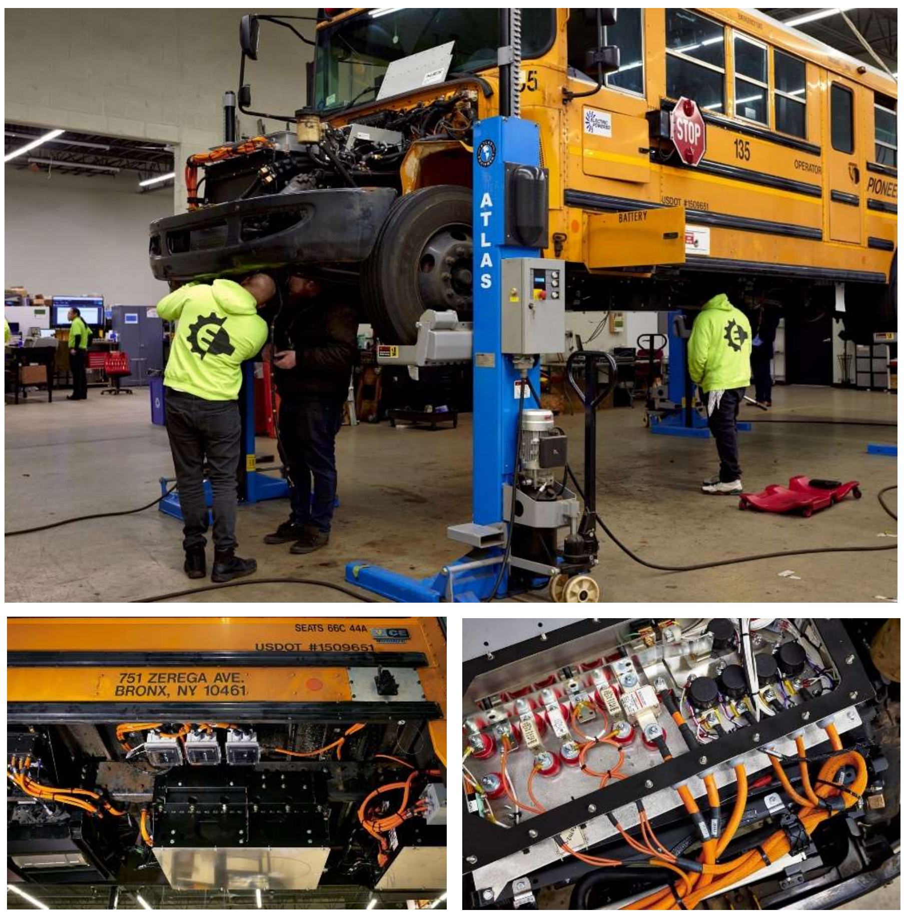
STUDY GUIDE

Theory of Energy and Sustainability Engineering (ENG 571)

Spring 2025

Prof. Leon Liebenberg

During the Industrial Revolution, there was rapid proliferation of railways, train transport, the telegraph, and steam-powered ships. More recently with the Information Revolution, we've watched the internet, smartphones and social media quickly take hold worldwide. And we're witnessing it now with solar power, electric vehicles, battery storage, heat pumps, hydrogen, and micro nuclear power.



Employees at Unique Electric Solutions in Holbrook, New York, work on retrofitting a school bus (top). Electric motor and batteries connected by high-voltage cables under a repowered school bus (left). The interior of a high-voltage junction box installed to a repowered school bus along with high-voltage cables (right). Image credits: Bloomberg, https://www.bloomberg.com/graphics/2023-electric-school-bus-battery-power/

SYLLABUS (subject to change)

Week #	For the lecture on …	… you should first study the following lecture notes / slides at home (Project deliverables stated in brackets)	… which is in the text-book, chapter #
1.	Wed. 22 Jan.	• **Lecture:** See Slides #0 • **Activity:** Overview of course, introduction to energy and the First Law of Thermodynamics	Study Guide Textbook: Chapters 1 and 2
	Fri. 24 Jan.	• **Lecture:** See Slides #1 • **Activity:** First Law of Thermodynamics, focusing on heat transfer in buildings • **Assignment:** Complete reading assignment for Quiz 1. Also, download and install the HOMER Pro simulation package.	1, 2
2.	Mon. 27 Jan.	• **Lecture:** See Slides #1, #2 • **Activity:** First Law of Thermodynamics, focusing on heat pumps, cooling load calculations; Second Law of Thermodynamics	1, 2
	Wed. 29 Jan.	• **Lecture:** See Slides #2, #3 • **Activity:** Second Law of Thermodynamics, entropy, and exergy	3
	Fri. 31 Jan.	• **Lecture:** See Slides #4 • **Activity:** Investigation of energy and society. • **Assignment:** Complete Quiz 1 (Due Week 3). Also, complete online survey by due date.	4
3.	Mon. 3 Feb.	• **Lecture:** See Slides #5 • **Activity:** Energy and the environment	5
	Wed. 5 Feb.	• **Lecture: See** Slides #6 • **Activity:** Energy economics	6
	Fri. 7 Feb.	• **Lecture:** See Slides #6 • **Activity:** Energy economics • **Assignment:** Complete Quiz 2 (Due Week 4)	6
4.	Mon. 10 Feb.	• **Lecture:** See Slides #7 • **Activity:** Refrigeration and air-conditioning	14
	Wed. 12 Feb.	• **Lecture:** See Slides #8 • **Activity:** Geothermal energy (focusing on geothermal heat pumps)	26
	Fri. 14 Feb.	• **Guest lecture** by Dr. Upasana Pandey and Dr. Andy Stumpf • **Activity:** Geothermal energy (focusing on geothermal heat pumps) and cooling of data centers • **Assignment:** Complete Quiz 3 (Due Week 5)	
5.	Mon. 17 Feb.	• **Lecture:** See Slides #9 • **Activity:** Fuels • **Assignment:** Mini Project 1 – "Data Center Cooling Requirements, with and without chilled water storage tank," (due by tonight at 10 p.m.)	7
	Wed. 19 Feb.	• **Lecture:** See Slides #10 • **Activity:** Coal	8
	Fri. 21 Feb.	• **Lecture:** See Slides #11 • **Activity:** Oil, natural gas, and hydrogen • **Assignment:** Complete Quiz 4 (Due Week 6)	9
6.	Mon 24 Feb.	• **Lecture:** See Slides #12 • **Activity:** Internal combustion engines	10

Week #	For the lecture on …	… you should first study the following lecture notes / slides at home (Project deliverables stated in brackets)	… which is in the text-book, chapter #
	Tue 25 Feb	• Activity: Voluntary site visit #1 of the Petascale Computing Facility colling system, Oak Street, Champaign; time will be announced in class. (Tour leader: Mr. Jeff Kohmstedt)	
	Wed. 26 Feb.	• **Lecture:** See Slides #13 • **Activity:** External combustion engines • Activity: Voluntary site visit #2 of the Petascale Computing Facility colling system, Oak Street, Champaign; time will be announced in class. (Tour leader: Mr. Jeff Kohmstedt)	13
	Fri. 28 Feb.	• **Lecture:** See Slides #14 • **Activity:** Steam power plants, and controlling their emissions • **Assignment:** Complete Quiz 5 (Due Week 7)	13
7.	Mon. 3 Mar.	• **Lecture:** See Slides #15 • **Activity:** Nuclear physics • **Assignment**: Mini Project 2 – "Incorporating Geothermal Cooling into a Data Center Energy System" (due by tonight at 10 p.m.)	16
	Wed. 5 Mar.	• **Lecture:** See Slides #16 • **Activity:** Nuclear fission and fusion	16, 17
	Fri. 7 Mar.	• **Lecture:** See Slides #16 • **Activity:** Nuclear fission and fusion • **Assignment:** Complete Quiz 6 (Due Week 8)	16, 17
8.	Mon. 10 Mar.	• **Lecture:** See Slides #16 • **Activity:** Nuclear fission and fusion	16, 17
	Wed. Mar. 12	• **Lecture:** See Slides #16 • **Activity:** Nuclear fission and fusion	16, 17
	Thu. March 13	• **Guest lecture** by Prof. Katy Huff in room 2035 of the Campus Instructional Facility, 12:30 p.m. – 1:30 p.m. • **Activity:** The future of nuclear power plants	
	Fri. Mar. 14	• **Lecture:** No in-person lecture today. Instead, you must study Slides #17 and watch Video #17 at your convenience. • **Activity:** Controlling nuclear waste • **Assignment:** Complete Quiz 7 (Due Week 9, after Spring Break)	18
	March 15 - 23	**Spring Break (no classes this week)**	
9.	Mon. 24 Mar.	• **Lecture:** No in-person lecture today. Instead, please study Slides #18 and watch Video #18 at your convenience. • **Activity:** Direct energy conversion	19
	Wed. 26 Mar.	• **Lecture:** See Slides #19 • **Activity:** Solar electricity ("photovoltaics")	19, 20
	Fri. 28 Mar.	• **Lecture:** See Slides #19 • **Activity:** Solar electricity ("photovoltaics") • **Assignment:** Complete Quiz 8 (Due Week 10)	19, 20
10.	Mon. 31 Mar.	• **Lecture:** See Slides #20 • **Activity:** Fuel cells and electrolyzers	21
	Wed. 2 Apr.	• **Lecture:** See Slides #20 • **Activity:** Fuel cells and electrolyzers	21

Week #	For the lecture on …	… you should first study the following lecture notes / slides at home (Project deliverables stated in brackets)	… which is in the text-book, chapter #
	Fri. 4 Apr.	• **Activity:** Site visit: C-U Mass Transit District (electrolyzer, hydrogen fuel cell buses) • **Assignment:** Complete Quiz 9 (Due Week 11)	21
11.	Mon. 7 Apr.	• **Lecture:** See Slides #21 • **Activity:** Solar heating	22
	Wed. 9 Apr.	• **Lecture:** See Slides #21, #22 • **Activity:** Solar heating; Solar-thermal electrical power plants	22, 23
	Fri. 11 Apr.	• **Lecture:** See Slides #22 • **Activity:** Solar-thermal electrical power plants • **Assignment:** Complete Quiz 10 (Due Week 12)	23
12.	Mon. 14 Apr.	• **Lecture:** See Slides #23 • **Activity**: Wind power	24
	Wed. 16 Apr.	• **Lecture:** See Slides #24 • **Activity**: Water power	25
	Fri. 18 Apr.	• **Lecture:** See Slides #24 • **Activity:** Water power • **Assignment:** Complete Quiz 11 (Due Week 13)	25
13.	Mon. 21 Apr.	• **Lecture:** See Slides #25 • **Activity**: Storage of electricity and heat • Assignment: Mini Project 3 – "Integrating a Micro Nuclear Plant with a Conventional Data Center Cooling System" (due by tonight at 10 p.m.)	27
	Wed. 23 Apr.	• **Lecture:** See Slides #25 • **Activity**: Storage of electricity and heat	27
	Fri. 25 Apr.	• **Lecture:** See Slides #25 • **Activity:** Storage of electricity and heat • **Assignment:** Complete Quiz 12 (Due Week 14)	27
14.	Mon. 28 Apr.	• **Lecture:** See Slides #26 • **Activity:** Decarbonization of transportation and buildings	28
	Wed. 30 Apr.	• **Lecture:** See Slides #26 • **Activity:** Decarbonization of industry and energy production	28
	Fri. 2 May	• **Activity:** Site visit, Abbott power plant and carbon capture pilot plant • **Assignment:** Complete Quiz 13 (Due Week 15)	
15.	Mon. 5 May	Discussion. Summary of semester's work.	
	Wed. 7 May	Project Winners' Day	

China added 62 gigawatts of solar and wind power capacity in the first four months of 2023. In comparison, the country added "only" around 26 gigawatts during the same period in 2022. That brings non-fossil fuel electricity generating capacity above half of the nation's total power mix for the first time.

Workers install solar panels in Wuhan, China. Buoyed by massive domestic demand, Chinese manufacturing of polysilicon and its processing results in a product that is two-thirds the price of a European-made product. Image credit: Financial Times.

Workers are seen at a project with an annual output of 10 gigawatt-hours of high-efficiency solar cells in Huai'an, East China's Jiangsu Province on March 18, 2024. China's installed solar power generation capacity rose by 55.2 percent in 2023, data released by the National Energy Agency showed. Photo: cnsphoto

COURSE ORGANIZATION

Instructor: Prof. Leon Liebenberg, Energy and Sustainability Engineering, Department of Nuclear, Plasma & Radiological Engineering, 121 Talbot Laboratory, 104 S. Wright St., Urbana 61801

E-mail: leonl@illinois.edu Tel: (217) 300-5496

Lectures: The course for Spring 2025 will be offered in-person. The in-person class will meet in room 403B2 of Engineering Hall on Mondays, Wednesdays, and Fridays from 3:00 p.m. – 3:50 p.m. Some students (from industry or taking internships) will potentially be allowed to register as online-only students.

Participation in all classes is mandatory for students registered as in-person, even though each lecture will be recorded and placed on Canvas for your use. Some lectures will feature class participation exercises, which will count toward your final grade. If online students cannot join a lecture synchronously to submit their class participation exercise, they will need to submit that exercise on Canvas by the next day's deadline; students registered for in-person classes however need to submit their class participation exercises during a lecture.

Slides will be made available for each lecture. However, it is important to purchase the prescribed textbook as it contains detailed analyses and worked problems, which the slides do not.

For those registered for the 3-credit-hour course, plan to spend approximately 12 hours per week on studying the course material and completing assignments. If you are enrolled for the 4-credit-hour version of this course, you should allocate around 16 hours per week for these activities. (Students who are registered for 4-credit hours will complete extra quiz questions.)

Course webpage (Canvas): https://canvas.illinois.edu/courses/54388

If you have difficulties accessing Canvas, then please contact consult@illinois.edu, *not* the instructor, *nor* the teaching assistant.

Course Organization: You are expected to adhere strictly to the syllabus, complete the readings, and meet all assignment deadlines. The instructor will usually not provide reminders for course deliverables; it is your responsibility to manage and complete these tasks independently. As a 500-level course, it requires you to develop proficiency in independent work and demonstrate mastery of the learned concepts. This course is therefore self-directed with minimal guidance from the instructor and teaching assistant.

Instructor's office hours: Professor Liebenberg's office hours will be held online-only via Zoom on Thursdays from 3:00 p.m. to 3:50 p.m. (excluding holidays):
https://illinois.zoom.us/j/89833760805?pwd=K1gvL1RLeDB5bjBYNVFqYisrOFJTdz09
Meeting ID: 898 3376 0805
Password: 511839

If these office hours are inconvenient for you, please email Professor Liebenberg detailing your difficulty and attaching any relevant information, such as calculations.

Your queries: You may submit queries or questions anytime via *Piazza*. Students are encouraged to view their classmates' questions and to participate in course discussions on *Piazza*.

Sign up at: https://piazza.com/illinois/spring2025/eng571

Private questions should be directed using the "Private" option on *Piazza*, else the whole class will see your query / request. The course assistant or the instructor will respond to your questions as soon as they can. The instructor and the teaching assistant will attempt to address your queries promptly from Mondays to Fridays (9 a.m. – 5 p.m.) and less promptly after these hours or over weekends. No questions will be taken during holidays.

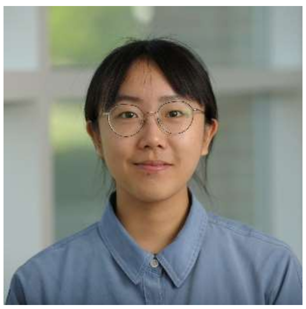
Grade appeal policy: Students have **one week** to appeal a grade after it has been published. After this period, all grades are considered final.

Grade appeals for any assignment should be directed to the instructor via email at leonl@illinois.edu. The appeal must include:

- A **clear statement** of your grade concern.
- A **justification** of how many points you believe you deserve for the specific question(s) in question.

Incomplete or vague appeals may not be considered.

Course assistants: The course assistants are **Mr. Vivek Shah and Ms. Runyu Zheng.** They will be responsible for grading your weekly quizzes, class participation exercises, and will also assist me in grading your three mini projects. The CAs will stage a weekly office hour via Zoom; details will be published later.



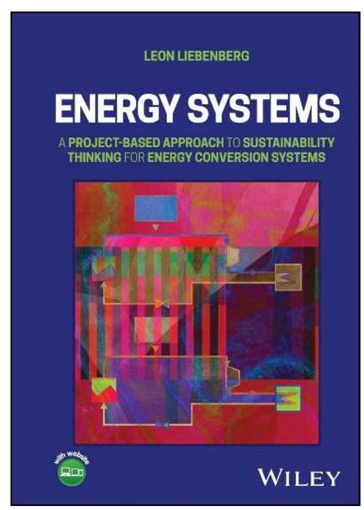
Ms. Runyu Zheng, runyu2@illinois.edu
Office hour: Tuesdays from 4 – 5 p.m.

Zoom link:
https://illinois.zoom.us/j/83697200811?pwd=YN9ZXfX2Kll3H7pjXstVKNdriZ19SR.1
Meeting ID: 836 9720 0811
Passcode: 221810

Mr. Vivek Shah, vivekms2@illinois.edu
Office hour: Mondays from 12:30 – 1:30 p.m.

Zoom link:
https://illinois.zoom.us/j/86423799362pwd=dhBqSZvGesIfiHLcnbbPejVYbA4iiH.1
Meeting ID: 864 2379 9362
Passcode: 956207

Prescribed (mandatory) textbook: Leon Liebenberg. *Energy Systems. A Project-Based Approach to Sustainability Thinking for Energy Conversion Systems.* New York: John Wiley and Sons, 2024.



This book (or e-book) is available from the Illini Union Bookstore or amazon.com, or from other reputable booksellers. You can also purchase the book or an e-book subscription from the publisher.

Reading material: The prescribed textbook is comprehensive, covering everything from fundamental physics to the crucial details of real-world energy systems. Lecture slides, which are linked to the chapters of the textbook, will be provided.

Assignments

All assignments and reading materials will be posted on Canvas. All completed assignments should be uploaded as a single PDF document (not multiple sheets). Please make sure that your work is neat and legible. Graded quizzes and feedback on mini project deliverables will also be posted on Canvas. Your assignments will comprise the following:

- Thirteen (13) take-home quizzes, to be completed independently *(around 6 days to complete a quiz)*.
- Series of three linked mini projects *(to be completed in teams of two over a period of several weeks)*.
- Many lectures will feature class participation exercises, which will count toward your final grade.
- No midterm exam and no final exam.

Quizzes: Quizzes will typically be posted toward the end of a lecture week, usually by Thursday evening. Completed quizzes must be uploaded on Canvas on the following Wednesday, implying that students will usually have six days to complete a quiz. Please refer to the "Assignments" folder on Canvas for details. Quizzes will be extensive in nature and cover material from the previous week or two. The questions may be either quantitative or qualitative. *Note:* Graduate students enrolled in the 4-credit-hour option will need to answer additional questions on each quiz. Be sure to read your quiz instructions carefully.

Mini projects: You will be assigned to a team (ideally, 2 to 3 members per team). Each team will complete a series of three mini projects based on quantitative and qualitative analyses. Teams will be provided with a project topic. Mini-project deliverables will be due on Monday evenings, as indicated in the "Assignments" folder on Canvas.

Peer-grading: Teams could be asked to peer-grade another team's project deliverables. Teams will then peer-grade a different team's project for each of the three mini-projects. The intention is to promote peer-learning. Teams will be penalized for being overly lenient or overly harsh in peer-grading. It is crucial to adhere strictly to the grading rubric and key. When grading open-ended questions, provide detailed comments. The teaching assistant and instructor will assign the final grades for each assignment, independent of peer grading.

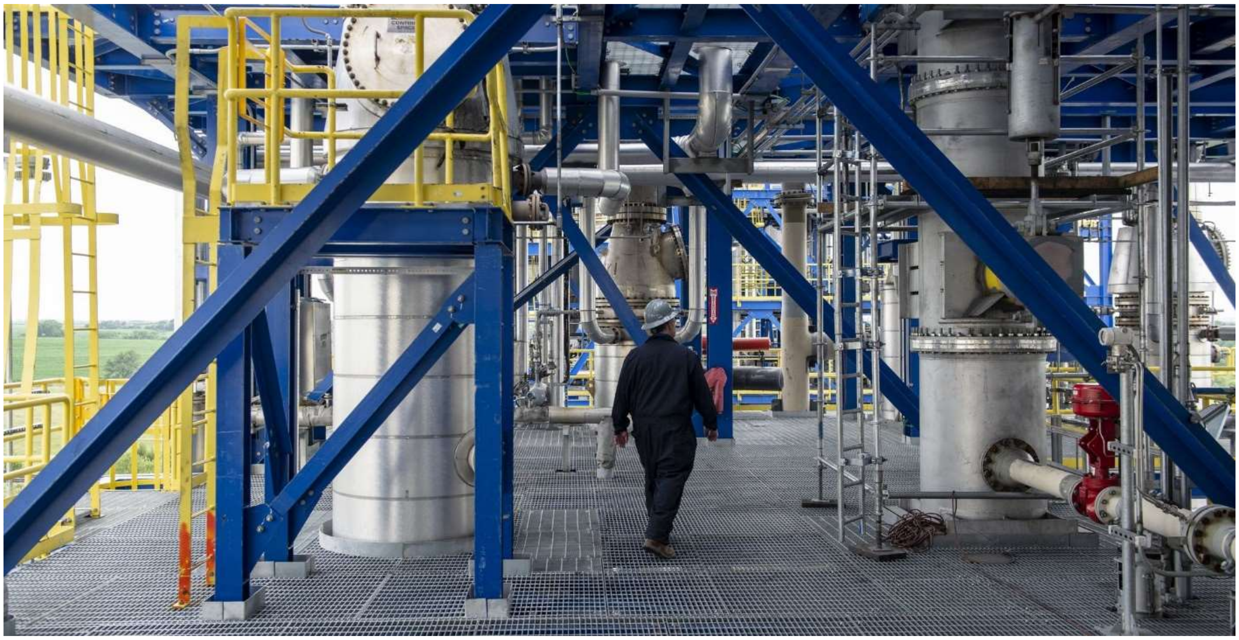
Voluntary Site visits

You are invited to participate in a few voluntary site visits that will help contextualize certain energy technologies. Potential site visits may include:

- Abbott Steam Power Plant and pilot carbon capture plant
- Oak Street Chiller plant, which provides chilled water for the entire campus, and for the UIUC Petascale Computing Facility.
- Green Hydrogen Production Facility and Fuel Cell Buses (Champaign-Urbana Mass Transit District)

Assessment

1. Take home-quizzes – individual (40% of grade):
    - Thirteen take-home quizzes based on the previous/current week's lecture material.
2. Class Participation exercises (10% of grade) – team and/or individual: Several exercises will be given during random lectures which will be graded.
3. Mini-project 1 – team (15% of grade)
4. Mini-project 2 – team (15% of grade)
5. Mini-project 3 – team (20% of grade)



Hydrogen production is seen as a viable fossil-fuel replacement for heavy industry, unlike many other renewable-energy sources. The image shows Monolith's plant in Nebraska runs on renewable power to turn natural gas into clean hydrogen and carbon materials. Image credit: The Wall Street Journal

MINI PROJECTS

MINI PROJECTS (Team-based): ***Cooling Strategies for Data Centers Using Conventional and Unconventional Approaches***

Overview: This series of three interconnected mini-projects invites you and your chosen (or assigned) teammate(s) to research and analyze advanced cooling strategies for a hypothetical medium-sized data center located in Chicago, Illinois, USA. You will evaluate the technical and economic benefits of integrating a chilled water storage system, a geothermal heat pump with geothermal wells, and a micro nuclear power plant to reduce the carbon footprint of an existing data center. You will use the *HOMER Pro* simulation package, in addition to performing hand calculations to substantiate some of the simulation results.

Team Formation: Teams must consist of two members. In the event of an uneven number of students in the class, or if a student joins the class late, or if a team member drops the course, one team of three members will be permitted. You may form your own team or request the instructor to assign one for you. This collaborative effort will encourage the exchange of diverse ideas and foster the development of well-rounded solutions. Note that the same quality of work is expected from teams regardless their size. However, proportionally more work is expected from a team of three students.

Context: The rapid growth of internet and AI services has led to data centers consuming approximately 1% of global electricity, globally. By 2030, this figure is projected to rise to 9%. Currently, data centers use 60% of their energy for computational processes, while the remaining 40% is dedicated to cooling. Traditional cooling methods, which often involve air-cooled systems and liquid (commonly water) for heat dissipation, are inefficient and unsustainable.

Renewable energy sources like wind and solar are not viable for powering data centers due to their intermittent nature, as data centers require continuous, dispatchable power. However, geothermal energy presents a promising alternative as a renewable heat sink for data centers. When combined with chilled water storage and a micro nuclear power plant for primary electricity (alongside grid electricity as needed), these strategies can create a more sustainable and efficient system.

Details: See the "Mini-Project" folder in the "Modules" section of Canvas for the detailed mini-projects and grading rubrics.

<u>Mini Project 1</u>: Data Center Cooling Requirements with and without a Chilled Water Storage Tank

Analyze the average annual energy requirements for the cooling of a data center's "computer room." This involves evaluating the energy consumption of the center's conventional cooling system and comparing it to a system incorporating a chilled water storage tank.

Key Deliverables:

- Energy Analysis: Calculate (with hand calculations and using *HOMER Pro*) the annual energy consumption of the conventional cooling system.
- Chilled Water Storage Integration: Model and estimate (with hand calculations and using *HOMER Pro*) the energy savings achieved by integrating a chilled water storage tank.
- Comparison: Provide a detailed comparison of the energy requirements and efficiency of the two systems.

<u>Mini Project 2</u>: Incorporating Geothermal Cooling into a Data Center Energy System

Analyze the integration of geothermal wells as a heat sink for the data center cooling system analyzed in Mini Project 1. Specifically, determine the capacity of a geothermal heat pump and the number of 100-meter-deep geothermal wells needed to absorb all or part of the data center's heat load, ensuring that geothermal saturation does not occur. Additionally, perform a techno-economic optimization and sensitivity analysis to evaluate the impact of key parameters on the system's performance and cost.

Key Deliverables:

- Geothermal System Design: Calculate the heat load of the data center that can be transferred to geothermal wells. Determine the heat pump capacity and optimal number and configuration of 100-meter-deep geothermal wells to manage the heat load sustainably.
- Techno-Economic Optimization: Using *HOMER Pro*, analyze the energy efficiency and cost-effectiveness of incorporating a geothermal heat pump and geothermal wells into the cooling system. Optimize for key variables such as well depth, spacing, and heat transfer efficiency.
- Sensitivity Analysis: Evaluate how changes in parameters such as heat load, ground thermal conductivity, well installation costs, and energy prices affect system performance and lifecycle costs.

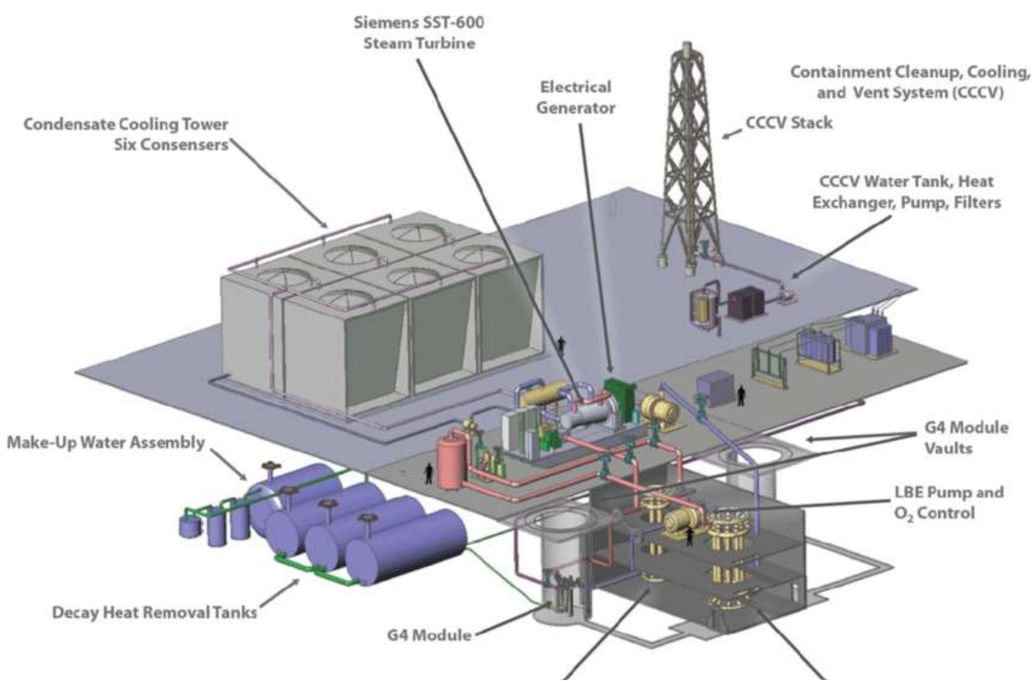
<u>Mini Project 3</u>: Integrating a Micro Nuclear Plant with a Conventional Data Center Cooling System

Develop an integrated optimization strategy by combining the traditional cooling system, geothermal wells, and a micro nuclear power plant to create a sustainable and efficient energy system for a data center.

Key deliverables:

- Integration of Prior Findings: Incorporate insights and results from Mini Projects 1 and 2 into the design of a hybrid cooling and energy system that includes a micro nuclear reactor.
- Simulation and Optimization: Utilize *HOMER Pro* to model and simulate the integrated system. Optimize for performance metrics such as energy efficiency, cost-effectiveness, and environmental impact.
- Expanded Sensitivity Analysis: Perform a detailed sensitivity analysis to evaluate how variations in parameters (e.g., energy demand, nuclear plant size, geothermal system capacity, and operational costs) influence the system's overall performance.
- Final Technical Report: Prepare a comprehensive technical report detailing all calculations, simulations, results, and key findings. Include a discussion of the feasibility, sustainability, and economic viability of the proposed system.

High-Impact Fact Sheet: Summarize the project's key results and recommendations in a visually compelling 1-page fact sheet. Include visuals such as graphs, charts, and system diagrams to highlight critical insights.



Conceptual drawing of a Generation-4-based micro nuclear power plant. Courtesy: Siemens

A recently completed 100-MW concentrated solar power plant located in Dunhuang, northwest China's Gansu Province. The plant uses 12,000 mirrors that concentrate the sunlight onto a receiver at the top of a solar tower, which then heats molten salt. The molten salt exchanges heat with water, to produce steam that drives turbines. The plant is designed to generate 390 million kWh of power annually, which can reduce carbon dioxide emissions by 350,000 metric tons per year, compared to a similarly sized natural gas-fired steam power plant. Image credit: www.xinhuanet.com

COURSE POLICIES

Late work: *Mini-project deliverables must be submitted on time so that the peer feedback process works properly*. There is no possibility of submitting a mini project late, nor is there the possibility of providing you with make-up assignments. Any late assignment or non-submission is awarded 0%.

a. To repeat, *there are no extensions for mini-project deliverables.* Teams have several weeks to plan and execute their work, so it's important not to leave tasks until the last moment. Teams should plan thoroughly and have contingencies in place to handle situations where a team member may be unable to contribute due to extenuating circumstances, such as illness.
b. Late quizzes or non-completion of class participation exercises will receive a 0% grade. Students will have around 6 days to complete each quiz, and solutions will be posted after the submission deadline passes.
c. No-penalty extensions for quiz or class participation due dates may however be granted by the instructor, but only if the student provides advance notice by email, except in emergencies. The *only* valid reasons for missing a quiz or class participation submission deadline are:
    i. student illness or accidental injury;
    ii. serious illness, serious injury, or death in the student's direct family;
    iii. birth of a child for which the student is identified as a parent on the birth certificate;
    iv. required duty in the U.S. military (active-duty, reserve, or in a National Guard unit activated by the President or a governor), required service in a foreign military organization acting in concert with the United States, or service under provisions of the Volunteer Emergency Worker Job Protection Act;
    v. participation in, or travel to, an obligatory AFROTC, NROTC, or ROTC event;
    vi. participation in, or travel to, varsity or DRES-sanctioned athletic events (excluding fencing, bowling, and other club sports);
    vii. participation in, or travel to, an organized extracurricular activity sanctioned by the College of Engineering or one of its departments, for which a full-time or emeritus faculty member of the College of Engineering attests that the student's participation is essential;
    viii. observance of a religious holiday;
    ix. any excuse allowed by the UIUC for students participating in online learning.

If the student was so seriously ill or injured as to be unable to communicate their intentions to the instructor prior to the beginning submission deadline, the advance notification requirement will be waived if the student subsequently provides satisfactory documentation of such incapacitation.

In those cases where advance notification of lateness or non-submission has been provided, or where such notice has been waived according to the provisions of the second sentence of the above paragraph, late submissions of non-submissions will be classified as unexcused unless the student provides satisfactory after-the-fact documentation, as indicated below.

For illness or injury of the student, a satisfactory letter stating that the student was medically unfit to complete the quiz by the submission deadline must be provided by an appropriate medical practitioner (C.N.P., D.D.S., D.M.D., D.O., D.P.M., M.D., O.D., or P.A.) after the quiz submission deadline. *Medical bills, prescriptions, e-mail or letters from friends or relatives, letters from naturopaths, chiropractors, psychologists, and mental health counselors, "visit slips" from McKinley Health Center, and records of calls to McKinley Health Center's Dial-a-Nurse program (with or without endorsement by an "emergency dean" in the Office of the Dean of Students) are among the types of documentation that will not be accepted.*

For serious illness, serious injury, or death in the student's family, the student's relationship to the ill, injured, or deceased party must be established, along with documentation of the illness, injury, or death.

For birth of a student's child, a photocopy of an original birth certificate, showing the student as a parent, is required.

For military duty, copies of valid military orders are required.

For participation in or travel to varsity or DRES-sanctioned athletic events or AFROTC/NROTC/ROTC events, a satisfactory letter from the Division of Intercollegiate Athletics, DRES, or the commanding officer of the detachment is required.

For participation in, or travel to, an organized extracurricular activity sanctioned by the College of Engineering or one of its departments, a satisfactory letter from the faculty sponsor is required.

Independent work: You may collaborate with your classmates to figure out the necessary concepts and approaches, *but you must solve the problems independently*. See *Academic Integrity* on page 15 of this study guide.

Communication etiquette: We welcome communications concerning possible errors, or constructive suggestions about the materials. Please do not contact us to request increases in your assigned grade, outside of errors in grading.

All class communications will use your UI NetID email; do not use any alternate such as gmail as such mail will be ignored.

If you believe that an assignment has been incorrectly graded, communicate this with the instructor within 5 working days after the assignment has been handed back to you. After that period, your assignment will not be regraded, and your grade will remain unchanged.

Most Valuable Players (MVPs): As mentioned, you should state all your queries via Piazza, not via email. <u>Piazza is configured to allow any student to post anonymously to their classmates whenever they prefer.</u> In each discussion thread, different anonymous posters are automatically differentiated with pseudonyms to avoid confusion. The instructor invites you all to help answer your classmate's Piazza questions. The course assistant and the instructor will keep track of each time a student suitably answers a fellow student's Piazza question. At the end of the semester, we will tally all the results to see which students *consistently* and *significantly* helped their fellow classmates the most. Those winning students will each receive a bump of 1% in their final grade! Those winning students will also win the "Most Valuable Player" certificates that will be awarded at the end of the semester. We encourage the students in our class to make the most of this opportunity. This helps you to learn from each other's understanding of the course and increase your grades! And, as you answer the questions posted by your fellow classmates, you will realize that it also betters your own understanding of any concept.

Note: When the course assistant or instructor award "good post" awards on Piazza, which will eventually be tallied to give us the MVPs, they will use the following criteria:

- Does the question or the answer clarify a technical (not class-administrative) issue which was vague or confusing in the class instructional materials (lecture announcements and syllabus)?
- Does the question or the answer demonstrate unique and thoughtful engagement with the course material?
- Is one student going out of their way to clarify something from the lecture to another student?
- Does reading what the student wrote make you excited to learn more about the energy systems?
- Other: (New justification which we can apply retroactively).

Final grade

At the end of the semester, letter grades are determined based on composite numerical scores, weighted as previously described. The instructor does not have a predetermined "target" grade distribution, and it may vary significantly from semester to semester. Additionally, there is no "curving" of grades in this class.

Grades will be rounded up to the nearest whole number. For example, a final grade of 93.2% will be rounded to 93%, while a final grade of 93.6% will be rounded to 94%.

Letter grades at semester's end

Grade meaning	Refined letter scale	Numerical scale of marks
Excellent	A+	97 to 100
	A	94 to <97
	A-	90 to <94
Good	B+	87 to <90
	B	84 to <87
	B-	80 to <84
Adequate	C+	77 to <80
	C	74 to <77
	C-	70 to <74
Marginal	D+	67 to <70
	D	64 to <67
	D-	60 to <64
Inadequate	F	<60

Skeptics argue that abatement technologies such as carbon capture and storage, or CCS, are expensive boondoggles that aren't nearly as effective in reducing emissions as proponents say and give energy giants an excuse to continue producing fossil fuels. Overreliance on CCS to counteract fossil-fuel emissions is dangerous, the Paris-based International Energy Agency warned in a November report, potentially requiring an "inconceivable" 32 billion metric tons of carbon captured at a cost of more than $3.5 trillion a year until 2050 if current oil and gas consumption trends continue.

BKV compressor units process carbon dioxide in Bridgeport, Texas, before it is injected into a well. Denver-based BKV says that by the 2030s it will store millions of tons of climate-warming carbon dioxide in wells deep underground to eliminate or offset all the emissions generated from manufacturing and using its gas. Image credit: The Wall Street Journal.

Course Objectives

Students will be asked to demonstrate their knowledge of the material covered in ENG 571 through their mastery of the following course objectives:

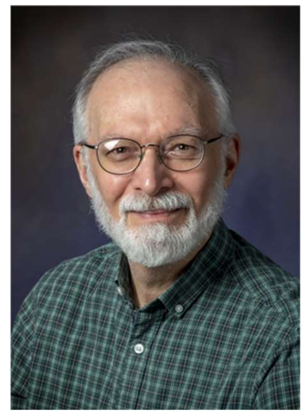
- Learning the scientific and engineering fundamentals, as well as elements of policy and economics needed to develop energy systems and infrastructure that are sustainable in terms of resources, security, and environmental impact.

The Energy and Sustainability Engineering (EaSE) graduate certificate

ENG 471 and ENG 571 are the core courses in the EaSE graduate certificate (or "microcredential"). If you are enrolled in any M.S. or Ph.D. degree program, consider adding the certificate to your credentials: EaSE.Illinois.edu. Enquiries may be directed to Ms. Amy McCullough: amccul2@illinois.edu

Guiding "big picture" questions for ENG 571

When he founded the Energy and Sustainability Engineering program at UIUC, *Professor John Abelson* generated some superb guiding "big picture" questions for ENG 571. As you go through the topics of ENG 571, Professor Abelson's questions will help you to form an understanding of the interconnected challenges and opportunities in the energy and sustainability fields and will stimulate you to ask probing questions.



Professor John Abelson, Department of Materials Science and Engineering, founder of the Energy and Sustainability Engineering program at UIUC.

There are many ways to frame these questions. As a starting point, Professor Abelson proposes the following:

Stakeholders: What groups of people, or regions of the world, are directly affected by a given issue? Or indirectly affected?

Time scale: How soon does this issue become critical enough to motivate a major stakeholder? Can changes in human activity be implemented in time to avoid or offset major consequences?

Solutions: Do there exist technologies or approaches that can make a substantial reduction in impact for this issue? If technologies are available, what are the challenges to implementation – scale-up, economic, policy, social acceptance, other?

If not currently available, can new technologies be developed soon enough that the anticipation of future availability can be used in current planning decisions? Here, one may include plausible incremental improvements (e.g., improved efficiency or cost reductions), but not breakthroughs, which are (by definition) unknown.

And we should not expect miracles. There are always fundamental (thermodynamic) and practical (engineering) limits to what is possible. Good technology may reach 50 % of the fundamental limit, and a great one 75% of the limit. Never believe a claim that obviously exceeds this.

Physical scale: Can the proposed technology be employed *at scale*, meaning enough units, soon enough to make an impact? This involves ramping up the *manufacturing supply chain*. In some cases, such as the fabrication of modular (compact) nuclear power plants, a supply chain does not yet exist and must be created!

Note that systems with major infrastructure investment – fossil energy, for example – *require decades to change*. That is because, from an investment point of view, CEOs prefer to use existing systems until they need physical replacement, rather than to invest in new systems earlier than otherwise needed. Only in a few cases (e.g., replacing incandescent light bulbs) is the saving from a new technology (compact fluorescent or LED bulbs) so great that early retirement makes economic sense.

The above is not good news from a sustainability perspective but is a reality that must be dealt with.

Fundamental tradeoffs: For a given situation – e.g., heating a home or driving a vehicle – *there does not exist a solution that simultaneously maximizes all benefits and minimizes costs and consequences*. (If there were, we would already be using it!)

Typically, we can lower environmental impact by investing in a more efficient system. An immediate question is whether we have (or want to spend) more money on capital costs. Also, the efficiency gain may, or may not, lower the net costs over the lifetime of the system, particularly if calculated using economic "discounting."

And there is always a minimum impact that cannot be reduced (unless we lower total demand for that technology). For example, if we insulate a house to enormous levels, the energy required to manufacture *surplus* insulation becomes greater than the energy saved by its use. Or if we reduce the fuel consumption of an automobile by changing the materials of construction to reduce the mass, above some level of improvement the energy needed to manufacture the lightweight materials is greater than the energy saved through their use. Also, it can be much more difficult – or impossible – to recycle advanced materials at the end of life of the auto.

Ecosystem services: Human activity – economic activity – cannot occur without impact on the earth and its ecosystem. Farming, logging, animal husbandry, etc., are examples of economic activity that derive from "ecosystem services." Mining, a crucial economic activity, also draws resources from the earth, but not from the active ecosystem; however, mining activity has ecosystem consequences.

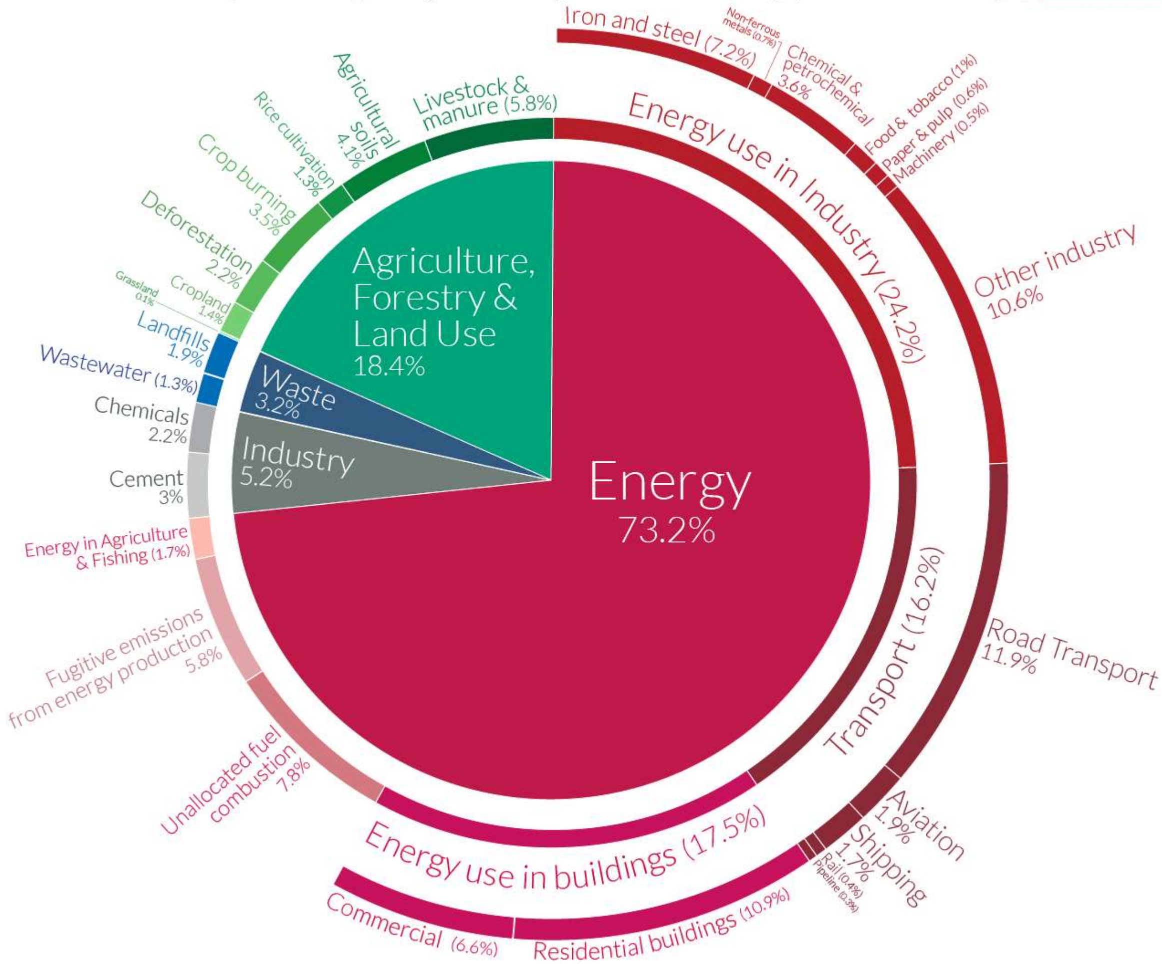
When does human economic activity trigger an ecosystem degradation from which recovery of important functions is difficult or impossible on intergenerational time scales?

At high levels of economic activity, the direct or secondary effects are large and the changes (damage) to the ecosystem are obvious. At very low levels, the effects of human activity may not be noticeable or significant compared with naturally occurring variations. At moderate levels, the ecosystem still functions, but operates in a new state that, although different from the original equilibrium, may not degrade rapidly. But ecosystems are very complex and interdependent, so the real impacts may not be clear in the short run.

Global greenhouse gas emissions by sector

Our World in Data

This is shown for the year 2016 – global greenhouse gas emissions were 49.4 billion tonnes CO_2eq.



OurWorldinData.org – Research and data to make progress against the world's largest problems.

Source: Climate Watch, the World Resources Institute (2020).

COURSE RULES

Teamwork: Effective teamwork requires empathy and respect. You should be willing and able to 'bend' your minds to recognize where others are coming from and what is important to them, and then to 'blend' with them, moving in a unified direction. You will learn techniques to be more receptive and connected, and to have greater influence whilst accommodating others. Rather than opposing or agreeing with other people, you will learn how to accept and acknowledge the other's position until you can understand what is important about it. This requires a willingness to flex, bend, and search to understand someone else's perspective. Once you understand their perspective, you can pivot and create an opening for that person to understand what is important to you.

Team members will communicate with each other using social media platforms of their own choosing. Historically, students enjoy collaborating using the following platforms: Discord, Zoom, Google Docs, WeChat, GroupMe, and Miro. You and your teammates should soon agree on your chosen method of online collaboration and then promptly get into that routine.

It is strongly suggested that teams use roving team leaders. For instance, a student could be team leader for the first mini-project, followed by another student leading the next mini-project, and yet another team member leading the third mini-project. This will help ensure that no single person dominates the team's actions.

Assigned team members will remain unchanged for the duration of the semester. Teams should however note that they must accommodate late-registered students into their teams, as directed by the instructor or TA. Teams may also have to negotiate lost team members as some students might drop the course. So, although ideal team sizes are 2 students, this number might become more (i.e., 3 students) depending on class size. Also, some students might join the class late and asked to merge with an existing team. The instructor and TAs will do their utmost to minimally disrupt existing teams. The full cooperation of every student is expected when forming or changing teams.

Grading the work of large teams and small teams: When grading the mini projects of small teams (say, with two team members), we expect the same quality (and correctness) of work compared to larger teams (say with three team members); but, for smaller teams we of course do not expect the same quantity of work than that of a larger team. Conversely, we expect the same quality of work from a large team compared to anyone else; however, we expect a greater quantity of work from a larger team than a smaller team.

Peer- and self-evaluations will be done in the middle and at the end of the semester. The purpose of these brief evaluations is to check that all students are contributing fairly and substantially to team-based activities. These peer evaluations provide an opportunity for your fellow team members to reflect on how the team activities are progressing and to reflect on how team functioning might be improved. The aggregate scores of these peer evaluations will be *directly used to correct all project-related grades.* For instance, if a team member's peers score his/her contribution to the team's efforts as 3.5/5 (i.e., 70%), then the specific student's *overall* mini-project grade will be adjusted by a 0.7 correction factor.

Uncooperative team members: In this engineering class, effective teamwork is paramount for successful collaboration and project completion. Students are encouraged to actively engage in open communication, share diverse perspectives, and contribute their unique skills to foster a collaborative and innovative environment. However, should any student fail to cooperate with their team or disrupt the collaborative process, appropriate measures will be taken. These measures include intervention by the instructor, potential reassignment of team roles, and, if necessary, disciplinary actions in accordance with class and University policies. This ensures a fair and conducive learning environment that promotes the development of both technical and interpersonal skills crucial for success in the field of engineering.

Academic integrity

The highest academic integrity is expected. Academic violations will however be dealt with according to the UIUC Student Code, Article 1, Part 4. Violations will be reported to the College of Engineering. The recommended penalty will be either failure of the course, or dismissal for the M.Eng. program and separation from the College of Engineering or UIUC.

Specific comments about academic integrity

- All students are responsible to refrain from infractions of academic integrity, conduct that may lead to suspicion of such infractions, and conduct that aids other in such infractions. "I did not know" is not an excuse.
- The following are academic integrity infractions (http://www.provost.illinois.edu/academicintegrity/students):
  - ✓ Cheating: using or attempting to use unauthorized materials.
  - ✓ Plagiarism: representing the words, work, or ideas of another as your own.
  - ✓ Fabrication: falsification or invention of information, including citations.
  - ✓ Facilitating infractions of academic integrity, helping, or attempting to help another commit infraction.
  - ✓ Bribes, favors, and threats: actions intended to affect a grade or evaluation.
  - ✓ Academic interference: tampering, altering, or destroying educational material or depriving someone else of access to that material.
  - ✓ Note: All infractions are documented in the campus-wide FAIR database.

- If you have difficulty completing your classwork, you should consult the instructor by showing him evidence of your attempts to solve the specific problem/s. However, most lecture time has been set aside exactly for this type of activity; use it to your full advantage.
- Copying (in whole or in part) another student's (or team's) quiz, project work, or exam is not permitted. Copying solutions from web-based answer keys such as Chegg is an honor code violation.
- Be sure to follow the course and University regulations and course or assignment policies/instructions regarding the use of AI tools like ChatGPT, Bing, CoPilot, ChatSonic, or Jasper. When using AI, substantiate or validate all claims, findings, or insights by citing credible sources such as peer-reviewed journal articles. And double-check simulation results by doing your own hand calculations. Remember, AI is a probabilistic tool based on a large database and can make mistakes; avoid simply copying answers from an AI tool, as this could lead to regret.
- If you choose to discuss your work with a fellow student, it should be a discussion in which one teaches the other, or where both work to a mutual understanding. The discussion should however relate to general concepts and not address the specifics of the quiz questions.
- It is not acceptable to give a fellow student your completed project work or quiz or other assignment so that they can copy it. In such a case, both you and your fellow student will have committed an academic violation.
- It is also unacceptable to copy work from a student who completed the course previously.
- You should properly cite references and sources in your written reports. Cases of cheating or plagiarism will be handled severely.

  Also, be wary to correctly use quotation marks for sentences or important data that did not originate with you. Further, paraphrasing should be kept to a minimum. When used, the paraphrased section should be specifically identified by citing the original source. It is not sufficient to simply provide a list of references but not indicate where a specific quotation or paraphrase was employed. In addition, all sources should be fully cited. As is done in scientific and engineering literature, you should briefly acknowledge in writing any significant discussions or interactions you had regarding the work you are reporting on.
- Ignorance of academic integrity or uncertainty regarding the instructor's wishes are not justifiable reasons for academic violations. If you are uncertain of the instructor's wishes or intentions, you should consult with him *before* acting.

COLLEGE OF ENGINEERING STATEMENTS

Sexual Misconduct Reporting Obligation: The University of Illinois is committed to combating sexual misconduct. Faculty and staff members are required to report any instances of sexual misconduct to the University's Title IX Office. In turn, an individual with the Title IX Office will provide information about rights and options, including accommodations, support services, the campus disciplinary process, and law enforcement options.

A list of the designated University employees who, as counselors, confidential advisors, and medical professionals, do not have this reporting responsibility and can maintain confidentiality, can be found here: wecare.illinois.edu/resources/students/#confidential.

Other information about resources and reporting is available here: wecare.illinois.edu.

Community of Care: As members of the Illinois community, we each have a responsibility to express care and concern for one another. If you come across a classmate whose behavior concerns you, whether in regards to their well-being or yours, we encourage you to refer this behavior to the Student Assistance Center (217-333-0050 or http://odos.illinois.edu/community-ofcare/referral/). Based on your report, the staff in the Student Assistance Center reaches out to students to make sure they have the support they need to be healthy and safe.

Further, we understand the impact that struggles with mental health can have on your experience at Illinois. Significant stress, strained relationships, anxiety, excessive worry, alcohol/drug problems, a loss of motivation, or problems with eating and/or sleeping can all interfere with optimal academic performance. We encourage all students to reach out to talk with someone, and we want to make sure you are aware that you can access mental health support at the Counseling Center (https://counselingcenter.illinois.edu/) or McKinley Health Center (https://mckinley.illinois.edu/).

Mental Health: Significant stress, mood changes, excessive worry, substance/alcohol misuse or interferences in eating or sleep can have an impact on academic performance, social development, and emotional wellbeing. The University of Illinois Urbana-Champaign offers a variety of confidential services including individual and group counseling, crisis intervention, psychiatric services and specialized screenings which are covered through the Student Health Fee.

If you or someone you know experiences any of the above mental health concerns, it is strongly encouraged to contact or visit any of the University's resources provided below. Getting help is a smart and courageous thing to do for yourself and for those who care about you.

- Counseling Center (217) 333-3704
- McKinley Health Center (217) 333-2700
- National Suicide Prevention Lifeline (800) 273-8255
- Rosecrance Crisis Line (217) 359-4141 (available 24/7, 365 days a year)

Academic Integrity: The University of Illinois at Urbana-Champaign Student Code should also be considered as a part of this syllabus. Students should pay particular attention to Article 1, Part 4: Academic Integrity. Read the Code at the following URL: http://studentcode.illinois.edu/.

Academic dishonesty may result in a failing grade. Every student is expected to review and abide by the Academic Integrity Policy: https://studentcode.illinois.edu/article1/part4/1-401/. Ignorance is not an excuse for any academic dishonesty. It is your responsibility to read this policy to avoid any misunderstanding. Do not hesitate to ask the instructor(s) if you are ever in doubt about what constitutes plagiarism, cheating, or any other breach of academic integrity.

Religious Observances*:* The Religious Observance Accommodation Request form is available at http://odos.illinois.edu/community-ofcare/resources/docs/Religious-ObservanceAccommodation-Request-Form.pdf. Submit the form to the instructor and to the Office of the Dean of Students (helpdean@illinois.edu) by the end of the second week of the course; in the case of exams or assignments scheduled after this period, students should submit the form to the instructor and to the Office of the Dean of Students as soon as possible.

Disability-Related Accommodations*:* To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must contact the course instructor and the Disability Resources and Educational

Services (DRES) as soon as possible. To contact DRES, you may visit 1207 S. Oak St., Champaign, call 333-4603, e-mail disability@illinois.edu or go to https://www.disability.illinois.edu. If you are concerned you have a disability-related condition that is impacting your academic progress, there are academic screening appointments available that can help diagnosis a previously undiagnosed disability. You may access these by visiting the DRES website and selecting "Request an Academic Screening" at the bottom of the page.

Family Educational Rights and Privacy Act (FERPA)*:* Any student who has suppressed their directory information pursuant to Family Educational Rights and Privacy Act (FERPA) should self-identify to the instructor to ensure protection of the privacy of their attendance in this course. See https://registrar.illinois.edu/academic-records/ferpa/ for more information on FERPA.

Inclusion: The intent is to raise student and instructor awareness of the ongoing threat of bias and racism and of the need to take personal responsibility in creating an inclusive learning environment. The Grainger College of Engineering is committed to the creation of an anti-racist, inclusive community that welcomes diversity along a number of dimensions, including, but not limited to, race, ethnicity and national origins, gender and gender identity, sexuality, disability status, class, age, or religious beliefs.

The College recognizes that we are learning together in the midst of the Black Lives Matter movement, that Black, Hispanic, and Indigenous voices and contributions have largely either been excluded from, or not recognized in, science and engineering, and that both overt racism and micro-aggressions threaten the well-being of our students and our university community.

The effectiveness of this course is dependent upon each of us to create a safe and encouraging learning environment that allows for the open exchange of ideas while also ensuring equitable opportunities and respect for all of us. Everyone is expected to help establish and maintain an environment where students, staff, and faculty can contribute without fear of personal ridicule, or intolerant or offensive language. If you witness or experience racism, discrimination, micro-aggressions, or other offensive behavior, you are encouraged to bring this to the attention of the course director if you feel comfortable.

You can also report these behaviors to the Bias Assessment and Response Team (BART) (https://bart.illinois.edu/). Based on your report, BART members will follow up and reach out to students to make sure they have the support they need to be healthy and safe. If the reported behavior also violates university policy, staff in the Office for Student Conflict Resolution may respond as well and will take appropriate action.

Emergency response recommendations can be found at the following website: http://police.illinois.edu/emergency-preparedness/. You are encouraged to review this website and the campus building floor plans website within the first 10 days of class. http://police.illinois.edu/emergencypreparedness/building-emergency-action-plans/

Enjoy the course!