CLIMATE GEOENGINEERING

EPC 390, Sec. 25

Winter 2022

2.00-3.20pm

Parkes Hall: 224

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Office hours: by appointment via phone or Zoom

Schedule appointments via Calendly:

- 30-minute phone call: https://calendly.com/wil_burns/30min
- 15-minute phone call: https://calendly.com/wil_burns/15min
- 60-minute Zoom session: https://calendly.com/wil_burns/60min
- 30-minute Zoom session: https://calendly.com/wil_burns/30-minute-zoom-call
- 15-minute Zoom session: https://calendly.com/wil_burns/15-minute-zoom-call

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. Moreover, many believe that we will also need to deploy solar radiation management approaches, which seek to reduce the amount of incoming solar radiation, to buy us time as we decarbonize the world economy.

This course will discuss the exigency of deploying SRM 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 solar radiation geoengineering approaches;
- Understand the technological aspects of various solar radiation management, potential risks and benefits, and constraints to large-scale deployment;
- Understand the technological aspects of carbon capture and storage, potential risks and benefits, and constraints to large-scale deployment;
- Assess the adequacy of current governance mechanisms for SRM and CDR options and identify gaps in governance;
- Assess the ethics and justice implications of SRM and CDR research and/or deployment

Class Contract

I am pretty "old-school" when it comes to how I view higher education. I do not consider students to be atomistic "customers" purchasing a "product," and I am not simply here to be a vendor of a "product." Rather, by enrolling in this course, you and I are entering into a social contract with each other, and with all the other students in the class, to foster an environment of learning and collaboration. Under the "terms" of this contract, it is my responsibility to always be well-prepared for class, responsive to communications outside of class, and to treat every student with fairness and respect. Consistent with this, I will always try to be accessible and try my best to return graded materials after no more than a week. In turn, by enrolling in the class students agree to: (1) attend classes regularly and punctually; (2) participate by asking questions and joining in class discussions; (3) read the assigned material and complete assignments on time; (4) Regularly consult the course Canvas site for updates and materials intended to facilitate class discussion, including current events pertinent to the topics we will discuss in class; (5) comply with class policies established in this syllabus, and (6) uphold Northwestern University's commitment to academic integrity: https://www.northwestern.edu/provost/policies/academic-integrity/

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	**Ongoing**	**30%**
Blog Posts	**March 13 & March 19**	**50%**
Class Participation	**Ongoing**	**20%**

Brief Description of Assignments

Special Topics Presentations [30% of grade]

Students will work in groups of 3-4 to prepare 10-15 minute presentations for class on assigned topics. Please see the "Assignment Guidelines/Resources " folder under the Files folder for further instructions.

Blog Post [50% of grade]

Each student will draft a blog post for potential publication in Northwestern's new blog on Medium website: "Scrubbing the Skies: Carbon Dioxide Removal and Climate Change." Please consult the "Blog Posting Assignment" subfolder under the Assignment Guidelines/Resources folder for guidelines in completing the assignment.

Class Participation [20% of grade]

Class participation assessment will be comprised of your participation during lectures, including responses to treaty-interpretation questions.

Policies

GRADING:

All grades will ultimately be scaled to a 100-point system: A (94-100); A- (90-93); B+ (87-89); B (83-86); B- (80-82); C+ (77-79); C (73-76); C- (70-72); D (60-69); F (<60).

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.

ACCOMMODATION:

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 (**by January 17-20**). All information will remain confidential.

	COURSE SCHEDULE
1.5	**Introduction to the Course**
Synchronous Online Class Session	▪ Instructor introduction ▪ Student introductions ▪ Review of syllabus

SECTION 1	**OVERVIEW OF CLIMATE SCIENCE**
1.10 **Synchronous Online Class Session**	**The Science of Climate Change & The Rationale for Climate Geoengineering** **READINGS:** O IPCC, AR6 Climate Change 2021: The Physical Science Basis 7-35 (2021)
SECTION 2	**Solar Radiation Management Approaches**
1.12 **Synchronous Online Class Session**	**Sulfur Aerosol Injection (SAI)/Marine Cloud Brightening, Part 1** **READINGS:** E U.S. National Academies of Sciences, *Climate Intervention: Reflecting Sunlight to Cool Earth* 66-90 (2015) E MacMartin, et al., *Geoengineering with stratospheric aerosols: What do we not know after a decade of research*?, 4 EARTH'S FUTURE 543-48 (2016) E Morton, *Climate Crunch: Great White Hope,* 458 NATURE 1097-1100 (2009) **STUDENT PRESENTATION:** ▪ **Topic: Cirrus Cloud Thinning** ○ Agalar ○ Zhou ○ Milfred
1.17	**NO CLASS** ▪ **OBSERVANCE OF MARTIN LUTHER KING DAY**
1.19 **Live Class Session**	**Sulfur Aerosol Injection/Marine Cloud Brightening, Part 2: The Role of Legal Institutions** **READINGS:**

	O Marie-Valentine-Florin, Using stratospheric aerosol injection to alleviate global warming: when?, EPFL, Dec. 16, 2021 O Text of the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (1976) and its Understandings **STUDENT LEARNING EXERCISE:** Please have access to **Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques Treaty Interpretation Exercise, and its Understandings,** which can be found in the "Treaty Interpretation Exercises" subfolder, under the Assignment Guidelines folder, under the Files tab, or via the links above.
1.24 **Live Class Session**	**Sulfur Aerosol Injection, Part 3: The Role of Legal Institutions** **READINGS:** E Biermann, et al., Solar geoengineering: The case for an international non-use agreement, WIRES Climate Change, e754 (2022) E Reynolds, *Why the UNFCCC and CBD Should Refrain from Regulating Solar Climate Engineering*, Geoengineering Our Climate? 137-42 (2019) O Burns, Climate Geoengineering: Solar Radiation Management and its Implications for Intergenerational Equity, 4 STANFORD JOURNAL OF LAW, SCIENCE & POLICY (2011) **STUDENT PRESENTATION:** **Topic: Space-Based Solar Radiation Management ("space mirrors"):** ○ Ahmad ○ Steck ○ Jameson
1.26 **Synchronous Online Class Session**	**Ethics and Justice Considerations: SRM Options** **READINGS:** E Stephens, et al., *The Dangers of Mainstreaming Solar Geoengineering: A critique of the National Academies Report*, ENVIRONMENTAL POLITICS 1-10 (2021) E Pamplany, *The Ethical Desirability of Geoengineering: Challenges to Justice*, BIOETHICS 1-11 (2020) O Parson, Geoengineering: Symmetric Precaution, 374 SCIENCE 795 (2021)

	Guest Speaker: Edward Parson, Dan and Rae Emmett Professor of Environmental Law, Faculty Co-Director, Emmett Institute on Climate Change and the Environment, UCLA School of Law.
SECTION 3	**Carbon Dioxide Removal Approaches**
1.31	**"Nature-Based" Climate Solutions: Forests**
Live Class Session	**READINGS:** E Bastin, *The global tree restoration potential*, 365 NATURE 76-9 (2019) E Waring, et al., *Forests and Decarbonization – Role of Natural and Planted Forests*, 3 FRONTIERS IN FORESTS & GLOBAL CHANGE 1-6 (2020) E Fagan, et al., *How feasible are global forest restoration commitments?,* 13 CONSERVATION LETTERS 1-8 (2020) E Bond, et al., *The Trouble with Trees: Afforestation Plans for Africa*, 34 TRENDS IN ECOLOGY & EVOLUTION 963-65 (2019) O Burns, Seeing the Forest for the Trees?: The Role of Afforestation and Reforestation in Combating Climate Change, ABA, Environment, Energy, & Resources, Jan. 14, 2021 **STUDENT PRESENTATION:** ▪ **Topic: The Potential Role of Agroforestry in Carbon Sequestration** ○ Alkio ○ Chen ○ Echtman
2.2	**"Nature-Based" Climate Solutions: Soils**
Live Class Session	**READINGS:** E Rumpel, et al., *Put more carbon in soils to meet Paris climate pledges,* 564 NATURE 32-4 (2018) E Bai, et al., *Responses of soil carbon sequestration to climate-smart agriculture practices: A meta-analysis*, 25(8) GLOBAL CHANGE BIOLOGY 2591-2606 (2019) O Evich & Monnay, *In rare bi-partisan move, Senate approves bill to help farmers profit on climate action,* Politico June 24, 2021 **STUDENT PRESENTATION:** ▪ **Topic: Biochar and Carbon Sequestration**

	○ de Boor ○ Downing ○ Kennedy
2.7 **Live Class Session**	**Bioenergy and Carbon Capture with Sequestration (BECCS): Overview** **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 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) O Tesfaye, Towards meaningful deployment of BECCS, Carbon180, Oct. 8, 2021 **STUDENT PRESENTATIONS:** ▪ **Topic: Algae with Bioenergy Carbon Capture and Storage (ABECCS)** ○ Greenfield ○ Kritikos ○ Sissel
2.9 **Live Class Session**	**Carbon Capture, 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
2.14 **Live Class Session**	**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)

	O Kunsnetz, Occidental is Eyeing California's Clean Fuels Market to Fund Texas Carbon Removal Plant, Inside Climate News, Apr. 6, 2022 **STUDENT PRESENTATION:** ▪ **Topic: The Climeworks Orca Facility** ○ Lebovitz ○ Olson ○ Miyamoto-Kim
2.16 **Synchronous Online Session**	**Carbon Mineralization** **READINGS:** O Carbon Dioxide Removal: Mineralization, Carbon Now.(video) 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, Department of 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**
2.21 **Live Class Session**	**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)
2.23 **Synchronous Class Session**	**The Oceans and CDR, Part 1: Overview** **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)

Guest Speaker: Dr. Grace Andrews, VP, Scientific Research, Project Vesta, Repurposing a paradigm: Coastal Enhanced Weathering as an emerging Negative Emission Technology, https://www.vesta.earth/the-project#Team

STUDENT PRESENTATIONS:

- **Topic: Electrochemical Ocean CDR**
  - Lifford
  - Casanova-Alaimo
  - Pollack

2.28 Live Class Session

The Oceans and CDR, Part 2: Legal Regulation of Ocean-Based CDR 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)

STUDENT GROUP EXERCISE:

We will engage in a group treaty interpretation exercise, focused on several marine treaties potentially pertinent to ocean-based carbon removal. You can find those instruments in the Module for this class session and in the "Assignment Guidelines/Resources" folder under the Files tab.

3.2

INCENTIVES TO DRIVE CDR RESEARCH AND DEPLOYMENT

READINGS:

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

	E Honegger, *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, and U.S. DOE's Carbon Negative Shot:** ○ Popat ○ Sparks ○ Tolbert ○ Lee
3.7 **Synchronous Online Class Session**	**Some Parting Thoughts: Roundtable Panel** ▪ Radhika Moolgavkar, Head of Methodology, Nori Carbon Removal Marketplace, https://nori.com/about ▪ Tom Green, Chief Executive Officer, Project Vesta, https://www.vesta.earth/the-project#Team ▪ Simon Nicholson, Director, Institute for Carbon Removal Law & Policy, American University, https://www.american.edu/sis/faculty/snichols.cfm **Moderator: Wil Burns**
3.13	**Submission of Medium Blog Posts** ▪ I will review all submissions, and suggest edits within two days. Re-submission must occur by 3.19.