CARBON REMOVAL, CAPTURE, AND USE

ISEN 432

Fall 2021: October 27-December 6

4:00-5:30pm

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Office hours: 1808 Chicago Ave., Room 110, 6:00-7:00pm, TTh

COURSE OVERVIEW

Climate change is the keystone environmental issue of this generation, and most likely for many generations to come. While the world community and individual countries have formulated policies to address climate change, these policies are almost universally recognized as being wholly inadequate to effectuate the objective of the Paris Agreement to hold global temperatures to well below 2ºC above pre-industrial levels, and to pursue efforts to limit increases to 1.5ºC.

Indeed, it has become increasingly obvious that achievement of Paris temperature objectives will require both aggressive emission reductions initiatives and large-scale deployment of carbon dioxide removal/negative emissions technologies and processes (CDR), sometimes also referred to as a major sub-category of climate geoengineering, and carbon capture and sequestration with storage (CCS), technologies that capture carbon dioxide remissions at the flue stack.

This course will discuss the exigency of deploying CCS and CDR approaches at scale, including potential benefits and risks of these options. It also will discuss regulatory and governance considerations at both the national and international level, as well as strategies to incentivize large-scale adoption of these approaches.

LEARNING OBJECTIVES

After taking this course you should be able to:

- Distinguish between carbon dioxide removal and carbon capture and storage approaches;
- Understand the technological aspects of carbon capture and storage, potential risks and benefits, and constraints to large-scale deployment;
- Understand the potential risks and benefits of natural and industrial carbon removal approaches;
- Assess the adequacy of current governance mechanisms for CCS and CDR options and identify gaps in governance;
- Identify constraints to large-scale deployment of carbon dioxide removal approaches

COURSE READINGS

The readings for the course will be derived from the following sources, designated in the class schedule with the icons listed below:

- E **Electronic readings**, which are available on the course Canvas site for this course. Click on the "Files" link and look for the "Readings" folder.
- O **Online Hyperlinks**, which must be accessed via the online version of the Syllabus on the course Canvas site.

ASSESSMENT/ASSIGNMENT SCHEDULE

Assignment	Deadline	% Grade
Special Topics Presentations	**Per Assigned Date in Syllabus**	**15%**
Term Paper Summaries: Class Presentations	**Per Assigned Date in Syllabus**	**15%**

Term Paper	**December 10**	**50%**
Class Participation	**Ongoing**	**20%**

BRIEF SUMMARY OF ASSIGNMENTS

Special Topics Presentations

Students will work in groups of 2-3 to prepare 10-minute presentations for class on assigned topics. Please see the "Assignment Guidelines" folder under the Files folder for further instruction.

Term Paper Summary Presentations/Term Paper

Each student will prepare a 10-page term paper, conforming to the guidelines set forth in the "Term Paper Guidelines" document, in the "Term Papers" folder under the Files folder on the Canvas site. Each student will also prepare an electronic presentation for class on their preliminary findings. Students and the instructor in the course will provide feedback on the paper, including suggestions.

Class Participation

Class participation assessment will be comprised of your participation during class sessions, including participation in statute/cases exercises. Being prepared for class is about more than just showing up, it's also about making sure you've completed the readings, homework, etc. so that you are able to make thoughtful contributions during class. Sitting silently and/or being unprepared can damage your participation grade. When in a virtual class, I expect students to keep their camera and mute on as much as possible. When in the classroom, I expect students to keep their phones off and put away.

Policies

GRADING/ASSESSMENT

All questions and problems regarding grades must be presented in writing within one week after the test, homework, or project has been returned. The grading scale is fixed, please do not wait until the

end of the quarter if you are concerned about the direction of your grade. Grades will be assigned based on all the work you have completed during the semester using the following scale:

A	93.333 to 100	**C**	73.333 to 76.666
A-	90.000 to 93.333	**C-**	70.000 to 73.333
B+	86.666 to 90.000	**D+**	66.666 to 70.000
B	83.333 to 86.666	**D**	63.333 to 66.666
B-	80.000 to 83.333	**D-**	60.000 to 63.333
C+	76.666 to 80.000	**F**	< 60.000

ACADEMIC INTEGRITY

Academic integrity is taken very seriously at Northwestern. Students are responsible for reading and understanding Northwestern's Academic Integrity policies. All suspected violations will be reported to the McCormick College of Engineering's Dean's Office. These include cheating, plagiarism, fabrication, unfair advantage, unauthorized collaboration, and aiding and abetting of academic dishonesty. Students found in violation of academic integrity may receive a zero on the assignment or a failing grade for the course and may be suspended or permanently expelled from the University. See Academic Integrity: A Basic Guide for more information.

In the specific context of plagiarism, please refer to Northwestern's resources on academic integrity for guidance on how to properly use and credit research in your work: http://www.northwestern.edu/provost/policies/academic-integrity/.

Suspected violations of academic integrity will be reported to the Dean's Office. For more information on Northwestern's academic integrity policies, see: http://www.weinberg.northwestern.edu/handbook/integrity/index.html.

ACCESSIBILITY/ACCOMMODATION:

Northwestern University is committed to providing the most accessible learning environment as possible for students with disabilities. Should you anticipate or experience disability-related barriers in the academic setting, please contact AccessibleNU to move forward with the university's

established accommodation process (e: accessiblenu@northwestern.edu; p: 847-467-5530). If you already have established accommodations with AccessibleNU, please let me know as soon as possible, preferably within the first two weeks of the term, so we can work together to implement your disability

Any student requesting accommodations related to a disability or other condition is required to register with AccessibleNU (accessiblenu@northwestern.edu; 847-467-5530) and provide professors with an accommodation notification from AccessibleNU, preferably within the first two weeks of class. All information will remain confidential.

COVID 19 CLASSROOM EXPECTATIONS STATEMENT

Students, faculty, and staff must comply with University expectations regarding appropriate classroom behavior, including those outlined below and in the COVID-19 Code of Conduct. With respect to classroom procedures, this includes:

- Policies regarding masking and social distancing evolve as the public health situation changes. Students are responsible for understanding and complying with current masking, testing, Symptom Tracking, and social distancing requirements.
- In some classes, masking and/or social distancing may be required as a result of an Americans with Disabilities Act (ADA) accommodation for the instructor or a student in the class even when not generally required on campus. In such cases, the instructor will notify the class.
- No food is allowed inside classrooms. Drinks are permitted, but please keep your face covering on and use a straw.
- Faculty may assign seats in some classes to help facilitate contact tracing in the event that a student tests positive for COVID-19. Students must sit in their assigned seats.

If a student fails to comply with the COVID-19 Code of Conduct or other University expectations related to COVID-19, the instructor may ask the student to leave the class. The instructor is asked to report the incident to the Office of Community Standards for additional follow-up.

CLASS RECORDING

This class or portions of this class will be recorded by the instructor for educational purpose and available to the class during the quarter. Your instructor will communicate how you can access the recordings. Portions of the course that contain images, questions or commentary/discussion by students will be edited out of any recordings that are saved beyond the current term.

Unauthorized student recording of classroom or other academic activities (including advising sessions or office hours) is prohibited. Unauthorized recording is unethical and may also be a violation of University policy and state law. Students requesting the use of assistive technology as an accommodation should contact AccessibleNU. Unauthorized use of classroom recordings – including distributing or posting them – is also prohibited. Under the University's Copyright Policy, faculty own the copyright to instructional materials – including those resources created specifically for the purposes of instruction, such as syllabi, lectures and lecture notes, and presentations. Students cannot copy, reproduce, display, or distribute these materials. Students who engage in unauthorized recording, unauthorized use of a recording, or unauthorized distribution of instructional materials will be referred to the appropriate University office for follow-up.

THE WRITING PLACE

When working on writing assignments for this class, I encourage you to visit the Writing Place, Northwestern's peer writing center. You will work with juniors and seniors who have been trained to provide you feedback and assistance on any type of writing at any stage in the writing process. They will not edit your work. Rather, they will work with you to brainstorm ideas, organize or outline an essay, clarify your argument, document your sources correctly, or refine grammar and style.

COURSE SCHEDULE

10.27	Introduction to the Course

- Instructor introduction
- Student introductions
- Review of syllabus
- Lecture/Discussion: The exigency for carbon capture and storage and carbon dioxide removal in climate policymaking

READINGS:

E Bistline & Blanford, *Impact of carbon dioxide removal technologies on deep decarbonization of the electric power sector*, 1 NATURE COMMUNICATIONS 1-12 (2021)

O Warszawski, et al, *All options, not silver bullets, needed to limit global warming to 1.5 ℃: a scenario appraisal*, 16 ENVIRONMENTAL RESEARCH LETTERS, Art. 064037 (2021)

O Climate Crisis Advisory Group, The Final Warning Bell: The Most Important Assessment of Humanity's Future on Earth to Date 1-12 (2021)

O Foley, Opinion: The World Needs Better Climate Pledges, Project Drawdown, June 17, 2021

SECTION 1 CARBON CAPTURE APPROACHES

11.1 Carbon Capture with Utilization and Storage (CCUS): Overview

READINGS:

E Bandilla, *Carbon Capture and Storage,* FUTURE ENERGY 669-692 (3rd ed. 2020)

O Biniek, Driving CO_2 emissions to zero (and beyond) with carbon capture, use, and storage, McKinsey Report, June 2020

11.3 Carbon Capture with Utilization and Storage (CCUS): Legal and Policy Considerations

READINGS:

E Mikunda, et al., *Carbon capture and storage and the sustainable development goals,* 108 INTERNATIONAL JOURNAL OF GREENHOUSE GAS CONTROL, Art. 103318 (2021)

E Wang, et al., *What went wrong? Learning from three decades of carbon capture, utilization and sequestration (CCUS) pilot and demonstration projects*, 158 ENERGY POLICY, Art. No. 112546 (2021)

O Carbon Capture is not a climate solution: Letter by NGO coalition to President Biden, et al., July 19, 2021

O Council on Environmental Quality, Report to Congress on Carbon Capture, Utilization, and Storage 23-37 (2021)

Guest speaker: Matt Bright, Senior Adviser, Advocacy and Communications, Global CCS Institute: https://www.globalccsinstitute.com/about/our-team/matt-bright/

11.8 Mineral Carbonation

READINGS:

E Clark, *CarbFix2: CO2 and H2S mineralization during 3.5 years of continuous injection into basaltic rocks at more than 250°C*, 279 GEOCHIMICA ET COSMOCHIMICA 45-66 (2020)

O Service, Industrial waste can turn planet-warming carbon dioxide into stone, Science, Sept. 3, 2020

O Energy Futures Initiative, Rock Solid: Harnessing Mineralization for Large-Scale Carbon Management 33-40 (2020)

	Guest Speaker: Greg Dipple, Prof. of Geology, Dept. Earth, Ocean and Atmospheric Sciences, The University of British Columbia, Carbon Mineralization in Mine Tailings: a Pathway to Carbon Removal, https://www.eoas.ubc.ca/people/gregdipple
SECTION 2	**"NATURE-BASED" CARBON REMOVAL SOLUTIONS**
11.10	**Afforestation/Reforestation**
	READINGS: E Di Sacco, et al., *Ten golden rules for reforestation to optimize carbon sequestration, biodiversity recovery and livelihood benefits,* GCB REVIEWS 1-21 (2020) E von Hedemann, *Forest policy and management approaches for carbon dioxide removal*, 10 INTERFACE FOCUS 1-16 (2020) **STUDENT GROUP PRESENTATION: SCIENCE-BASED TARGETS INITIATIVE (SBTi) AND FOREST PROTOCOLS**http://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf
11.15	**Soils/Regenerative Agriculture**
	READINGS: E Paustian, *Climate Smart Soils*, 532 NATURE 49-57 (2016) O Evich & Monnay, *In rare bi-partisan move, Senate approves bill to help farmers profit on climate action,* Politico June 24, 2021 E Baveye, *The 4 per 1000 initiative: a credibility issue for the soil science community?*, 309 GEODERMA 118-23 (2018) O Ranganathan, et al., Regenerative Agriculture: Good for Soil Health, but Limited Potential to Mitigate Climate Change, World Resources Institute, May 12, 2020 **Guest Speaker: Radhika Moolgavkar, Head of Methodology, Nori Carbon Removal Marketplace, https://nori.com/about**
SECTION	**Bioenergy and Carbon Capture with Storage (BECCS)**

3	
11.17	**Overview of BECCS**
	READINGS: E Babin, et al. *Potential and challenges of bioenergy with carbon capture storage as a carbon-negative energy source: A Review*, 146 BIOMASS & BIOENERGY, Art. 105968 (2021) E Full, *A New Perspective for Climate Change Mitigation — Introducing Carbon-Negative Hydrogen Production from Biomass with Carbon Capture and Storage (HyBECCS),* 13 SUSTAINABILITY 1-22 (2021) E Burns, *Human Rights Dimensions of Bioenergy With Carbon Capture and Storage: A Framework for Climate Justice in the Realm of Climate Geoengineering*, in CLIMATE JUSTICE: CASE STUDIES IN GLOBAL AND REGIONAL GOVERNANCE CHALLENGES 149-70 (2016) **Student Group Presentation: Algae with Bioenergy Carbon Capture and Storage (ABECCS)**
SECTION 4	**DIRECT AIR CAPTURE**
11.22	**Overview of Direct Air Capture**
	READINGS: E Sabatino, et al., A comparative energy and costs assessment and optimization for direct air capture technologies, 5 Joule 2047-76 (2021) E Jacobson, *The health and climate impacts of carbon capture and direct air capture*, 12 ENERGY ENVIRON. SCI. 3567-74 (2019) **Guest Speaker: Klaus Lackner, Arizona State University & Scientific Advisor, Carbon Collect: https://mechanicaltrees.com/klaus-lackner-phd/**
11.24	**NO CLASS: THANKSGIVING BREAK**
SECTION 5	**ENHANCED MINERAL WEATHERING**
11.29	**Overview and Legal Regulation of Enhanced Mineral**

Weathering

READINGS:

E Beerling, et al., *Farming with crops and rocks to address global climate, food and soil security*, 4 NATURE PLANTS 138-47 (2018)

E Goll, et al., *Potential CO2 removal from enhanced weathering by ecosystem responses to powdered rock,* NATURE GEOSCIENCE 1-4 (2021)

E Lawford-Smith & Currie, *Accelerating the Carbon Cycle: the ethics of enhanced weathering*, 13 Biology Letters, Art. 20160859 (2016)

Guest Speaker, Romany Webb, Senior Fellow and Associate Research Scholar Sabin Center for Climate Change Law Columbia Law School:
https://climate.law.columbia.edu/directory/romany-m-webb

SECTION 6 THE OCEANS AND CARBON DIOXIDE REMOVAL

11.16 Overview of Ocean-Based Approaches

READINGS:

E KELLER, *Marine Climate Engineering*, HANDBOOK ON MARINE ENVIRONMENTAL PROTECTION 261-76 (2018)

E Krause-Jensen, et al., *Sequestration of macroalgal carbon: the elephant in the Blue Carbon room*, 14 BIOLOGY LETTERS, Art. 20180236 (2018)

E Renforth, et al., *Engineering challenges of ocean liming,* 60 ENERGY 442-52 (2013)

11.18 Legal Regulation of Ocean-Based Approaches

READINGS:

E Brent, *Marine geoengineering governance and the importance of compatibility with the law of the sea*, in RESEARCH HANDBOOK ON CLIMATE CHANGE, OCEANS, AND COASTS 442-61 (2021)

E Burns & Corbett, *Antacids for the Sea? Artificial Ocean Alkalinization and Climate Change*, 3 ONE EARTH 154-56 (2020)

E Lezaun, *Hugging the Shore: Tackling Marine Carbon Dioxide Removal as a Local Governance Problem*, 3 FRONTIERS IN CLIMATE, Art. 684063 (2021)

O London Convention, Annex 4, Resolution LP.4(8) on the Amendment to the London Protocol to Regulate the Placement of Matter for Ocean Fertilization and Other Marine Geoengineering Activities (2013)

STUDENT GROUP EXERCISE:

We will engage in a group treaty interpretation exercise, focused on the London Convention, Annex 4, Resolution LP.4(8)

SECTION 7 INCENTIVES TO DRIVE CDR RESEARCH AND DEPLOYMENT

11.23 Policies to Drive CDR

READINGS:

E Nemet, *Negative Emissions – Part 3: Innovation and upscaling,* 13 Environmental Research Letters, Art. No. 063003 (2018)

E Honneger, *Who Is Paying for Carbon Dioxide Removal? Designing Policy Instruments for Mobilizing Negative Emissions Technologies*, 3 FRONTIERS IN CLIMATE, Art. 672996 (2021)

O Stower, Unlocking Blue Carbon Offsets – The problems and solutions for ocean-based carbon removal, Cleantech Group, Aug. 5, 2021

Student Group Presentation: CCS/CDR Support in the U.S. federal budget