as well as multi-objective and goal programming. Tools include Microsoft Excel and AMPL mathematical programming language. Prerequisites: MATH 20, 41, or MATH 51, or consent of instructor. Programming experience helpful (e.g., CS 106A, CS 106B).
Same as: ENERGY 291

ENERGY 192. Undergraduate Teaching Experience. 1-3 Unit.
Leading field trips, preparing lecture notes, quizzes under supervision of the instructor. May be repeated for credit.
ENERGY 193. Undergraduate Research Problems. 1-3 Unit.
Original and guided research problems with comprehensive report. May be repeated for credit.

ENERGY 194. Special Topics in Energy and Mineral Fluids. 1-3 Unit.
May be repeated for credit.

ENERGY 199. Senior Project and Seminar in Energy Resources. 3-4 Units.
Individual or group capstone project in Energy Resources Engineering. Emphasis is on report preparation. May be repeated for credit.

ENERGY 201. Laboratory Measurement of Reservoir Rock Properties. 3 Units.
In this course, students will learn methods for measuring reservoir rock properties. Techniques covered include core preservation and sample preparation; Rock petrography; Interfacial tension of fluids; Measurement of contact angles of fluids on reservoir media; Capillary pressure measurement and interpretation; Absolute and effective porosities; Absolute permeability; Multiphase flow including relative permeability and residual saturation. The class will be 1 3-hour lecture/lab per week, with readings and weekly assignments. A field trip to a professional core characterization lab may be included.

ENERGY 202. Petroleum Industry Performance Management. 1 Unit.
Coming up with the right technical solution is only the beginning. It must be implemented. The art and science of Performance Management. How to guarantee results with Leading and Lagging KPI’s (Key Performance Indicators). Assessment using the FAIRTM Model (Focus, Accountability, Involvement, Response). Operating RhythmTM: Business Reviews, Boardwalks, One-Pagers, Handover, and Crew Talks. Project management’s implementation plans, milestones, and clear deliverables. Sustainability. After Action Reviews (AAR’s). Continuous Improvement (CI). Coaching¿s GROW Model (Goal, Reality, Options, Will). The ABC Model (Antecedent ¿ Behavior ¿ Consequence). Students will solve three Case Studies with these tools; the instructor will present the actual solution, what worked, what didn’t, and why.

ENERGY 203. The Energy Transformation Collaborative. 1-2 Unit.
Solving the global energy challenge will require the creation and successful scale-up of hundreds of new ventures. This project-based course provides a launchpad for the development and creation of transformational energy ventures and innovation models. Interdisciplinary teams will research, analyze, and develop detailed launch plans for high-impact opportunities in the context of the new energy venture development framework offered in this course.

ENERGY 204. Achieving Universal Energy Access by 2030: Can it be done?. 2-3 Units.
Today 1.2 billion people have no access to electricity; many more don’t have power that is reliable. Activities the developed world counts on for economic growth are severely limited where there isn’t reliable electricity. Cost reductions in distributed, renewable energy generation and battery storage technologies are creating opportunities to bring affordable power to communities that have never had it. This course will examine what will need to be in place so that electricity can reach everyone by 2030.

ENERGY 214. The Global Price of Oil. 1 Unit.
Understanding the current and future price of oil requires the synthesis of geologic, engineering, financial, geopolitical, and macroeconomic information. In this seminar, we will build a global supply curve for petroleum by studying the marginal and full-cycle production costs for each of the major resource categories. We will study how reserve classification varies globally, and how global petroleum resources and reserves have changed and are likely to change over time. We will further investigate how the time lag between resource discovery, project sanctioning, and full production will affect future supply. Finally, we will study the elasticity of oil demand and how that demand is likely to change over time as the developing world gets richer and as competition from other energy sources increases.

ENERGY 216. Entrepreneurship in Energy. 2 Units.
The combined forces of climate change, technological development, and geopolitics are disrupting the energy industry, yet the competitiveness and regulated nature of the mature markets for fuel, power, and materials have created meaningful barriers to entry for startup companies. In this case based course, students will study real energy startups to understand what challenges they have overcome and continue to face. Each week, the course will focus on a different company and the founder or CEO of that company will present. Topics will include advanced battery technologies, photovoltaic manufacturing, solar and wind project development, oil & gas exploration & production, advanced biofuels, electric vehicles, distributed power generation, and financing energy startups.

ENERGY 217. Research Seminar: Energy Development in the Emerging Economy. 2-3 Units.
Through this research project, students will dive into and gain firsthand experience on evaluating the efficacy of a portfolio of 34 energy technology start-up projects in emerging economies that encompasses a range of regions, energy sectors, and technologies. Student’s will learn from each project’s unique experiences, and gather critical data that may help support the success of future similar endeavors. Some questions students will be looking to answer include (1) Was the project able to accomplish its goal(s)? (2) Are there common success factors or similar roadblocks? (3) Is the technology and/or solution still effective and operational?Prerequisite: submit survey https://precourt.typeform.com/to/NdItUO2 and permission of instructor.

ENERGY 221. Fundamentals of Multiphase Flow. 3 Units.
Multiphase flow in porous media. Wettability, capillary pressure, imbibition and drainage, Leverett J-function, transition zone, vertical equilibrium. Relative permeabilities, Darcy’s law for multiphase flow, fractional flow equation, effects of gravity, Buckley-Leverett theory, recovery predictions, volumetric linear scaling, JBN and Jones-Rozelle determination of relative permeability. Frontal advance equation, Buckley-Leverett equation as frontal advance solution, tracers in multiphase flow, adsorption, three-phase relative permeabilities.
Same as: ENERGY 121

ENERGY 222. Advanced Reservoir Engineering. 3 Units.
Lectures, problems. General flow equations, tensor permeabilities, steady state radial flow, skin, and succession of steady states. Injectivity during fill-up of a depleted reservoir, injectivity for liquid-filled reservoirs. Flow potential and gravity forces, coning. Displacements in layered reservoirs. Transient radial flow equation, primary drainage of a cylindrical reservoir, line source solution, pseudo-steady state. May be repeated for credit. Prerequisite: 221.

ENERGY 223. Reservoir Simulation. 3-4 Units.
Fundamentals of petroleum reservoir simulation. Equations for multicomponent, multiphase flow between gridblocks comprising a petroleum reservoir. Relationships between black-oil and compositional models. Techniques for developing black-oil, compositional, thermal, and dual-porosity models. Practical considerations in the use of simulators for predicting reservoir performance. Class project. Prerequisite: 221 and 246, or consent of instructor. Recommended: CME 206.

ENERGY 224. Advanced Reservoir Simulation. 3 Units.
Topics include modeling of complex wells, coupling of surface facilities, compositional modeling, dual porosity models, treatment of full tensor permeability and grid nonorthogonality, local grid refinement, higher order methods, streamline simulation, upscaling, algebraic multigrid solvers, unstructured grid solvers, history matching, other selected topics. Prerequisite: 223 or consent of instructor. May be repeated for credit.
ENERGY 225. Theory of Gas Injection Processes. 3 Units.

ENERGY 226. Thermal Recovery Methods. 3 Units.

ENERGY 227. Enhanced Oil Recovery. 3 Units.
The physics, theories, and methods of evaluating chemical, miscible, and thermal enhanced oil recovery projects. Existing methods and screening techniques, and analytical and simulation based means of evaluating project effectiveness. Dispersion-convection-adsorption equations, coupled heat, and mass balances and phase behavior provide requisite building blocks for evaluation.

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

ENERGY 240. Geostatistics. 2-3 Units.

ENERGY 241. Seismic Reservoir Characterization. 3-4 Units.
(Same as GP241) Practical methods for quantitative characterization and uncertainty assessment of subsurface reservoir models integrating well-log and seismic data. Multidisciplinary combination of rock-physics, seismic attributes, sedimentological information and spatial statistical modeling techniques. Student teams build reservoir models using limited well data and seismic attributes typically available in practice, comparing alternative approaches. Software provided (SGEMS, Petrel, Matlab). Offered every other year. Recommended: ERE240/260, or GP222/223, or GP260/262 or GES253/257, ERE246, GP112. Same as: ENERGY 141, GEOPHYS 241A

ENERGY 242. Topics in Advanced Geostatistics. 3-4 Units.
Conditional expectation theory and projections in Hilbert spaces; parametric versus non-parametric geostatistics; Boolean, Gaussian, fractal, indicator, and annealing approaches to stochastic imaging; multiple point statistics inference and reproduction; neural net geostatistics; Bayesian methods for data integration; techniques for upscaling hydrodynamic properties. May be repeated for credit. Prerequisites: 240, advanced calculus, C++/Fortran. Same as: ESS 263

ENERGY 246. Reservoir Characterization and Flow Modeling with Outcrop Data. 3 Units.
Project addressing a reservoir management problem by studying an outcrop analog, constructing geostatistical reservoir models, and performing flow simulation. How to use outcrop observations in quantitative geological modeling and flow simulation. Relationships between disciplines. Weekend field trip. Same as: ENERGY 146, GS 246

ENERGY 247. Stochastic Simulation. 3 Units.
Characterization and inference of statistical properties of spatial random function models; how they average over volumes, expected fluctuations, and implementation issues. Models include point processes (Cox, Poisson), random sets (Boolean, truncated Gaussian), and mixture of Gaussian random functions. Prerequisite: 240.

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

ENERGY 253. Carbon Capture and Sequestration. 3-4 Units.
CO2 separation from syngas and flue gas for gasification and combustion processes. Transportation of CO2 in pipelines and sequestration in deep underground geological formations. Pipeline specifications, monitoring, safety engineering, and costs for long distance transport of CO2. Comparison of options for geological sequestration in oil and gas reservoirs, deep unmineable coal beds, and saline aquifers. Life cycle analysis. Same as: ENERGY 153

On-the-job training for master's degree students under the guidance of on-site supervisors. Students submit a report detailing work activities, problems, assignments, and key results. May be repeated for credit. Prerequisite: consent of adviser.

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

ENERGY 267. Engineering Valuation and Appraisal of Oil and Gas Wells, Facilities, and Properties. 3 Units.
Appraisal of development and remedial work on oil and gas wells; appraisal of producing properties; estimation of productive capacity, reserves; operating costs, depletion, and depreciation; value of future profits, taxation, fair market value; original or guided research problems on economic topics with report. Prerequisite: consent of instructor. Same as: ENERGY 167

ENERGY 269. Geothermal Reservoir Engineering. 3 Units.
Conceptual models of heat and mass flows within geothermal reservoirs. The fundamentals of fluid/heat flow in porous media; convective/conductive regimes, dispersion of solutes, reactions in porous media, stability of fluid interfaces, liquid and vapor flows. Interpretation of geochemical, geological, and well data to determine reservoir properties/characteristics. Geothermal plants and the integrated geothermal system.
ENERGY 271. Energy Infrastructure, Technology and Economics. 3 Units.
Oil and gas represents more than 50% of global primary energy. In delivering energy at scale, the industry has developed global infrastructure with supporting technology that gives it enormous advantages in energy markets; this course explores how the oil and gas industry operates. From the perspective of these established systems and technologies, we will look at the complexity of energy systems, and will consider how installed infrastructure enables technology development and deployment, impacts energy supply, and how existing infrastructure and capital invested in fossil energy impacts renewable energy development. Prerequisites: Energy 101 and 102 or permission of instructor.

Same as: ENERGY 171

ENERGY 273. Special Topics in Energy Resources Engineering. 1-3 Unit.

ENERGY 274. Complex Analysis for Practical Engineering. 3 Units.
Complex analysis is closely related to potential theory, appearing in a variety of engineering disciplines, including fluid dynamics, electrostatics, heat conduction and gravity fields. This course is devoted to explaining the fundamentals of complex analysis and instructing on how to develop mathematical tools to solve engineering problems in potential theory. Individual topics are lectured with motivating problems, so that students can understand why these subjects need to be covered and how these are applied to practical engineering problems.

Examine the physical processes operating in sedimentary basins by deriving the basic equations of fundamental, coupled geologic processes such as fluid flow and heat flow, deposition, compaction, mass conservation, and chemical reactions. Through hands-on computational exercises and instructor-provided "recipes," students will deconstruct the black box of basin modeling software. Students write their own codes (Matlab) as well as gain expertise in modern finite-element modeling software (PetroMod, COMSOL).
Same as: GS 256

ENERGY 280. Oil and Gas Production Engineering. 3 Units.
Design and analysis of production systems for oil and gas reservoirs. Topics: well completion, single-phase and multi-phase flow in wells and gathering systems, artificial lift and field processing, well stimulation, inflow performance. Prerequisite: 120.
Same as: ENERGY 180

ENERGY 281. Applied Mathematics in Reservoir Engineering. 3 Units.
The philosophy of the solution of engineering problems. Methods of solution of partial differential equations: Laplace transforms, Fourier transforms, wavelet transforms, Green’s functions, and boundary element methods. Prerequisites: CME 204 or MATH 131, and consent of instructor.

ENERGY 282. Chemical Kinetics of Fossil Fuel Creation and Utilization. 1 Unit.
Chemical kinetics are an integral part of optimizing recovery of fossil fuels. After reviewing the genesis of various kinds of fossil fuels and the history of their use, the course describes the molecular structure of the various types and how that influences their pyrolysis kinetics. Methods for deriving reliable kinetics are covered, including how to determine which phenomenological models are appropriate. Applications discussed are petroleum formation, oil shale retorting, heavy oil upgrading, and coal liquefaction.

ENERGY 284. Optimization and Inverse Modeling. 3 Units.

Requirements: CME 106 and 200 (or equivalent courses).

ENERGY 285A. SUPRA-A Research Seminar: Enhanced Oil Recovery. 1 Unit.
Focused study in research areas within the department. Graduate students may participate in advanced work in areas of particular interest prior to making a final decision on a thesis subject. Current research in the SUPRA-A group. May be repeated for credit. Prerequisite: consent of instructor.

ENERGY 285B. SUPRA-B Research Seminar: Reservoir Simulation. 1 Unit.
Focused study in research areas within the department. Graduate students may participate in advanced work in areas of particular interest prior to making a final decision on a thesis subject. Current research in SUPRA-B (reservoir simulation) program. May be repeated for credit. Prerequisite: consent of instructor.

ENERGY 285C. SUPRA-C Research Seminar: Gas Injection Processes. 1 Unit.
Study in research areas within the department. Graduate students may participate in advanced work in areas of particular interest prior to making a final decision on a thesis subject. Current research in the SUPRA-D well test analysis group. May be repeated for credit. Prerequisite: consent of instructor.

ENERGY 285D. SUPRA-D Research Seminar: Well Test Analysis. 1 Unit.
Study in research areas within the department. Graduate students may participate in advanced work in areas of particular interest prior to making a final decision on a thesis subject. Current research in the SUPRA-D well test analysis group. May be repeated for credit. Prerequisite: consent of instructor. (Horne).

ENERGY 285F. SCRF Research Seminar: Geostatistics and Reservoir Forecasting. 1 Unit.
Study in research areas within the department. Graduate students may participate in advanced work in areas of particular interest prior to making a final decision on a thesis subject. Current research in the SCRF (Stanford Center for Reservoir Forecasting) program. Prerequisite: consent of instructor.

ENERGY 285G. Geothermal Reservoir Engineering Research Seminar. 1 Unit.
Study in research areas within the department. Graduate students may participate in advanced work in areas of particular interest prior to making a final decision on a thesis subject. Current research in the geothermal energy group. Presentation required for credit. Prerequisite: consent of instructor.

ENERGY 285S. Smart Fields Research Seminar: Horizontal Well Technology. 1 Unit.
Study in research areas within the department. Graduate students may participate in advanced work in areas of particular interest prior to making a final decision on a thesis subject. Current research in Smart Fields (productivity and injectivity of horizontal wells) program. Prerequisite: consent of instructor.
ENERGY 290. Numerical Modeling of Fluid Flow in Heterogeneous Porous Media. 3 Units.
How to mathematically model and solve elliptic partial differential equations with variable and discontinuous coefficients describing flow in highly heterogeneous porous media. Topics include finite difference and finite volume approaches on structured grids, efficient solvers for the resulting system of equations, Krylov space methods, preconditioning, multi-grid solvers, grid adaptivity and adaptivity criteria, multiscale approaches, and effects of anisotropy on solver efficiency and accuracy. MATLAB programming and application of commercial or public domain simulation packages. Prerequisite: CME 200, 201, and 202, or equivalents with consent of instructor.

ENERGY 291. Optimization of Energy Systems. 3-4 Units.
Introductory mathematical programming and optimization using examples from energy industries. Emphasis on problem formulation and solving, secondary coverage of algorithms. Problem topics include optimization of energy investment, production, and transportation; uncertain and intermittent energy resources; energy storage; efficient energy production and conversion. Methods include linear and nonlinear optimization, as well as multi-objective and goal programming. Tools include Microsoft Excel and AMPL mathematical programming language. Prerequisites: MATH 20, 41, or MATH 51, or consent of instructor. Programming experience helpful (e.g., CS 106A, CS 106B).

Same as: ENERGY 191

ENERGY 293A. Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution. 3-4 Units.
Operating principles and applications of emerging technological solutions to the energy demands of the world. The scale of global energy usage and requirements for possible solutions. Basic physics and chemistry of solar cells, fuel cells, and batteries. Performance issues, including economics, from the ideal device to the installed system. The promise of materials research for providing next generation solutions. Undergraduates register in 156 for 4 units; graduates register in 256 for 3 units.

Same as: EE 293A, MATSCI 156, MATSCI 256

ENERGY 293B. Fundamentals of Energy Processes. 3 Units.
For seniors and graduate students. Covers scientific and engineering fundamentals of renewable energy processes involving heat. Thermodynamics, heat engines, solar thermal, geothermal, biomass. Recommended: MATH 19-21, or Math 41,42; PHYSICS 41, 43, 45. Same as: EE 293B

ENERGY 293C. Energy from Wind and Water Currents. 3 Units.
This course focuses on the extraction of energy from wind, waves and tides. The emphasis in the course is technical leading to a solid understanding of established extraction systems and discussion of promising new technologies. We will also cover resource planning and production optimization through observations and computer simulations. The course includes at least one weekend field trip, and may include experiments in wind tunnel and/or flume. Prerequisites: CEE176B or EE293B, programming experience, understanding of fluid mechanics, electrical systems, and engineering optimization.

ENERGY 295. Quantitative Environmental Assessment of Energy Systems. 1 Unit.
Graduate seminar on quantitative environmental assessment of energy technologies. Assessment methods for analyzing multi-device and multi-technology energy systems (e.g., full energy production pathways). Methodological coverage includes process-model life cycle assessment (LCA), energy embodied in materials, energy return on energy invested, and cumulative exergy consumption. Exploration of theoretical modeling of multi-technology systems using matrix formulations. Tools used include MATLAB and openLCA life cycle assessment software. Prerequisites: linear algebra and some programming experience helpful (e.g, CS 106A-B).