MCSC | 2022 Annual Symposium Posters

(p.3) **Decarbonization strategies for Long-Haul Trucking - Hydrogen, Battery Electric and Biofuels**

Sayandeep Biswas, Kariana Moreno, Rob Jones, Wai K. Cheng, and William H. Green

We explore different decarbonization options for long-haul trucking using a standard comprehensive framework that covers costs and emissions from well to wheel. Our technoeconomic and emissions analysis helps identify the major pain points of today's biofuel, battery, and hydrogen productions schemes. Our analysis determines that hydrogen is a promising fuel for the future but suffers from high transportation and delivery costs. We are currently exploring Liquid Organic Hydrogen Carriers (LOHC) that benefit from being room temperature liquids. Our work focuses on developing an integrated dehydrogenation unit with a hydrogen powertrain onboard a long-haul truck. It improves upon existing LOHC supply chain by benefiting from waste heat integration on the truck, eliminating the need to compress hydrogen.

(p.4) **Anthro-Engineering Decarbonization at the Million-Person Scale**

Manduhai Buyandelger, Michael Short, and Lauren Bonilla

We are trying to establish the field of Anthro-Engineering as an anthropology-led problem-solving methodology, using ethnographic and observational data to reveal the hidden boundary constraints which separate successful engineering solutions from failures in solving problems with people at their core. We focus specifically on the task of decarbonizing Ulaanbaatar, the capital of Mongolia, where many groups have tried and failed to craft a solution which stuck with the people despite the immediate, choking need to reduce coal and carbon emissions in the world's most polluted capital city.

(p.5) **ECO-LENS: Mainstreaming Biodiversity Data through AI**

MIT Environmental Solutions Initiative

Biodiversity is declining worldwide, driven foremost by the intensification in land management and the transformation of natural areas for agriculture, industrial-scale forestry production, and human settlements. Notably, most of the urban growth is often located in regions of high biodiversity and affects ecosystems far beyond urban areas, through resource demands, pollution, and climate impacts. Mainstreaming biodiversity data is a priority to improve decision-making processes that enhance the relationships between cities and the biodiversity and ecosystems that support them. We propose the implementation of a biodiversity detection and classification framework using AI and multi-stakeholder engagement to overcome urban biodiversity mapping challenges in the context of two Colombian cities located in biodiversity and carbon-rich ecosystems, namely, Quibdó and Leticia.

(p.6) **In Situ Agriculture & Aquaculture Microbiome Monitoring Using Scalable Optofluidic Microscopy**

Charlene Xia, Katana Finlason, Stefanie Muller, David Wallace, and Rodrigo Costa

Understanding and predicting the impact of climate change on agriculture and aquaculture microbes and the ecosystem services they provide present grand challenge and major opportunity. We are developing a real time in-situ continuous microbiome monitoring system using holographic micro fluidic microscopy.

(p.7) **CP4All: Fast and Local Climate Projections with Scientific Machine Learning**

Björn Lütjens, Dava Newman, Mark Veillette, and Chris Hill

We research machine learning (ML) models that will enable decision-makers across industry and government to explore local climate risks. Our core challenge is how to reshape machine learning into fast emulators of large-scale weather or climate models while ensuring physical-consistency and trust.

(p.8) **The Impact of Uncertainty on Wind Energy Modeling**

Storm A. Mata, Kerry S. Klemmer, and Michael F. Howland

An overview of two projects taking place in parallel: 1. Characterizing the effect of uncertainty in data sources on predicting annual energy production (AEP) and wind farm efficiency using the Vineyard Wind 1 site as a case study, and 2. Developing an analytical model for single-turbine power production based on incident wind speed and direction over the rotor area to explain and replicate trends observed in field data.

(p.9) **Enabling Rapid Assessment of Marsh Ecosystem Services and Resilience using Drones and Modeling**

Heidi Nepf, Megan Tyrell, Samantha Chan, and Trinity Stallins

The flow resistance provided by coastal marshes mitigates flooding by slowing storm surge and damping waves. The flow resistance (drag) provided by a marsh varies with seasonal growth, marsh loss to erosion, and marsh area gained by restoration. A quick method to measure marsh drag would enable more accurate predictions of a marsh's impact on coastal flooding, improving coastal planning, and risk assessment. Marshes provide additional ecosystem services, such as carbon storage, habitat, and water quality improvement. Like marsh drag, these services are correlated with marsh size and spatial structure, such as vegetation type and density. A quick method to measure and monitor changes in marsh structure and vegetation health would facilitate assessment of marsh economic value and resilience. Current methods are invasive, requiring walking through the marsh, which can damage the marsh surface. A remote method would facilitate more frequent and detailed mapping without damaging the marsh.

(p.10) **Thermochemical H2O and CO2 Splitting for Renewable Syngas and Transportation Fuels**

Aniket S. Patankar, Xiao-Yu Wu, Wonjae Choi, Harry L. Tuller, and Ahmed F Ghoniem

(p.11) **MIT Climate Grand Challenge: Bringing Computation to the Climate Challenge**

Noelle Eckley Selin, Raffaele Ferrari, Themistokis Sapsis, Youssef Marzouk, Elsa Olivetti, Tamara Broderick, Alan Edelman, Arlene Fiore, Glenn Flierl, Christopher Knittle, John Marshall, Bethany Patten, Chris Rackauckas, Daniela Rus, Adam Schlosser, Gregory Wagner, Claire Walsh, Jennifer Morris, Sebastian Eastham

An MIT Climate Grand Challenge project, "Bringing Computation to the Climate Challenge" seeks to develop a novel platform that leapfrogs existing climate decision-support tools by leveraging artificial intelligence (AI) approaches to both improve the accuracy of Earth System Models (ESMs) used to make climate projections and to derive reduced models trained with full ESMs that are cheap to run and provide actionable information for stakeholders.

(p.12) **Sensitivity Analysis of Modular Heterocycles for CO2 Capture**

Avin Singhal, Glen P. Junor, Rafael Gomez-Bombarelli

This work explores ylides as a class of potential carbon capture molecules. We enumerate candidate molecules using cheminformatics approaches and perform high-throughput DFT calculations in order to understand the tunability of binding energy through the reactive atom center and attached heterocycle.

(p.13) **Carbon Sequestration through Sustainable Practices by Smallholder Farmers**

Joann de Zegher , Y. Karen Zheng and Yuan Shi

We study design of effective incentive systems that motivate large-scale sustainable practices by smallholder farmers. The proposed research will take a data-driven, community-centered, iterative approach to address several key questions in the incentive design: (i) identify local operational and behavioral constraints for interpretability and practical implementation, (ii) how to account for inherent uncertainty and nonlinearity in carbon measurement outcomes, and (iii) how to coordinate collective efforts by farmers as a group.

(p.14) **Dare to Invent the Future: Trans-hemispheric Knowledge in the Service of and through Problem-solving**

Chakanetsa Mavhunga, Tamuka Nhimatiwa, Lovemore Sekani, Ashmi Mridal, Chief Mudehwe

This poster is a summary of four applied-STS (Science, Technology, and Society) initiatives brought into the conversation on Climate and Sustainability voices from marginalized knowledge systems to expose our students to the leading voices from these marginalized cultures, to train our students in how to work with and among these communities, and to build with them capacities to solve their own problems. It is the sort of work that does not always sit snuggly with the 'speed and scale' that corporations love, but is often missing in our conversations in the consortium. These cultures of knowing have their own entrepreneurial models driven by sustainability ethics and rooted in local forms of custodianship and resource utilization. They are, very often, the first victims of 'speed and scale,' when big companies come in as "foreign direct investment." A key piece in my life's work lies in seeing these peoples and cultures not simply as victims that need our pitying conscience, but active agents that must be urgently engaged as compatriots in designing sustainable futures. This is the first time I am bringing some kind of unity to this initiative, which sees scale through trans-hemispheric dialogue. For an institute that draws the best of the best from all corners of the world, this is a great opportunity for us to design the future at-the-intersection of cultures of knowing.

Decarbonization strategies for Long-Haul Trucking - Hydrogen, Battery Electric and Biofuels

Sayandeep Biswas[a], Kariana Moreno[a], Rob Jones[a], Wai K. Cheng[b] and William H. Green[a]
[a]MIT Department of Chemical Engineering
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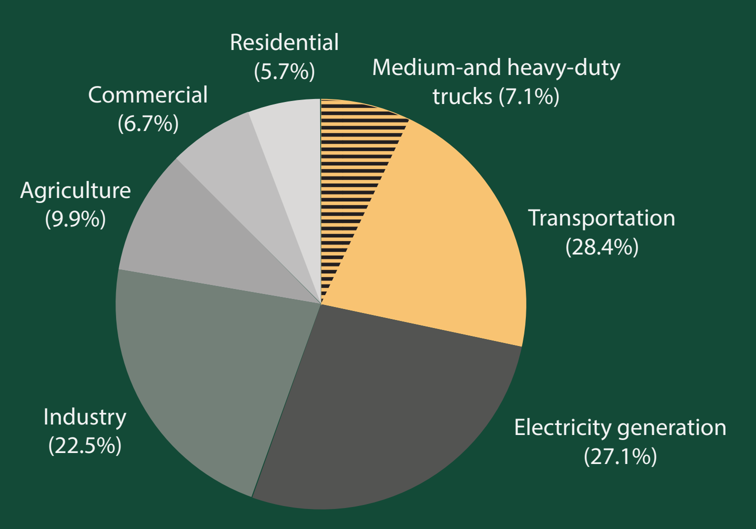
MIT Green Group

Why do we care?

Greenhouse Gas Emissions by Sector



- Medium and heavy duty trucks account for 7.1% of the total GHG emissions
- Trucks are an indispensable part of the modern supply-chain, any increase in cost of trucking is felt universally
- Solutions must be economically viable and practically implementable

Decarbonization of trucks is a hard problem

Understanding Long-haul

*"Long-haul trucks often **do not return to depots at night**, need to refuel/recharge at many locations"*

Flexible Routes

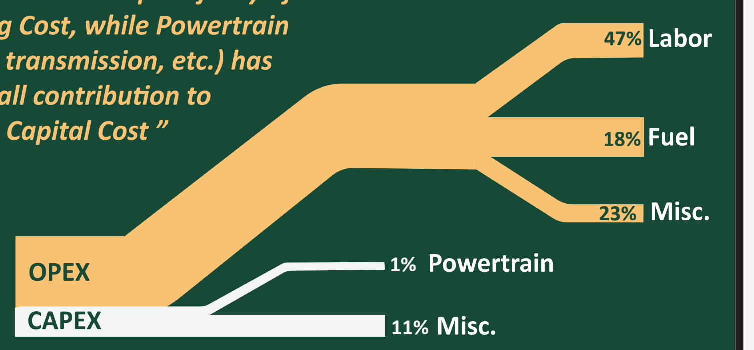
*"**Trucks have high energy demand.** One day of driving consumes 80 gallons of diesel"*

11 hours/day

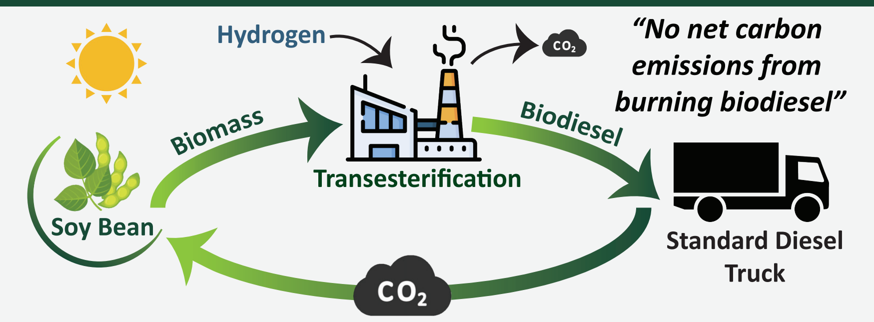
*"**Operating Cost dominates Capital Cost** by a **factor of 5** over the lifetime of the truck"*

600 miles/day

"Labor & Fuel make up majority of Operating Cost, while Powertrain (engine, transmission, etc.) has small contribution to Capital Cost"



Biofuels



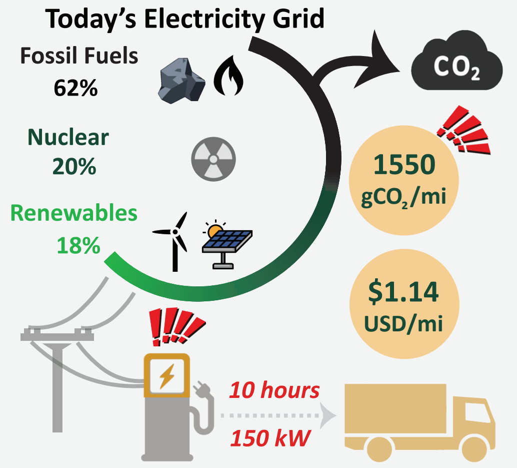
"No net carbon emissions from burning biodiesel"

*"**Biodiesel** is functionally equivalent to diesel, thus compatible with standard trucks"*

"Relatively inexpensive" | $0.42 USD/mi | 157 gCO_2/mi | "89% reduction from diesel"

Crops need land and water to grow.
*Both scarce resources, leading to **scalability concerns***

Battery Electric



"CO_2 emissions arise from burning fossil fuels to generate electricity"

"Grid is expected to be cleaner in the future"

*"We need a **1500** kWh battery, weighs ≈**6** tonnes, costs **$200k**"*

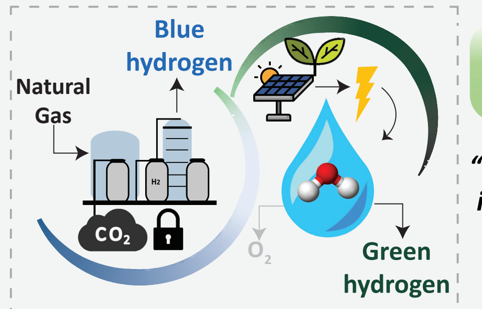
"Batteries are getting cheaper each year"

*Major changes to trucking practices necessary to accomodate for charging. **Practical implementation is challenging.***

Hydrogen

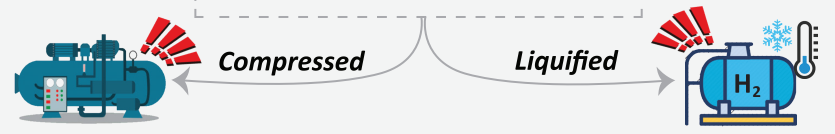
$2 USD/kg
3.6 gCO_2/gH_2
*90% Carbon Capture

"Blue hydrogen is cheap and relatively clean"



$8 USD/kg
0.6 gCO_2/gH_2

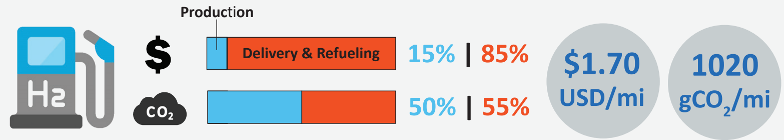
"Green hydrogen is expensive but very clean"



Energy lost - 20 to 30%
Compressor cost > $1MM USD

Boil-off losses
Liquifier is expensive

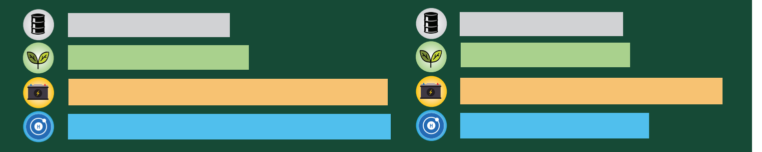
At gas station



$1.70 USD/mi | 1020 gCO_2/mi

Hydrogen needs better deliver and refuelling methods

Summary



*"Long-haul trucking remains an **open problem** with no clear winner"*

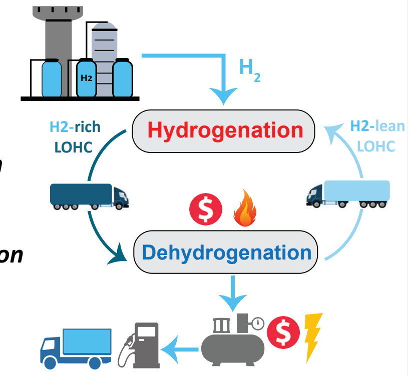
*"**Hydrogen has practical advantages** for long-hauling such as scalability and fast refueling time. Also, there is a enormous potential to improve delivery and refueling to further reduce H_2 cost"*

Liquid Organic Hydrogen Carriers (LOHCs)

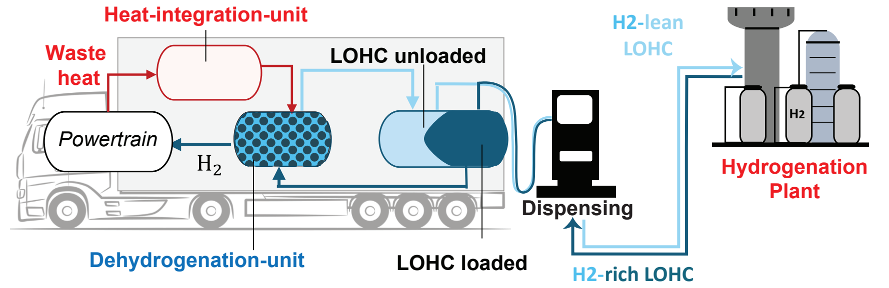
They are organic molecules that can be reversibly **hydrogenated (exothermic)** and **de-hydrogenated (endothermic)** to absorb and release hydrogen as needed

Pros	Cons
Liquid fuel - Synergistic with existing fuel infrastructure	*30% energy penalty due to highly endothermic dehydrogenation*
High thermo-stability and inert	*Hydrogen still needs compression before using it as a fuel*
Mature technology can handle fuel demand for long-hauling	

LOHC Today



Our Idea: On-board Hydrogen Generation



"40% of the fuel's energy is wasted in the exhaust of an internal combustion engine. We will use this to power dehydrogenation"

"No need for compression as we eliminate any need to store hydrogen as a gas"

Meet the Team

Prof. William H. Green — ChemE Professor
Prof. Wai K. Cheng — MechE Professor
Sayandeep Biswas — PhD Student
Kariana Moreno — PhD Student

Scan QR code to read white papers from the Green Group and learn more about decaronization of trucking

Anthro-Engineering Decarbonization at the Million-Person Scale

Project Leads: Manduhai Buyandelger (Anthropology) and Michael Short (Nuclear Science & Engineering)
Postdoctoral Associate: Lauren Bonilla

Abstract

With the growing urgency of climate change, large-scale communities must decarbonize as quickly as possible. Top-down solutions such as carbon credits and heavy-handed, local energy policies have yet to bear sufficient fruit, leading us to hypothesize that social, political, and anthropological factors must be given equal consideration to technical ones. We will develop a generalized framework to anthro-engineer decarbonization at the scale of millions of people – creating a solution for one focused demographic while generalizing our results to be used in other million-person scale communities.

We focus on Ulaanbaatar, Mongolia, where drastic environmental degradation to air pollution and climate change have led to rapid erosion of both environmental and democratic living conditions. This cross-school project will explore the contexts for designing and implementing a locally specific, culturally acceptable, and socio-economically viable reusable molten salt heat bank, amenable to energy input by concentrated solar and nuclear power, to reduce this dependency of citizens on their government, and sustainably decarbonize the city.

Anthropology + Engineering

By fusing together Anthropology (the study of socio-cultural specificities in a holistic way) and Nuclear Science and Engineering, we will build a foundation for a trans-disciplinary field of Anthro-Engineering where the products are co-designed by a variety of actors and are based on socio-economic, environmental, and cultural constraints.

This project focuses squarely on *the sustainability of sustainability solutions*, by giving equal weight to the people whose lives will be affected by climate change solutions as the solutions themselves.

Prototyping Solutions in Mongolia

The coldest capital city in the world, Ulaanbaatar, requires the most heat per person for its citizens to keep warm. Ulaanbaatar's air quality is also among the worst (Guttikunda 2013), causing widespread respiratory illness and death, particularly in children (Allen 2013). To combat this catastrophe, the Mongolian government banned both the use of coal and migration to the city and enforced the use of cleaner burning charcoal briquettes. However, these interventions have failed to solve the crisis, even causing further illness, death, and societal discontent.

Through utilizing a human- and anthropology-first perspective, we will prototype a molten salt heat bank, which both *meets the heating needs of households* and *positively impacts their livelihoods.*

MIT students will travel to Mongolia during IEP in 2023/2024 to conduct research in partnership with mentors and peers at the National University of Mongolia. Together, they will:

1. Study and design the heat bank distribution network,
2. Carry-out sociological surveys of residents on topics related to heat and energy,
3. Conduct formal and informal interviews with residents,
4. Conduct participant observation of *ger* districts and home-stay with heat bank usage observation,
5. Organize workshops with key stakeholders.

Expected Outcomes

Our project aims to create a generalized workflow for MCSC aim #8: "Equity-centered sustainable solution-building in climate and sustainability." Ulaanbaatar is a perfect example, where its poorest and most vulnerable residents are disproportionately affected by both the negative effects of climate change and misapplied solutions. Due to the extreme and multiple climatic, logistical, and socio-economic constraints, the findings of our project will be applicable to diverse contexts of varying scales.

Key Questions for MCSC Members

- How can we sustainably scale million-person decarbonization efforts?
- How have member companies performed people-centric (not just user-centric) research to ensure that their products, solutions, and ideas will stick?
- How do member companies build in solution sustainability beyond the product/solution launch for similar scale efforts?
- How can we meaningfully affect decarbonization, especially in areas which cannot afford the up-front capital expenditures on their own?

Allen, Ryan W., Enkhjargal Gombojav, Baldorj Barkhasragchaa, Tsogtbaatar Byambaa, Oyuntogos Lkhasuren, Ofer Amram, Tim K. Takaro, and Craig R. Janes. "An assessment of air pollution and its attributable mortality in Ulaanbaatar, Mongolia." Air Quality, Atmosphere & Health 6, no. 1 (2013): 137-150.

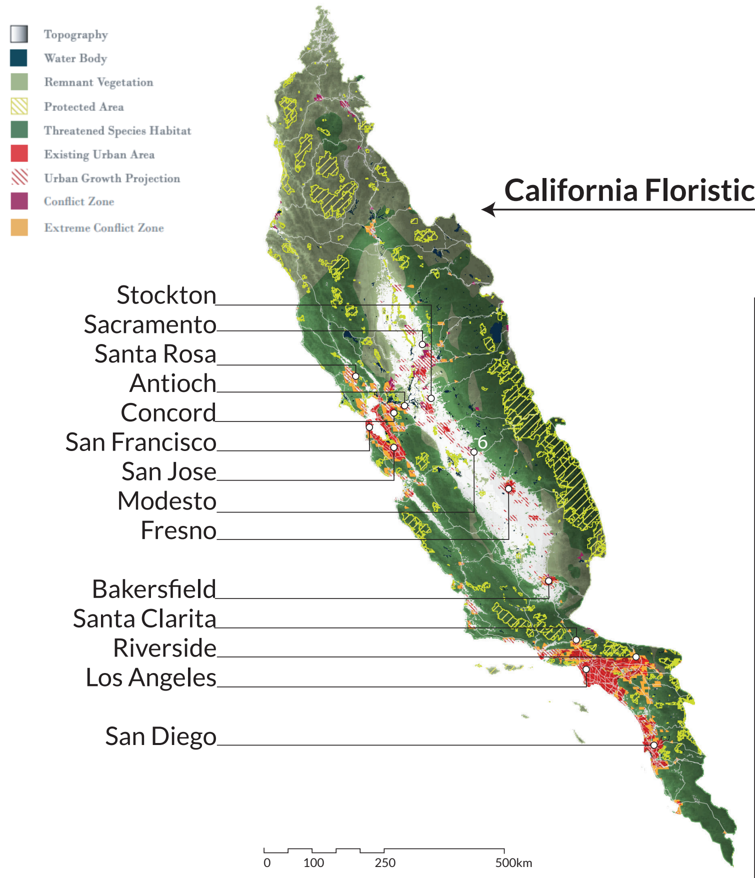
Guttikunda, Sarath K., Sereeter Lodoysamba, Baldorj Bulgansaikhan, and Batdorj Dashdondog. "Particulate pollution in Ulaanbaatar, Mongolia." Air Quality, Atmosphere & Health 6(3):589-601 (2013).

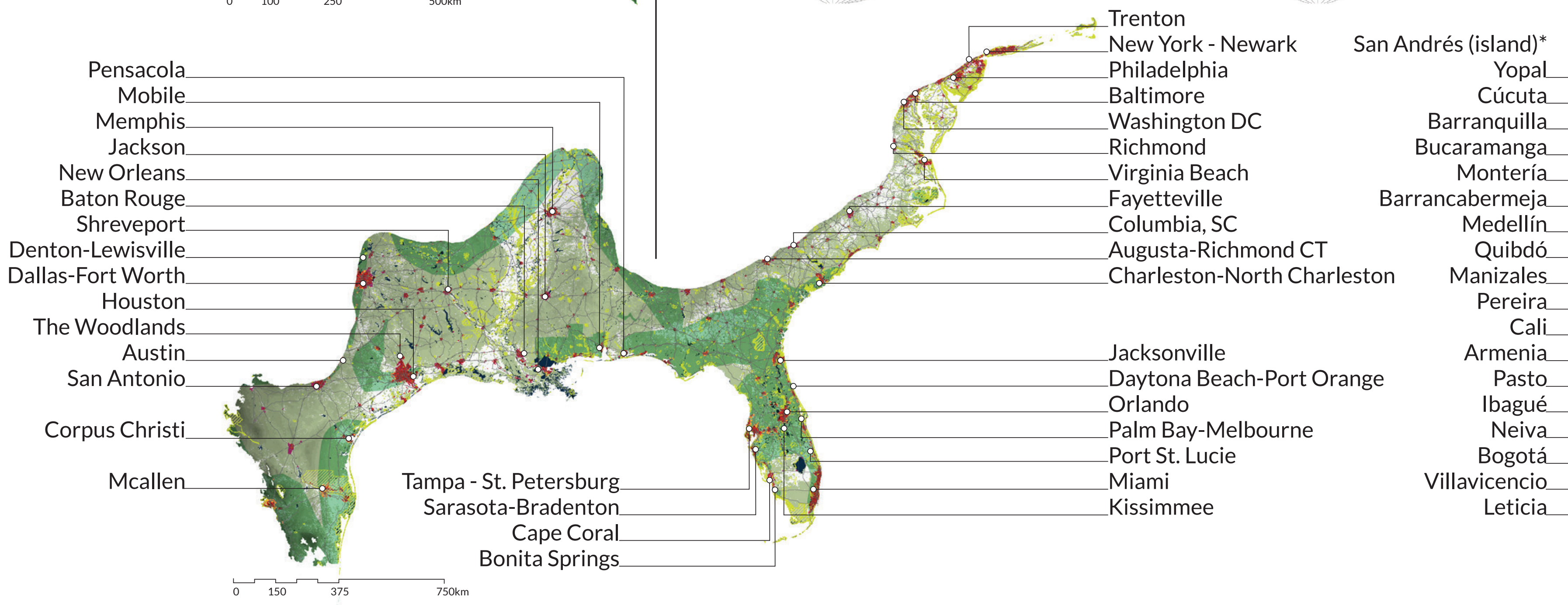
ECO-LENS: Mainstreaming biodiversity data through AI

ENVIRONMENTAL SOLUTIONS INITIATIVE

Hotspot urban areas in the US

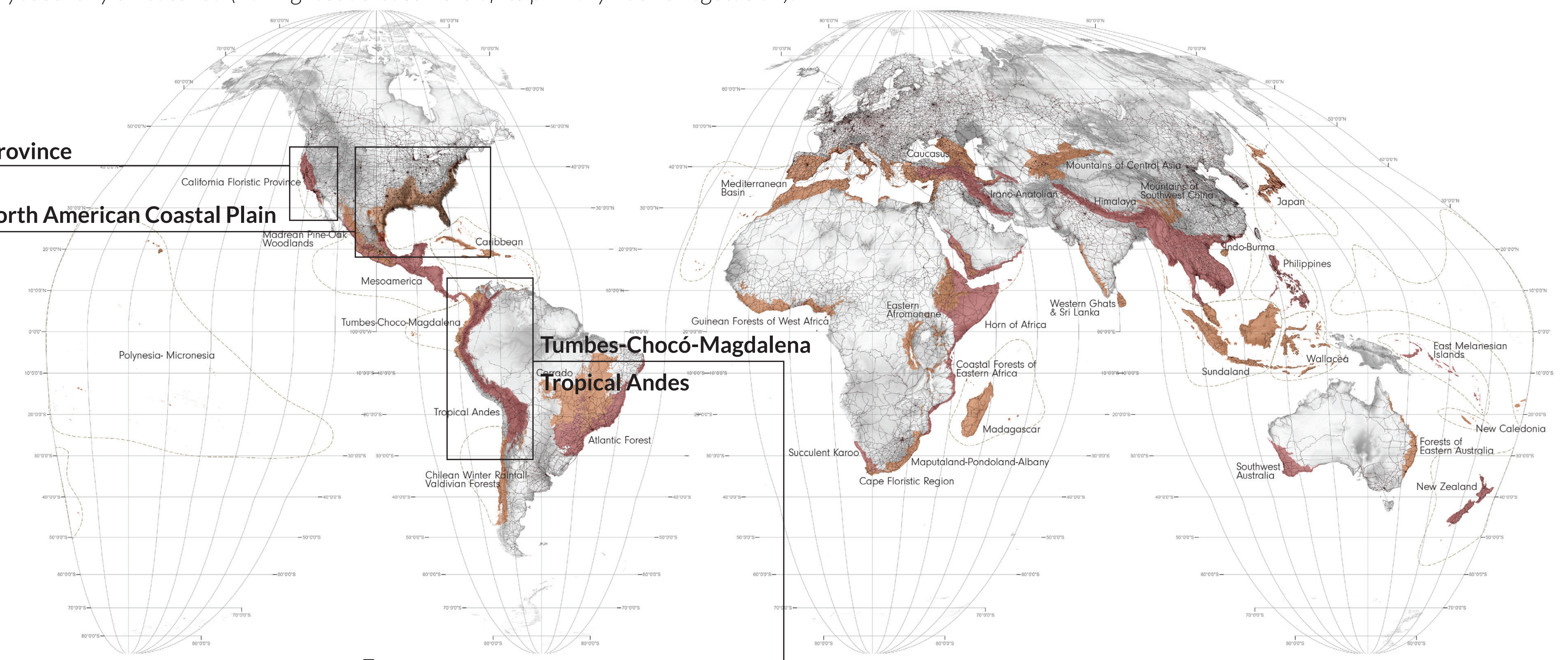
Sample of 51 Urban Areas over 300.000 people located in the two main Biodiversity Hotspots in the US.





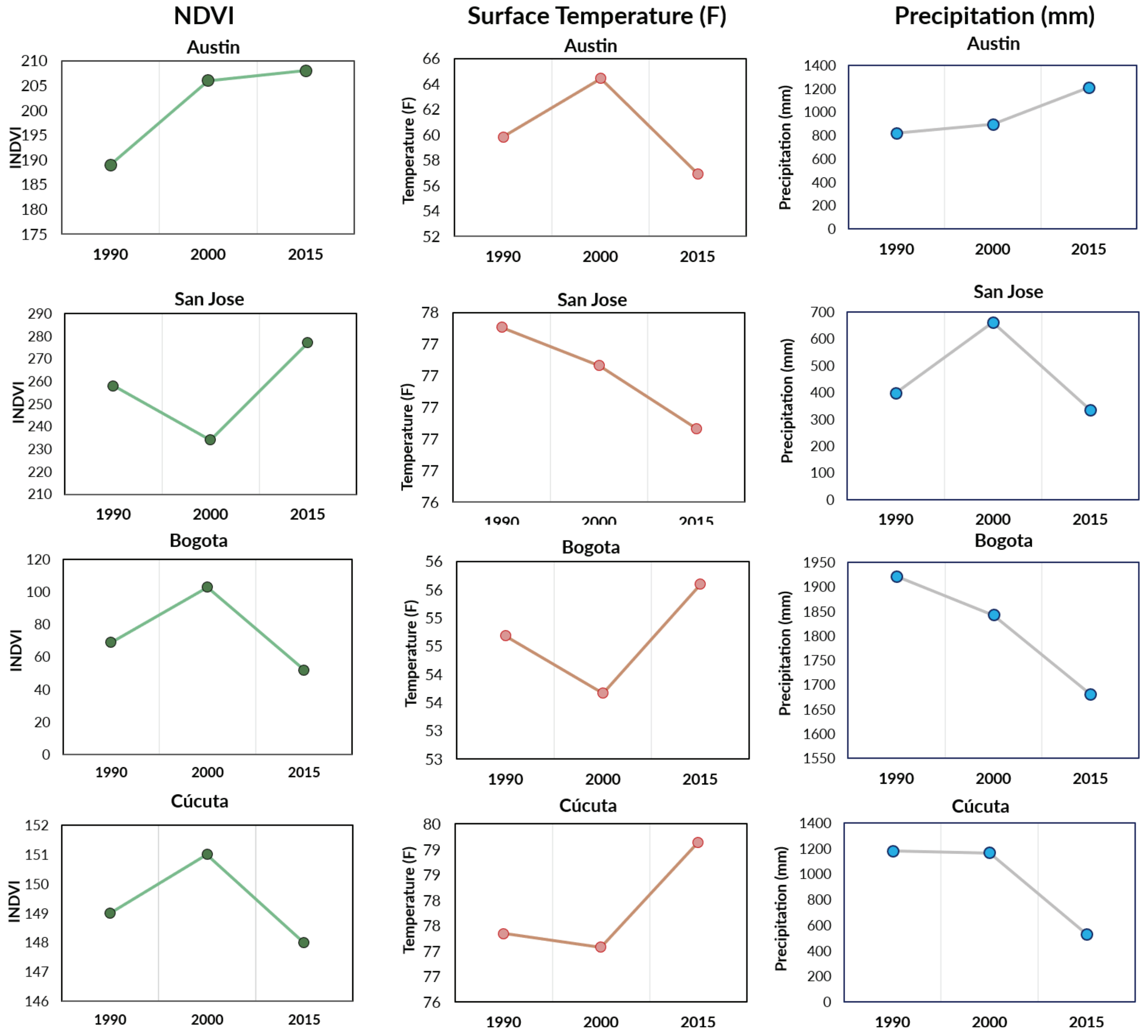
Global Biodiversity Hotspots

36 global biodiversity hotspots, characterized by being the most biologically rich regions (containingat least 1,500 endemic vascular plants), yet severly threatened (having lost at least 70% of its primary native vegetation).



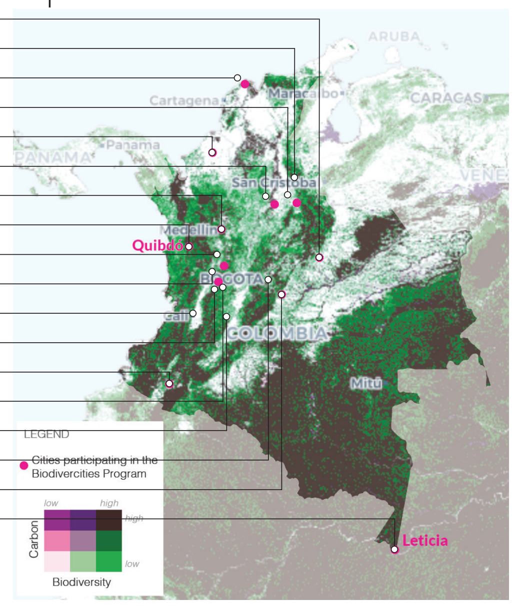
Global Biodiversity Loss

Biodiversity is declining worldwide, driven foremost by the intensification in land management and the transformation of natural areas for agriculture, industrial-scale forestry production, and human settlements. Urban areas have doubled since 1992 and, in comparison with 2020, are projected to expand between 30% and 180% until 2100. Notably, most of the urban growth will happen in the global south in regions of high biodiversity and it will affect global ecosystems far beyond urban areas, through resource demands, pollution, and climate impacts. Urban biodiversity management is an emerging field and there are significant gaps in our understanding that are critical to improving biodiversity conservation policies and management in urban areas to support global biodiversity outcomes.



Biodivercities - Colombia

Colombia, the most biodiverse country by square kilometer, launched the Biodivercities program in 2021 to support cities in the development of sustainable, inclusive and nature-positive urban development strategies. The program is led by the Ministry of Environment and Sustainable Development, in coordination with the mayor's and planning offices of 14 cities in Colombia. In addition to the 14 biodivercities, cities over 300,000 people (6) located in the two global hotspots were included in the sample for Task 1.

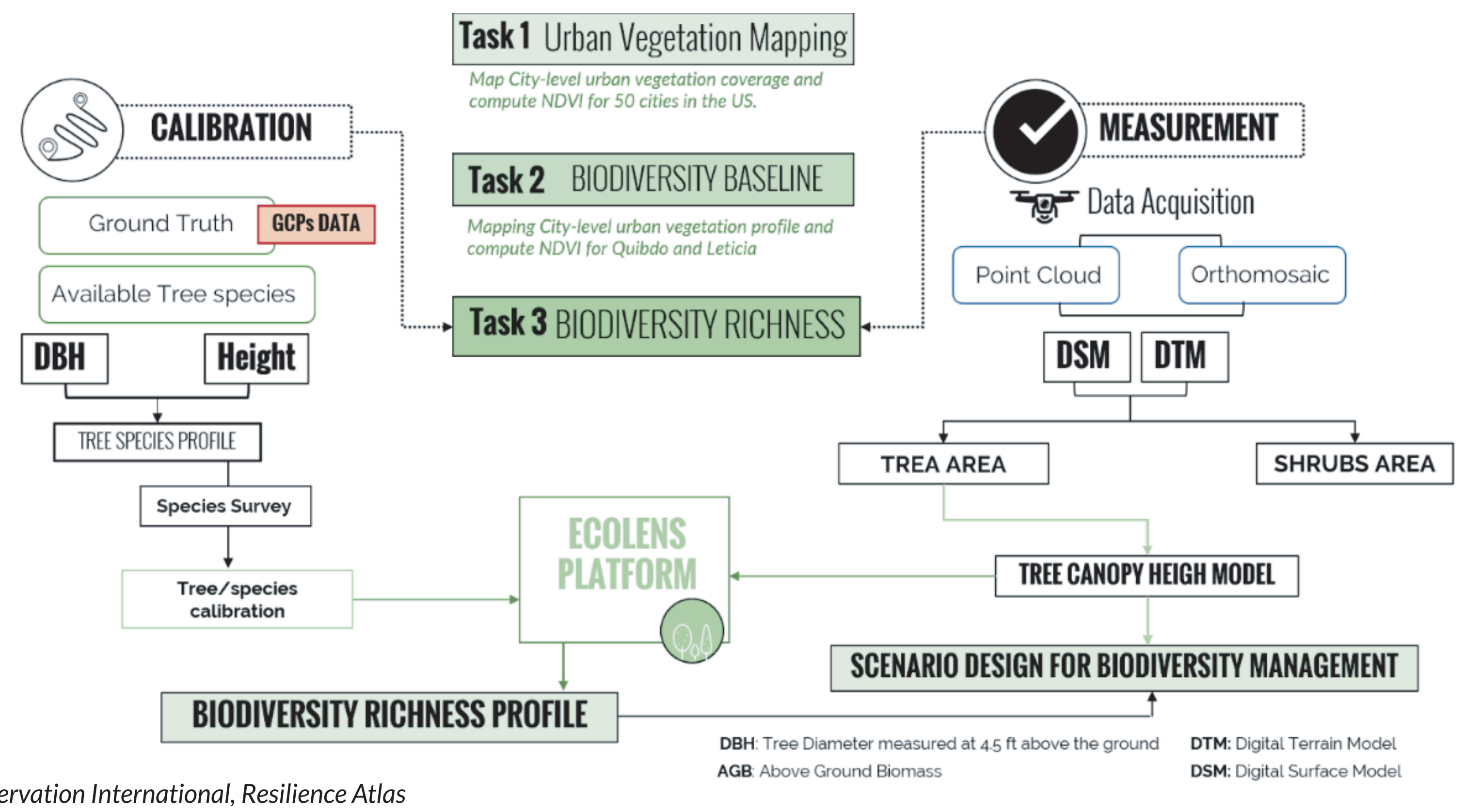


Deep CNN model and Object-Based Classification

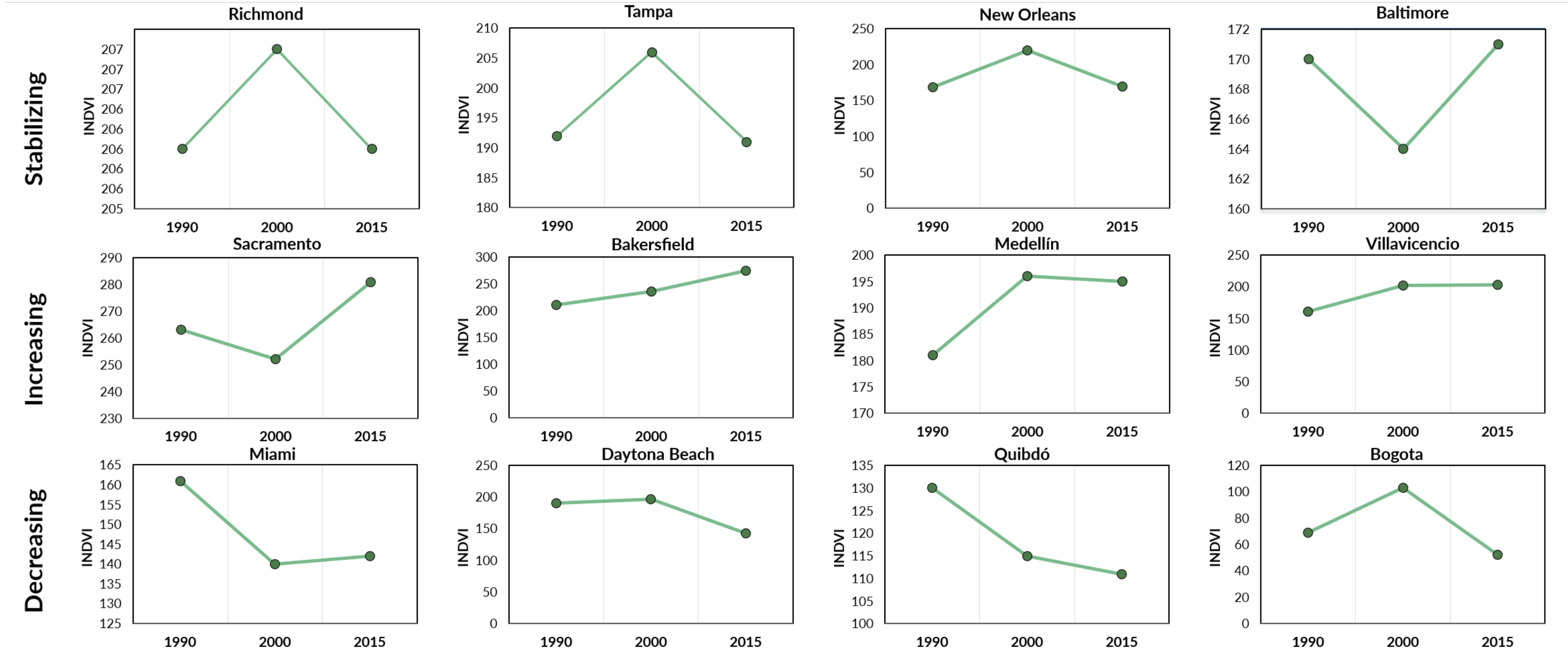
Component 1: Remote sensing. Using high-resolution Sentinel-2 (MSI) multispectral images that are suited to map city-level urban vegetation and non-urban vegetation around a city. The data from Sentinel-2 (MSI) will be used for <u>Task (1) to map urban vegetation coverage</u>.

Component 2: Tree Canopy Identification. Detailed mapping using high resolution LiDAR data collected from Unmanned Aerial Vehicles (UAVs) for <u>Task (2)</u>. Collected data will be used as input to train deep CNN models to <u>detect the individual tree crown delineation</u> using Multiscale Analysis and Segmentation (MSAS) methods to output Tree Canopy Height (TCH) profile.

Component 3: Urban Biodiversity Profile. Output from Task (2) alongside labeled wildlife habitat for various tree types will be used as a training input for <u>Task (3) to output tree class and related urban wildlife habitat</u>.



ECO-LENS Task 1: Urban Vegetation Mapping



Map sources: Weller, Hoch, Huang, Atlas of the End of the World; Conservation International, Resilience Atlas

In situ agriculture & aquaculture microbiome monitoring using scalable optofluidic microscopy

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Motivations & Goal

Microbes is critical in

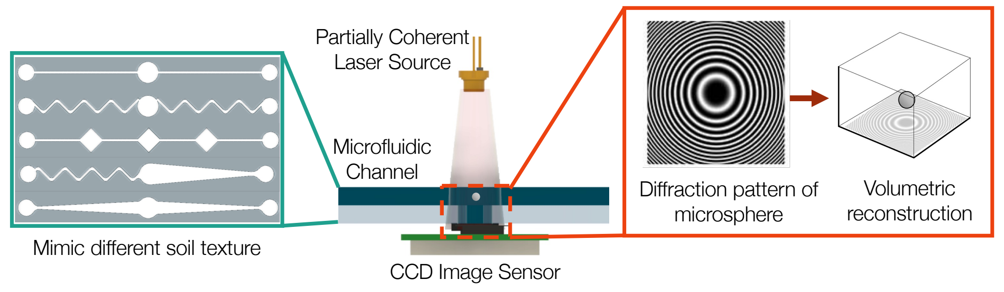
- Global nutrients cycles
- Plant & animal life stability & resiliency
- Land-ocean-atmosphere carbon exchange

Yet it is one of the biggest unknown in global climate change. Understanding and predicting the impact of climate change on microbiomes and the ecosystem services they provide present a grand challenge and major opportunity.

We are developing a real time in-situ continuous microbiome monitoring system using holographic microfluidic microscopy for aquaculture & agriculture resiliency.

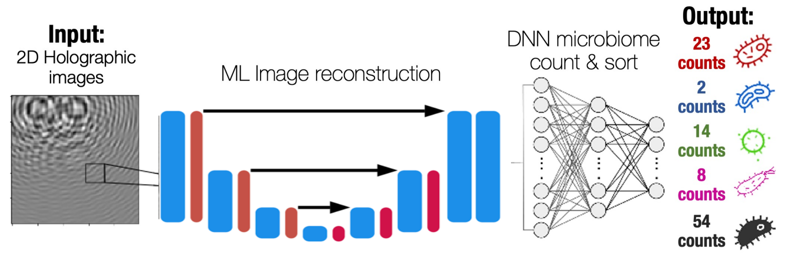
Methodology

Optofluidic microscopy combining lens-free in-line digital holographic microscopes (DIHM) with microfluidic channels for microbes filtering. Scalable design enable higher spatial resolution.



Schematic of DIHM. Coherent light illuminates an object and forms a highly magnified diffraction pattern captured by the image sensor. The 2D diffraction pattern captures 3D information.

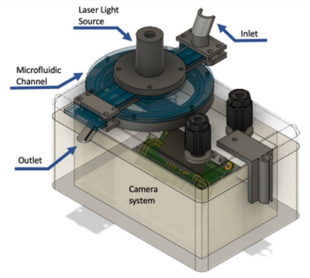
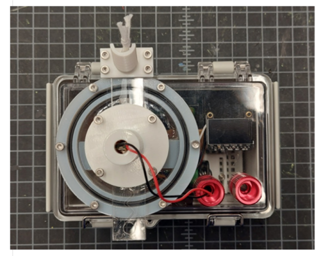
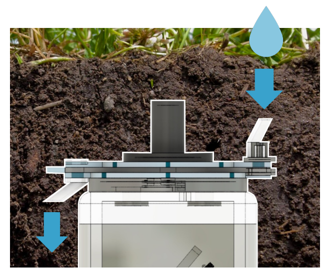
Deep Neural Network for image & volume reconstruction and estimate microbe population distribution. Data collected can be synthesize to monitor crop health and improve resiliency.



The monitoring system is designed for a network of optofluidic sensors and continuous week-long, in-situ monitoring.

Progress

Soil Microbiome Monitoring

1. Bury the sensor under the soil
2. Rain & irrigation carries the microbes through the channel
3. Capture diffraction image of the microbes as they flow through

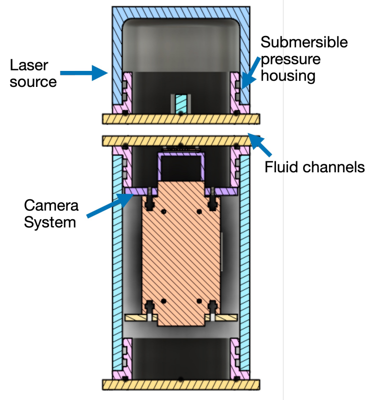
Progress

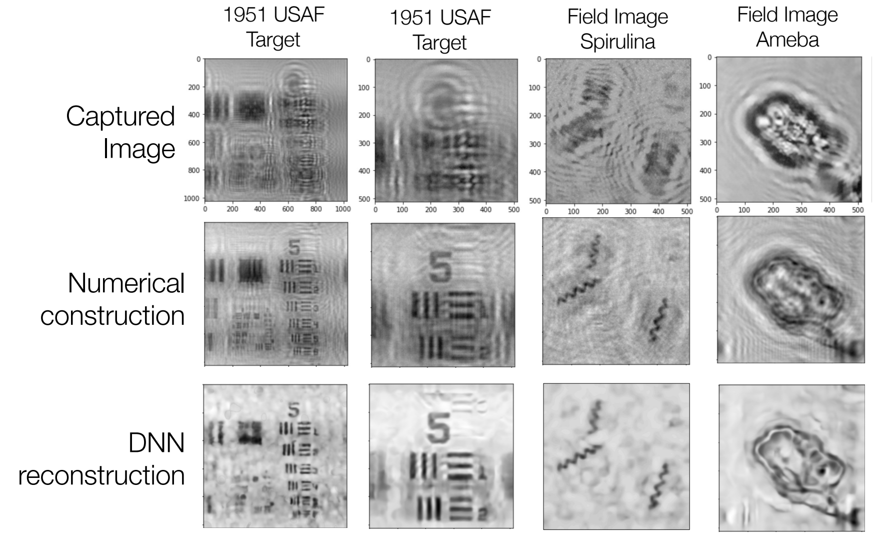
Marine Microbiome Monitoring

Submersible up to ~300m.

Achieved resolution of down to 6um

Frame rate up to 24/sec. With 1 image per 5 minutes, the system can last up to3 days.



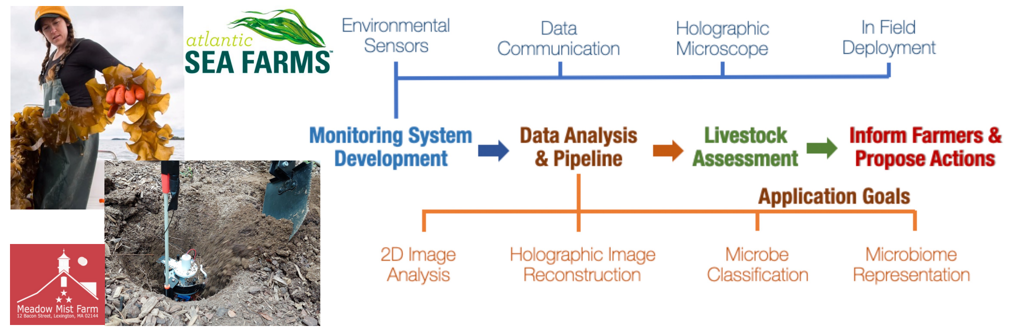
Next step is to reduce reconstruction computation resources and improve speed. Another network will be used to evaluate microbiome population and potentially infer health of crop.

Deployment

Local Wi-Fi LAN — GMS & Cellular Connection

Sensors → Base station → Cloud Storage & Computation → Web portal

We partner with local agriculture farm and seaweed aquaculture farms for deployment and testing.



The novel opto-fluidics monitoring system will further contribute to the modeling and understanding of microbes' activity in the environment and the health of our planet.

References:

[1] M. Bentzon-Tilia, E. C. Sonnenschein, and L. Gram, "Monitoring and managing microbes in aquaculture - Towards a sustainable industry," In *Microbial Biotechnologie,* 2016.

[2] UN FAO. "The Global Status of Seaweed Production, Trade and Utilization", *Fisheries and Aquaculture Policy and Resources Division*, 2018.

[3] Niknam, F., Qazvini, H. & Latifi, H. Holographic optical field recovery using a regularized untrained deep decoder network. *Sci Rep* **11,** 10903 (2021). https://doi.org/10.1038/s41598-021-90312-5

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CP4All: Fast and Local Climate Projections with Scientific Machine Learning

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Fast pocket* climate models help policymakers explore climate decisions

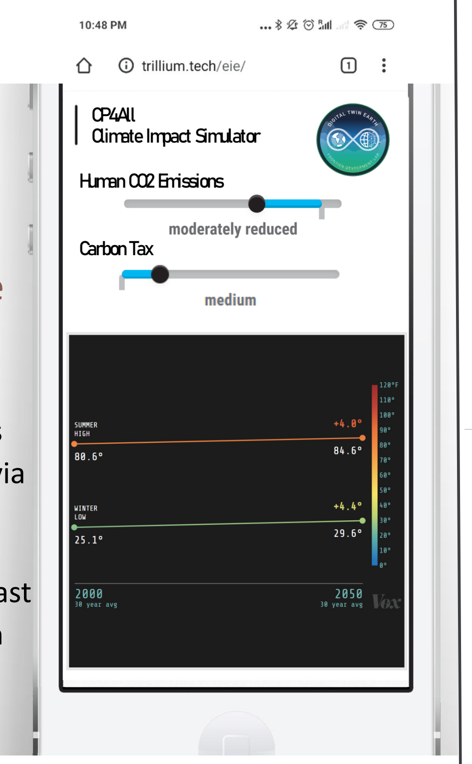
- **Possible**: How will 10% reduction in global deforestation impact global temperature? [1]
  - ✅ Accessible ✅ Education
  - ❌ No local impacts ❌ Inaccuracies from global averages
- **Not possible**: How will local carbon tax impact local climate risks?

Fig. 1.. The MIT en-roads model runs a globally-averaged climate model to help decision-exploration
* O(secs)/simulation year on Intel i7 CPU

Research Question:
Can we leverage SOTA ML to create emulators that can quickly generate useful, accurate local weather statistics for possible future climate scenarios?

CP4All: Climate Impact Simulator

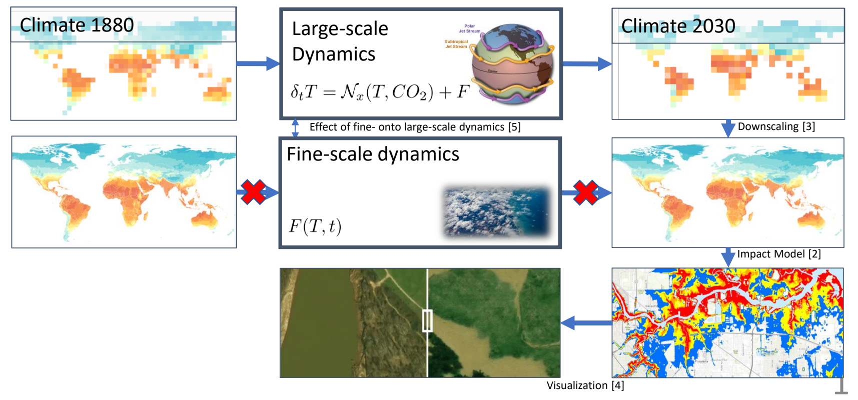
Fast physics-informed neural networks for interactive climate impact assessments



Approach:
- Display local impacts of custom policies
- Enable fast and trustworthy modeling via physics-informed machine learning

Pro:
- ✅ **Accessible** via relatable weather forecast
- ✅ **Education** via fast scenario exploration
- ✅ **Local** relevance via local statistics
- ✅ **Trust** via physical basis

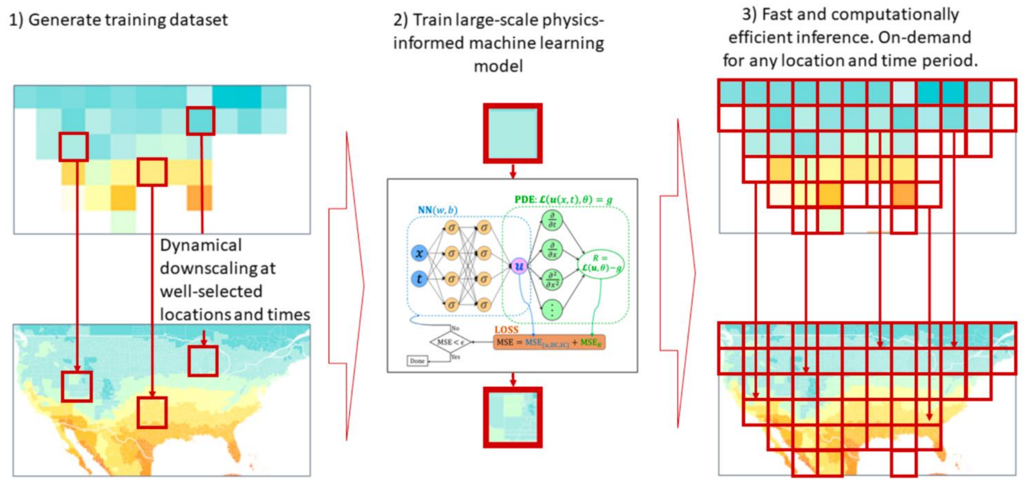
How to generate high-resolution climate impact predictions:



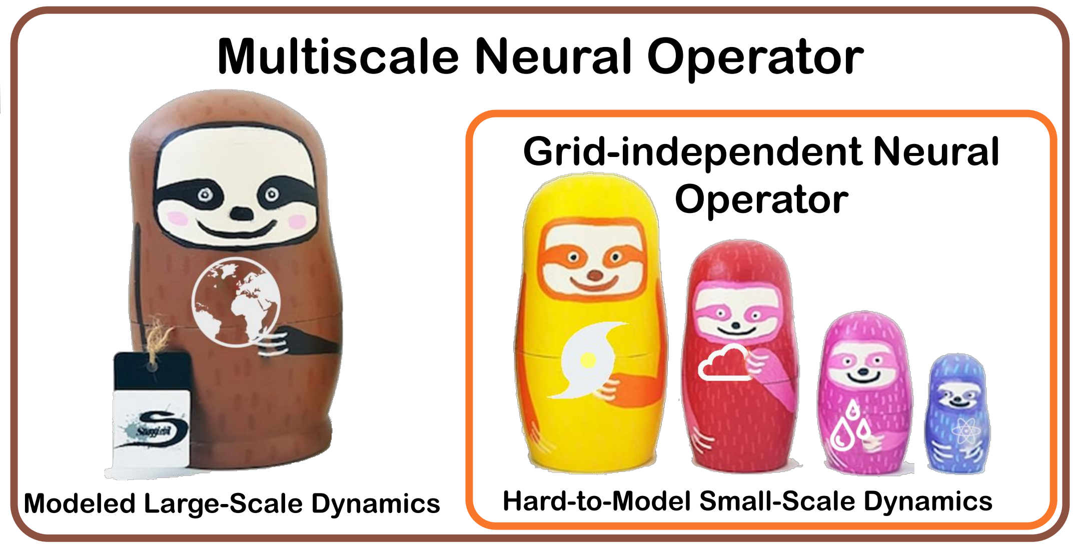
Downscaling climate to weather predictions

Issue:
- Dynamical downscaling models (WRF) of climate projections, e.g., CMIP, are computationally very expensive

Approach:
- Create fast machine learning-based emulator with slightly reduced accuracy, but XXX-times computational speed [2]
- Ensure trust by pioneering novel combinations between neural operators and weather models



Multiscale Neural Operator: Combining Small and Large Scales via Scientific ML



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The Impact of Uncertainty on Wind Energy Modeling

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Massachusetts Institute of Technology, Department of Civil and Environmental Engineering

Civil and Environmental Engineering

Motivations

Research Goals:

- Quantify the effects of uncertainty in wind conditions on the prediction of wind farm annual energy production (AEP) and efficiency
- Study and model the effect of wind shear on single turbine power production, including direction shear, an often-neglected component

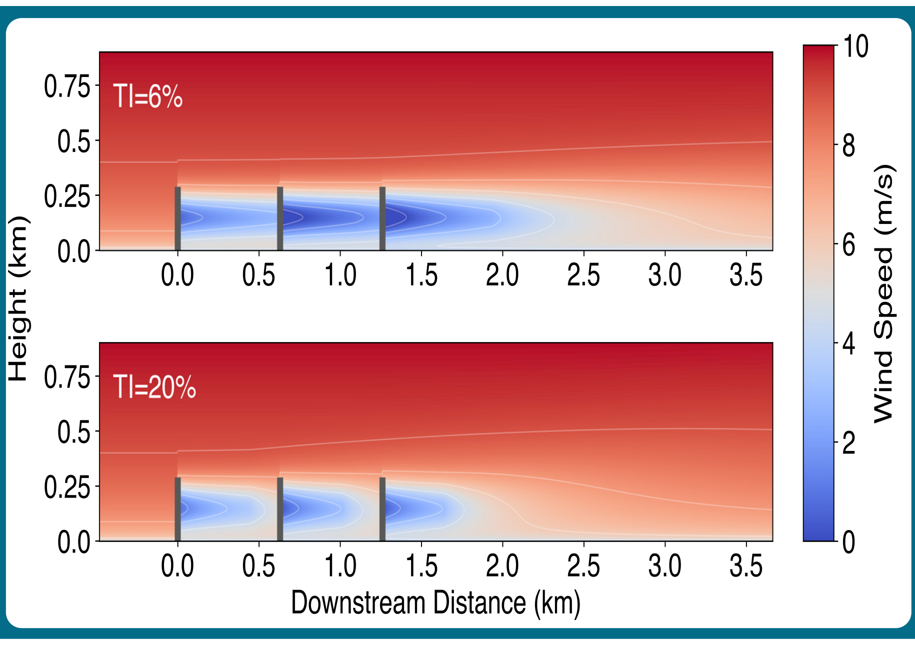


Fig. 1 Wind speed is shown for an array of three IEA 15MW[1] turbines. The top figure has a turbulence intensity (TI) of 6% and the bottom figure has a TI of 20%. With a higher value of TI, the wake losses in the bottom array of turbines are reduced, leading to higher AEP and efficiency.

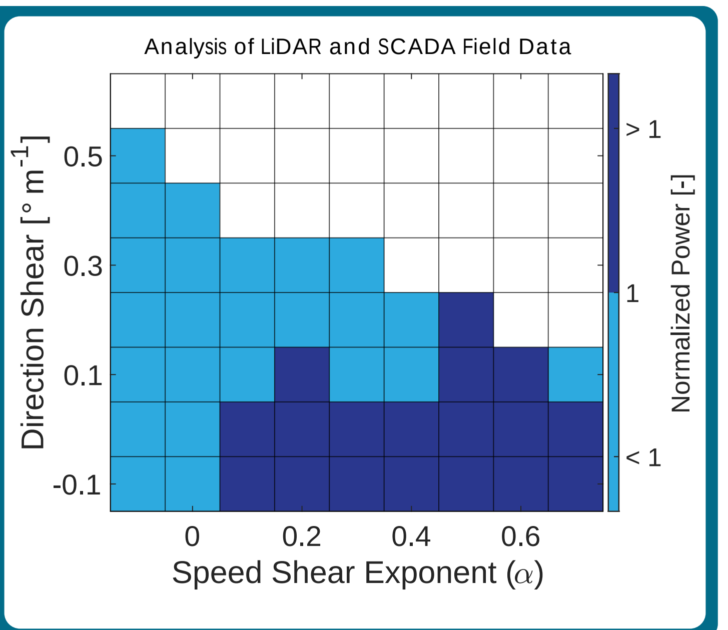


Fig. 2 Normalized turbine power production with different wind shear combinations. Two distinct performance regimes are evident: 1. low performance with low speed shear and high direction shear, (light blue region), and 2. high performance with high speed shear and low direction shear (dark blue region). This trend is qualitatively consistent with a similar study conducted by Sanchez Gomez and Lundquist[2] with data from different turbines at a different geographic location.

A. Characterizing Input Uncertainty in Vineyard Wind 1 Predictions

Hypothesis:

Uncertainty in wind conditions, acquired from different data sources, has a measurable effect on the prediction of AEP and farm efficiency

Approach:

Use data from two different sources: 1. LiDAR from the Air Sea Interaction Tower at the Martha's Vineyard Coastal Observatory run by the Woods Hole Oceanographic Institute (MVCO LiDAR)[3], and 2. numerical weather prediction data from the Wind Integration National Dataset Toolkit at the location of the Vineyard Wind 1 farm (NWP VW1)[4]

Calculate Annual Energy Production (AEP) and farm efficiency for VW1 with the two different datasets over a range of years using FLORIS[5], a steady-state wake modeling tool

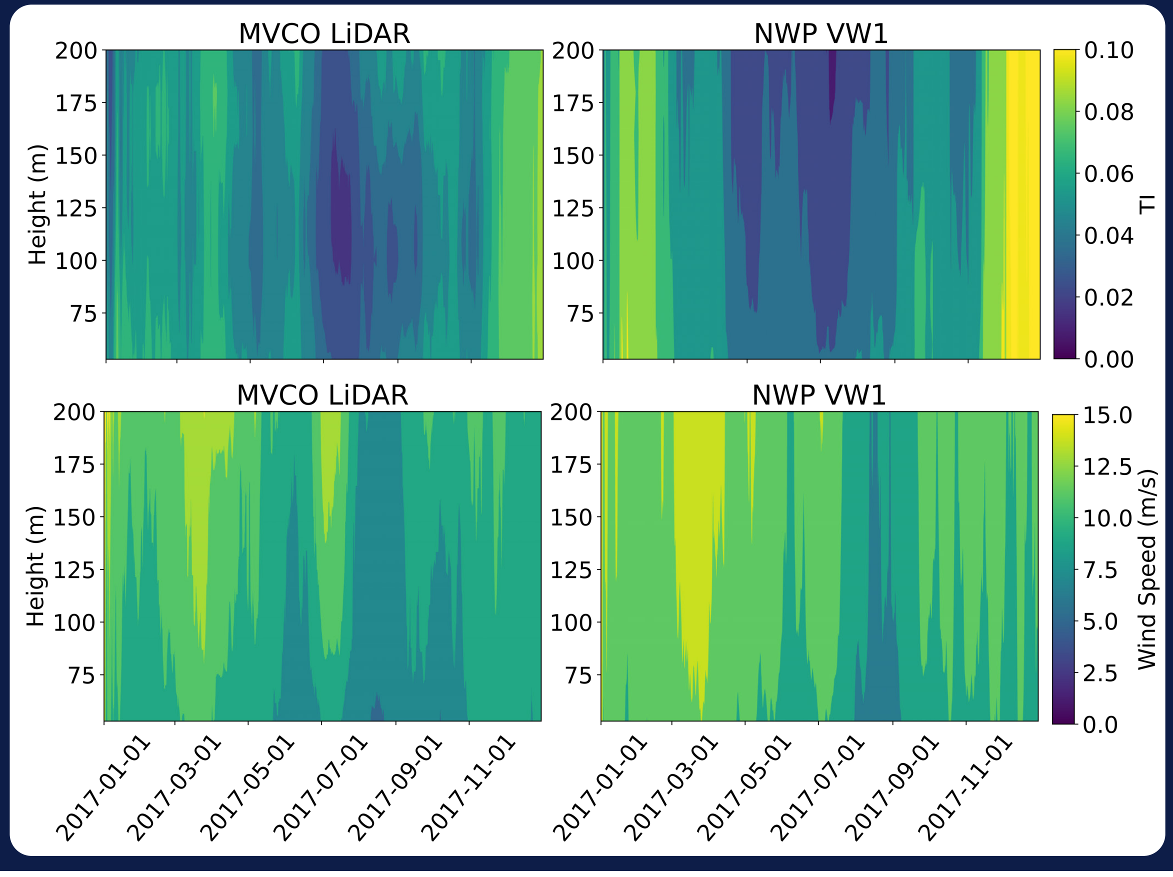


Fig. 3: Annual cycle of turbulence intensity for 2017 for the two different data sources. Trends in seasonal variability are replicated in the two datasets, but trends with height are divergent. Data have been smoothed using a 30-day rolling mean at each height.

Fig. 4: Annual cycle of wind speed for 2017 for the two different data sources. Trends in seasonal variability are replicated in the two datasets, as are trends with height. Data have been smoothed using a 30-day rolling mean at each height.

B. Development of an Analytical Model for Turbine Power Production

Hypothesis:

It is possible to replicate the trends shown in Fig. 2 with a sufficiently detailed model that incorporates information about wind shear incident on a turbine rotor

Approach:

Build on a previous model[6] using blade element theory to resolve forces on the turbine blades that contribute to power output

Determine how the model performs when given idealized wind speed and direction profiles

Subsequently, use a unique LiDAR dataset of wind conditions as inputs to the developed model and compare power predictions to Supervisory Control and Data Acquisition (SCADA) data recorded during the same period

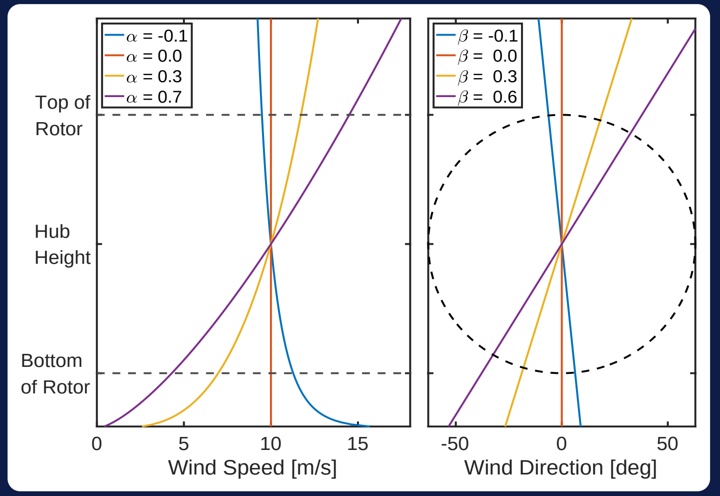


Fig. 5: An illustration of speed and direction shear as used on the axes in Figs. 2, 6, and 7. Speed shear is characterized by the exponent of the power law fit to the wind speed profile as a function of height (left plot and equation below). Direction shear is the degree of turning (in degrees per meter) from the bottom to the top of the rotor (right plot).

The Power Law: $u(z) = u_{ref}\left(\frac{z}{z_{ref}}\right)^{\alpha}$

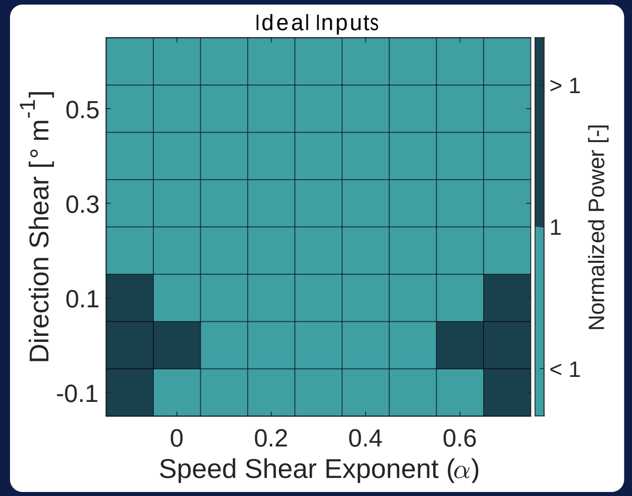


Fig. 6: The predicted normalized power output from a blade element model that takes in idealized wind speed and direction profiles as a function of height as shown in Fig. 5. Notably the empirical trend is absent when idealized profiles are used, indicating a limitation in their use for quantifying the effect of shear on power production.

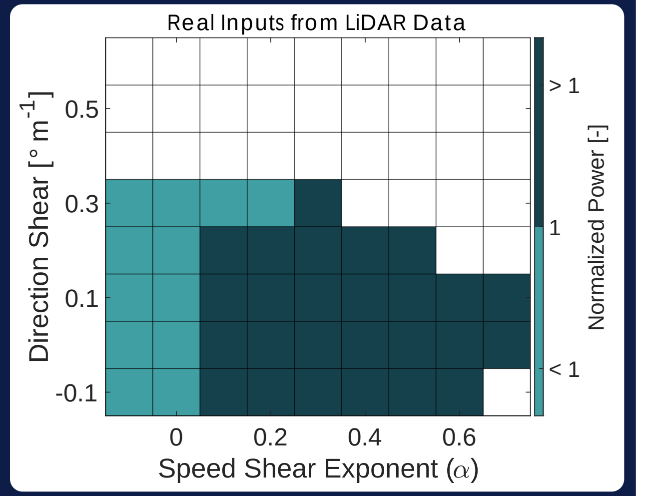
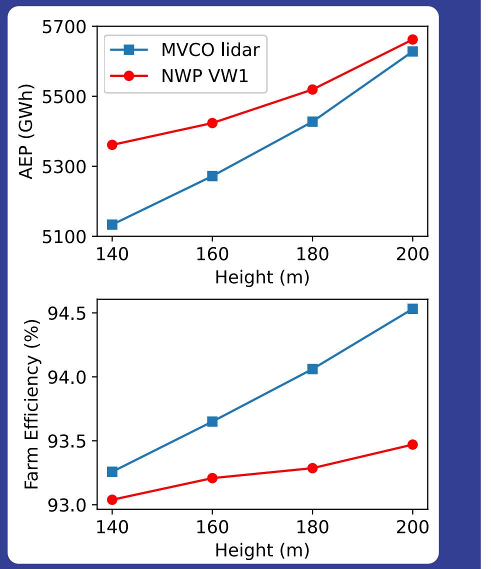


Fig. 7: The predicted normalized power output from a blade element model when given the same three inputs from real wind speed and direction LiDAR measurements. The model roughly replicates the empirical trend shown in Fig. 2.

Conclusions

- Uncertainty in the data source has a significant effect on predictions of AEP (4.4%) and farm efficiency (1.1%)

Fig. 8: Predictions of mean AEP (top) and mean farm efficiency (bottom) for the Vineyard Wind 1 farm with the LiDAR data (MVCO LiDAR) and the numerical data (NWP VW1). Differences between these two data sources are indicative of uncertainty. Uncertainty in AEP decreases with increasing height from 4.4% to 0.6% and uncertainty in farm efficiency grows with increasing height from 0.2% to 1.1%.



- Similar effects of wind shear on turbine power production are observed between two geographically and topographically distinct locations, indicating this trend is not site-specific
- Preliminary results with the blade element model employed here illustrate the utility of a physics-based model for turbine power production
- Continued exploration of the effect of uncertainty in wind conditions is shown here to be useful for modeling single-turbine power production, AEP, and wind farm efficiency, which has implications for future wind farm siting and design

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Enabling Rapid Assessment of Marsh Ecosystem Services and Resilience using Drones and Modeling

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Nepf Lab https://nepf.mit.edu/

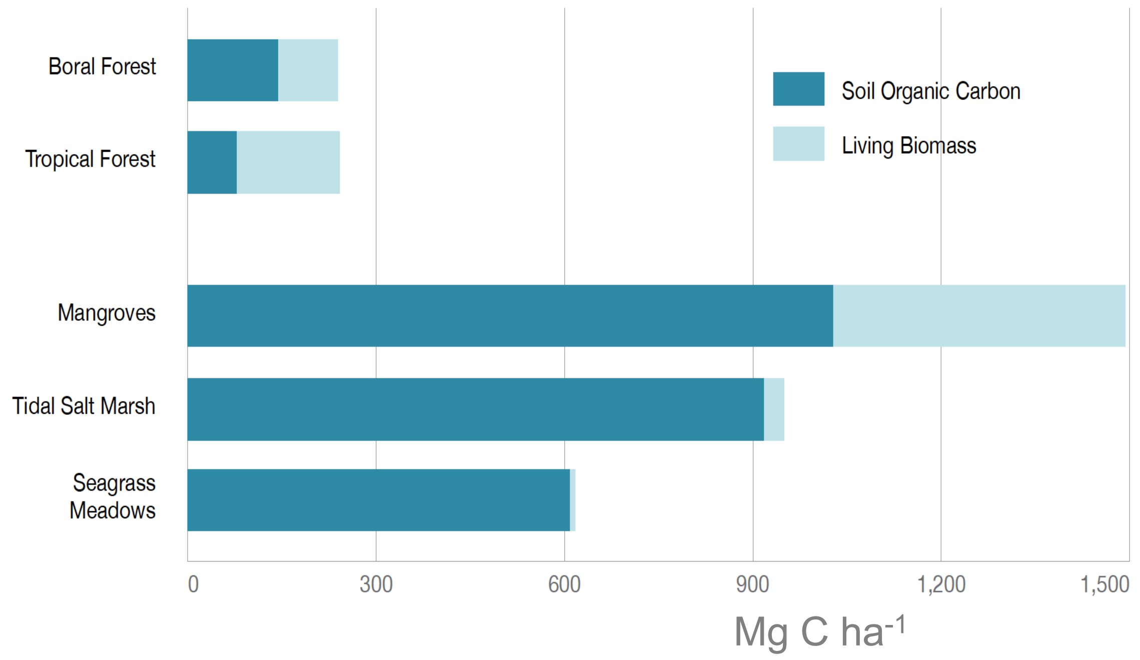
Dr. Megan Tyrrell, Director, Waquit Bay National Estuarine Research Reserve

Samantha Chan, MIT Graduate student; Trinity Stallins, MCSC UROP

Green Infrastructure: Adaptation

During Hurricane Sandy coastal marsh reduced flood damages by 625 million dollar
[Narayan et al. 2017]

Green Infrastructure: Mitigation



Howard et al (2014), based on Pan et al. (2011), Fourqurean et al (2012), and Pendleton (2012)

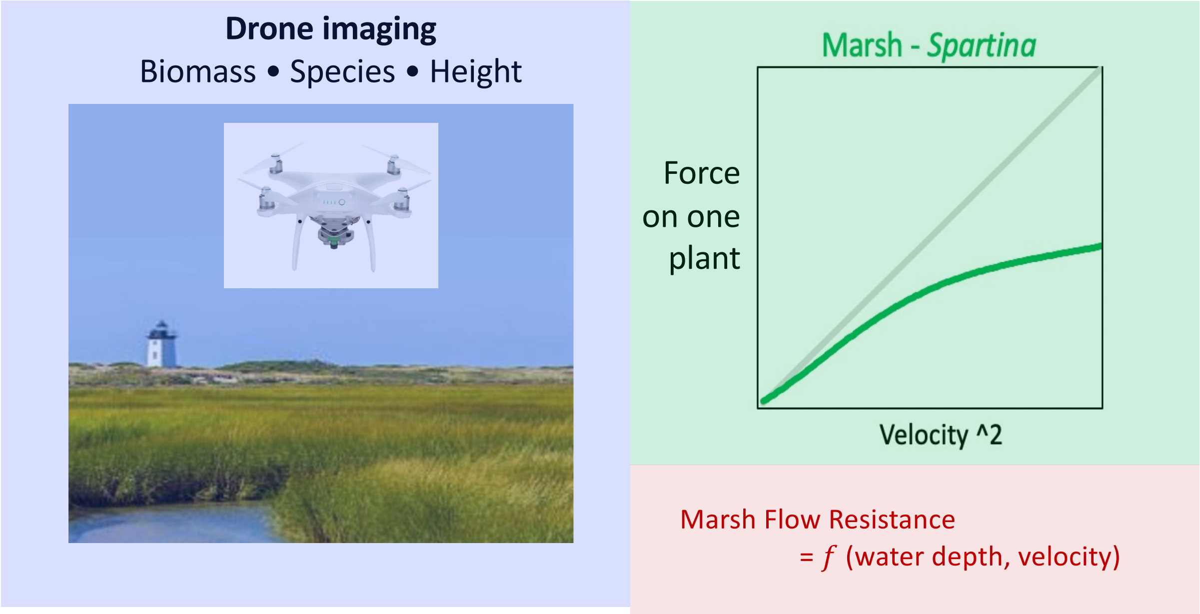
Coastal Flood Mitigation

The flow resistance provided by coastal marshes mitigates flooding by slowing storm surge and damping waves. The flow resistance (drag) provided by a marsh varies with seasonal growth, marsh loss to erosion, and marsh area gained by restoration. A quick method to measure marsh drag would enable more accurate predictions of a marsh's impact on coastal flooding, improving coastal planning, and risk assessment.

Ecosystem Services

Marshes provide additional ecosystem services, such as carbon storage, habitat, and water quality improvement. A quick method to measure and monitor changes in marsh structure and vegetation health would facilitate assessment of marsh economic value and resilience.

Marsh-Scale:
(plants per area) X (drag per plant) = (drag per area)



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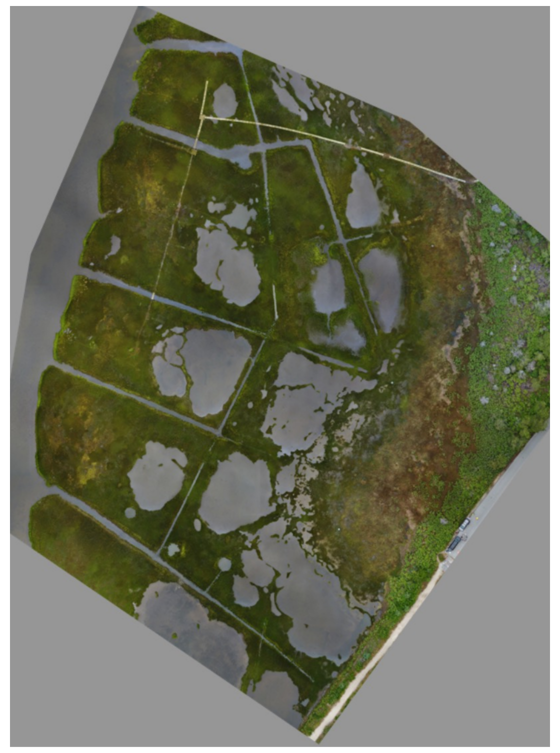
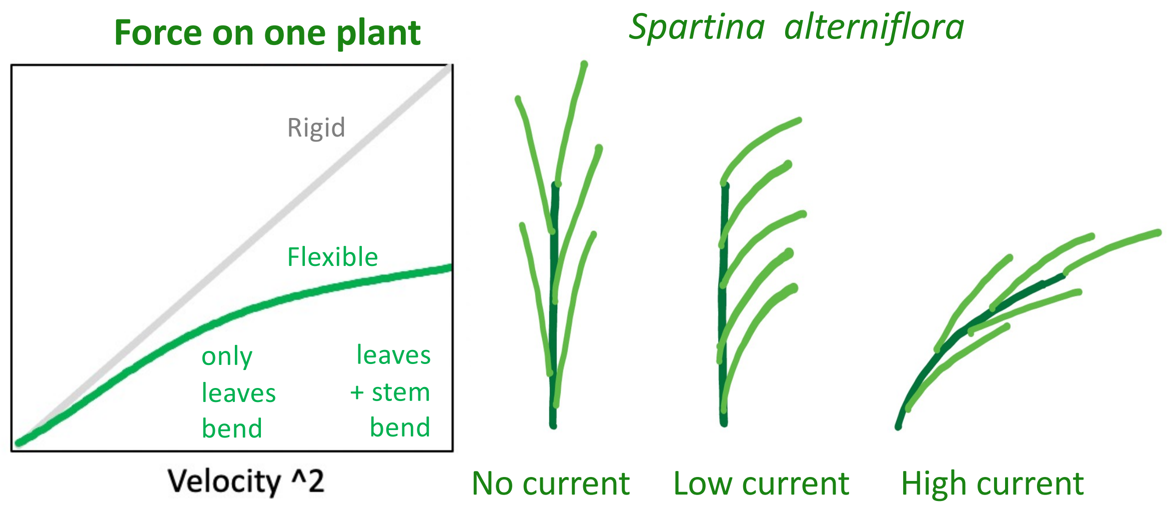
RESERVE

massDOT
Massachusetts Department of Transportation



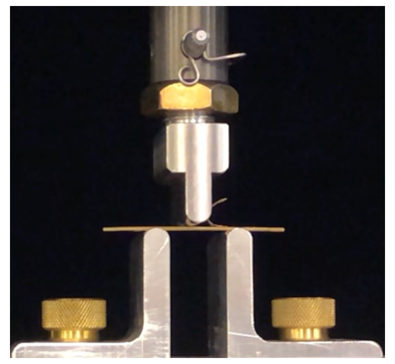
Plant-Scale: Drag is a function of plant rigidity and morphology

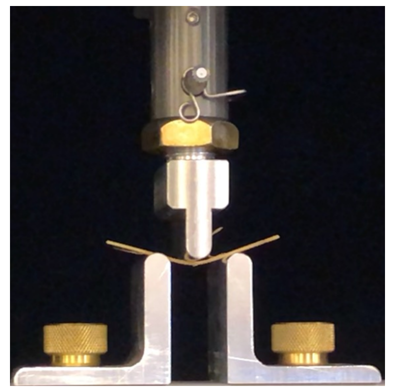
$$Ca = \frac{1}{2}\frac{\rho C_D\, U^2 D L^3}{EI}$$

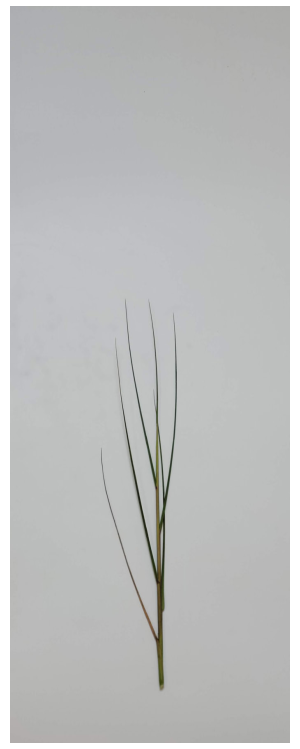


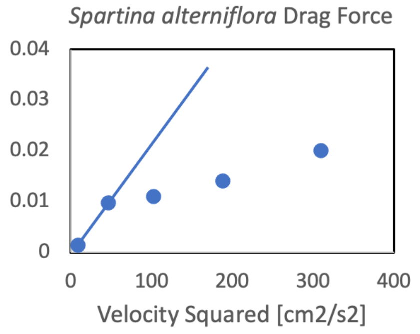
Reconfiguration = bending and motion of plant in response to current and wave

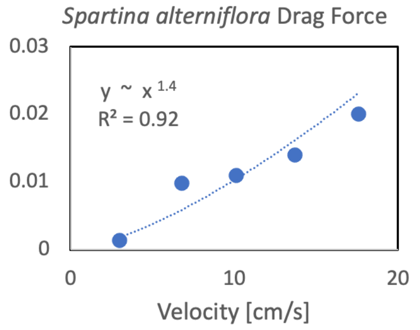
Plant Material Properties

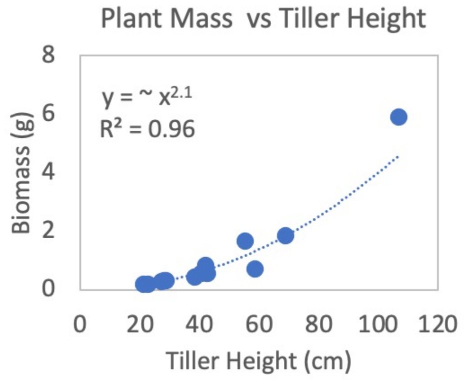


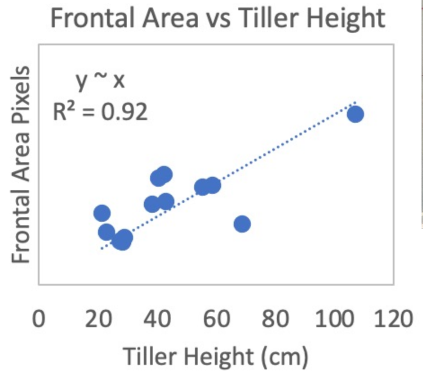












Thermochemical H_2O and CO_2 Splitting for Renewable Syngas and Transportation Fuels

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MITMECHE

Centers for Mechanical Engineering Research and Education at MIT and SUSTech

Thermochemical Redox Cycles: Heat-driven H_2O/CO_2 splitting

Step 1. Metal Oxide Reduction

T = 1400-1500°C
$p_{O_2} < 10$ Pa

$$MO \rightarrow M + \frac{1}{2} O_2$$

M →
← MO

Step 2. H_2O and CO_2 Splitting

$$M + a.H_2O + b.CO_2 \rightarrow MO + a.H_2 + b.CO$$

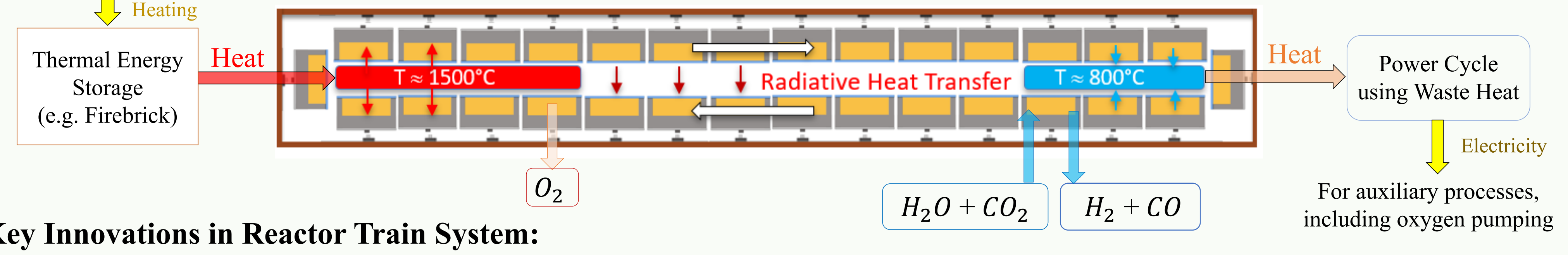
T = 700-1000 °C
p = 1 bar

MO – Metal Oxide (e.g. CeO_2, $MgFe_2O_4$, $LaMnO_3$)
M – Reduced Metal Oxide (e.g. $CeO_{2-\delta}$ – Oxygen vacancies)

Reactor Train System: Novel System for *efficient and continuous* syngas production

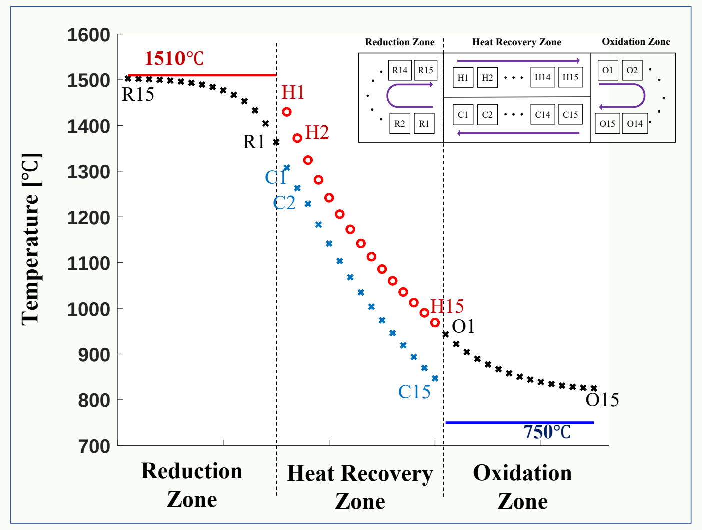
Renewable electricity during low price periods

- Heat-to-Fuel conversion efficiency = 37-42% (6X of existing state-of-the-art).
- Continuous fuel production despite wind/solar intermittency.

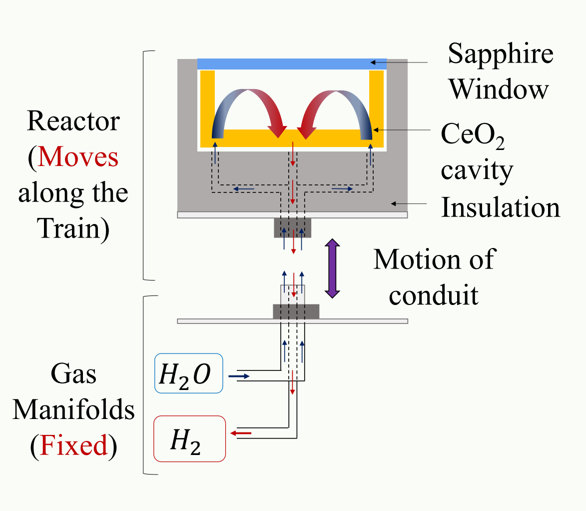


Key Innovations in Reactor Train System:

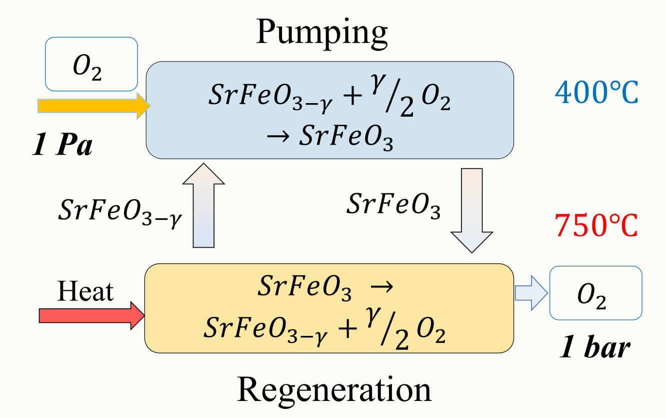
Internal Heat Recuperation > 80%



Mass Transfer System

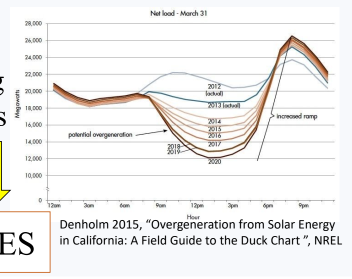


Thermochemical Oxygen Pumping



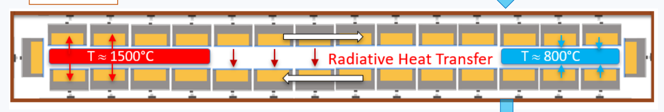
Liquid Hydrocarbon Production at Competitive Cost

Renewable electricity during low price periods



TES

32% LHV efficiency



Heat Integration

H_2O
- Seawater Desalination

CO_2
- Peaker power plants
- Cement/Steel
- Direct Air Capture

H_2 + CO

71% LHV efficiency with Heat Integration

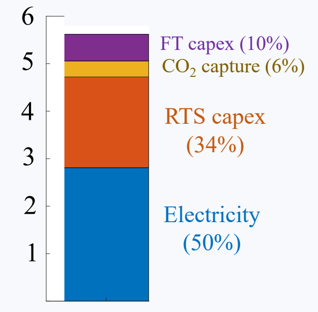
Syngas-to-Liquid
- Fischer Tropsch
- Hydrocracking of wax
- Steam/dry reforming of C_1-C_4

Jet Fuel (55%) + Naphtha (45%)

Cost of Liquid Hydrocarbon [$/gal]

Off-peak elec. cost	CO_2 capture cost: $20/ton	$40/ton	$100/ton
$5/MWh	$3.35	$3.53	$4.07
$10/MWh	$4.04	$4.22	**$4.77**
$20/MWh	$5.44	**$5.62**	$6.16

- Fossil Jet fuel cost ~ $2.40/gal
- IRA Tax credit ~ $1.6/gal



$/gallon ($20/MWh, $40/ton)

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MIT CLIMATE GRAND CHALLENGE

BRINGING COMPUTATION TO THE CLIMATE CHALLENGE

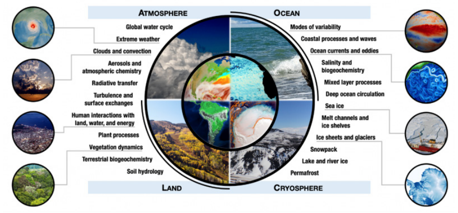
GOAL

To develop a novel platform that leapfrogs existing climate decision-support tools by leveraging artificial intelligence (AI) approaches to both improve the accuracy of Earth System Models (ESMs) used to make climate projections and to derive reduced models trained with full ESMs that are cheap to run and provide actionable information for stakeholders.

OBJECTIVE 1

Develop an ESM which makes accurate climate projections with quantified uncertainties. This objective complements and expands the work done by the Climate Modeling Alliance (CliMA) by developing additional components which are essential if the ESM is to be used to provide actionable information for stakeholders. As part of this effort, we aim to:

- Develop and test an ocean carbon cycle model
- Couple the atmosphere, ocean, and land components of the new ESM
- Incorporate human system components
- Propagate the uncertainty from individual ESM components to the overall uncertainty of the climate projections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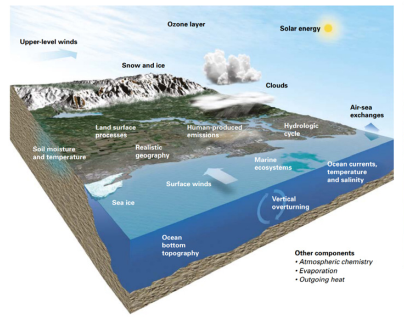
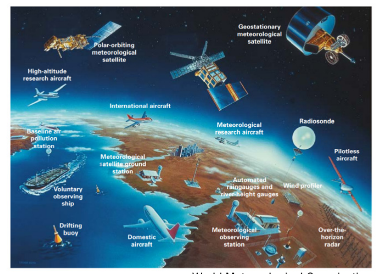
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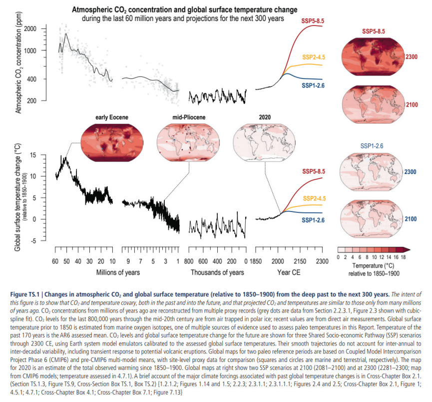
OBJECTIVE 2

Develop robust and flexible procedures to derive simple surrogate models trained with the full ESM to predict a subset of climate variables of interest for specific applications. This objective centers on the development of new emulator approaches. Specifically, we aim to:

- Improve emulator techniques based on model output
- Develop a novel emulator approach based on model code
- Design the architecture to interface between emulators and users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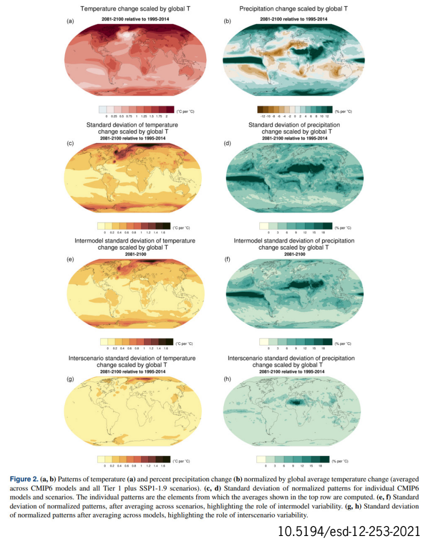
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OBJECTIVE 3

Address stakeholder needs through pilot test cases. Stakeholder engagement is critical to the successful implementation of our project. In order to achieve this objective we will focus on a set of Pilot Test Cases that connect our work to the end users. Prospective cases include:

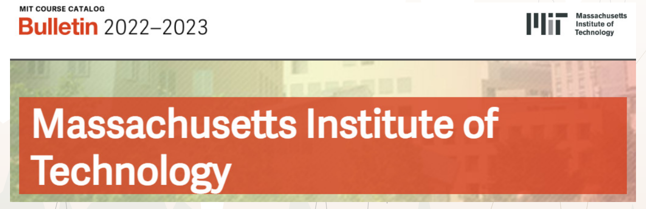
- Users of Climate Interactive's En-ROADS model who are interested in gridded projections of climate impacts
- Member companies of the MIT Climate & Sustainability Consortium
- Users interested in localized predictions of heat, air quality, & extreme weather events (joint with our peer MIT Climate Grand Challenge projects)

MCSC MIT Climate & Sustainability Consortium

CLIMATE INTERACTIVE tools for a thriving future

OBJECTIVE 4

Train a new generation of climate model developers and users who can help inform action by offering classes that introduce MIT students to the work done by the BC3 team. A first year class, "Julia - solving real world problems with computation", will introduce students to the real world problems of climate change and epidemics using some of the software tools being developed as part of BC3.



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Themistoklis Sapsis, Youssef Marzouk, Elsa Olivetti, Tamara Broderick, Alan Edelman, Arlene Fiore, Glenn Flierl, Christopher Knittel, John Marshall, Bethany Patten, Chris Rackauckas, Daniela Rus, Adam Schlosser, Andre Souza, Gregory Wagner, Claire Walsh, Jennifer Morris, Sebastian Eastham

Sensitivity analysis of modular heterocycles for CO_2 capture

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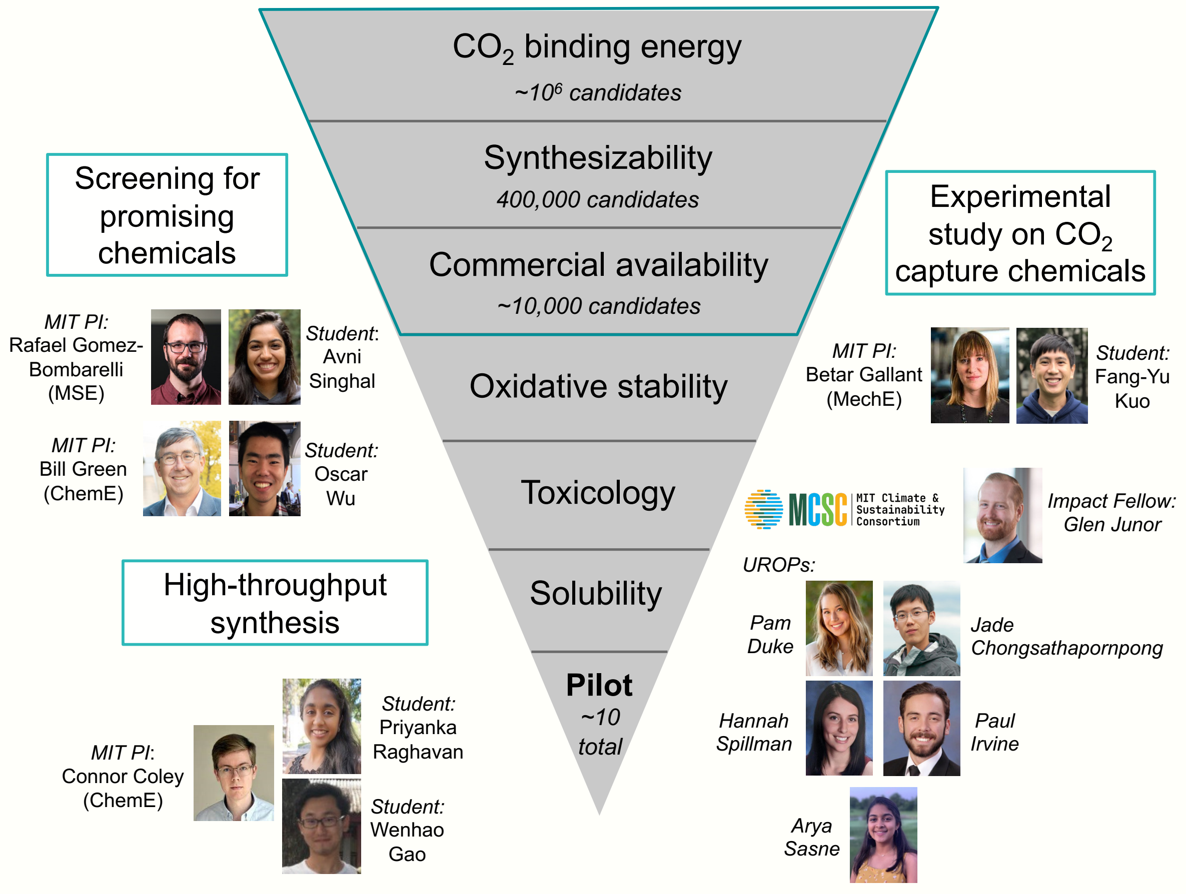
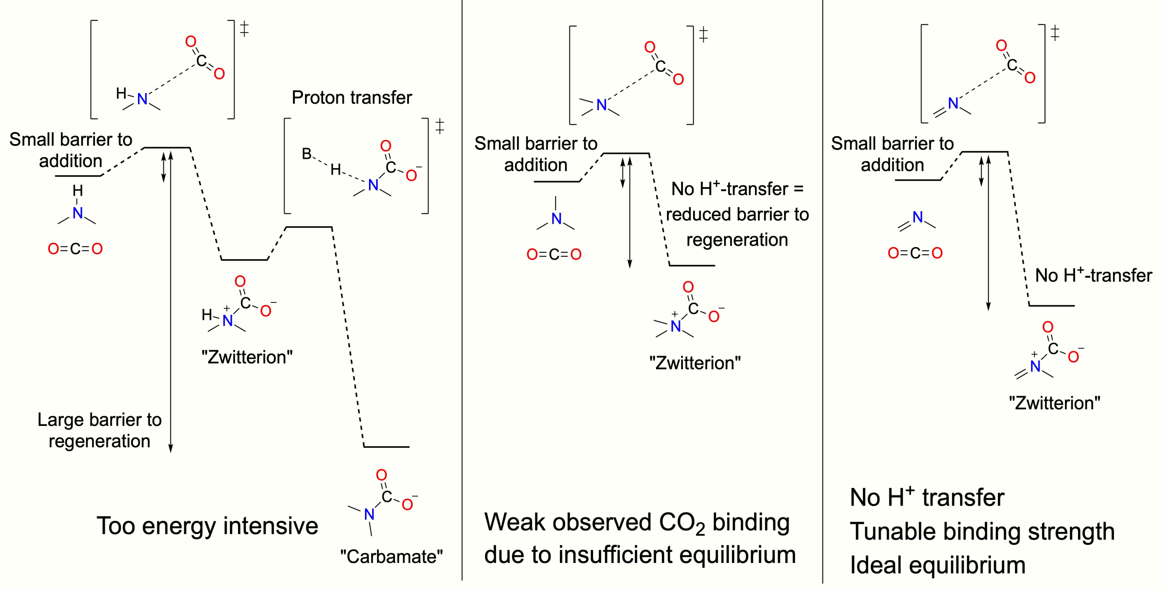
Project overview

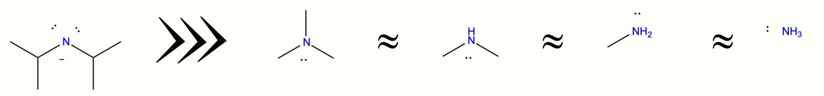
Develop structure-activity relationships to characterize stronger and weaker CO_2 binders and design optimal binders through a modular approach



Binding energy of amines



Alkylamines



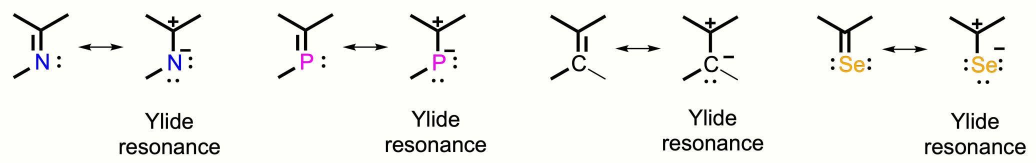
Conjugate Acid pKa	36	9.76	10.64	10.62	10.5

Large jumps — Minimal tunability

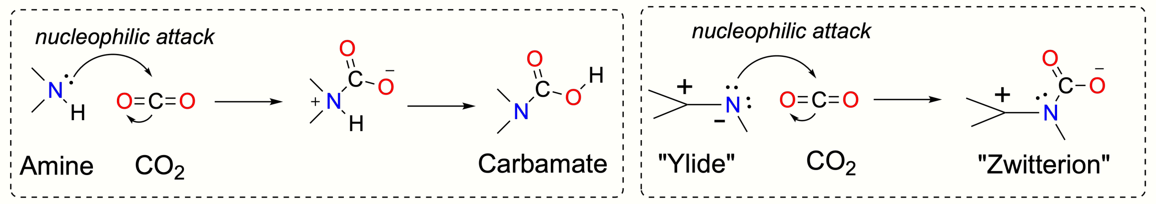
Interest in exploring additional classes of potential CO2 binders with high tunability in binding energy that do not experience H+ transfer

Ylide binding mechanism and tunability

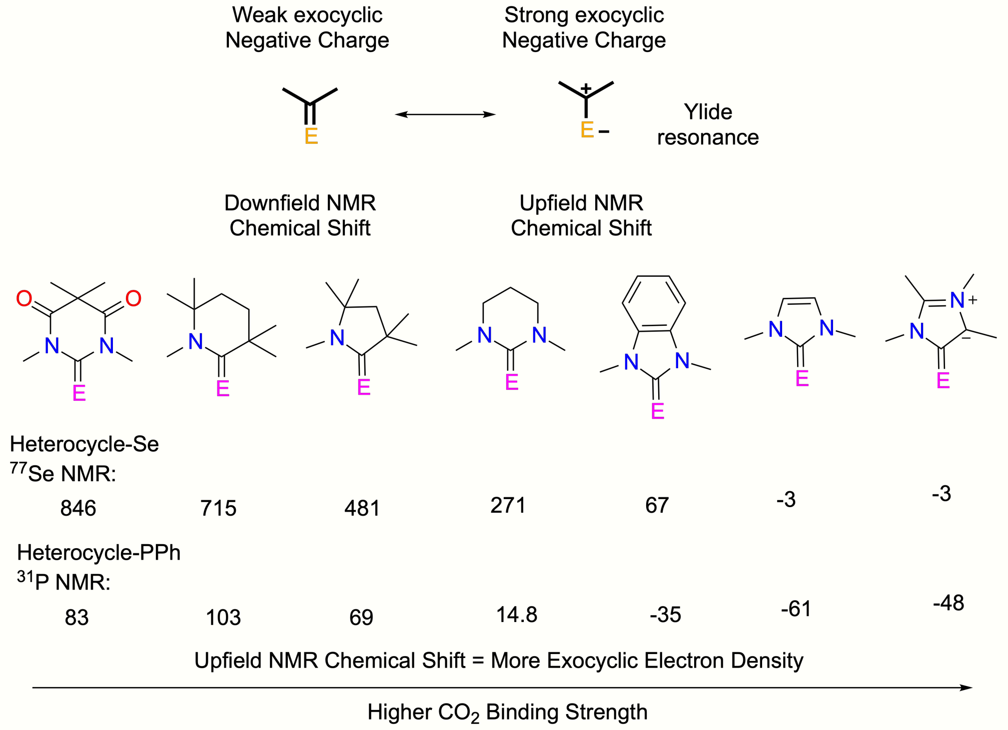
Ylide Scaffolds



Arrow-Pushing Mechanism

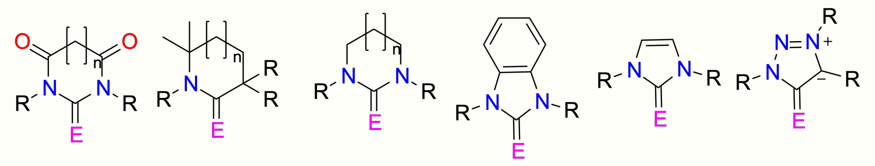


Effects of Heterocycle on Exocyclic Electron Density

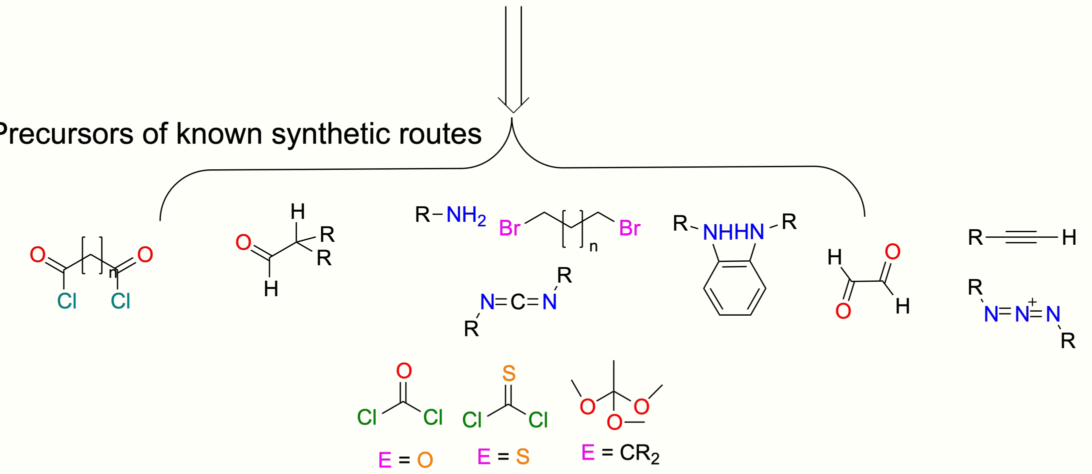


Enumeration of ylide candidates

Heterocyclic Ylides

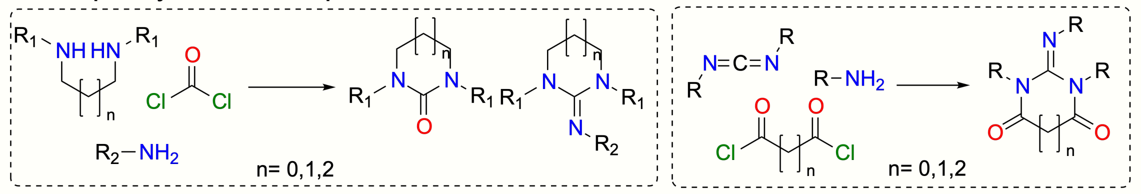


Precursors of known synthetic routes



Computational methods

Example synthesis templates

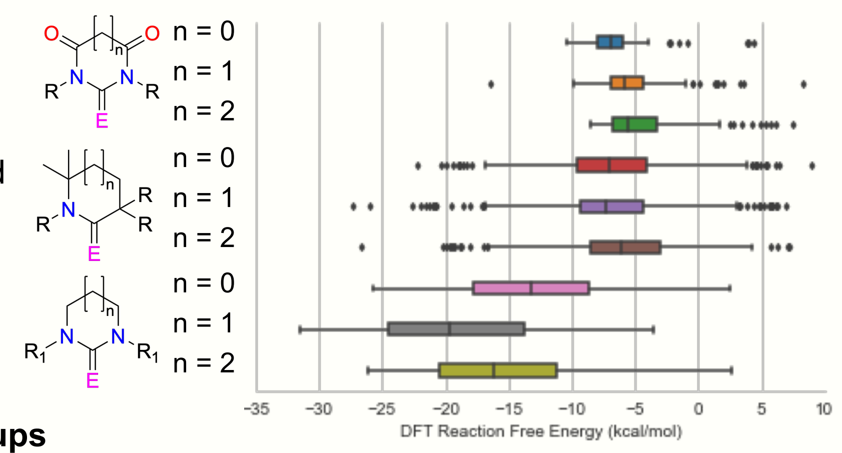


- Database of 6+ million commercial molecules scraped from online chemical catalogs represented as SMILES
- SMARTS reaction templates used to substructure-match potential CO_2 binders based on precursors of known synthetic routes
- Additional reaction templates used to enumerate all CO_2 binding modes for each candidate molecule
- High-throughput DFT pipeline to generate conformers and calculate free energies at (U)B3LYP-D4/def2-SVP level of theory

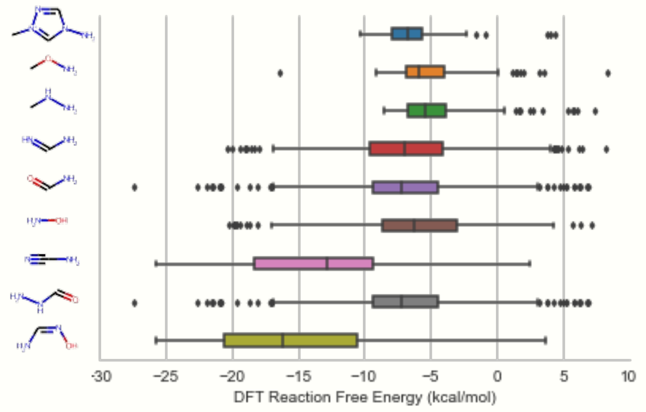
Preliminary trends

Heterocycles

Free energies of CO_2 binding for candidates produced from 9 heterocycles (~ 3000 molecules)



Binding Groups



Free energies of CO_2 binding for candidates produced from 9 binding groups (40+ molecules per group)

Core structure, ring size, and binding group can each have significant influence on range of achievable binding energies

Summary

- Ylides are a promising class of potential capture molecules due to their ability to tune CO_2 binding through both the reactive atom center and attached heterocycle
- Sensitivity analysis of the influence of peripheral structural changes can support design of a framework that displays optimal performance characteristics while balancing tradeoffs in other properties

Acknowledgments

This work was supported by the MCSC and the NDSEG fellowship.

MCSC MIT Climate & Sustainability Consortium NDSEG

Climate & Sustainability Consortium

MIT MANAGEMENT SLOAN SCHOOL

Carbon Sequestration through Sustainable Practices by Smallholder Farmers

A Data-driven, Community-centered Approach

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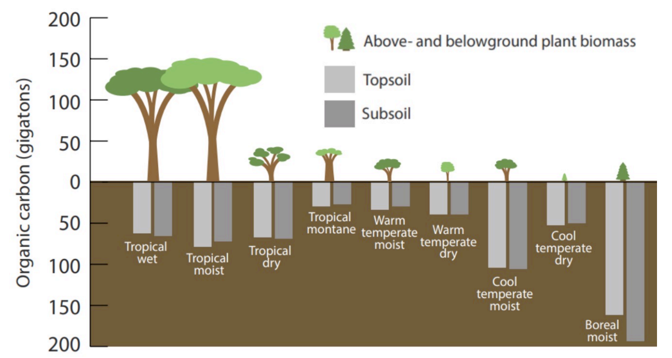
Motivation

- Nearly 20% of humanity's yearly carbon footprint can be sequestered by farmers through sustainable agricultural practices.
- Carbon rewards can be offered to farmers as incentives, financed by the global carbon markets



How to design effective incentive systems based on carbon measurements to motivate large-scale sustainable practices?

Additionality | Permanence | Leakage | Verifiability

Challenges and Design Questions

Data-driven resource allocation

- Different landscapes and agricultural activities differ in carbon sequestration potential and costs
- Targeted planning based on geospatial, social-economic data and biological modeling to maximize desired environmental and social impact

Payment for outcome

- Coping with external uncertainties and nonlinear biological processes
- Evaluating the impact of payment delays due to outcome verification
- Providing transparency and involving the local community in outcome monitoring

Working as a group

- Group efforts can lead to greater impact and easier monitoring
- Success depends on behavioral/social preferences
- Challenges include heterogenous opportunity costs, moral hazard and free-riding in teams

- Field visits, stakeholder interviews
- Data collection & analysis

Develop Models

- Simulation, Statistical analysis
- Optimization, game theory

Understand

Objective

Hypothesis & candidate schemes

Controlled experiments

- Policy recommendations
- Update model

- Experimental Design

Design research questions with collaborators to ensure maximum impact

DARE TO INVENT THE FUTURE

Trans-Hemispheric Knowledge *in the Service of and through Doing*

Dare to Invent the Future is a program of research, teaching, and design/making addressing two questions:

- *1. How may we deploy our diverse living experiences and ways of seeing, thinking, knowing and doing across the world so that each culture brings its unique and indispensable perspective to help us holistically understand a specific problem common to all of us and together design-build sustainable solutions to it?*
- *2. What if responsibility to community, to others, and the planet was the basis for the courses we choose to teach or take, the problems we investigate, or the things we invent?*

Inspired by one of Thomas Sankara's most famous speeches, this project derives from my conclusion that we can not rely solely on the knowledge systems, methods, and tools that created the climate crisis, systemic racism, colonialism, and global poverty in the first place to reform themselves or self-correct. This discipline-based knowledge system excluded ways of seeing, thinking, knowing, and doing outside the western epistemic order and created orthodox disciplinary silos that reduced the knowledge of the rest--majority--of the world into fodder for its theories. The initiative therefore sets aside this hierarchical and arbitrary order of knowledge and invites us to a trans-hemispheric conversation between ways of seeing, thinking, knowing, and doing. The goal of this dialogue is to understand why what happened happened, why what did not happen ended up not happening, and to reconstitute history and speculative thinking as tools for re-membering dismembered knowledges and forging sustainable futures. We are then able to freely ask: "What if what happened (colonialism, racism, and slavery, say) had not happened? What if what did not happen had happened? Where were Global South's knowledge systems going when interrupted, even killed, by European colonial occupation, enslavement, and the deployment of racism as method of science? Where could they go in our hands, now? We explore these questions in one graduate and one undergraduate class, one field research & development open lab, and a book series with access to multimedia platforms for open access dissemiation worldwide.

STS.421. THE GRADUATE SUPER-SEMINAR ON GLOBAL SOUTH COSMOLOGIES & EPISTEMOLOGIES

The challenges facing the planet and world today (specifically climate change and its social and political effects) can only be successfully met if anchored in trans-hemispheric conversations that include ways of seeing, thinking, knowing, and doing marginalized by European slavery, imperialism, colonialism, and racism. This course assembles a distinguished cast of instructors drawn from all seven continents in diverse disciplines and non-academic everyday design-maker spaces to train the next-gen grad student at the intersection of Global South cosmologies and epistemologies. We specifically dare them go beyond theory to deploy these and their own cultures as frames, methods, and ingredients for sustainable design and making. It is the rule that students pick the thing that excites them most as their project, complete with a form that need not always be a written paper; rather, a product that is tangible, sonic, can be eaten or drunk, a website, a tool, a song, etc. Inevitably, this has become a trans-hemispheric design class. Website: https://www.globalsouth.live/the-graduate-super-seminar

STS.053. MULTI-DISCIPLINARY INTERACTIVE LEARNING THROUGH PROBLEM-SOLVING (MDPS)

STS.053 is an interdisciplinary problem-solving class at the intersection of Humanities, Arts, and Social Sciences (HASS) and science, technology, engineering, and mathematics (STEM), corporate, government, and community. The specific problem this class is focusing on is Climate and Sustainability, taking regenerative agriculture as an example. Our objective is to build affordable state of the art capacity within socially disadvantaged communities in the United States and internationally so that these communities can anticipate and solve their own problems. We (the student and the professor) assume the role of bridge between MIT and communities and act as climate and sustainability catalysts on either end by bringing the community to campus and taking the university to the people. Topics vary from year to year, but are always framed around "multi-disciplinary problem-solving," "diversity as method," "responsibility to community," and "value-addition at point of primary production." We work with materials like air, water, soil, and stone; plant matter like trees, grasses, and field crops; animals like cattle, goats, pigs, and rabbits, chicken, ducks, geese, guinea fowl, fish, insects like bees and termites, and invertebrates like earthworms. Always, our starting point is what local people know and are doing well, identifying with them what is out there that enhances local solutions.

RESEARCH || DESIGN || BUILD (RDB)

RDB is a catalytic space I established in 2018 for synthesizing academic and non-academic knowledge and turning them into institutions, goods, and services. It is located in the community to feel the pulse of everyday challenges, opportunities, experiences, and knowledge among the people and generate reliable, actionable, and real-time data. As a space where academic knowledge meets everyday knowledge, RDB is better able to deploy applied Science, Technology & Society (STS) methods to forge people-driven partnerships between actors that seldom collaborate. From rural electrification to weir dam construction to replenishing depleted pastures, forests, and fish populations in rivers and initiating community fisheries , RDB is creating a model for cost-efficiently equipping communities with technical, organizational, and knowledge capacity to design, run, and evaluate their own projects, and become effective partners in development. RDB's Africa field HQ is at Nyamudira Hills in Marondera District, Zimbabwe, from where it runs several decentralized farming projects that anchor its grain and waste to feed/fertilizer/solid fuel operations. We are currently setting up a branch in Worcester and Middlesex counties in Massachusetts to offer fresh, high quality food and after-school programs for school kids from low-income families and help farmers from historically disadvantaged groups to enter and stay in farming.

The Global South Cosmologies & Epistemologies Book Series

THE GLOBAL SOUTH COSMOLOGIES & EPISTEMOLOGIES BOOK SERIES

The Global South Cosmologies & Epistemologies Book Series (MIT Press) publishes work that explores how different societies make sense of and develop a knowledge of the physical and animate world and of the human itself. The series will specifically focus on ways of being, seeing, meaning-making, doing, ordering, and making worlds, an expanded meaning of what is often called cosmogony or gnosis, but going beyond theoretical or academic ends to constitute knowledge in the service of and through problem-solving . The works solicited for publication shall be nuanced in their historical and philosophical understanding of specific cosmologies and must derive their theory from concepts deployed in that culture, not outside it. In this book series, "Global South" is strategically deployed as an experiential location defined by and productive of specific ways of seeing, knowing, and doing rendered marginal, displaced, and/or erased by European/white enslavement/colonialism. The book series will accept manuscripts under two thematic streams: 1) Cosmologies and epistemologies/the sciences; 2) Cosmology, Innovation, & Design-Maker Experiences. Only manuscripts that respect and are written by people who come from and/or take seriously cosmologies and epistemologies from the Global South will be considered. We will reject manuscripts or proposals that simply take the Global South as fodder for Western theory. Acceptable projects are those that show demonstrable tangible benefit to makers and keepers of the cosmologies and epistemologies the authors are writing about. Works that are engaged in South-South conversations are especially encouraged, provided they are engaging cosmological and epistemological questions that have implications for the everyday lives of the Global South. A diverse range of books will be accepted, among them animated books and storybooks; books in indigenous and English languages; edited volumes; science fiction; historical fiction; academic books; poetry, etc. The target audiences of manuscripts will be: communities across the Global South, academic and non-academic, creatives and/or makers, engineers, designers, and policymakers. Web: https://www.globalsouth.live/the-book-series

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