Yale Center for Natural Carbon Capture

2022 Fiscal Year Report

A Letter from the Center Directors

To our corporate partners:

We are delighted to reflect on the growth and accomplishments of the Yale Center for Natural Carbon Capture during its inaugural year. We would not be where we are now without the transformative vision of Fred Smith and the unwavering support of the FedEx Corporation, as well as generous investments from Southwest Airlines and The Boeing Company. It has been our honor to embark on this journey over the past year and nothing short of inspirational to see the Yale community gather to help meet the existential challenge of climate change. The Yale Center for Natural Carbon Capture is the flagship institute of Yale's Planetary Solutions Project, which is a campus-wide initiative designed to address complex environmental crises such as climate change and biodiversity loss. As we all know, climate change is a challenge of global dimensions. The fundamental mission of the Center is to provide scientific innovation informed by natural processes – in essence, to work with the Earth's largest carbon cycles in forests, in rocks, and in the oceans to capture and sequester carbon at massive scale. By harnessing natural systems, we further seek co-benefits such as improved health of forests, soils, and wetlands, deacidification of the ocean, and recovery of coral reefs. It will take rigorous and dedicated work across Yale and other universities, corporations big and small, as well as government agencies and non-governmental organizations, to address this imminent threat to humanity and the environment.

It is our privilege to share this first annual report summarizing what has been accomplished this past year. We are especially excited to provide updates on the research and activities you have already supported, and by the promise of further exploration with the hiring of four additional faculty members. We greatly look forward to your comments, feedback, and ideas for the future.

Sincerely,

Dave Bercovici & Liza Comita

Co-Directors, Yale Center for Natural Carbon Capture

"Climate change is a defining issue of our time. The vast challenges it poses can only be addressed through innovative, multidisciplinary collaboration. We are fortunate to have deep expertise in many of the relevant fields at Yale, and we are grateful that FedEx is helping amplify the scale and impact of this work. We are proud to be building powerful solutions for our planet."

—

Scott Strobel, Yale University Provost

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Front page image credit: Stas Kulesh - Unsplash

View of the landscape mosaic surrounding the Sinharaja Man and Biosphere Reserve, Sri Lanka; Photo by Luke Sanford

Preface

Since its launch in May 2021 with a transformative gift from the FedEx Corporation, the Yale Center for Natural Carbon Capture has made remarkable progress in establishing the programs, administrative support structures, and institutional frameworks needed to identify socially, economically, and environmentally sustainable strategies for natural carbon capture. Additional generous investments from Southwest Airlines and The Boeing Company have positioned the Center to leverage interdisciplinary research efforts and talented investigators to study natural climate solutions. In doing so, Yale has joined a community of universities, institutes, and industry and government laboratories committed to dramatically reducing greenhouse gas concentrations in the atmosphere. The Center is strategically positioned within Yale to execute its collaborative research agenda and establish a network of experts across departments and schools.

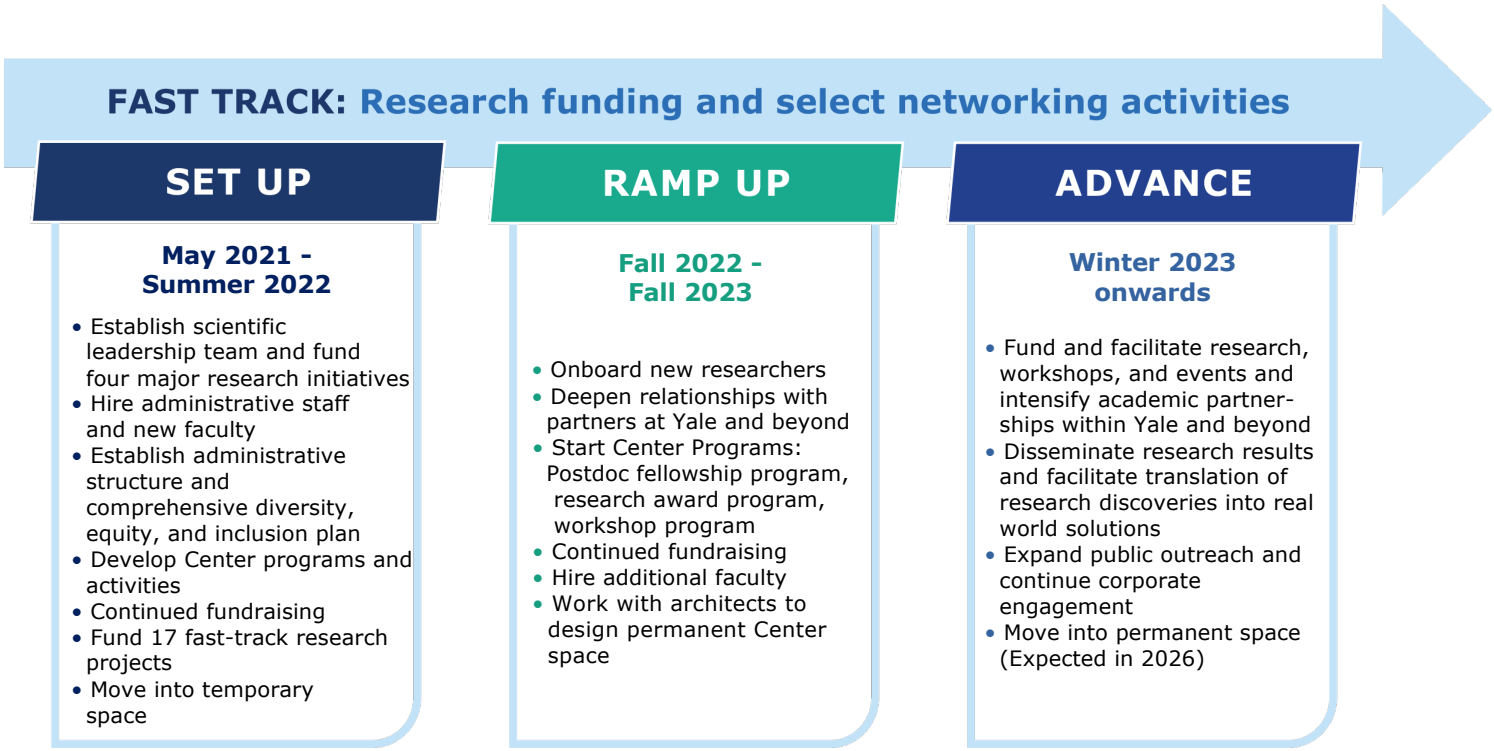
We are grateful for the opportunity to update our corporate partners on the Center's meaningful progress toward identifying short-term, long-term, and ongoing strategies for reducing net greenhouse gas emissions through natural carbon capture. This progress report outlines the Center's growth in the Set Up Phase, which extends through summer 2022. The Report starts by providing descriptions of the Center's administrative structure, fundraising efforts, and events aimed at bringing together academic and industry stakeholders, followed by a list of the major research projects that have been initiated with fast-track funding and then ends with a brief overview of the main challenges related to implementing and scaling up climate solutions, which we will address going forward.

Set-up Phase: Structure, Administration, and More

The Yale Center for Natural Carbon Capture has made remarkable progress in its Set Up Phase, which extended from its inception in May 2021 through the summer of 2022. Our main goals for this phase were to set up the administrative structure for the Center, hire staff, develop the core Center programs, identify high-impact research projects led by current Yale faculty for fast-track funding, conduct a search for four new faculty to fill the endowed professorships in carbon capture and climate solutions, and continue our fundraising efforts. In implementing these steps, we have been guided by our diversity, equity, and inclusion plan to ensure that we attract and recruit top scientists conducting cutting-edge research that will result in scalable climate solutions.

Additionally, the Center has organized, sponsored, and hosted a variety of events, including small gatherings to connect researchers from different fields and departments, a series of 15 in-depth scientific talks by leading experts in the field through the faculty interview process, and the first annual Spring Symposium featuring discussions between industry and academia.

The following sections highlight the progress the Center has made in its first year and how this momentum will be carried through the next phase, when operations will ramp up and all programs will be up and running.



LEADERSHIP

The leadership for the Yale Center for Natural Carbon Capture consists of FOUR COMPONENTS:

1. Two Faculty Co-Directors

LIZA COMITA
DAVE BERCOVICI

- Set research agenda
- Determine hiring and recruiting needs
- Oversee Center programs and activities

2. Managing Director

ANNA SCHUERKMANN

- Set up and implement center programs
- Establish and maintain administrative structure
- Manage day-to-day activities

3. Scientific Leadership Team

MARK ASHTON
MARK BRADFORD
NILAY HAZARI
NOAH PLANAVSKY
PETE RAYMOND
MARY-LOUISE TIMMERMANS
JULIE ZIMMERMAN

- Serve as advisors to faculty co-directors
- Head major research themes
- Provide a direct connection to departments and schools across campus

4. Steering Committee

JEFF BROCK
GARY BRUDVIG
INDY BURKE
MICHAEL CRAIR
ROBERT DUBROW
AMY FERRARO
MAUREEN LONG
WILLIAM NORDHAUS
CARLA STAVER
GERALD TORRES

- Provide guidance on Center strategies and initiatives
- Help steward Center resources
- Receive updates on plans and progress

Liza Comita, Professor of Tropical Forest Ecology at Yale School of the Environment, and Dave Bercovici, Frederick William Beinecke Professor of Earth & Planetary Sciences, were appointed in May 2021 as the inaugural faculty co-directors at the Yale Center for Natural Carbon Capture. They will serve an initial three-year term.

Anna Schuerkmann was hired as the full-time managing director of the Center in February 2022. She brings expertise in science management and has a background in Geoecology.

The scientific leadership team is composed of faculty members from Yale School of the Environment and the Yale School of Engineering and Applied Science, as well as the Department of Earth and Planetary Science and Department of Chemistry in the Faculty of Arts and Sciences. This group of advisors provides the range of expertise and varied experiences and perspectives that are crucial to successfully implementing the Center's interdisciplinary research agenda.

The steering committee is co-chaired by Indy Burke, Dean of the School of the Environment, and Jeff Brock, Dean of the School of Engineering & Applied Science. The committee is composed of high-level university leaders from across campus, including representatives from the provost's office, School of Law, School of Public Health, Yale Energy Sciences Institute, Yale Institute for Biospheric Studies, Yale Center on Climate Change and Health, and the Faculty of Arts and Sciences. The steering committee provides high-level feedback on strategic planning for the Center and interfaces with internal and external stakeholders.

View of Osborn Memorial Laboratory including the Kroon Hall courtyard

Staff

The Yale Center for Natural Carbon Capture has several staff that are either directly employed and funded by the Center or that are members of Yale University's administrative staff and appointed to support Center activities.

STAFF

Core Center Staff

Senior Administrative Assistant
KAT GAYNOR

- Coordinates schedules and meetings
- Organizes logistics for Center events
- Joined in August 2021

University Assigned Staff

Outreach and Corporate Engagement Officer
LAUREN HUNT

- Manages corporate partnerships and engagement activities
- Joined in February 2022

Lead Administrator
HARLEY PRETTY
Prev. Darlene Jones

- Oversees Center finances, budgeting, and spending
- Ensures compliance with university guidelines
- Joined in May 2021

Operations Manager
NEW POSITION

- Provides financial and administrative support to Center Directors and the Lead Administrator
- Expected start: Fall 2022

Faculty Search

The generous gift from the FedEx Corporation to establish the Yale Center for Natural Carbon Capture included funding for four new endowed faculty positions to expand the breadth and depth of relevant scientific expertise on campus. These endowed faculty members will develop and lead major research projects funded by the Center and will serve on the Center's Scientific Leadership Team. The new faculty members will be housed within different units at Yale: one position each within the Departments of Ecology and Evolutionary Biology and Earth and Planetary Sciences, and two positions within Yale School of the Environment. The Yale Center for Natural Carbon Capture headed a cluster faculty search from Fall 2021 – Summer 2022, involving search committees at the Center and each of the involved academic units.

FACULTY SEARCH COMMITTEES

Center for Natural Carbon Capture

DAVID BERCOVICI
Co-Director Yale Center for Natural Carbon Capture; Committee Co-Chair, Professor, Department for Earth and Planetary Sciences

LIZA COMITA
Co-Director Yale Center for Natural Carbon Capture; Committee Co-Chair; Committee Diversity Officer, Professor, Yale School of the Environment

MARK BRADFORD
Professor, Yale School of the Environment

ERIKA EDWARDS
Professor, Department for Ecology and Evolutionary Biology

NOAH PLANAVSKY
Associate Professor, Department for Earth and Planetary Sciences

PETER RAYMOND
Professor, Yale School of the Environment

CARLA STAVER
Associate Professor, Department for Ecology and Evolutionary Biology

MARY-LOUISE TIMMERMANS
Professor, Department for Earth and Planetary Sciences

Department for Earth Planetary Sciences

NOAH PLANAVSKY
Committee Chair, Associate Professor

PINCELLI HULL
Committee Diversity Officer, Assistant Professor

JUAN LORA Assistant Professor

PETER RAYMOND, Professor

Ecology and Evolutionary Biology

CARLA STAVER
Committee Chair, Associate Professor

DAVID VASSEUR
Committee Diversity Officer, Professor

MARTHA MUÑOZ Assistant Professor

Yale School of the Environment

MARK BRADFORD
Committee Co-Chair & Diversity Officer, Professor

PETER RAYMOND Committee Co-Chair, Professor,

YUAN YAO Assistant Professor

CRAIG BRODERSEN Professor

JAMES SAIERS Professor

We received a total of 181 applications, of which 15 of the most promising candidates whose research and expertise were aligned with the mission of the Center were invited for remote interviews in March and April 2022. The candidates' research spanned diverse research areas ranging from the fundamental science of carbon capture in oceans, minerals, rocks, to mathematical modeling, field measurements, and lab studies of ecological and biological carbon capture.

Faculty interviews consisted of:

- A one-hour scientific presentation of past research, which was open to the entire Yale community
- A one-hour scientific presentation on future research plans, including how such plans would advance the Yale Center for Natural Carbon Capture's mission, and followed by a Q&A session with current Yale faculty from relevant departments/schools
- Individual interviews with search committee members and other YCNCCC-affiliated faculty (typically 10 to 15 meetings across two days)

After all interviews were complete, the full faculty of each department/school agreed on their top candidate, and that list was approved by the Center search committee and relevant Dean and Provost's office. The four final candidates received offers and were invited for in-person visits to campus in June and July 2022. Two of the four candidates have officially accepted their offers and we are in final discussions with the remaining two candidates about accepting their Yale appointments.

Dave Bercovici presenting on the global carbon cycle during the Yale Center for Natural Carbon Capture's Spring Symposium

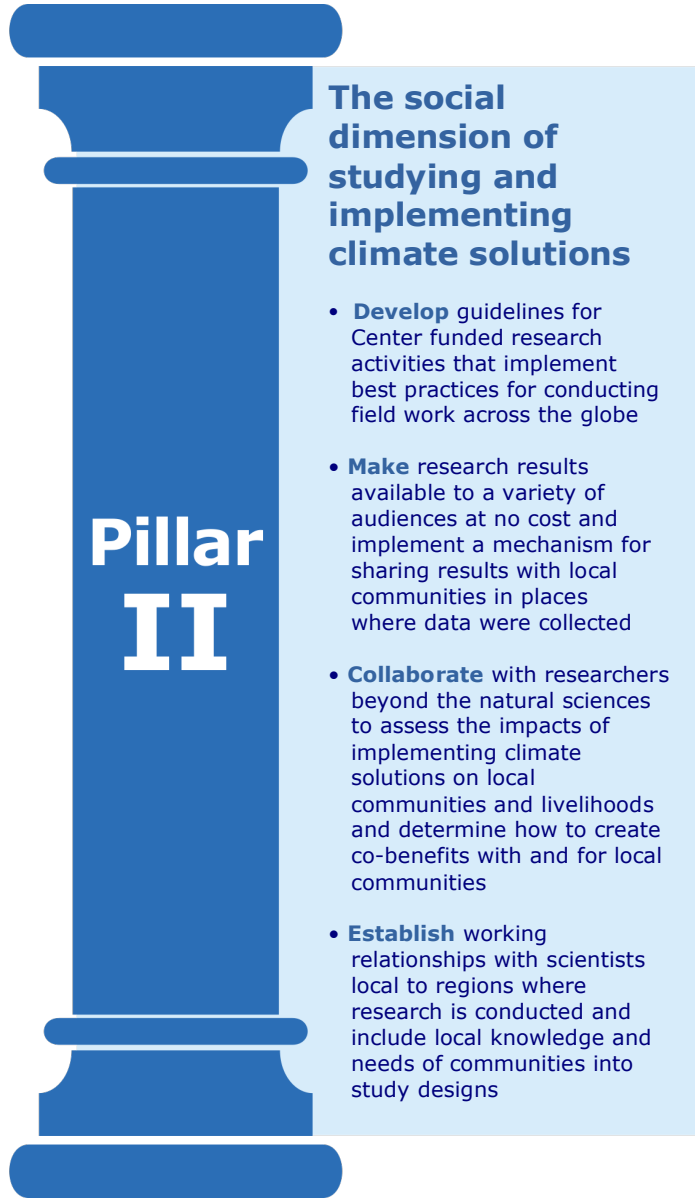
Diversity, Equity, and Inclusion: Plan and Implementation

At the Yale Center for Natural Carbon Capture, we believe that innovative climate solutions are the culmination of diverse perspectives from individuals of different races, ethnicities, genders, nationalities, socioeconomic status, career stages, and other characteristics.

To foster an environment that attracts talented researchers and allows all members to thrive, we have established a two-pillared strategy addressing diversity, equity, and inclusion. The first pillar involves creating and maintaining an inclusive and equitable work environment and attracting a diverse group of candidates across students, faculty, and staff. The second pillar focuses on understanding and addressing the social dimensions and real-world implications of research on and implementation of potential climate solutions.

An inclusive and equitable work environment

- **Develop** Center programs and activities that follow current best practices for increasing diversity, fostering equality, and building an inclusive environment
- **Create** transparent documentation for each program and activity and make information available to Center members for reference and feedback
- **Implement** inclusive decision-making for Center-related matters by including researchers and staff across relevant departments and career stages
- **Establish** open and welcoming lines of communication among Center members and implement clear processes and support structures for conflict resolution
- **Ensure** that all seminars, symposia, and Center events are accessible to all individuals, including those of different abilities and disabilities
- **Follow** current best practices for attracting diverse candidates for fellowships and research funding, such as carefully selecting where and how to advertise open positions
- **Leverage** existing efforts at Yale University for Fostering a diverse and inclusive work environment and solicit input and feedback on Center policies and procedures from experts across campus



The social dimension of studying and implementing climate solutions

- **Develop** guidelines for Center funded research activities that implement best practices for conducting field work across the globe
- **Make** research results available to a variety of audiences at no cost and implement a mechanism for sharing results with local communities in places where data were collected
- **Collaborate** with researchers beyond the natural sciences to assess the impacts of implementing climate solutions on local communities and livelihoods and determine how to create co-benefits with and for local communities
- **Establish** working relationships with scientists local to regions where research is conducted and include local knowledge and needs of communities into study designs

Space

A substantial amount of the initial funding for the Yale Center for Natural Carbon Capture will be dedicated to renovating the space that will permanently house the Center starting in 2026. The Center's location in the Osborn Memorial Laboratory building was chosen by University and Center leadership to strategically position the Center in a location that is conducive to fostering cooperation and collaboration across units at Yale University. The building is located at the southern end of Yale University's Science Hill and is near other relevant units such as the School of Engineering & Applied Sciences, the Carbon Containment Lab, and Yale Ventures. The current, temporary Center space is located at the Kline Geology Laboratories, home of the Department of Earth and Planetary Sciences, and provides office and meeting space to Center staff and incoming researchers. The map below shows the location of relevant areas of Yale University's campus.

The objective for the renovation is to create a new space that reflects the Center's interdisciplinary mission by creating a welcoming atmosphere and providing space for work and casual interactions. The Center will be one of several units housed at the building, and will include shared offices, dedicated rooms for large and small meetings and workshops, laboratories, classrooms, faculty offices, and study spaces for students.

Osborn Memerial Laboratora at 165 Sacehm St, New Haven

CAMPUS MAP

The Yale Center for Natural Carbon Capture is temporarily housed at Kline Geology Laboratory (**A**)

The Center's permanent location will be at Osborn Memorial Laboratories (**B**)

Academic units and Centers we work with:

Department of Earth and Planetary Sciences (**A**)

Department of Ecology and Evolutionary Biology (**B**)

School of the Environment, Kroon Hall (**C**)

Yale Program for Climate Change Communication (**D**)

Yale Advanced Science Synthesis Program (**E**)

Environmental Training and Leadership Initiative (**F**)

Center for Green Chemistry & Green Engineering at Yale (**G**)

Environmental Science Center (**I**)

School of Engineering & Applied Science (**J**)

Center for Innovative Thinking at Yale (**K**)

Carbon Containment Lab (**L**)

Yale Ventures (**M**)

Department of Chemistry (**N**)

Fundraising

The Yale Center for Natural Carbon Capture has raised $120 million of its $150 million fundraising goal – this includes a $100 million gift from the FedEx Corporation, a $10 million gift from The Boeing Company, and a $10 million gift from Southwest Airlines. Additional fundraising efforts are ongoing.

A managed wetland at Yale-Myers Forest includes cattail and sedge groupings, whose poor drainage and slow decomposition makes them ideal carbon sinks.

Programs and Activities

Since the Center's inception in May 2021, we have been working to design and establish a series of core programs and activities that will be integral to achieving the Center's goal of advancing natural climate solutions. These include a research award program to foster novel research ideas and provide critical support for new scientific studies and a postdoctoral fellowship program that will attract early-career researchers working at the forefront of carbon capture science. We will also convene leading scientists from around the globe to share knowledge, establish new collaborations, and drive innovation in climate science by providing funding and logistical support for workshops.

In addition, through our outreach and engagement activities, as well as events held at Yale University, we will work to ensure that the most recent research findings are shared not only within the scientific community, but also with practitioners on the ground, decision makers at local to global levels, and corporate partners. Each program is currently at a different stage, but all programs will be fully implemented by summer of 2023. Programs will run on a regular schedule and provide a reliable source of support for natural carbon capture research at Yale University and beyond.

Postdoctoral Fellowship Program

Early-career researchers often have novel, innovative, and potentially high impact ideas, but require funding, dedicated mentorship, and networking opportunities for turning those ideas into successful scientific studies. Together with administrators and with feedback from faculty of various relevant departments, we developed a postdoctoral fellowship program that launched in September 2022. The program is designed to recruit promising junior researchers, connect them with resources and senior scientists at Yale University and beyond, and support them in conducting their pioneering research. The program is open to candidates from any discipline that have received their PhD within the past 5 years, propose research aligned with the Center's mission, and can identify a faculty advisor with relevant expertise to provide mentorship and access to research infrastructure. The Center will award up to three fellowships each year, each for a two-year term.

Fellows will have access to:

- Office space at the Yale Center for Natural Carbon Capture, shared with other YCNCC postdocs
- Research facilities, such as lab space, field sites, equipment, and instruments
- Professional development opportunities, such as training in writing for different audiences, project management, and other skills that are relevant to careers in the public and private sectors

The administrative structures and Center internal guidelines for the fellowship program have been established, and we are ready for first round of applications and candidates. The program will follow the same schedule each year with the goal of becoming a reliable and well-known resource for early-career scientists whose research will advance the Center mission of climate change mitigation.

Research Award Program

Funding research studies is one of the most direct tools for advancing the Center's mission and research agenda and therefore one of the components that were prioritized at the Center's inception. The research award program has followed a twofold strategy during the Set Up Phase of the Center:

I. Two rounds of fast-track research funding to immediately facilitate carbon capture science at Yale University

II. Creation of an annual research award program inviting applications from researchers across Yale University with the goal to fund innovative pilot studies, producing results that can support applications for follow-on funding from other sources

The first round of fast-track research funding was released in summer 2021 and supports four major research projects led by researchers in the Department of Earth and Planetary Science and Yale School of the Environment. The second round of fast-track funding, which was released in July 2022, funds 17 research projects, nine pilot grants of up to $100,000 and eight large grants of up to $300,000. Pilot grants support cutting-edge research projects that require preliminary data before they are eligible for follow-on funding from federal agencies and/or private foundations. Large grants are awarded to collaborative research initiatives, preferably across groups and departments, that aim to enable novel, interdisciplinary research. Detailed project descriptions and progress reports are included in the section "Research Projects and Updates".

Workshop Program

Workshops serve as a crucial part of the scientific process by enabling training in novel methods or skills, providing space and time for focused collaborative work by top experts in the field, or introducing researchers to fresh perspectives. The Center will support the organization of workshops to foster continued skill development and collaboration between units at Yale University and with researchers from other institutions. The Workshop program will be open to the entire Yale community as long as the workshop topic is relevant to and advances the Center's mission.

The Workshop program will be announced by spring 2023.

Outreach and Engagement

The Yale Center for Natural Carbon Capture dedicates effort and resources to developing, updating, and disseminating up to date information related to climate change and natural carbon capture. Currently this happens in two ways: through direct interaction with our corporate partners and by working with the Environmental Leadership and Training Initiative at Yale School of the Environment.

Corporate engagement: activities with our donors

The exceptional commitment from FedEx Corporation, The Boeing Company, and Southwest Airlines has opened the unique opportunity for direct engagement between academic experts and industry leaders. At the Center, we value the opportunity to learn directly about the perspectives of corporate leadership and to explore how we can work together to advance meaningful climate solutions. With this understanding, our scientists are able to share educational and informational materials for corporate audiences.

During the Center's first year we engaged the corporate roundtable on campus:

- On October 28, 2021, we held the first Yale Center for Natural Carbon Capture Corporate Roundtable Meeting via Zoom. Eleven Yale University faculty members participated in the meeting. The meeting included presentations on current research streams at the Center, an overview of the Center vision, and a roundtable discussion.
- On May 3, 2022, we held the first in person Corporate Roundtable Meeting at Yale University. The meeting was attended by twelve members from FedEx Corporation, Southwest Airlines, and The Boeing Company and included eight members of the Center's scientific leadership team who gave insights into ongoing research at the Center and participated in the roundtable discussion. Our corporate partners were invited to join the preceding public symposium which featured a panel discussion with Dean Indy Burke (Yale University), Stacey Malphurs (Southwest Airlines), Mitch Jackson (FedEx Corporation), and Sheila Remes (The Boeing Company). The symposium brought in about fifty attendees from the Yale community at the symposium, and over one hundred remote participants for the panel discussion.

Training

The Yale Center for Natural Carbon Capture works with the Environmental Leadership and Training Initiative, ELTI, to develop educational materials about carbon capture and carbon credits for practitioners. ELTI has over a decade of experience in developing training and certification programs for practitioners such as landowners, farmers, policy makers, etc. The Initiative is part of Yale's School of the Environment and has a wide network of experts who frequently contribute information and content to their training modules. Over the past year the Environmental Training and Leadership Initiative has worked on several levels towards developing training materials that directly relate to the mission on the Yale Center for Natural Carbon Capture:

- **Two new video lectures** for a new module on climate change and carbon in ELTI's year-long Tropical Forest Landscapes certificate program. The certificate program has a diverse audience of 74 people working on conservation and restoration in different capacities worldwide, including participants from governments, NGOs, aid agencies, business, and academia). While the immediate use of the content has been for the certificate program, the recording will be used for other courses, such as a MOOC-style course, or materials for a corporate focused audience:
    - **Climate, carbon, and capture – David Bercovici**: The lecture provides foundational concepts and science on climate, carbon storage, and climate change as a baseline for our participants to consider as they develop restoration and conservation strategies that contribute to carbon sequestration.
    - **Forests and carbon markets: what conservation practitioners need to know – Frances Seymour:** The lecture discusses the foundations of carbon markets, including demand and supply-side risks and the different types of carbon credits available.
- **Initial market exploration for a new course targeting buyers of carbon credits**. ELTI conducted research on training opportunities for carbon credit buyers and interviewed individuals working with relevant organizations. Preliminary findings suggest that there is demand for such a course. ELTI is developing initial course outlines and scaling up the market research with a survey.
- **Multiple internal planning and strategy sessions** involving Center leadership and ELTI director, Eva Garen, to discuss key objectives and goals as they relate to ELTI's activities around carbon capture and climate change.

Practitioners in the field as part of a training program by the Environmental Leadership and Training Initiative

Events at Yale University

The Yale Center for Natural Carbon Capture organized and hosted several seminars and a symposium at Yale University during its first year. Those events were tailored towards the Yale community and provided a platform for bringing in external experts from both academia and industry.

- On October 15, 2021, the Center's co-directors Profs. Comita and Bercovici gave a presentation to the Yale community as part of the Yale Institute for Biospheric Studies weekly seminar series. They laid out the vision for the Center, described how they planned to implement the Center's research agenda, and invited the audience to give feedback and apply for upcoming funding opportunities.
- In March and April 2022, the Center hosted a series of seminars by 15 experts in the field of natural climate solutions and carbon capture that were short listed candidates for the open YCNCC faculty positions ([*]). Talks were open to the entire Yale community and were attended by faculty, students, and staff.
    - *"Microbial drivers of large-scale carbon dynamics: deciphering the role and contributions of microbes, geochemistry, and vegetation in novel Amazon peatlands"*
    - *"Leveraging remote sensing to understand forests in a changing world"*
    - *"Carbon in context: Understanding the soil environment to manage the terrestrial carbon cycle"*
    - *"A journey in carbon cycle science: from plots to the global scale"*
    - *"A thirsty future: Will tropical forests survive with more droughts?"*
    - *"Natural-based solutions: Managing ecosystems for a resilient future"*
    - *"Informing nature-based climate solutions with the best available science"*
    - *"From minerals to macrosystems: Understanding soil carbon cycling across scales"*
    - *"Soil - plant - atmosphere interactions: structure, function, and predictive scaling for climate change mitigation"*
    - *"Evaluating sustainable solutions in climate change and conservation"*
    - *"Electrochemical ocean alkalinity enhancement and its role in a balanced portfolio of natural carbon capture solutions"*
    - *"Geochemical carbon dioxide removal"*
    - *"Understanding combined climate change and variability impacts on global ocean chemistry and ecology"*
    - *"Submarine basalt carbonation as a gigaton-per-year scale climate solution"*
- The first annual Yale Center for Natural Carbon Capture Spring Symposium was held on May 2, 2022. The symposium's theme was "Perspectives from Industry and Academia" and featured a panel discussion with Mitch Jackson, Chief Sustainability Officer at FedEx Corporation, Stacy Malphurs, Vice President Supply Chain Management & Environmental Sustainability at Southwest Airlines, and Sheila Remes, Vice President of Environmental Sustainability at The Boeing Company. The discussion was moderated by Indy Burke, Dean of Yale School of the Environment. After the panel discussion, participants convened in discussion groups around the three focus areas: Ecological & Biological Capture, Geological & Ocean Capture, Industrial Carbon Utilization. Each discussion was led by a faculty member with subject matter expertise and was open to the Yale community and invited guests.

[*] Names of candidates are not included because many candidates have asked for confidentiality about their application.

Researchers in the Hazari Group focus on chemical catalysis (photo curtesy of Prof Hazari)

Research Projects and Updates

This section gives an update on each project that was funded with the first round of fast-track funding that was disbursed in Summer 2021 and the second round of funding in 2022. Strategies for increasing the uptake of atmospheric carbon fall into three major categories: ecological & biological capture, geological & ocean capture, and industrial carbon utilization. Because a combination of these approaches is likely necessary for reducing atmospheric greenhouse gas concentrations in the coming decades, the Yale Center for Natural Carbon Capture is working to develop strategies across all three categories.

Pilot grants support cutting-edge research projects that require preliminary data before they are eligible for follow-on funding from federal agencies and/or private foundations. Large grants are awarded to collaborative research initiatives, preferably across research groups and departments, that aim to enable novel, interdisciplinary research.

Initiatives funded in 2021

Yale Applied Science Synthesis Program (YASSP)

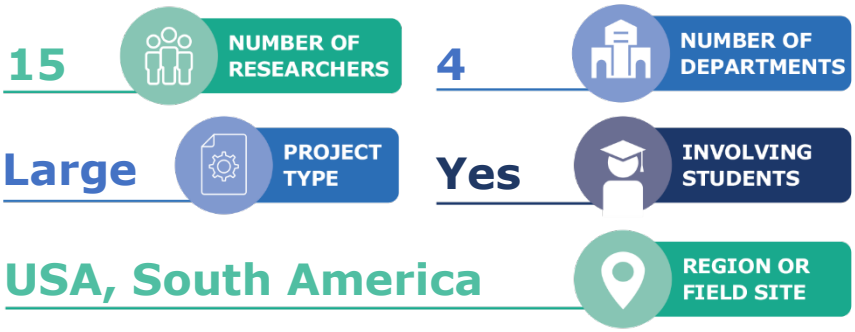
What this project investigates: The effect of different land management practices on how much and for how long plants and soils store carbon in four major systems: Cattle pastures with enhanced tree cover across Latin America; Agriculture forestry mosaics in lands that were converted from tropical forests; Secondary forests in the northeastern United States; Croplands across the United States.

How this will be addressed: By synthesizing the current scientific literature and data from land manager partners and compiling information into formats that are accessible to a broad audience.

Why it matters: Currently information is not available in a form and at a scale that landowners and managers can use to make informed carbon-relevant land management decisions. Providing this information enables practitioners to include carbon budget considerations into their management practices and can play an important role in mitigating the climate crisis.

Update from the first year: Five new postdoctoral associates joined the program and began working on the following projects:

- Conducting research on the impacts of temperate silvo-pasture and agroforestry practices (windbreaks, alley cropping, etc.) on carbon sequestration.
- Assessing differences in carbon sequestration between primary tropical forests, naturally-regenerating tropical forests, and plantation forests in South America.
- Developing a synthetic dataset that can be used to benchmark the major soil carbon MRV protocols underlying programs to build soil carbon stocks in agricultural lands. The work is part of a larger initiative to evaluate the potential for agricultural soil carbon credits to provide a meaningful mitigation option.
- Initiating new collaborations with timber management organizations to estimate the carbon storage potential of improved management for the U.S. The work is part of a larger effort to provide a report to guide the Biden Administration's 2050 Getting to Neutral plan and to provide guidance as to what is a high-quality forest carbon credit for US temperate forests.



Cranberry harvest, MA, USA, similar to one type of YASSP's study sites; Photo by David Trinks (Unsplash)

Blue Carbon and Carbonate

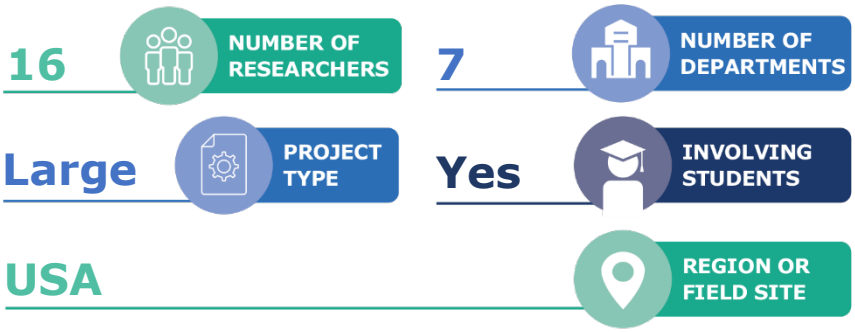
What this project investigates: How carbon moves through coastal systems such as mangrove forests, salt marshes, and seagrass meadows and how much carbon and other greenhouse gases are stored in different parts of these systems and for how long. Carbon stored in these systems is often referred to as *blue carbon*.

Why this is important: Coastal systems are increasingly altered by human activity and extreme weather events. Scientists still lack a fundamental understanding of how carbon and other elements move through and are stored in the biomass and sediments of coastal ecosystems which also provide additional economic benefits and services, such as protection from storm surge, water filtration, and maintenance of fisheries.

Updates from the first year:

- Finished a prototype of a field alkalinity instrument that operates using load cells. Building five new versions for placement in the field and started the patent process with Yale Ventures for the device.
- Deployed measuring devices in several locations supporting the following activities: measuring of alkalinity generation in salt marsh sites in New England; investigating the interplay between alkalinity enhancement and oyster growth; collaborating with the Sound School on a "Living Laboratory" for inspiring the next generation of scientists and practitioners.
- Completed the first round of field measurements on methane emissions in the Long Island Sound and the Florida Everglades
- Initiated the "Blue Carbon Timescale Network"; this network connects scientist from around the globe to establish the first global data set of the age of peat profiles.

Deployed measurement prototype; Photo by Pete Raymond



Enhanced Mineral Weathering in Agricultural Settings

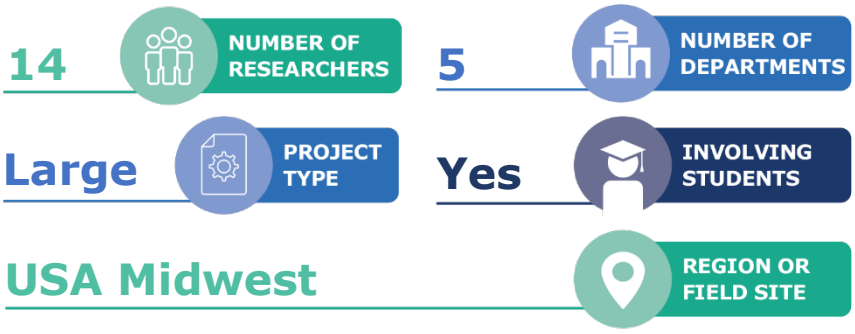
What this project investigates: The effects of adding ground minerals to agricultural soils using a process called "enhanced mineral weathering" in various agricultural settings with an initial focus on industrial agriculture in the United States.

How this will be addressed: Through field trials adding ground minerals to fields growing different crops and measuring carbon uptake, storage, and leakage from soil samples. This is complemented by more laboratory analyses and synthesis of existing scientific literature.

Why it matters: Although agriculture is responsible for a large portion of greenhouse gas emissions, agricultural lands have tremendous potential for carbon capture and storage and may be a valuable tool in mitigating the climate crisis. Enhanced mineral weathering has the potential not only to contribute to carbon capture, but to enhance crop yields.

Updates from the first year:

- Submitted to two scientific publications, both of which have been accepted with revisions.
- Conducted field experiments with the following outcomes: Completed an end-to-end demonstration of carbon capture at the 10-ton scale; Documented yield increases from basalt application in a range of common midwestern crops; Demonstrated that basalt soil amendments can decrease nitrous oxide fluxes—done in a fertilized corn system.
- Developed new estimates for the extent of carbon dioxide that is released back to the atmosphere after the initial carbon capture through mineral weathering. This is called carbon leakage and is a critical process to understand and quantify when attempting to assess net carbon capture in agricultural settings.



Experimental field site; Photo by Noah Planavsky

Ocean Based Carbon Capture and Storage: Mineral Weathering and Alkalinity Enhancement

What this project investigates: The ocean environment, from seafloor to surface, to better understand the potential for large-scale oceans-based carbon capture and storage.

How this will be addressed: By modeling the optimal wind/wave settings for mineral dust deposition, rates of mineral dissolution across a range of marine environments, and the unintended negative consequences of enhanced mineral weathering in the oceans.

Why it matters: The oceans have a tremendous potential for capturing and storing greenhouse gases. However, scientists currently have a limited understanding of the potential consequences of increasing the oceans' ability to capture and store greenhouse gases for marine environments. This modeling study will provide scientists with the understanding needed to plan and execute meaningful field trials.

Updates from the first year:

- Hired two new postdoctoral associates who will begin refining and developing models on ocean dynamics.
- Completed first modeling study to track the evolution of carbon dioxide and carbon species along with ocean temperature and salinity. This model used a simple numerical model of the ocean water column, driven by realistic atmospheric forcing and was extended to include a model of the marine carbonate system.

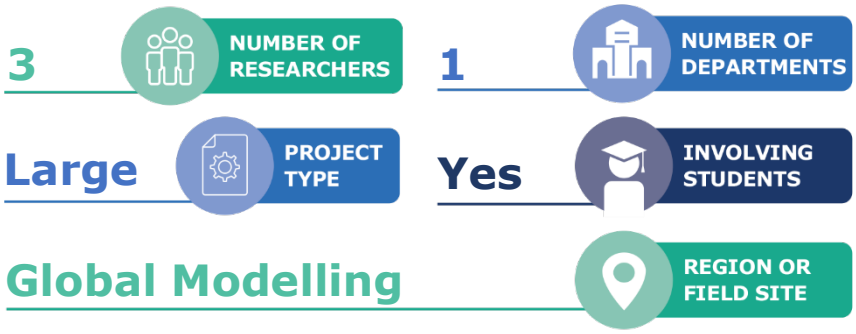


Photo by Silas Baisch - Unslpah

Projects funded in 2022

A Case Study of Industrial Reforestation in Mata Atlantica, Brazil

What this project investigates: 1) The role industrial plantations can play in increasing the carbon stored in soils and above-ground biomass as compared to former and current agricultural and pastoral lands; 2) the potential for long-term carbon storage in manufactured wood products; 3) the potential for these wood products to be substitutes for more energy intensive materials; and 4) their potential to restore and protect recovering second growth forests within reforested areas.

Why it matters: Most studies focus on native trees when examining the potential role of tree planting for carbon sequestration in the tropics, but the vast majority of today's reforestation is for industrial purposes and uses non-native tree species. This type of nature-based climate solution has enormous potential because non-native, industrial plantations can be economically appealing to landowners.

Fragmented landscape in Brazil, photo by Mark Ashton

13 NUMBER OF RESEARCHERS	3 NUMBER OF DEPARTMENTS
Large PROJECT TYPE	Yes INVOLVING STUDENTS
Brazil REGION OR FIELD SITE	

Climate benefits of releasing degraded hardwood forests from liana loading

What this project is about: Estimating the climate mitigation potential of liana management in Central Appalachian and Mid-Atlantic forests of Virginia, West Virginia, and North Carolina.

How this will be addressed: By creating the first distribution map of liana impact on forests in this region.

Why it matters: Liana management is a large and low-cost opportunity for delivering large amounts of carbon removal by restoring native forest growth rates, but the scale, location, and best methods for liana monitoring and management in eastern US forests are poorly understood. Findings from this project will be applied nationally to deliver actionable policy and silvicultural recommendations, and globally to deliver technologically advanced methods for mapping, monitoring, and verifying the climate impacts of liana management.

Overgrown forest in the Eastern US, photo by Mark Ashton

7 NUMBER OF RESEARCHERS	4 NUMBER OF DEPARTMENTS
Large PROJECT TYPE	Yes INVOLVING STUDENTS
Eastern USA REGION OR FIELD SITE	

Developing a blue carbon enhancement plan for Sri Lanka

What researchers want to know: The optimal locations of large-scale seagrass and mangrove restoration to lower global temperatures and reduce greenhouse gas concentrations in the atmosphere.

How they will find out: By measuring the amount of carbon stored in seagrass across the Sri Lankan coast and by mapping the location of all seagrass fields in Sri Lanka.

Why it matters: With these data, researchers will be able to develop a nation-wide Blue Carbon Enhancement Plan that will provide actionable information about seagrass and mangrove restoration to decision makers and practitioners.

Collecting seagrass samples, photo by Anitra Thorhaug

8 NUMBER OF RESEARCHERS	4 NUMBER OF DEPARTMENTS
Pilot PROJECT TYPE	Yes INVOLVING STUDENTS
Sri Lanka REGION OR FIELD SITE	

Evaluating Modeling Approaches for Enhanced Weathering

What this project is about: Comparing different mathematical models and their results to estimate the effects of adding crushed minerals and rocks to agricultural lands, often referred to as enhanced mineral weathering.

How this will be addressed: By integrating data from a field experiment measuring daily rainfall and temperature with different mathematical models for soil conditions, temperatures, and the mineralogy and grain-size distributions of crushed basalts applied to agricultural soils.

Why it matters: Enhanced mineral weathering has significant potential to aid in reducing greenhouse gasses in the atmosphere and for mitigating the climate crisis. Accurate and usable models will greatly increase the ability of practitioners to successfully apply this technique.

Applying minerals to field, photo by Ed Bolton

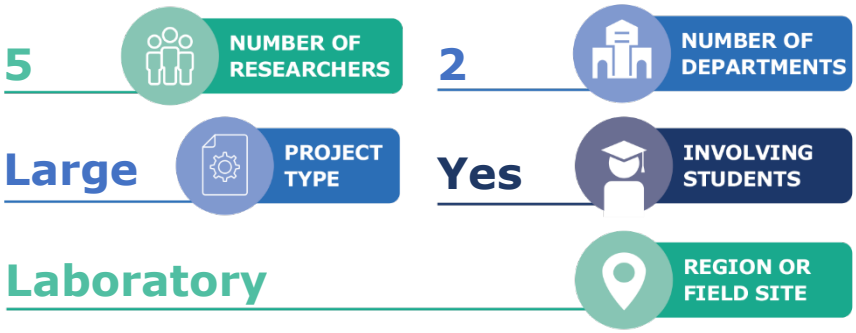
7 NUMBER OF RESEARCHERS	5 NUMBER OF DEPARTMENTS
Pilot PROJECT TYPE	No INVOLVING STUDENTS
Laboratory REGION OR FIELD SITE	

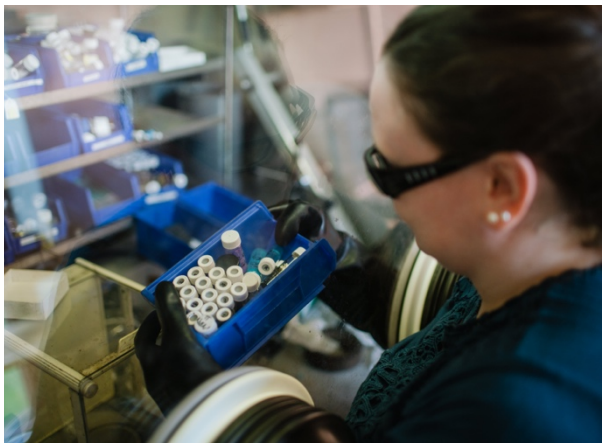
Capturing Carbon Dioxide from Dilute Sources for Chemical Catalysis

What this project is about: Developing processes and chemicals for capturing carbon dioxide from dilute sources, such as capturing it directly from the air to transform it into usable materials.

How this will be addressed: By exploring materials for carbon dioxide capture and measuring their ability to capture carbon dioxide based on varying their chemical structures.

Why it matters: One of the major challenges associated with converting carbon dioxide into valuable products, such as fuels or plastics, is that most materials for chemical carbon dioxide utilization do not work when carbon dioxide is very diluted, as it is in the air.





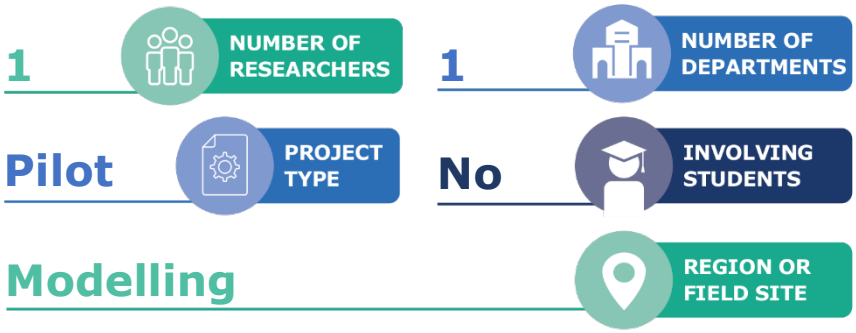
Researcher in the Hazari Group at Yale University

A theoretical framework to assess the realistic potential for carbon mineralization

What this project is about: Developing one-dimensional reactive transport models to explore a range of different possibilities for carbon mineralization, by varying the mode of water transport, the permeability model, and the relation between porosity and elastic strain energy.

How this will be done: By developing a range of mathematical models to explore a range of possibilities, such as mode of water transport, the permeability model, and the relation between porosity and elastic strain energy.

Why it matters: By allowing researchers to test a variety of possibilities, the new framework resulting from this project will enable future technological developments on carbon mineralization and assist in the life cycle analysis of promising solutions.



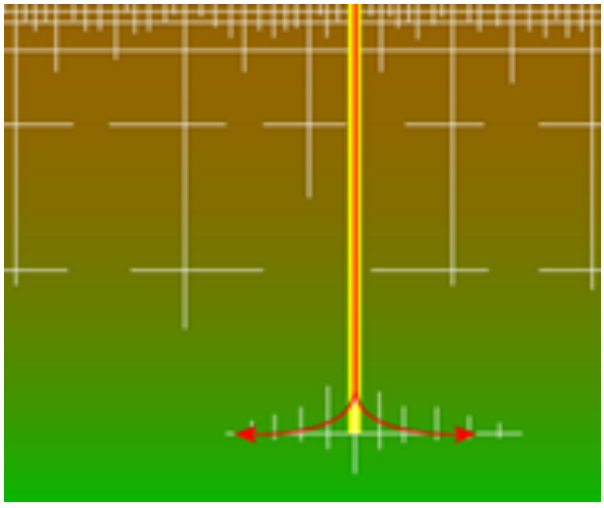


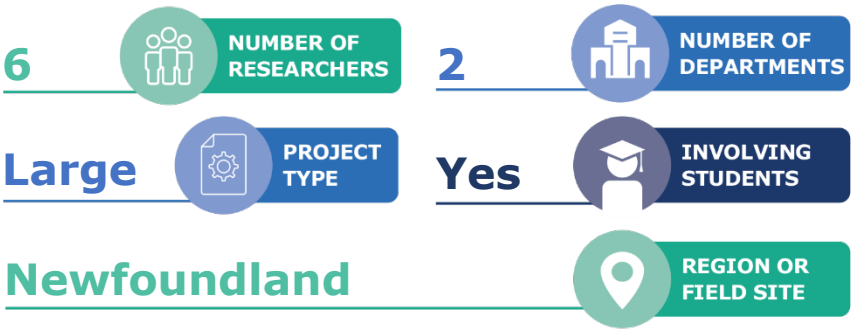
Diagram of model results

Moose management for enhancing boreal forest carbon storage

What this project investigates: How moose impact carbon storage in forests and what population size would be optimal for enabling carbon storage and biodiversity conservation.

How this will be addressed: By measuring plant and soil carbon capture in two national parks where moose populations are large and protected, and in landscape locations between the parks where moose populations are smaller because they are hunted.

Why it matters: Forests store large amounts of carbon and understanding each component of the forest ecosystem is important for implementing effective conservation and forest management strategies.

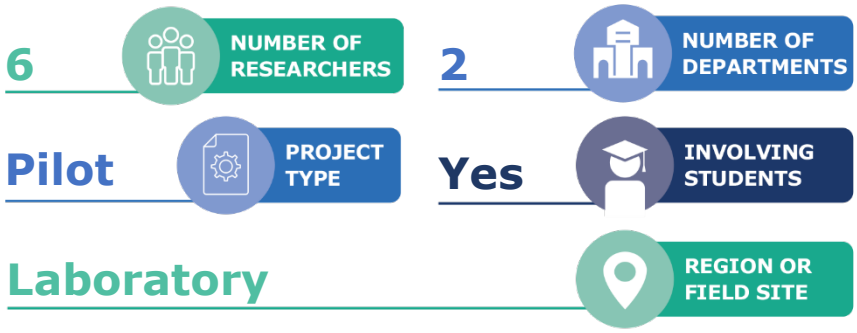


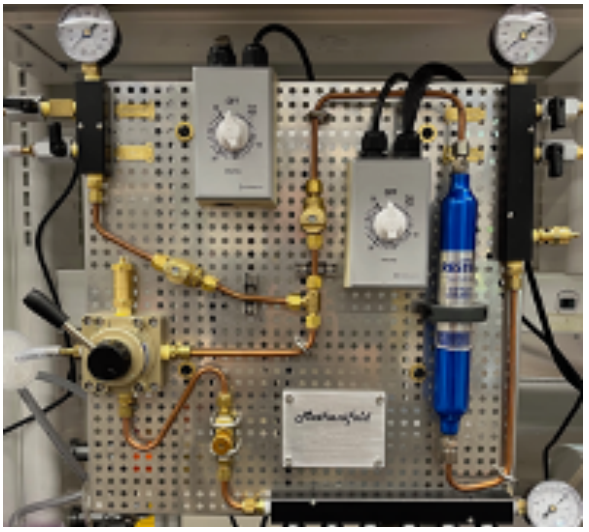
Moose browsing in a boreal forest in Canada, photo by Coulter Schmitz

Molecular tools for resolving microbial methane production and oxidation in natural systems

What researchers want to achieve: To build and validate tools that quantify methane production and methane degradation rates in systems where methane is emitted such as soils, wetlands, and inland waters. The initial focus is on methane emission from tree tissue.

Why it matters: Understanding the rate of methane emission from trees will improve the carbon accounting in forests on which global climate models, carbon markets, and emission targets are based.





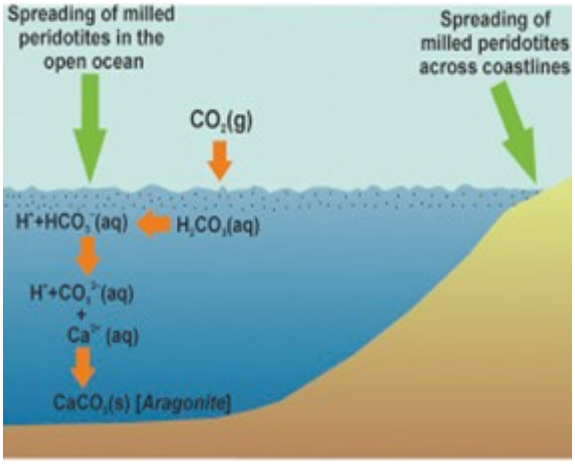
Lab set up in the Peccia lab

Calibrating Enhanced Weathering with Osmium and Strontium Isotopes

What this project investigates: The rates and efficiency of removing carbon dioxide from the air by using accelerated weathering, adding a very common rock – basalt – in the form of rock powder to agricultural fields, and identifying potential practical limitations.

How this will be addressed: By combining field studies, laboratory experiments, and modeling of chemical reactions.

Why it matters: Our ability to accurately track how much carbon dioxide would be removed by accelerated weathering is still in its infancy, and further validation of this approach is needed before it can be deployed at scales necessary to stave off the worst of global warming. The project will help identify best practices to achieve the most cost-effective and efficient ways to remove harmful greenhouse gasses from our atmosphere.



4 NUMBER OF RESEARCHERS

2 NUMBER OF DEPARTMENTS

Large PROJECT TYPE

Yes INVOLVING STUDENTS

Mid-West USA REGION OR FIELD SITE

Capacity to recover: Carbon storage and capture in the Sinharaja land use mosaic

What this project investigates: The potential for forest regrowth and regeneration in places where forests are "fragmented" or interspersed with cropland or other land uses.

How this will be done: By using the extensive existing documentation of land ownership and the long record of aerial and satellite images documenting land use over time in Sinharaja Man and Biosphere Reserve, Sri Lanka.

Why it matters: Studying this data-rich setting will enable researchers to understand the likely carbon consequences of decisions like increasing the size of forest reserves, changing the land tenure structure, or changing agricultural crop export policies.

14 NUMBER OF RESEARCHERS

2 NUMBER OF DEPARTMENTS

Pilot PROJECT TYPE

Yes INVOLVING STUDENTS

Sri Lanka REGION OR FIELD SITE

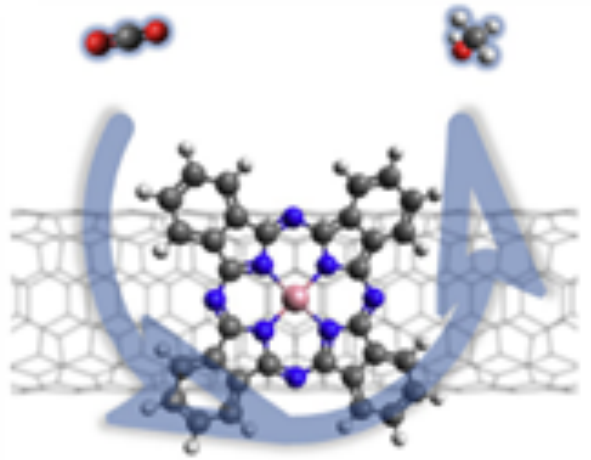
Tea plantation in the Sinjahara Man; Sri Lanka; Photo by Luke Sanford

Developing CO_2 Electrolyzers for Methanol Production

What this project investigates: A catalytic reaction that turns carbon dioxide into methanol, which has the potential to outperform or complement natural processes that remove carbon from the air and transform it into methanol.

How this will be addressed: By building on existing research and performing lab experiments to identify limiting factors and improve process design and equipment engineering.

Why it matters: The results of this project will move scientists one critical step closer to developing the technology for producing methanol from carbon dioxide.



A molecular catalyst on a carbon nanotube converting carbon dioxide to methanol.

5 NUMBER OF RESEARCHERS	2 NUMBER OF DEPARTMENTS
Large PROJECT TYPE	Yes INVOLVING STUDENTS
Laboratory REGION OR FIELD SITE	

The Natural Carbon Consequence of Cross Laminated Timber

What this project investigates: The net carbon consequences of cross laminated timber adoption at varied scales (e.g., US, Europe, global) over the next 100 years.

How this will be addressed: By using life cycle analysis to quantify the life-cycle carbon emissions due to production, use, and demolition of cross laminated timber, along with materials substitution benefits. The project will also use an economic-ecological-timber model to simulate the changes in global forest carbon stock under different socioeconomic pathways and timber demand.

Why it matters: The impacts of large-scale cross laminated timber adoption on global forests and relevant carbon pools remain unclear. Such impacts are highly dynamic and driven by various ecological, socio-economic, and managerial factors, and understanding them is therefore crucial for using cross laminated timber as an effective carbon removal strategy.

Example of a cross laminated timber building

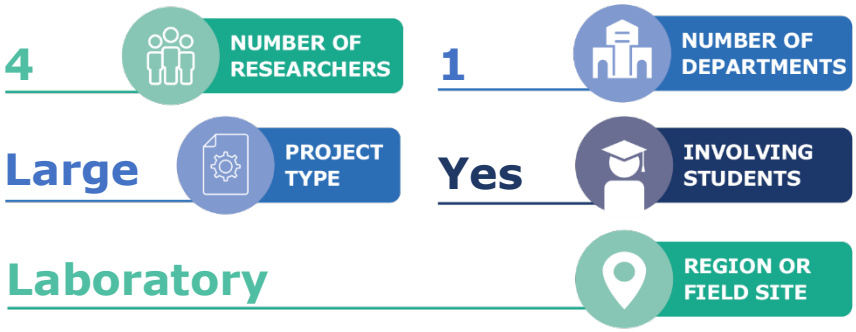
5 NUMBER OF RESEARCHERS	3 NUMBER OF DEPARTMENTS
Pilot PROJECT TYPE	Yes INVOLVING STUDENTS
Global REGION OR FIELD SITE	

Storing Carbon Dioxide in the Form of Sustainable Plastics

What this project investigates: The design and synthesis of chemical components that enable the production of plastics made from carbon dioxide captured from the atmosphere.

How this will be addressed: y conducting laboratory experiments and trials with different chemical components.

Why it matters: Directly converting atmospheric carbon dioxide to functional materials with neutral environmental impacts is an efficient and desirable strategy for greenhouse gas mitigation and utilization.



Researcher in the Hazari Group examining a sample

An Integrated Biorefinery Pathway for Carbon Dioxide via Biological Carbon Fixation

What this project investigates: An integrated biorefinery strategy to sequester carbon dioxide by employing microbially-induced carbonate precipitation and cyanobacteria.

How this will be addressed: By using cyanobacteria as the biological nucleation seeds for biogenic calcium carbonate precipitation, resulting in a sellable carbonate-encapsulated cyanobacteria end product.

Why it matters: The oceans are a large carbon dioxide sink and cyanobacteria provide one mechanism for capturing and storing carbon. Accelerating this naturally occurring process for carbon sequestration has tremendous potential for mitigating climate change.

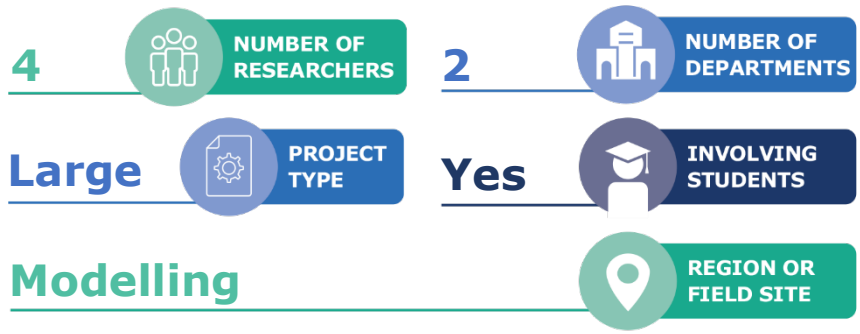


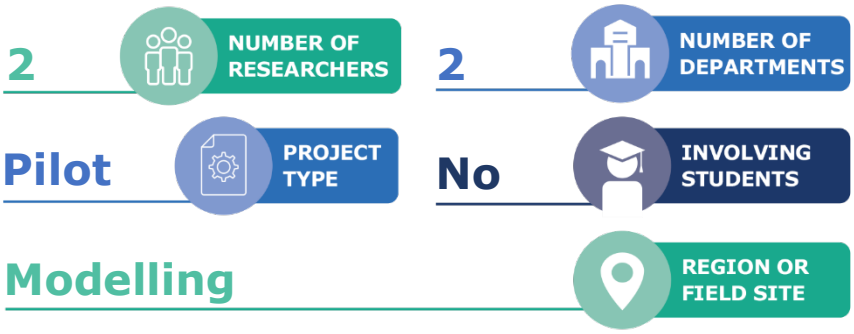
Photo by Cristian Palmer - Unsplash

The Impact of temperature, grazing, and acclimation on algae

What this project investigates: How temperature, grazing, and acclimation affect carbon capture and storage by algae.

How this will be addressed: By conducting field experiments and developing mathematical models using algae and zooplankton.

Why it matters: Algae are responsible for a large portion of the earth's carbon fixation; temperature and herbivory (grazing) play important roles in determining the fate of carbon fixed by algae.



Algae field; photo by David Vasseur

Conclusion

With the exceptional engagement and support of the FedEx Corporation and our corporate partners, The Boeing Company and Southwest Airlines, the Yale Center for Natural Carbon Capture has made great strides in its first year to bring together students, staff, and world-leading experts to accelerate the development and implementation of natural carbon capture around the globe. Central to this year's success were the rapid disbursement of fast-track research funding to Yale University scientists, an intensive search for four new endowed faculty members, and the development of a flagship fellowship program that will support the brightest early-career climate researchers from around the globe. In addition, we were able to engage with our corporate partners, the Yale community, and practitioners through our outreach activities and campus events.

As the Center enters its next phase, we will address some of the most urgent and challenging questions related to implementing scalable and cost-effective natural solutions to address climate change:

- Which mechanisms can we best use for implementing scientific results to enable large-scale climate solutions? How can we do this most effectively?
- How can we accurately assess the risks associated with scaling up and implementing different potential solutions?
- How can we realistically assess co-benefits of novel climate solutions, such as protecting biodiversity, boosting local economies, or reducing pollution?

By bringing industry and the academy together to realize a better future, we are confident that the Center is ideally positioned to answer these bold questions in the years to come.

From left to right: Dave Bercovici (Yale), Liza Comita (Yale), Mitch Jackson (FedEx Corporation), Stacy Malphurs (Southwest Airlines), Sheila Remes (The Boeing Company), and Indy Burke (Yale)