# ME498/505 Carbon Capture and Storage

Instructor: Jiajun He

Spring 2025

**Class Contents:**

**Part I Carbon Capture:**

Thermodynamics/kinetics of chemical capture
Carbon capture from the industrial sector and power sources
IGCC, oxy-fuel combustion, and chemical looping
Reliable storage options
Carbon dioxide removal from the atmosphere

**Part II Carbon Sequestration:**

Fundamentals of Carbon Sequestration
Injection Methods and Pressure Buildup
Modeling Fate and Transport
Sequestration Capacity Assessment
Health Safety and Environmental Risks of Sequestration
Monitoring $CO_2$ Storage
Cost of sequestration and institutional issues

**Skills You Will Acquire:**

Minimum and real work calculations
2nd-Law efficiency calculations
Evaluation of tradeoffs between capture technologies
Running IECM Capture Economic Model
Assessment of the potential of CCS for global $CO_2$ emissions reduction
Estimates of $CO_2$ saturation and migration after injection
Evaluation of $CO_2$ storage potential
Awareness of $CO_2$ storage risks as well as monitoring and mitigation methods

**Class Meetings:**

**On-Campus Sections: Mon, Wed and Fri 10:00 am – 10:50 am at 403B2 Engineering Hall.**

**Online Sections:** Synchronous sessions can be accessed through the following Zoom link:
https://illinois.zoom.us/j/87146685138?pwd=GKIEtlngaAsvpliVgh8jGylXMb0m6P.1
Meeting ID: 871 4668 5138
Password: 142346

Lecture recording will be provided after class.

You are expected to attend every class session or watch the lecture recording.

**Office hours:** If some aspect of the course material is unclear to you after independent study, you are expected to raise the issue in class or during office hours.

Prof. Jiajun He <jiajunhe@illinois.edu> , **Mondays 2:00 pm – 3:00 pm** or by appointment in 2026 LuMEB. For online students, meetings can be scheduled via Zoom. Please let me know if you need to schedule one.

TA: Sadman Sakib < ssakib2@illinois.edu>, time and location TBA

Questions can also be posted on the Piazza site:
https://piazza.com/illinois/spring2025/me505me498

**Text and Notes:**

Part 1: **Carbon Capture** by Jennifer Wilcox (Springer, 2012)
Part 2: Lecture notes and supplemental reading

**Homework:** Problem sets (x6) and writing assignments (x2, for 4-hour sections only) will be assigned throughout the semester. The due date will be announced when the assignment is made. Late homework will not be accepted, unless you make prior arrangements with the instructor (or for a medical emergency). When a homework set involves computer analysis, do not submit a printout alone as your solution. The printout may be part of your solution; however, your approach must be clearly explained and independent of the program listing.

**Exams:** There will be one midterm exam and one final exam to be announced later in class. Both exams will be take-home exams, where you will be allowed 48 hours to complete them. Make-up exams will only be permitted by prior arrangement and only for reasons described in the U of I Student Code.

**Software:** The main computer tool we will use is Integrated Environmental Control Model (IECM). IECM is a tool for calculating the performance, emissions, and cost of a fossil-fueled power plant, developed by Carnegie Mellon University and Department of Engineering & Public Policy. You will need to download the software at https://www.uwyo.edu/iecm/index.html. Video Tutorials can be accessed at https://www.uwyo.edu/iecm/videos/.

**Grades:** Course grades for the 3-hour option will be based on the problem sets, the midterm exam, and the final exam according to the following scheme:

- Problem Sets 40%
- Midterm Exam 30%
- Final Exam 30%

Course grades for the 4-hour option will be based on the problem sets, the writing assignments, the midterm exam, and the final exam according to the following scheme:

- Problem Sets 20%
- Writing Assignments 20%
- Midterm Exam 30%
- Final Exam 30%

Final letter grades will be assigned based on the scale below.

| *Letter Grade* | *Final Course Average* |
|---|---|
| A+ | 97 – 100 |
| A | 94 – 96 |
| A- | 90 – 93 |
| B+ | 87 – 89 |
| B | 84 – 86 |
| B- | 80 – 83 |
| C+ | 77 – 79 |
| C | 74 – 76 |
| C- | 70 – 73 |
| D+ | 67 – 69 |
| D | 64 – 66 |

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|---|---|
| D- | 60 – 63 |
| F | 0 – 59 |

For final grades that are very close to the cutoff lines (**less than 0.5 below the cutoff**, e.g., 96.5, 93.5, …), the upper letter grade will be given. The instructor has no predetermined 'target' grade distribution, and the distribution can vary significantly from semester to semester.

**Extra Credit:** You will have a chance to earn extra credit (1 pt towards your final score mentioned above) if you choose to complete an extra task. Tasks may vary for different semesters. Please refer to the update-to-date announcement made via Canvas.

**Academic Integrity:** Violations of University policy with respect to academic integrity will not be tolerated and infractions may lead to suspension or dismissal from the University. See: http://admin.illinois.edu/policy/code/article1_part4_1-401.html

**Campus Safety:** Important information regarding Campus Safety and General Emergency Response are available at http://illinois.edu/emailer/newsletter/39474.html. Please take some time to review these documents.

**See Next Page for Course Schedule**

**Course Schedule (Tentative)**

| | Day | Date | Assignments | Topics | Reading |
|---|---|---|---|---|---|
| **1** | Wed | 1-22 | | First Day of Class<br>Introduction to Carbon Capture | |
| **2** | Fri | 1-24 | | Introduction to Carbon Capture<br>$CO_2$ Utilization | Wilcox 2012<br>Chapter 1 |
| **3** | Mon | 1-27 | | Minimum work, Separation process overviews<br>Minimum work example problem | |
| **4** | Wed | 1-29 | PS #1 Posted | Carbon Capture Processes (Post, Pre, Oxy)<br>Absorption, Gas/liquid diffusion, Henry's Law | Wilcox 2012<br>Chapter 3 |
| **5** | Fri | 1-31 | | Modified Henry's Law Coefficient, Liquid-Phase Diffusivity, $CO_2$-Water, $CO_2$-amine Reactions | |
| **6** | Mon | 2-3 | | Film Theory, $CO_2$ Absorption Rate, Real Work Calculations | |
| **7** | Wed | 2-5 | | Intro to Adsorption, Physisorption/Chemisorption<br>Lennard-Jones, Isotherms | Wilcox 2012<br>Chapter 4 |
| **8** | Fri | 2-7 | PS #1 Due<br>PS #2 Posted | Isotherm Types, Langmuir and BET Isotherms<br>Intro to different Sorbents, Activated Carbon | |
| **9** | Mon | 2-10 | | Zeolite, MOF, Example Problem - Film Model, Example Problem - Langmuir Isotherm | |
| **10** | Wed | 2-12 | | Mass Transport During Adsorption, Breakthrough Curves, Molecular Simulations | |
| **11** | Fri | 2-14 | | PSA vs TSA, Pressure Drop, Real Work<br>Intro to Membrane Technology | |
| **12** | Mon | 2-17 | PS #2 Due<br>PS #3 Posted | Membrane Selectivity, Single/Multistage Configurations, Membrane Modules | Wilcox 2012<br>Chapter 5 |
| **13** | Wed | 2-19 | | Adsorption Example Problems | |
| **14** | Fri | 2-21 | | Intro to Integrated Environmental Control Model (IECM) | |
| **15** | Mon | 2-24 | | IECM Tutorial (cont.) | |
| **16** | Wed | 2-26 | PS #3 Due<br>WA #1 Posted | Negative Emissions Technologies<br>Direct Air Capture | |
| **17** | Fri | 2-28 | | Watch Jennifer Wilcox, Katherine Hayhoe and Marshall Shepard's TED Talks – Online | |
| **18** | Mon | 3-3 | | Natural Solutions for Carbon Dioxide Removal | |
| **19** | Wed | 3-5 | | $CO_2$ Conversion | Wilcox 2012<br>Chapter 8 |
| **20** | Fri | 3-7 | | Midterm Review | |
| **21** | Mon | 3-10 | | $CO_2$ Mineralization | Wilcox 2012<br>Chapter 9 |
| **22** | Wed | 3-12 | | **Midterm** | |

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|---|---|---|---|---|
| **23** | Fri | 3-14 | | Watch Jaeson Cardiff, Bas Sudmeijer, and Steve Oldham's TED Talks – Online |
| | Mon | 3-17 | | *Spring Break* |
| | Wed | 3-19 | | *Spring Break* |
| | Fri | 3-21 | | *Spring Break* |
| **24** | Mon | 3-24 | | Fundamentals of $CO_2$ storage |
| **25** | Wed | 3-26 | WA #1 Due<br>PS #4 Posted | Thermodynamic properties of $CO_2$ |
| **26** | Fri | 3-28 | | Pipeline transport of $CO_2$ |
| **27** | Mon | 3-31 | | Fundamentals of multi-phase flow of $CO_2$ and brine |
| **28** | Wed | 4-2 | | Multiphase flow and $CO_2$ plume migration |
| **29** | Fri | 4-4 | PS #4 Due<br>WA #2 Posted<br>PS #5 Posted | Injection pressure of single-phase water |
| **30** | Mon | 4-7 | | Injection pressure of *$CO_2$* into water reservoir |
| **31** | Wed | 4-9 | | Reservoir seals (caprocks) |
| **32** | Fri | 4-11 | | Secondary trapping mechanisms |
| **33** | Mon | 4-14 | PS #5 Due<br>PS #6 Posted | Numerical simulation of storage efficiency and long-term fate of stored $CO_2$ |
| **34** | Wed | 4-16 | | Environment, health, and safety risks of $CO_2$ storage; risk management |
| **35** | Fri | 4-18 | | Monitoring |
| **36** | Mon | 4-21 | | Capacity assessment |
| **37** | Wed | 4-23 | PS #6 Due | Final Review 1 |
| **38** | Fri | 4-25 | | Final Review 2 |
| | Mon | 4-28 | | |
| | Fri | 5-2 | WA #2 Due | |
| | Fri-Sat | 5-9 thru 5-10 | | **Take-Home Final Exam** |