Advanced Energy Systems

Degrees Offered
- Master of Science in Advanced Energy Systems (Non-Thesis)
- Doctor of Philosophy in Advanced Energy Systems

Program Description
The Advanced Energy Systems graduate program will leverage significant interdisciplinary technical, techno-economic and policy strengths with basic and applied research at Mines and NREL to create a unique educational and research experience. It will integrate the research strengths of both institutions to develop solutions to global challenges. Mines has a rich tradition of seeking responsible solutions to using earth resources (especially minerals and water) from survey to extraction to use and re-use, and NREL pushes the state of the art in advanced energy technologies.

With a focus on emerging energy technologies, the program is designed to empower researchers at both institutions to tackle a variety of compelling needs, including:

- Integrating a wide range of energy sources into a flexible grid as power derived from renewables approach cost parity
- Implementing digitized and optimized energy control and management through artificial intelligence that maintains robust cybersecurity
- Addressing economic and policy barriers to deployment of new clean and high-efficiency technologies for energy conversion and storage.

All enrolled students will be part of a community of students, faculty, and NREL technical staff which will foster professional development, cross-disciplinary thinking, and systems understanding of grand energy challenges. A unique aspect of the program, pertaining to the enrolled doctoral students are two, 4-month rotations at NREL to gain insight into technology research and quantitative analysis in advanced energy systems. These rotations will be integrated with professional development toward developing skills for energy research and technical leadership careers. Graduates of this degree program will be uniquely positioned to enter the workforce in roles supporting advanced energy innovation and high-efficiency technologies for energy conversion and storage.

Degree Requirements
The Advanced Energy Systems graduate program will offer the following two degrees:

- a 30-credit Master of Science Non-Thesis (MS-NT) degree in Advanced Energy Systems targeted for students interested in professional careers in industry, government, or non-governmental organizations;
- a PhD program in Advanced Energy Systems requiring 36 credit hours of coursework, 36 credit hours of research, and the standard on-campus residency requirement.

Both degree programs will require the three new core courses that support the program as described below. Because of the multidisciplinary nature of Advanced Energy Systems, there will be significant demands for flexibility in the Program’s curriculum beyond those three core courses. Program faculty will serve as advisors to students based on each student’s interests and research focus. The flexibility of the program will allow for students to pursue energy topics across the existing breadth of energy-related course offerings in the Mines graduate curriculum. It is expected that the Advanced Energy Systems degree program will encourage new energy-systems courses in an array of disciplines as the PhD and MS enrollment grows.

Students will apply to enter these Advanced Energy Systems program through Mines’ Graduate School. After passing their qualifying exam (Research Performance Evaluation), PhD students will be under the discretion of the Mines’ faculty research advisor and co-advising NREL staff. The Faculty Executive Committee will formally approve elective courses and monitor each student’s progress.

The Master of Science, Non-Thesis (MS-NT) is a stand-alone degree wherein students are self-supported or supported by industry or other outside sources. The MS and PhD curricula have overlap where new students in both programs will enroll in the three core program courses as part of their degree program. These core courses will be required for all MS-NT students as part of their degree and for all PhD students who enter the program without appropriate courses that can serve as transfer credits for the core courses.

MS-Non-Thesis Degree Program Requirements
The Master of Science degree program will be exclusively non-thesis and the MS students will not participate in the rotation courses (NREL Rotation: Analysis and Technology) at NREL. The MS degree program, coursework, will require 30 credit hours of coursework and start with the three core classes, worth nine credit hours. The additional 21 credit hours can be any graduate level course at Mines as long as the courses form a coherent focus for an in-depth energy study and are approved by the advisor and the Faculty Executive Committee. The intention is to allow for a wide range of specializations and needs required by the energy sector. Assigned program faculty advisors will assist MS students in course selection and approval. Faculty advisors will be selected by the Executive Committee at the beginning of each MS students’ program. MS students may apply for the PhD program and will not be required to retake the three core courses listed below.

Mines’ Combined Undergraduate / Graduate Degree Program
Students enrolled in Mines’ combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any 400+ level courses that count towards the undergraduate degree requirements as “Elective Coursework” or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor. These courses must have been passed with a “B-” or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

Framework of the 9-credit core courses required for the MS-NT and PhD curricula.

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<tr>
<th>Code</th>
<th>Course Name</th>
<th>Credits</th>
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<tbody>
<tr>
<td>ENGY501</td>
<td>ENERGY RESOURCES AND ELECTRIC POWER 3.0</td>
<td>SYSTEMS</td>
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<tr>
<td>ENGY502</td>
<td>ENERGY FOR TRANSPORTATION</td>
<td>3.0</td>
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PhD Degree Program Requirements

The PhD degree program requires 72 total credit hours, consisting of at least 36 credit hours of coursework beyond the B.S. and at least 36 research credit hours. PhD coursework beyond the MS degree program will not be restricted other than approved by the student’s advisor and dissertation committee. Students who enter the PhD program with an MS degree in a relevant engineering or science field will be expected to take at least the 9 credit hours of the core classes listed in Table 1 and the NREL-Research rotation as described below.

PhD students will be required to participate in two rotations at NREL which each count as will a 3 credit courses. The rotation courses are listed in Table 2. The 1st rotation would be carried out in the 2nd (Spring semester) and the 2nd rotation during summer. These credits will count as research credits. Both rotations will be coupled with professional development on best research practices, networking, writing of journal articles, and preparing impactful research presentations. Assessment will be based on the work carried out, a 10-page written report, and a group presentation at end of the rotation.

Framework of 6-credit requirement for PhD students gained via rotations at NREL.

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<th>Credit Hrs</th>
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<tr>
<td>ENGY691</td>
<td>NREL ROTATION: ANALYSIS OF INTEGRATED ENERGY SYSTEMS</td>
<td>3.0</td>
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<tr>
<td>ENGY692</td>
<td>NREL ROTATION: ENERGY SCIENCE &amp; TECHNOLOGIES</td>
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In accordance with other PhD programs at Mines, students in the Advanced Energy Systems PhD degree program must successfully complete qualifying examinations, defined as a research performance evaluation. This will consist of an oral defense and 10-page document based on a Research Hypothesis. PhD students who do not successfully pass the qualifying exam will be allowed to finish and MS-NT program without program financial support in subsequent semesters.

In addition to this, a minimum GPA of B+ in courses/rotations will be required to pursue doctoral studies. After completion of their course work with a satisfactory GPA, students will be required to present a dissertation research proposal to their thesis committee, which involves presenting a compelling research plan for completing the degree. Successful completion of a committee-approved plan will allow the student to be admitted to candidacy for completing the PhD program.

PhD research is aimed at fundamentally advancing the state of art in analysis and development of Advanced Energy Systems. PhD students are expected to submit the dissertation work for at least two archival publications in scholarly journals and present research findings in at least one professional conference. Students are also required to participate in the Advanced Energy Systems seminar series both by attending seminars of distinguished speakers and by presenting their research on no less than an annual basis.

Doctoral students in the Advanced Energy Systems program will be advised by a faculty advisor affiliated with the program and by an interdisciplinary Doctoral Dissertation committee, which will include two additional faculty from Mines and an affiliated researcher from NREL. The committee, together with the student, will also approve the course plan including elective courses to be taken to complete the 36 credit hour course requirement. The PhD degree program culminates in a research dissertation that significant scholarly contribution to Advanced Energy Systems as a field. Full-time enrollment is strongly encouraged and in accordance with all other graduate programs at Mines, the PhD program will have a two-semester minimum residency requirement as described in the general section of the Graduate Bulletin.

Courses

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<td>ENGY503</td>
<td>ENERGY SYSTEMS INTEGRATION AND EFFICIENCY</td>
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(i) This course will provide successful students a quantitative understanding of how fossil, renewable and nuclear energy resources are harnessed to electric power. A foundational underpinning will be the thermodynamics of energy conversion, using fundamental principles and language bridging physics, chemistry and engineering. Examples will be taken from both established and emerging technologies spanning solar, nuclear, wind fossil fuel and bioenergy conversion. Students will also learn how to analyze electricity generation, transmission, and grid-scale storage systems with a focus on the U.S. as a framework for analyzing other developing markets.

(ii) This course focuses on multiple aspects of current and proposed transportation technologies to analyze the challenges and opportunities of moving toward more sustainable transportation infrastructure. This course is designed to train students to develop analytical skills and to use computational tools for evaluating performance and environmental impacts of various vehicle and fueling technologies. Successful students will develop a basis for assessing energy resource requirements and environmental concerns within the context of technical performance, policy frameworks, and social perspectives. The course will include the following topics: travel demand and travel modes; transportation technologies; fossil-fuel and electric power plants and associated fuels; emissions (CO2 and pollutants) formation and impacts on air quality, climate, and human health; national/international transportation policy; and transportation planning.

(iii) This course will provide students with basic skills to analyze the operation and evolution of the electric grid and electricity utilization with a particular emphasis on trends toward increased renewable energy penetration. The course will develop students’ analytical skills to evaluate how electricity generation, transmission, distribution and storage are managed and controlled. Successful students will gain a basic understanding of electromechanical machines for power conversion and AC power distribution as well as renewable energy sources and battery systems with DC storage. The course will introduce students to how efficient energy utilization and demand response management impact the electric grid performance and electricity markets. An emphasis on managing energy loads in buildings, the commercial sector, and energy-intensive manufacturing will expose students to system-level modeling tools that can assess how to manage power demands with transient power generation and market forces. The course will also address the integrated nature of energy systems with an emphasis on connections to water demands and on risks arising due to cybersecurity and resiliency threats facing the electric grid.
ENGY691. NREL ROTATION: ANALYSIS OF INTEGRATED ENERGY SYSTEMS. 3.0 Semester Hrs.
(I) This course introduces graduate students enrolled in the Advanced Energy Systems Program to research opportunities, culture, and expectations in energy science and technology with a particular emphasis on systems and/or policy analysis. Students will work within directorates at NREL with an emphasis on systems modeling, analysis, and/or integration. This class will engage students in a semester-long research project in energy system analysis and prepare students for best practices with respect to research project and data management, literature reading, report writing, and presentation. 1 hour lecture; 6 hours lab; 3 semester hours.

ENGY692. NREL ROTATION: ENERGY SCIENCE & TECHNOLOGIES. 3.0 Semester Hrs.
(I) This course prepares graduate students enrolled in the Advanced Energy Systems Program in research practices, culture, and expectations in energy science and technology with a particular emphasis on science and engineering related to energy materials, processes, and/or systems. Students will work within directorates at NREL with an emphasis on science and/or technology. This class will engage students in a semester-long research project in energy science and/or technology. Students will also learn and practice journal publication and research poster best practices, research career path planning, and proposal funding strategies. 1 hour lecture; 6 hours lab; 3 semester hours.