Duke | NICHOLAS SCHOOL of the ENVIRONMENT

Energy Technology and its Impact on the Environment

ENVIRON/ENERGY 631—Spring 2025

Monday and Wednesday, 10:05 to 11:20
Grainger Hall 1112 (Field Auditorium)

Instructor

Timothy Johnson
Senior Associate Dean for Academics
Chair, Energy and Environment MEM Program
Professor of the Practice of Energy and the Environment
timothy.l.johnson@duke.edu | 919-681-9339 | Grainger Hall 5115
Office hours: Wednesdays and Thursdays 2:00 to 3:00, or by appointment

Teaching Assistants

Aishwarya Patankar (EE-BE MEM 2025) | aishwarya.patankar@duke.edu
Office hours: tbd

Cecilia Su (EE-BE MEM 2025) | keqin.su@duke.edu
Office hours: tbd

Course Description and Learning Objectives

After a century of incremental development, the global energy system is entering a period of unprecedented change. New technologies and resources, new markets and business models, and new policy drivers and regulatory challenges are emerging, with concern about climate and the need to make deep reductions in greenhouse gas emissions adding momentum to the transition. Understanding this transition and its ability to mitigate the negative environmental impacts that energy supply and use create requires an awareness of how the current energy system came to be, how it operates, and how it might evolve to continue providing the energy services on which our quality of life depends. Familiarity with energy technology and science is at the core of this understanding. Technology change alone will not solve our environmental problems, but knowledge of the factors that drive the design, performance, and costs of both current and emerging energy technologies is central to any assessment of what might be feasible going forward.

This course examines conventional and emerging energy technologies in this larger context, with a focus on electricity generation and transmission, power system planning, vehicle design, and low-energy building construction. While the course grounds the material in the basics of energy science and uses this knowledge to explore the design and operation of a fascinating technical system, the course recognizes that you cannot evaluate the potential for new energy technologies and systems apart from their economic, policy, and social contexts. By the end of the semester, you will be able to:

- Describe trends in the development of conventional and emerging energy technologies, and compare the economic, performance, and regulatory factors driving their deployment
- Apply basic energy science principles (such as thermodynamics and electromagnetics) to characterize the operation of and improvement potential for both conventional and emerging technologies
- Critically evaluate claims about the performance, economics, and environmental impacts of energy technologies, and evaluate tradeoffs among these factors
- Assess the extent to which technology deployment may help achieve environmental goals
- Speak to technology subject matter experts
- Know what you do not know about energy technology!

Class Format

Class time will consist of background lectures, discussions based on readings and the material presented in class, and small group problem solving and other participatory exercises.

Respect for Diversity and Honest Analysis

Energy supply and use are inseparable from our daily lives and lifestyle choices. Hence, many of the topics we will cover have a political and even personal subtext, and some of you may arrive with strong opinions about the past, present, and future of energy and all that it affects. My goal is to help you reason through the complexities of how we might balance conflicting societal goals that require more than technical problem solving or idealistic visions of how cultural change occurs. I also understand the temptation to see the issues we will encounter this semester in either-or terms (e.g., “fossil fuels are always bad”, “renewable energy is always better”). While I will respect the individual conclusions you reach, I ask that you *lead with evidence and analysis rather than opinion* and I will try to model this behavior in class. In short, let’s strive to be honest brokers and respect differences in personal preferences. The fact that we come from many different places and backgrounds is an asset, and I will draw on the range of your experiences as a valuable resource.

Beyond that, **I teach because I like spending time with students and helping them develop in their careers**. If you all looked, felt, and thought like me it wouldn’t be nearly as much fun, and I wouldn’t learn nearly as much as I continue to do after many years in the classroom. I enjoy

getting to know you as individuals and will do whatever I can to create a comfortable environment in which we can all be challenged and learn together.

Prerequisites

Energy and the Environment (either the undergraduate ECS 231 or the grad-level ENVIRON 711) is a prerequisite, and we will pick up where the class left off at the end of Fall Semester 2024. While the sequence of topics is similar, I will assume that students have the broad energy system foundation ECS 231/ENVIRON 711 provides and will therefore not spend significant time on review. Note that I will also assume this level of background knowledge on assignments and exams.

Coursework and Grading

Your grade will be based on the following:

Assignments	25%
Group Project	15% (All group members receive the same grade)
Exam 1	30%
Exam 2	30%

I will use the following rubric to translate your cumulative weighted score (percentage) into a final grade (e.g., a final score between 90.00 and 92.99 corresponds to an A-):

SCORE	GRADE	SCORE	GRADE
[99 to 100]	A+	[80 to 83)	B-
[93 to 99)	A	[77 to 80)	C+
[90 to 93)	A-	[73 to 77)	C
[87 to 90)	B+	[70 to 73)	C-
[83 to 87)	B	Below 70	F

Assignments: The assignments will consist of quantitative problem solving and short-answer reflective questions. **You must complete each assignment individually; though you may discuss assignment questions with your colleagues, the work you submit must be your own (per the Duke Honor Code).** Due dates follow, though note that these dates are subject to change.

ASSIGNMENT	DUE DATE	ASSIGNMENT	DUE DATE
1	23 Jan (Th)	**6**	20 Mar (Th)
2	30 Jan (Th)	**7**	27 Mar (Th)
3	06 Feb (Th)	**8**	03 Apr (Th)
4	20 Feb (Th)	**9**	10 Apr (Th)
5	27 Feb (Th)		

Group Project: The project will give you an opportunity to explore an emerging energy technology or system that we would not otherwise cover in class. Working in groups, you will prepare and submit a short research brief examining the extent to which the existing energy system "locks out" your technology and what would need to happen for your technology to achieve a significant market share in the next 15 years. See the project overview on Canvas for details.

Exams: The two exams will take place on your own time outside of class per the schedule below. You will have ninety minutes to complete each exam online through Canvas once you begin and you may not leave without submitting and return to the exam at a later time. The exams will consist of a mix of quantitative problems and short-answer questions. While you may use your personal notes and all class materials available on Canvas, you may not collaborate with anyone else in or out of the class or use external resources. Use of generative AI apps (e.g., ChatGPT) on the exams is expressly prohibited. I will report all violations of this policy to the Nicholas School Dean's Office, and you will automatically fail the class. We will not have a separate exam during the final exam period.

EXAM	COVERAGE	AVAILABLE	DUE
1	Classes 1 through 13 (transmission through technology change)	Monday, March 3 at 8:00 am	Wednesday, March 5 by 5:00 pm
2	Classes 14 through 24 (geothermal through transportation)	Monday, April 14 at 8:00 am	Wednesday, April 16 by 5:00 pm

Policy on Late Assignments and Missed Exams and Illnesses

All assignments must be uploaded to Canvas by the posted deadline. Assignments handed in after the posted deadline will incur a 25-point penalty for each 24-hour period they are late. **Assignments submitted more than 3 days (72 hours) after the posted due date and time will not receive credit**. Please do not ask for exceptions for reasons other than serious illnesses and personal emergencies.

Exams cannot be made up and you will not receive credit for an exam if you fail to submit your work on time. I will make exceptions only for serious illnesses and personal emergencies.

Undergraduates: If you are sick and cannot complete assigned work, please submit a Short-Term Illness Notification Form (STINF) at: https://trinity.duke.edu/undergraduate/academic-policies/illness. In the event of something even more serious, of course, I will make every effort to accommodate your situation.

Grad students: If you are sick and cannot complete assigned work, please contact me. If your illness will affect multiple class sessions and you are a Nicholas School MEM or MF, you should also notify Cynthia Peters, Nicholas School Assistant Dean Student Services, at petersca@duke.edu.

Readings

Readings are available on Canvas with each week's lesson, and we will not use a separate textbook. The schedule below also lists reading assignments, which you must complete prior to each day's class. I may also assign additional readings based on your interest in related topics. Your job is to read critically and use the factual basis we develop in class to reach your own conclusions about the issues we discuss.

Canvas

You will have complete access to our Canvas website if you are registered for the class. All course materials, including this syllabus, readings, assignments, and exams, are available on Canvas.

Use of Generative AI (e.g., ChatGPT)

All work you submit for this class must be your own. The world of generative artificial intelligence (AI), however, has complicated what "your own" involves. Just as use of a calculator to solve math problems is not only acceptable but expected, AI is quickly finding its way into everyday use through online search applications and word processing software. The line between acceptable and unacceptable use is therefore blurry. At minimum, copying results from ChatGPT or a similar application verbatim into an assignment is plagiarism and a violation of the Duke Community Standard and Nicholas School Honor Code that is subject to punishment for academic misconduct. Use of AI as a starting point (i.e., the equivalent of a Google search) on assignments is fine, though your submitted work must reflect significant original thought, problem solving, and effort on your part. Think of AI as one of your classmates: any use of a peer on an assignment that is improper (e.g., copying from another's work, having a buddy complete assignment questions for you) is also an improper use of AI.

Classroom Etiquette

Please arrive on time and refrain from checking email and social media, texting, and web browsing while we are together. These activities are more obvious than you might think, and I will not hesitate to cold call anyone who appears to be using their device for anything other than notetaking or researching the occasional discussion question. I will ask everyone to turn off and store all phones, laptops, and other devices during class if I feel that electronic media are becoming too much of a distraction.

My Expectations of You

This is your course. At minimum, I expect you to attend class and be an active participant, which, in turn, requires that you prepare for each class in advance and arrive having completed the readings. I also expect you to have an open mind, think critically, and use what we learn to make your own judgments.

In addition, if you have suggestions on how to improve the course, please let me know. Feedback received midstream is often more useful to you and me than end-of-term evaluations, and I am happy to make reasonable changes if a majority concurs.

What You Can Expect from Me

I am here to help you learn. I will do my best to understand and appreciate the diversity in your backgrounds, interests, and analytical strengths, and I have tried to design the course to accommodate these differences while providing opportunities to help you develop in new areas. Again, I appreciate feedback. I am available during my office hours if you have questions about the class (or life in general) and am happy to find mutually agreeable times outside of these windows to meet. Just let me know what works best for you.

Nicholas School Honor Code and the Duke Community Standard

All activities of Nicholas School students, including those of you in this course, are governed by the Duke Community Standard (https://students.duke.edu/get-assistance/community-standard/), which states:

"Duke University is a community dedicated to scholarship, leadership, and service and to the principles of honesty, fairness, respect, and accountability. Members of this community commit to reflect upon and uphold these principles in all academic and nonacademic endeavors, and to protect and promote a culture of integrity.

To uphold the Duke Community Standard:

- I will not lie, cheat, or steal in my academic endeavors;
- I will conduct myself honorably in all my endeavors; and
- I will act if the Standard is compromised."

You will need to attest to the Duke Community Standard with each assignment and exam submission.

The Nicholas School Honor Code (https://nicholas.duke.edu/about/policies/nicholas-school-honor-code) describes implementation of the Duke Community Standard and its terms govern violations related to this class.

Zoom

This is an in-person class. That said, Covid remains with us and colds, the flu, and other illnesses will likely make the rounds. I will open a Zoom link only for those who are genuinely ill

and cannot attend class in person. If you are sick, please let me know as soon as you can, and I will send you meeting information.

Schedule

This schedule below is subject to change, and I may modify it as we go along if extra time is needed (or desired) for particular topics. I will provide updates in class and via email. See the relevant sections above for assignment and project due dates. The bibliography below provides full citations.

WEEK	DATES	TOPIC	READING
1	Jan 08	Class Introduction Electric Power Transmission	*See the Week 2 readings if you want to get an early start!*
2	Jan 13/15	Electric Power Transmission	Electric Power Systems, Chapter 1 ("The Physics of Electricity"), Sections 1.1 through 1.4 (pages 1 to 18) "Grid-Enhancing Technologies" Can Squeeze a Lot More Power from the Existing Electric Grid
3	Jan 22	Electric Power Transmission *Monday, January 20 is the Dr. Martin Luther King Jr. holiday*	*If you need a review of basic power grid concepts, see:* The Future of the Electric Grid, Appendices A and B (pages 235 to 260) Reactive Power Primer
4	Jan 27/29	Electric Power Generation	Electric Power Systems, Chapter 4 ("Generators"), Sections 4.1 through 4.3.1 (pages 85 to 101) Sources of Grid Reliability Services
5	Feb 03/05	Variable Energy Resource Grid Integration Steam (Rankine) Cycles	Electricity Grids and Secure Energy Transitions, Executive Summary (pages 7 to 9) and Chapter 1 ("State of Play", pages 13 to 56)

WEEK	DATES	TOPIC	READING
6	Feb 10/12	Steam (Rankine) Cycles Energy Technology Cost Assessment	Energy for Sustainability (2008 Edition), Sections 4.5.4, 4.5.5, and 10.5 (pages 136 to 141 and 410 to 413) Introduction to Engineering and the Environment, Sections 5.4 to 5.5 (pages 183 to 210)
7	Feb 17/19	Carbon Capture Use and Storage	Pathways to Commercial Liftoff: Carbon Management, Chapter 2 ("Current State," pages 7 to 21) and Chapter 3 ("Pathways to Widespread Deployment," pages 22 to 35) What's the Deal with Carbon Capture and Storage? The Outlook for Improved Carbon Capture Technology, Sections 1 and 2 (pages 630 to 638) Putting CO2 to Use (pages 1 to 27)
8	Feb 24/26	Energy Technology Change: Lock-in and Learning Geothermal Energy	Technological Learning: Lessons Learned on Energy Technologies Understanding Carbon Lock In A Theory of Rapid Transition GeoVision: Harnessing the Heat Beneath Our Feet, Chapter 2 ("What is Geothermal Energy?," pages 9 to 46)

WEEK	DATES	TOPIC	READING
9	Mar 03/05	Nuclear Power **Exam 1**	Pathways to Commercial Liftoff: Advanced Nuclear, Chapter 2 (“Nuclear Technologies and Value Proposition,” pages 8 to 38) Nuclear Power and Secure Energy Transitions, Chapter 4 (“Small Modular Reactors”, pages 79 to 93) Pursuing Fusion Power *Optional if you want details on the nuclear fuel cycle and waste processing*: Energy Systems and Sustainability, Chapter 11 ("The Future of Nuclear Power," pages 427 to 464)
	Mar 10/12	*Spring Break*	*Read a novel!*
10	Mar 17/19	Solar Energy	Renewable Energy Crash Course, Chapter 8 (“Solar Photovoltaics,” pages 69 to 82) The Future of Solar Energy, Appendix A (“The Solar Resource,” page 253 to 270) and Appendix B (“Photovoltaics Primer,” pages 271 to 283) *Optional if you want technical details on CSP*: The Future of Solar Energy, Chapter 3 (Concentrated Solar Power technology," pages 47 to 73)
11	Mar 24/26	Wind Energy	Renewable Energy Crash Course, Chapter 3 (“Wind Power,” pages 15 to 30)

WEEK	DATES	TOPIC	READING
12	Mar 31/ Apr 02	Energy Storage Batteries	The Future of Energy Storage, Chapter 1 ("Introduction and Overview," pages 1 to 14) Pathways to Commercial Liftoff: Long Duration Energy Storage, Chapter 2 (“Current State,” pages 9 to 21) How do Lithium-Ion Batteries Actually Work? The Many Varieties of Lithium-Ion Batteries Battling for Market Share Competitors to Lithium-Ion Batteries in the Grid Storage Market *Optional if you want a more technical introduction to batteries*: The Future of Energy Storage, Chapter 2 ("Electrochemical Energy Storage," pages 15 to 65)
13	Apr 07/09	Hydrogen Transportation Electrification	Hidden Hydrogen Pathways to Commercial Liftoff: Clean Hydrogen, Chapter 2 (“Current State,” pages 9 to 30) Optional if you want a more technical overview of hydrogen: The Future of Energy Storage, Chapter 5 ("Chemical Energy Storage", pages 147 to 170) Emerging Technologies for Higher Fuel Economy Automobile Standards How to Make EVs Get Along with the Grid

WEEK	DATES	TOPIC	READING
14	Apr 14/16	Building Energy Use Class Wrap-Up **Exam 2**	Building Electrification How Heat Pumps of the 1800s Are Becoming the Technology of the Future

Bibliography

Armstrong, Robert, et al (2022). The Future of Energy Storage: An Interdisciplinary MIT Study. Cambridge: Massachusetts Institute of Technology. https://energy.mit.edu/research/future-of-energy-storage/

Baraniuk, Chris (2023). How Heat Pumps of the 1800s Are Becoming the Technology of the Future. Knowable Magazine, 11 January 2023, https://knowablemagazine.org/content/article/technology/2023/heat-pumps-becoming-technology-future

Carey, John (2024). "'Grid-Enhancing Technologies' Can Squeeze a Lot More Power from the Existing Electric Grid." Proc. Natl. Acad. Sci. U.S.A., 121 (4) e2322803121, https://doi.org/10.1073/pnas.2322803121

Everett, B., et al. (2012). Energy Systems and Sustainability: Power for a Sustainable Future (Second Edition). Oxford: Oxford University Press.

Gonchar, Joann (2020). Continuing Education: Building Electrification. Architectural Record, 1 December 2020. https://www.architecturalrecord.com/articles/14883-continuing-education-building-electrification

Haas, Reinhard, Sayer, Marlene, Ajanovic, Amela and Auer, Hans (2022). Technological learning: Lessons learned on energy technologies. Wires Energy and Environment 12(2), March/April 2023, https://doi.org/10.1002/wene.463

Hand, Eric (2023). Hidden Hydrogen. Science: 3793(6633), 17 February 2023. https://www.science.org/content/article/hidden-hydrogen-earth-may-hold-vast-stores-renewable-carbon-free-fuel

Hossain, Eklas and Petrovic, Slobodan (2021). Renewable Energy Crash Course: A Concise Introduction. Cham, Switzerland: Springer Nature Switzerland AG. *This book is available online through Duke Libraries at* https://find.library.duke.edu/catalog/DUKE99119493442308501

IEA (2019). Putting CO2 to Use: Creating Value from Emissions. Paris: International Energy Agency, https://www.iea.org/reports/putting-co2-to-use, License: CC BY 4.0

IEA (2022). Nuclear Power and Secure Energy Transitions: From Today's Challenges to Tomorrow's Clean Energy Systems. https://www.iea.org/reports/nuclear-power-and-secure-energy-transitions

IEA (2023). Electricity Grids and Secure Energy Transitions: Enhancing the foundations of resilient, sustainable and affordable power systems. Paris, International Energy Agency, https://www.iea.org/reports/electricity-grids-and-secure-energy-transitions, License: CC BY 4.0

Kassakian J.G., et al. (2011). The Future of the Electric Grid: An Interdisciplinary MIT Study. Cambridge: Massachusetts Institute of Technology. https://energy.mit.edu/research/future-electric-grid/

Lipman, T.E. (2017). Emerging Technologies for Higher Fuel Economy Automobile Standards. Annu. Rev. Environ. Resour. 2017. 42:267–88. https://www.annualreviews.org/content/journals/10.1146/annurev-environ-110615-085844

Milligan, Michael (2018). Sources of Grid Reliability Services. The Electricity Journal 31(9): 1-7, November 2018, https://doi.org/10.1016/j.tej.2018.10.002

Oglesby, Cameron (2023). What's the Deal with Carbon Capture and Storage? Yale Climate Connections, 20 October 2023, https://yaleclimateconnections.org/2023/10/whats-the-deal-with-carbon-capture-and-storage/

Randolph J. and Masters G.M. (2008). Energy for Sustainability: Technology, Planning, Policy. Washington, DC: Island Press.

Roberts, David (2021). How do Lithium-Ion Batteries Actually Work? David Roberts Explains. Canary Media, 16 April 2021. https://www.canarymedia.com/articles/batteries/the-basics-of-how-lithium-ion-batteries-work

Roberts, David (2021). The Many Varieties of Lithium-Ion Batteries Battling for Market Share. Canary Media, 21 April 2021. https://www.canarymedia.com/articles/batteries/the-many-varieties-of-lithium-ion-batteries-battling-for-market-share

Roberts, David (2021). Competitors To Lithium-Ion Batteries in the Grid Storage Market. Canary Media, 14 May 2021. https://www.canarymedia.com/articles/batteries/battery-week-competitors-to-lithium-ion-batteries-in-the-grid-storage-market

Rubin, E.S. (2001). Introduction to Engineering and the Environment. New York: McGraw-Hill.

Rubin E.S., et al. (2012). The Outlook for Improved Carbon Capture Technology. Progress in Energy and Combustion Science 38:630-671, https://www.sciencedirect.com/science/article/abs/pii/S0360128512000184

St. John, Jeff (2024). How to Make EVs Get Along with the Grid. Canary Media, 13 December 2024, https://www.canarymedia.com/articles/utilities/how-to-make-evs-get-along-with-the-grid

Schmalensee, Richard, et al. (2015). The Future of Solar Energy: An Interdisciplinary MIT Study. Cambridge: Massachusetts Institute of Technology. https://energy.mit.edu/research/future-solar-energy/

Seto, K.C. (2016). Carbon Lock-In: Types, Causes, and Policy Implications. Annu. Rev. Environ. Resour. 2016. 41:425–52. https://www.annualreviews.org/content/journals/10.1146/annurev-environ-110615-085934

Sheldon, V. (2014). Reactive Power Primer. SolarPro, Issue 7.4, June/July 2014.

Speelman, Laurens and Numata, Yuki (2022). A Theory of Rapid Transition: How S-Curves Work and What We Can Do to Accelerate Them. RMI, October 2022, https://rmi.org/wp-content/uploads/2022/10/theory_of_rapid_transition_how_s_curves_work.pdf

United States Department of Energy (2019). GeoVision: Harnessing the Heat Beneath Our Feet. DOE/EE–1306, May 2019. https://www.energy.gov/eere/geothermal/geovision

United States Department of Energy (2023). Pathways to Commercial Liftoff: Carbon Management. April 2023. https://liftoff.energy.gov/

United States Department of Energy (2023). Pathways to Commercial Liftoff: Clean Hydrogen. March 2023. https://liftoff.energy.gov/

United States Department of Energy (2023). Pathways to Commercial Liftoff: Long Duration Energy Storage. March 2023. https://liftoff.energy.gov/

United States Department of Energy (2024). Pathways to Commercial Liftoff: Offshore Wind. April 2024. https://liftoff.energy.gov/

United States Department of Energy (2024). Pathways to Commercial Liftoff: Advanced Nuclear. September 2024. https://liftoff.energy.gov/

Unruh, G.C. (2000). Understanding Carbon Lock-in. Energy Policy 28(12): 817-830. https://www.sciencedirect.com/science/article/pii/S0301421500000707

vonMeier, A. (2006). Electric Power Systems: A Conceptual Introduction. Hoboken, NJ: John Wiley and Sons, Inc. *This book is available online through Duke Libraries at* https://find.library.duke.edu/catalog/DUKE99119287547808501

Waldrop, M. Mitchell (2023). Pursuing Fusion Power. Knowable Magazine, 01 November 2023, 10.1146/knowable-110123-1, https://knowablemagazine.org/content/article/physical-world/2023/the-challenge-of-fusion-power