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 (AES) graduate program is an interdisciplinary engineering program designed in collaboration with researchers at the National Renewable Energy Laboratory (NREL). The AES MS/PHD graduate program offers unique educational and research experiences that integrate the research strengths of both institutions to develop solutions to complex global energy challenges. Mines has a rich tradition of seeking responsible solutions to using earth resources (including 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 energy professionals and researchers to tackle a variety of compelling problems, including:

• Integrating a wide range of energy sources into a flexible grid as power

• 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, Mines faculty, and NREL technical staff who 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, semester-long courses offered onsite at NREL to gain insight into technology research and quantitative analysis in advanced energy systems. The PhD courses will be integrated with professional development toward developing skills for energy research and technical leadership careers. Graduates of the AES program are uniquely positioned to enter the workforce in roles supporting advanced energy innovation and energy systems integration in government, academia, nonprofits, and the private sector.

Program Description

The Advanced Energy Systems graduate engineering degree program offers the Master of Science and the Doctor of Philosophy of Advanced Energy Systems. The master's program is a course-based, non-thesis program designed to prepare graduates for diverse careers in industry, government, and non-profit organizations or for additional graduate study at the PhD level. The PhD degree program prepares graduates for careers in academia, industry, government, or non-profit leadership.

Prospective AES students apply to enter the Advanced Energy Systems program through Mines' Graduate Admissions. Final admissions decisions are made by AES after a holistic admissions review. MS and PhD curricula have overlap where new students in both programs complete three core courses as part of the degree program. Three core courses are required for all MS-NT students and all PhD students. Two additional core courses are required of all PhD students.

The following information provides detail on each of the degree options.

Mines' Combined Undergraduate/Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program may double count up to six credits of graduate coursework to fulfill requirements of both their undergraduate and graduate degree programs. These courses must have been passed with "B-" or better, not be substitutes for required coursework, and meet all other University, Department, and Program requirements for graduate credit.

Students are advised to consult with their undergraduate and graduate advisors for appropriate courses to double count upon admission to the combined program.

Program Requirements

Admitted Students: The Advanced Energy Systems graduate admissions committee may require that any admitted student complete undergraduate remedial coursework to overcome technical deficiencies. Such coursework may not count toward the graduate degree. The AES admissions committee will decide whether to recommend regular or provisional admission. In accordance with Mines institutional policy, all AES students are required to maintain a minimum cumulative GPA of 3.0.

Transfer Courses: Graduate-level courses taken at other universities for which a grade equivalent to a "B" or better was earned may be considered for transfer credits for the AES MS and PhD degree program. Approval must be granted after all appropriate documentation has been submitted to the AES Program Director who will conduct a review of the transfer petition. Review of transfer credits is based on the relevance of the coursework to AES and the recency of completion for any transfer credits requested. Some exceptions may apply, however, coursework completed more than five years from AES enrollment will not be considered. Transfer credits may not have been used as credit toward a bachelor's degree. For the MS degree, no more than nine credits may transfer. For the PhD degree, up to 24 credits may be transferred. Students who enter the PhD program with a thesis-based master's degree from an accredited institution may request to transfer up to 36 hours in recognition of the course work and research completed for that degree. All transfer credits are to be submitted in the first semester of enrollment for program consideration and review for recency and AES relevance.

400-level Courses: As stipulated by the Colorado School of Mines Graduate School, students may apply a maximum of nine (9.0) semester hours of STEM based approved 400-level course work toward their AES graduate degree requirements. Mines combined students who have completed a cross-listed or 400-level course as an undergraduate cannot retake the same course at the higher level for credit toward the AES MS degree. When a course is offered at the 400-level and the 500-level, newly enrolled graduate students must enroll in the 500-level course.

Master of Science – Non-Thesis Degree Requirements

The AES Master of Science, Non-Thesis (MS-NT) is a stand-alone graduate engineering degree wherein students are self-supported or supported by industry or other outside sources. The AES MS-NT degree is course-based and targeted for students interested in professional careers in industry, government, or non-governmental positions. Students enrolled in the MS program do not participate in the two PhD core courses offered onsite at NREL. The MS-NT degree requires 30 credit hours of coursework as stipulated below. Approved elective credit hours must be taken at the graduate level at Mines and are reviewed to ensure that they form a coherent focus for an in-depth energy science and engineering study.

Advisor: All AES MS students will have an advisor to guide and monitor their academic plan and progress toward graduation.

MS Non-Thesis Degree

ENGY501	PHYSICS OF ENERGY RESOURCES & CONVERSION	3.0
ENGY502	ENERGY FOR TRANSPORTATION	3.0
ENGY503	ENERGY & POWER SYSTEMS INTEGRATION	3.0
Economics	Student must select one graduate-level Economics course from the approved program list.	3.0
Technical Electives	Technical Electives-Energy Related STEM graduate-level courses approved by Advisor and Program Director	12-18
Economics or Policy	Student may select one graduate-level Economics or Policy course from the approved program list.	0-6

Advanced Energy Systems Doctor of Philosophy Degree Requirements

The PhD degree in Advanced Energy Systems requires 72 total credits. A minimum of 36 credits of coursework and 36 credits of research credits must be completed. A minimum of 15 of the 36 credits of required coursework must be taken at Colorado School of Mines as three core courses plus the two PhD courses onsite at NREL.

The AES PhD program is designed as a full-time, four-year program of study for students having completed a minimum of a bachelor's degree in Science or Engineering. In accordance with all other graduate programs at Mines, a minimum of two semesters of full-time enrollment is required and follows the program as detailed below.

PhD Degree Requirements

ENGY501	PHYSICS OF ENERGY RESOURCES & CONVERSION	3.0
ENGY502	ENERGY FOR TRANSPORTATION	3.0
ENGY503	ENERGY & POWER SYSTEMS INTEGRATION	3.0
ENGY691	INTRODUCTION TO RESEARCH METHODS IN THE ENERGY SCIENCES	3.0
ENGY692	PROJECT FOCUSED RESEARCH IN ENERGY SCIENCE & TECHNOLOGY	3.0
Economics	Student must select one graduate-level Economics course from the approved program list *	3.0
Technical Electives	Technical Electives-Energy Related STEM graduate-level courses approved by Advisor and Program Director *	15-18
Economics or Policy Elective	Student may select one graduate-level Economics or Policy course from the approved program list *	0-3

Timeline and Milestones: PhD students must make adequate progress and reach appropriate milestones toward their degree by working with their faculty Advisor and thesis committee. The AES Program has adopted a standard Mines PhD timeline that outlines milestones that students are expected to reach on a semester-by-semester basis. Each milestone is listed here with detail.

PhD MILESTONE	EXPECTED TIMELINE
Select a permanent advisor	By Second semester
Complete the PhD qualifying examination	In June of first year of enrollment
Establish a dissertation committee	By Fourth semester
Complete all core curriculum course requirements	Fourth semester
Present Research Proposal Submit Degree Audit and Admission to Candidacy forms	Fifth semester or earlier
Present a preliminary defense	9-12 months before dissertation defense
Present a dissertation defense	End of Year Four

Funding: Students admitted to the AES PhD program are fully funded. Typically, first-year funding is provided by the Program. Subsequent funding is provided for the subsequent three years by the research group to which the PhD student is aligned.

Advisor : Preliminary and permanent: AES students are assigned a first-year advisor to guide and monitor their progress toward the qualifying exam. First-year PhD advisors are assigned based on the student's emergent research interests stated at the time of application. By the end of the first-year, students select a permanent academic advisor, closely aligned with their academic and research interests, who will serve to guide, monitor, and evaluate their progress toward the final dissertation defense. A unique aspect of the AES program is the NREL mentors who are engaged to support the student's research efforts. While the lead advisor is the Mines academic graduate faculty, the NREL research provides additional guidance for the student's research agenda.

Qualifying Exam: All AES PhD students are required to pass a Qualifying Exam given at the end of the second semester of enrollment. PhD students must have earned a minimum grade point average of 3.3 and have completed the first-year required core courses to sit for the qualifying exam. The AES Program Director oversees the process and ensures that the exam is administered fairly.

In accordance with other PhD programs at Mines, the purpose of the qualifying exam is to assess attributes expected of a successful PhD student, including:

- Ability to review, synthesize and apply fundamental concepts,
- Creative and technical ability to propose research solutions to solve open-ended and challenging problems;
- Technical Communication Skills.

The AES qualifying exam requires students to develop a hypothesis-driven research proposal on the student's topic of interest, in consultation with the academic advisor and research mentor. Students submit their research proposal to a panel of reviewers to include the AES Program Directors and one invited subject matter expert. The student presents the research proposal and, similar to the thesis-proposal process, answers a series of questions from the panel.

Exam results of Pass, Conditional Pass, or Fail are provided to the students immediately following the oral defense portion of the exam. Written feedback is provided within three days of the exam. Students who fail the exam, may be offered one additional opportunity to pass the exam before the start of the third semester. Students who fail on the second attempt, may be offered an opportunity to complete the MS-NT as the terminal degree and may be provided one immediate final semester of support to do so.

Thesis Committee: Upon successful completion of the qualifying exam and in consultation with the Mines academic advisor, each PhD student will assemble a five-person Thesis Committee that includes: the student's Mines academic advisor and NREL mentor (as the student's co-advisor); two additional Mines faculty who have a science and/or engineering background; and a fifth member of the committee who serves as the Chair and is not in the home department of the advisor. Additional committee members with specific expertise may be allowed. If there is no NREL mentor, the committee composition may constitute four members, minus the co-advisor. The AES Program Director must review and approve all committee requests prior to submission to the Office of Graduate Studies.

Research Proposal: After passing the qualifying exam, the PhD student will prepare a written Research Proposal for the Dissertation and present it formally to the Dissertation Committee, which will have been selected by the student in consultation with the Mines academic advisor and approved by the Program Director.

A written Research Proposal document will be provided to the Committee in advance of the presentation with the expectation of achieving the following:

- Demonstrate a knowledge of background and motivation of the research problem being undertaken as embodied by a review of the relevant literature;
- Enumerate specific aims and/or hypotheses;
- Identify preliminary techniques, materials, and specific measurements for the proposed research project;
- Explain clearly the scientific merit ("value added") of the proposed work;
- Provide a general idea of the timeline for the research program;
- Specify potential publications and presentations that may arise from the work.

The student and the advisor must convene a meeting of the full Dissertation Committee in which the student gives an oral summary of their written proposal in a 30 to 45-minute presentation. This Research Proposal gives the Committee an early chance to discuss the work and to help the student more clearly define the work and identify the salient aspects. The Research Proposal presentation should ideally occur before the beginning of Year 3of the Program. The research proposal must be completed before admission to candidacy.

Degree Audit and Admission to Candidacy: PhD students must complete the Degree Audit form by the posted deadlines and the Admission to Candidacy form by the first day of classes of the semester in which they want to be considered eligible for reduced registration.

Additionally, full-time PhD students must complete the following requirements within the first two calendar years after enrolling in the AES PhD program:

- have a Thesis Committee appointment form on file in the Graduate Office;
- complete all prerequisite and core curriculum course requirements;
- demonstrate adequate preparation for, and satisfactory ability to conduct doctoral research; and
- be admitted into full candidacy for the degree.

Preliminary Defense: Prior to the final Dissertation Defense, the PhD student will make an oral presentation to the student's Committee to summarize research accomplishments and remaining goals and work plan. This meeting serves as a final check to assess if the student's progress is on schedule for graduation. This meeting should present a preliminary document that will likely evolve and expand into the Dissertation. The preliminary document should include basic literature review, methodologies used, results to date, and an estimated timeline for remaining work. The student must give no more than a 45-minute presentation that summarizes the work already accomplished, including their relevant publication(s) and a proposed plan of the work needed to culminate in a formal defense and graduation. The Committee will provide feedback and, as necessary, revisions to the proposed work plan such that its completion should lead to a successful Dissertation Defense and publication record in a realistic time frame. The time period between the Research Proposal and the Preliminary Defense can span a few years, but the Preliminary Defense should take place 12 months and no less than 6 months prior to the date of Dissertation Defense.

Publications and Presentations: The required and recommended journal publications for PhD students prior to graduation are listed below. Students wanting to defend before meeting these requirements must submit a one-page petition with a reasonable explanation to the AES Program Director.

Journal Publications: **-** *Required:* Minimum of one first-author paper accepted or published (DOI is required) in a peer-reviewed journal (recognized as high quality in the research field), before Dissertation Defense. *Recommended:* Three or more first-author papers accepted or published in peer-reviewed journals. More than three first author journal publications are recommended for students interested in academic positions.

Presentations: **-** *Required:* Minimum of one research presentation (poster or podium) at an external technical conference before the Dissertation Defense. Minimum of three presentations in the AES graduate seminar or equivalent (such as campus-wide graduate student research conference, research sponsor meetings, or additional conference presentations) during PhD program. *Recommended:* Two or more conference presentations (poster or podium), before the Dissertation Defense in which the student is the first author on these presentations. Numerous conference presentations are strongly encouraged to establish a reputation amongst researchers in a field for students interested in academic positions.

Thesis Defense: At the conclusion of their PhD program, students are required to make a formal presentation and defense of their thesis research. A student must “pass” this defense to earn a PhD degree. The Dissertation document should be submitted to the Dissertation Committee at least 10 days prior to the Defense. The Committee will perform a post-presentation review of the Dissertation, technical contributions, and publications with the student. The Committee may request revisions to the Dissertation and additional work that requires subsequent review by the advisor and or the Committee.

Unsatisfactory Progress: To ensure that a student receives proper feedback if progress toward the Preliminary Defense or the Dissertation Defense is not satisfactory, the Advisor must provide the student and the Committee a brief, written progress evaluation. If the student's progress is unsatisfactory such that the Advisor gives them a PRU grade for research credits, the student will go on academic probation as outlined in the Graduate Bulletin.

Courses

ENGY501. PHYSICS OF ENERGY RESOURCES & CONVERSION. 3.0 Semester Hrs.
(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. 3 hours lecture; 3 semester hours.

ENGY502. ENERGY FOR TRANSPORTATION. 3.0 Semester Hrs.
(I) 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 (CO_2 and pollutants) formation and impacts on air quality, climate, and human health; national/international transportation policy; and transportation planning. 3 hours lecture; 3 semester hours.

ENGY503. ENERGY & POWER SYSTEMS INTEGRATION. 3.0 Semester Hrs.
(II) 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 emphases on connections to water demands and on risks arising due to cybersecurity and resiliency threats facing the electric grid. 3 hours lecture; 3 semester hours.

ENGY599. INDEPENDENT STUDY. 0.5-6 Semester Hr.
Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

ENGY691. INTRODUCTION TO RESEARCH METHODS IN THE ENERGY SCIENCES. 3.0 Semester Hrs.
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.

ENGY692. PROJECT FOCUSED RESEARCH IN ENERGY SCIENCE & TECHNOLOGY. 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.