PhD Training Program in Sustainable Energy Recovery from the Earth
-- Educational Innovation at the Intersection of Geosciences and Engineering
Guiding Philosophy of Cornell’s Earth-Energy PhD Program

Providing affordable energy to meet the demands of both developed and developing nations without further damaging the natural environment and the Earth’s climate system, is a Grand Challenge for the 21st century. Our quality of life and the stability of the world’s nations ultimately depend on having accessible energy resources and an equitable and sustainable energy supply and distribution system.

Achievement of these goals requires the participation, ingenuity, and hard work of people with a range of specialized backgrounds, working collaboratively and thinking globally.

New Technology Needs

• to exploit a range of subsurface energy sources (geothermal as well as fossil fuel) in an environmentally sustainable manner
• to use Earth’s subsurface to mitigate the energy waste products (e.g., CO₂ sequestration).

Future Workforce Needs

A new generation of scientists and engineers, able to work across the engineering-geosciences fields, and to appreciate, anticipate, and communicate about risks and economic balances of importance to communities.
Research Domain: Uses of the Earth’s Subsurface

Numerous challenges exist in this system, for which new research is vital.
Student Funding Alternatives

- U.S. citizens and permanent residents may apply to be NSF-IGERT Fellows, which would provide a 2-year fellowship, to be followed by GRA support arranged by an individual faculty member.
- Students are welcome to participate who hold fellowships from industry or another agency.
- International students are welcome who hold fellowships from their home country or industry.

Off-campus parts of the program and laboratory use will entail added fees, for which the student’s sponsor must be responsible.
Multidisciplinary Leadership of an NSF-sponsored IGERT
“Earth-Energy Integrated Graduate Research and Education Training Program”

Principal Investigator: Jefferson W. Tester
Department of Chemical and Biomolecular Engineering &
Director of Cornell’s Sustainable Energy Institute

Leadership Team:

Teresa Jordan
Earth & Atmospheric Sciences

Anthony Ingraffea
Civil & Environmental Engineering

Donald Koch
Chemical & Biomolecular Engineering

Paulette Clancy
Chemical & Biomolecular Engineering
A Multidisciplinary Faculty Team for the Earth-Energy Graduate Program
Faculty Participants & Fields

Richard Allmendinger  Earth & Atmospheric Sciences
Christopher Andronicos  Earth & Atmospheric Sciences
Wilkins Aquino  Civil & Environmental Engineering
Antonio Bento  Applied Economics & Management
Larry Brown  Earth & Atmospheric Sciences
Lawrence Cathles  Earth & Atmospheric Sciences
Louis Derry  Earth & Atmospheric Sciences
Park Doing  Bovay Program in History & Ethics of Engineering
Emmanuel Giannelis  Materials Science & Engineering
Andrew Hunter  Chemical Engineering
Ronald Kline  Electrical & Computer Engineering Science & Technology Studies
Rowena Lohman  Earth & Atmospheric Sciences
Jason Phipps-Morgan  Earth & Atmospheric Sciences
Matthew Pritchard  Earth & Atmospheric Sciences
Susan Riha  New York State Water Resources Institute; Earth & Atmospheric Sciences
Christine Shoemaker  Civil & Environmental Engineering
Jery Stedinger  Civil & Environmental Engineering
Rolf Verberg  Chemical Engineering
Derek Warner  Civil & Environmental Engineering
Nature of the Educational Program: Cornell’s Earth-Energy Graduate Training Program

Interdisciplinary student participants
- brings together students seeking degrees in engineering and in geosciences
- designed to provide both communities with a common language

Teaching methods
- mini-courses, collaborative projects and exposure to real-world case studies lead to interdisciplinary training
- hands-on in the field teaching and practice of methodologies and interdisciplinary teamwork
- internships
- student teams collaborate on complex technical challenges
- case studies regarding the social impacts and ethical issues of energy solutions

Schedule
- Interdisciplinary Earth-Energy courses and project work during years 1-2
- Disciplinary Courses during years 1-3
- Focus on disciplinary research in years 3-5
## Educational Program Overview: Components of NSF IGERT Earth-Energy Graduate Training Program

<table>
<thead>
<tr>
<th>IGERT Fellow Requirements</th>
<th>Modular courses</th>
<th>Field Project Course</th>
<th>Seminars</th>
<th>Internships</th>
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<tr>
<td><strong>Nature of training activity</strong></td>
<td>Technical background (see course list above); ~4-week-duration</td>
<td>Off-campus courses ≥ 3-week duration, following a semester-long preparatory seminar; engineering-geoscience student team investigates solutions meeting economic, risk, environmental and social criteria; co-led by resident faculty members. Travel to (a) geological sites (e.g., revealing a pertinent “fossil” subsurface environment) and (b) a geoengineering site (<em>i.e.</em>, geothermal production field; oil shale extraction facility; CO₂ sequestration test field).</td>
<td>Discussions with professional earth scientists and engineers, economists, environmentalists, ethicists, sociologists, <em>etc.</em>, Follow-up seminar to develop design report and presentations.</td>
<td>Internship with energy–related non-academic organization (<em>i.e.</em>, energy industry, government lab, NGO, <em>etc.</em>).</td>
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<tr>
<td><strong>Fellow Requirement</strong></td>
<td>4 required within first two years; another 6 strongly encouraged in the remaining years.</td>
<td>Taken at least once by all Fellows. Participation requires payment of expenses for each student.</td>
<td>All fellows for at least two semesters; open to other students by permission.</td>
<td>Strongly encouraged at least once during PhD program (funded by host agency or company)</td>
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<tr>
<td><strong>Taken When?</strong></td>
<td>At least 2 in first year and at least 2 by end of second year</td>
<td>January break and/or summer session during second Fellow year; preparatory seminar during preceding semester and wrap-up during following semester</td>
<td>Weekly during semesters</td>
<td>Summer or semester-long; timing flexible</td>
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# Mini-Course Topics: Cornell’s Earth-Energy Graduate Training Program

<table>
<thead>
<tr>
<th>Course Title (tentative lead instructor)</th>
<th>Core concepts</th>
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<tr>
<td>Analysis of Sustainable Energy Systems (Tester, Anton)</td>
<td>Life cycle analysis: cradle-to-cradle concepts</td>
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<tr>
<td>The Earth System (Derry, Riha, Jordan)</td>
<td>Biogeochemical cycles; climate as coupled atmosphere-ocean-solid earth phenomena; natural change and anthropogenic change</td>
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<tr>
<td>Earth Materials (Allmendinger, Phipps Morgan, Jordan, Cathles)</td>
<td>Minerals and phase equilibria; brittle and ductile deformation; pores and fractures; heterogeneity; thermodynamics and kinetics of extraction processes</td>
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<tr>
<td>Fluids in the Earth (Cathles)</td>
<td>Flow in porous media; chemical variability and distribution; flow velocities and antiquity; multiphase fluid flow;</td>
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<td>Detection of Subsurface Conditions and Changes (Lohman, Pritchard)</td>
<td>Theory of geophysical, geodetic, and geochemical methods for subsurface monitoring; seismic and geodetic examples; borehole tests</td>
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<tr>
<td>Computational Modeling Tools for Earth Engineering (Ingraffea)</td>
<td>Modeling methods in reservoir engineering include reactive and non-reactive transport in fractured porous rock, coupled physics problems, and implementation strategies</td>
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<tr>
<td>Energy Capture, Conversion and Recovery Processes (Tester)</td>
<td>Fundamentals of energy recovery and conversion for both conventional and unconventional geothermal and fossil resources</td>
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<td>Interplay of pore- and reservoir-scale reactive transport processes in CO2 sequestration (Koch, Verberg)</td>
<td>Large-scale models of transport processes, dissolution and precipitation in the CO2-brine-rock system; small-scale models of pore-space flow fields based on lattice-Boltzmann method</td>
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<tr>
<td>Energy Efficiency and Energy system performance (Clancy, Hunter)</td>
<td>Thermomechanical and chemical availability/exergy, second law efficiencies, net-energy analysis, full life cycle energy accounting on a national level</td>
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<tr>
<td>Risk and Uncertainty (Stedinger, Shoemaker)</td>
<td>Quantitative methods for risk and uncertainty assessment and management in energy and the environment</td>
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<tr>
<td>Economics of Energy and Environmental Modeling and Policy (Bento, Hunter)</td>
<td>Macro and micro economic modeling, dynamic demand analysis and adjustment processes, economic development, energy intensity, energy substitution, national energy models</td>
</tr>
<tr>
<td>Ethical, Social, and Political Issues in Energy System Research, Design, and Use (Doing, Kline)</td>
<td>The historical context of the energy system; Social issues in sustainability; The concept of risk from a social perspective; Social and cultural issues in energy use; The relation between research and system design; International relations.</td>
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