# Example MEng Climate, Environment, and Sustainability Thesis Projects

## Analytics for Natural Resource Supply Chains (Prof. Saurabh Amin)

Supply chains of natural resources (e.g., forest products, natural gas) crucially impact the prosperity and resilience of human society. However, these complex systems are inherently vulnerable to a variety of disruptions, ranging from criminal activities to natural disasters. Research lead by Prof. Saurabh Amin in the Resilient Infrastructure Networks group focuses on developing new methods and tools for monitoring and control of large-scale networks in the face of such disruptions. Potential MEng CES projects include the following:

1. Use of advanced machine learning models that leverage multi-source data (e.g. satellite observations, trade statistics) to detect and track illegal activities in the global supply chain of lumber and wood products.
2. Game-theoretic design of inspection strategies that account for the presence of criminal networks engaged in illegal exploitation and transport of natural resources.
3. Predictive and prescriptive analytics to improve the resilience of critical infrastructure networks in the face of extreme events (e.g., hurricanes, extreme floods, and wildfires).

## Engineering microbiomes (Prof. Otto Cordero)

The degradation of complex algal (green) carbohydrates is central to food industries like aquaculture as well as a key part of the global carbon cycle in the ocean. This process is mediated by diverse communities microorganisms like bacteria, which carry sophisticated adaptations to break down the most complex biomaterials found in the environment. The Cordero lab studies the dynamics of carbohydrate degradation in natural environments from a eco-evolutionary perspective, using a combination of genomics, modeling and experimentation in order to learn how to engineer microbial ecosystems. Potential MEng CES projects include the following:

1. Using samples from animals with a highly specialized carbohydrate diet to reconstruct the composition of their microbiomes and cultivate the most active carbohydrate degraders (experiments + computation).
2. Study the evolution of carbohydrate degrading genes across the ocean (computation).

3. Develop model systems to assess the effect of candidate probiotics for aquaculture (experimental).

## Plant Responses to Climate Change (Prof. Dave Des Marais)

Plants evolved in a dynamic and often stressful environment, which is now changing at an unprecedented rate. Whether not plant populations, and the natural communities and human agriculture which they support, will adapt quickly enough is a central challenge for life sciences in the 21st Century. The Des Marais Lab uses tools in molecular genetics, genomics, physiology, and quantitative genetics to develop models of plant-environment interaction with a focus on plant response to the abiotic environment. Potential MEng projects include:

1. Integrate diverse datasets to assess how changing atmospheric CO2 alters the development and physiology of natural and crop species
2. Use quantitative genetic approaches to understand how and why constraints arise in evolution and breeding.
3. Develop models of environmentally responsive gene regulation using model grass species.

An undergraduate background in plant science, genetics, or data analysis will prepare you to tackle these and other related projects in the Lab.

## Regional Impacts of Climate Change on Water, Agriculture, and Food Production (Professor Elfatih Eltahir)

Climate change will redistribute availability of water resources at regional and local scales. At the same time, increases in human population and improvements in standards of living are likely to increase demand on water for use in agriculture to feed the world. These two trends present serious challenges to many local societies, motivating a more rigorous analysis and new projections of the impacts of future climate change on water and agriculture at local and regional scales. In some regions such as in Africa, control of population growth and adoption of agricultural technologies may offer feasible solutions to these challenges. In others, such as in North America, advanced agricultural systems will need to adapt based on better understanding of the nature of the projected changes in regional hydrology.

## Earth System Science (Prof. Dara Entekhabi Research Group)

The global climate system and its regional variations are principally determined by its top three constituent cycles: The energy, water and carbon cycles. How these three cycles are linked (and hence anomalies in one influence another) are not consistent among Earth system models resulting in wide range in regional future climate future (aka climate change projection uncertainties). Our research group aims at making direct and global measurements of these three cycles using remote sensing instruments on board Earth-orbiting satellites so that a benchmark observational dataset on the three cycles can be produced. The benchmark data set allows diagnosing global climate models, leading to reduced uncertainties in model future climate projections. Research opportunities in working with remote sensing data and models in our research group require background in Earth and environmental science, statistical analysis and programming (Matlab and/or Python).

## Air Pollution and Atmospheric Aerosols (Prof. Colette Heald)

Atmospheric particulate matter (PM), also known as aerosols, are a key driver of global air quality and climate. However, the various sources and properties of atmospheric aerosols can challenge our ability to constrain their atmospheric lifecycle and impacts. Research in the Atmospheric Chemistry and Composition Modeling Group at MIT (led by Prof. Colette Heald) attempts to explore these topics by bringing together observations and global models. Potential MEng CES projects include the following:

1. Use new satellite products to explore the vertical distribution of aerosols in the atmosphere from various sources (e.g. fires, anthropogenic, natural) and how this distribution affects air quality and climate impacts.
2. Explore the distribution and variability of surface PM over the United States, comparing low-cost sensor measurements (Purpleair citizen science network) with satellite-based datasets.
3. Explore how the extremes in air pollution have been changing over time from observations in the US and Europe, for example via the influence of smoke.

These projects are primarily data analysis in nature; some facility or experience with programming tools (e.g. R, python, Matlab, etc.) is recommended.

## Optimizing wind energy systems (Prof. Michael Howland)

Wind energy production must rapidly increase in the next decade to mitigate climate change. However, the complex interactions between wind turbines and the winds in the atmosphere reduce wind farm efficiency and predictability. We combine modeling, simulations, and laboratory and field experiments to investigate wind energy systems with the goal of improving wind farm siting, design, predictability, and operation.

Potential MEng CES projects include the following:

1. Wind farm optimization relies on efficient computational models which have uncertain representations of physical processes. Use wind energy data to calibrate and quantify the uncertainty of wind farm models.
2. Explore the seasonal and interannual variability of wind energy production at the wind farm and the collective energy system scales.
3. Use wind farm and atmospheric data to develop machine learning approaches to wind energy forecasting, modeling, and control.

Experience with programming (e.g. Matlab, Python, Julia) is recommended.

## Atmospheric Chemistry and Air Quality (Prof. Jesse Kroll)

The atmosphere contains an enormous number of chemical species, present as both gases and particles; despite their very low concentrations, these species can have dramatic impacts on human health and climate. Our research tackles two major challenges associated with these trace species: understanding the chemical transformations they undergo when in the atmosphere, and developing new ways to measure them using distributed low-cost (as opposed to research- or regulatory-grade) techniques. Potential MEng CES projects in these areas include the following:

1. Development of new approaches to measuring atmospheric chemistry and composition using low-cost air quality sensors.
2. Calibration and analysis of data collected from existing low-cost air quality sensor networks.
3. Laboratory studies of the atmospheric degradation of key atmospheric species and pollutants, to better understand their rates and mechanism.

Previous research or classwork in in chemistry, air quality, and/or the use of numerical computing software is useful background for these and related projects.

## Materials-based Innovation for AgriFood Systems (Prof. Benedetto Marelli)

The need to mitigate the environmental impact of agriculture and food industries coincides with the required increase in crop productivity to feed the ever-growing population and the challenges that climate change brings on agriculture productivity and food logistics. Research in the Laboratory for Advanced Biopolymers at MIT (led by Prof. Benedetto Marelli) uses biomaterials and nanotechnology to find new solutions that can impact several AgriFood systems. Potential MEng CES projects include the following:

1. Design of biomaterials for the delivery of vaccines in aquaculture settings. The project is focused on exploring the synthesis and nanofabrication of new materials that can operate in seawater to deliver vaccines to fishes.
2. Design of a high-throughput system to investigate seed coating- rhizobacteria interactions for the delivery of biofertilizers. Facilitated by analytical studies of rhizobacteria-biomaterials interactions, the project will consist in building a physical device where several biomaterials can be tested in parallel to define specific properties that enhance microorganism survival, colony formation and roots infection.
3. Explore the use of new AI tools to design and synthesize de novo structural proteins for the engineering of edible coatings. Using a combination of AI and synthetic biology, the project is focused on engineering the next generation of silk-based materials for nanotechnology

These projects require good wet lab skills and experience with programming tools, e.g. Python and Matlab

## Chemical Ecology in the Rhizosphere (Prof. Darcy McRose)

Soils and the microorganisms that live in them play a key role in shaping climate and agriculture, but the soil environment is often governed by complex chemical and biological interactions that are challenging to study. The McRose lab focuses on the experimentally tractable chemical tools (“secondary metabolites”) that plants and microbes use to navigate the soil environment. We study the ways small-scale interactions involving these metabolites affect plant growth and large-scale biogeochemical processes (such as the release of greenhouse gases) in order to develop sustainable management and engineering strategies for soils. Potential MEng CES projects include:

1. Explore the capacity of plant secondary metabolites to supress nitrous oxide release from natural and agricultural soils. Determine the susceptibility of nitrifying and denitrifying bacteria to various plant compounds and test their mechanism(s) of action.
2. Identify bacteria that increase the bioavailability of phosphorus. Isolate bacteria from the rhizosphere and screen for the production of metabolites that help solubilize mineral-adsorbed phosphorus, begin building environmentally relevant synthetic communities of secondary-metabolite producers.
3. Determine the effects of plant vs microbial iron-solubilizing metabolites on microbial growth and carbon cycling (respiration).

We use techniques from microbial physiology, genetics, analytical chemistry, and the geosciences. Some previous wet lab experience as well as a basic background/familiarity in some of these areas will be helpful.

## Physical Studies for Stream and Coastal Restoration and Blue Carbon (Prof. Heidi Nepf)

Coastal and flood plain vegetation, such as marsh grass, seagrass, mangrove, kelp, and large wood provide many ecosystem services, including excess nutrient mitigation, soil carbon retention [called blue carbon], habitat that supports biodiversity, flood and storm impact mitigation, and erosion reduction. Each of these services in enhanced by the damping of current and waves. The Nepf lab examines the physical mechanisms that define these ecosystem services and that can inform successful restoration efforts. Potential MEng projects include:

1. Physical experiments to understand the modification of current and waves by vegetation and the impact on sediment retention processes.
2. Meta-analysis of blue carbon accretion rates focusing on the physical aspects of the vegetation (geometry and rigidity) and hydrodynamic exposure.
3. Physical and/or numerical modeling study of kelp farm layout to optimize production
4. Physical studies to optimize the design of engineered wood for stream restoration.

## Reactor engineering for environmental chemistry (Prof. Desiree Plata): NOT ADVISING STUDENTS IN 2023-24

Informing sustainable design of industrially important materials and processes requires an understanding of the environmental impacts of those processes in advance of a priori. Unfortunately, understanding the fate of chemicals in the environment is often too slow to inform industrial innovation.  Research in the Plata lab seeks to overcome this limitation through the construction of reactors to simulate Earth- and Industrial-processes (e.g., material weathering or manufacture, respectively), generation of parametric datasets, and modeling to guide environmentally benign design.  Potential MEng CES projects include:

1. Helping design and build a high-throughput photoreactor to improve understanding of plastics weathering
2. Developing automation and data processing to interface with high-throughput weathering reactors
3. Conducting biochemical weathering experiments in high and low throughput

An understanding of chemistry, mechanical engineering, and modeling or automation are all assets.

## Terrestrial carbon ecology and climate solutions (Prof. César Terrer)

Land ecosystems currently buffer about one third of anthropogenic $CO_2$-emissions. Research at Prof. Terrer's lab aims to quantify and design nature-based solutions to sequester $CO_2$ by synthesizing field and remote-sensing data with machine-learning methods. Potential MEng CES projects include the following:

1. Quantify the global potential of grasslands as carbon sinks
2. Develop technology to monitor changes in soil carbon stocks from space
3. Quantify the efficiency of regenerative farming practices to sequester carbon
4. Do more biodiverse forests sequester more carbon?
5. Study tradeoffs between sequestering carbon above and belowground in forest plantations.