Yale Energy Studies

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Class of 2022 Yale Energy Scholars


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Yale Energy Studies

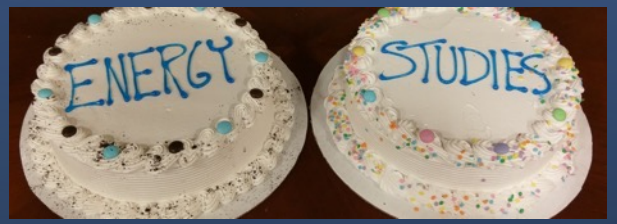
SOCIETY • TECHNOLOGY • ENVIRONMENT

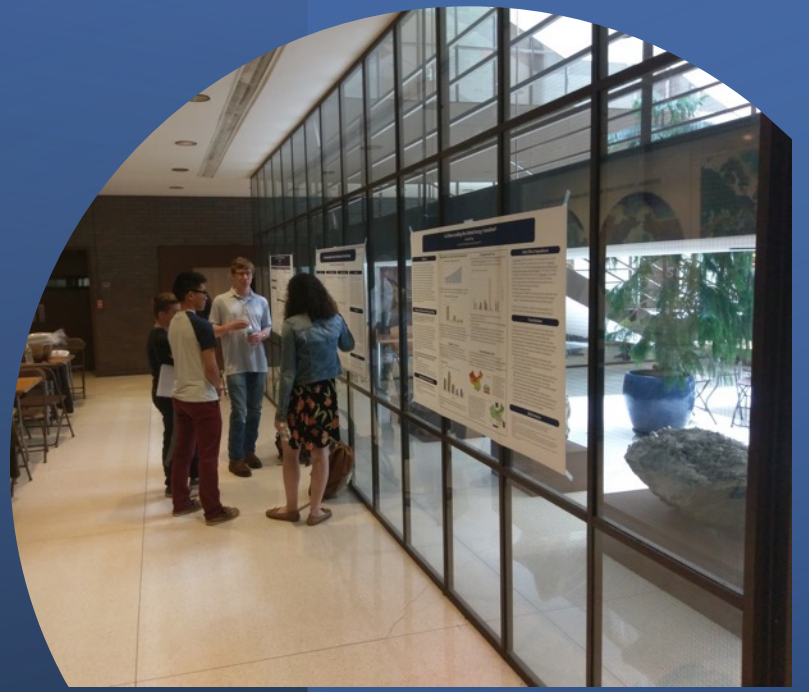
Class of 2022 Yale Energy Scholars

33 Graduating with Energy Studies Certificates in May 2022
(13 delaying until the Fall or next Spring)

39 B.A./B.S. Degrees in 19 Different Majors

African Studies (1); Architecture (1); **Chemical Engineering (3)**; Computer Science (2); **Earth & Planetary Sciences (3)**; East Asian Studies (1); Ecology & Evolutionary Biology (1); **Economics (5)**; Electrical Engineering (2); Engineering Science-Chemical (2); Engineering Science-Environmental (2); Engineering Science-Mechanical (1); Environmental Engineering (2); **Environmental Studies (6);** Global Affairs (1); History (1); Molecular Biophysics and Biochemistry (1); **Political Science (3)**; Statistics & Data Science (1)


ENERGY
STUDIES



JANUARY 2018 CLASS OF 2021+

SEPTEMBER 2019

Silver-Doped Hematite Nanosheet Catalyst for Oxidation of Methane to Methanol

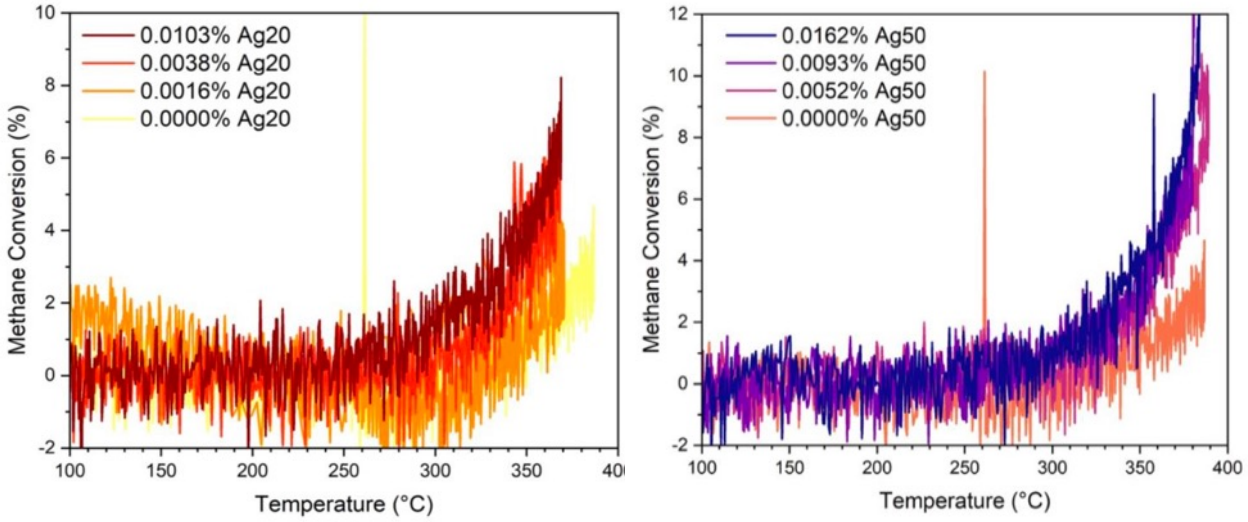
Michael Adeyi '22

Grace Hopper | Chemical Engineering

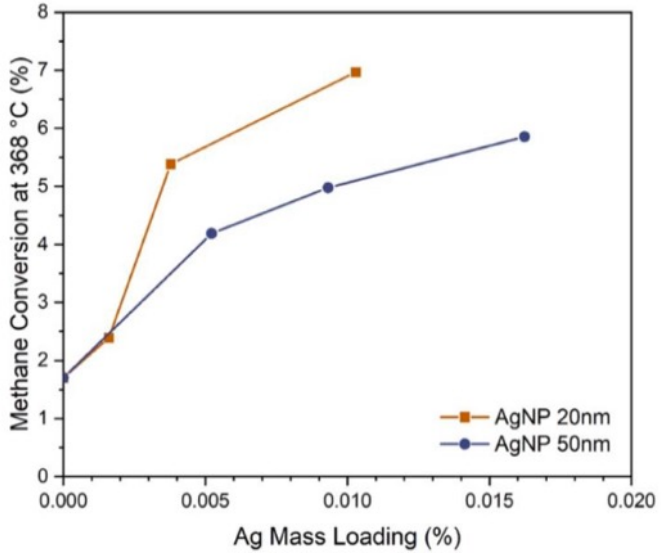
Our lab group is focused on achieving and optimizing a partial oxidation of methane to methanol, effectively converting a greenhouse gas into a clean fuel source. We are using hematite (α-Fe_2O_3) nanosheets as a catalyst for that partial oxidation process.

To increase the efficiency and likelihood of success of the conversion, the hematite nanosheet catalysts are given different functionalizations, such as hydrophobic coatings or dopants with a hydrophobic coating. The hydrophobic coating serves to increase the catalyst's affinity for methane, therefore promoting methane's conversion to methanol, and decreases the catalyst's affinity for methanol, therefore allowing for methanol to leave the reaction system more easily. The dopant can serve several purposes.

This report focuses on silver-doping to improve photoreactivity.



↑ Percentage of methane conversion as a function of temperature by hematite (α-Fe2O3) nanosheets, doped with 20 nm silver particles (Ag20, LEFT) and 50 nm silver particles (Ag50, RIGHT) as a co-catalyst.

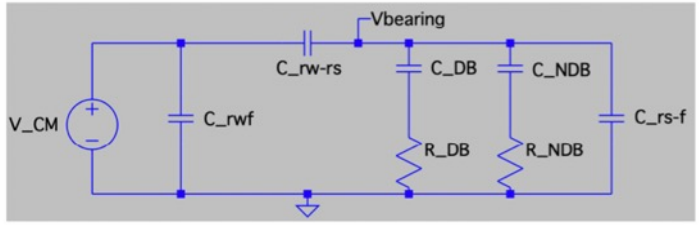


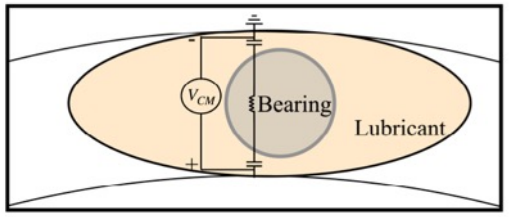
↑ Percentage of methane conversion at 368°C as a function of silver mas loading percentage for Ag20 and Ag50 particles.

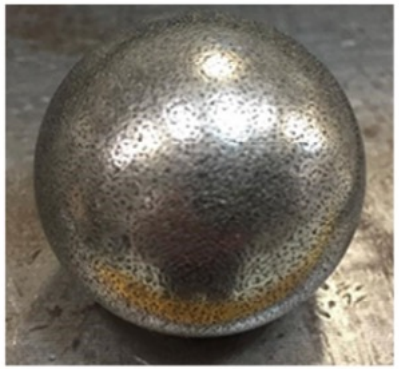
Electrical Discharge Machining in Wind Generator Systems: A Review of Origins, Detection, and Proposed Solutions

Daniel Bacheschi '22

Berkeley | Electrical Engineering



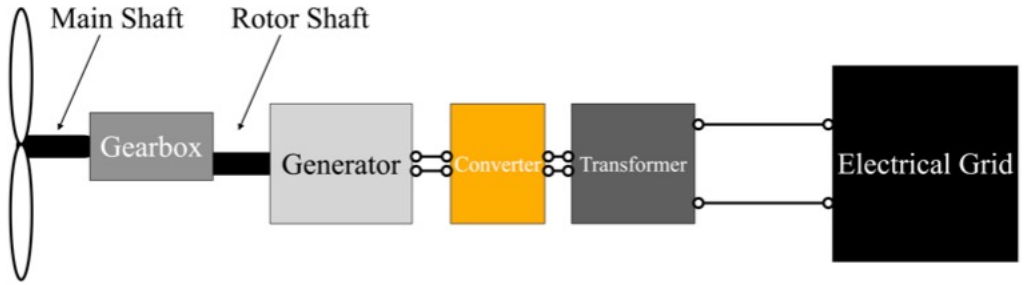




↑ (CLOCKWISE FROM TOP LEFT) Circuit diagram of the rotor's capacitive couplings between the coils, shaft, and frame. Illustration of the capacitive couplings responsible for EDM in a bearing system. Pitting on the surface of a ball bearing caused by EDM. Fluting on the outer raceway of a ball bearing caused by EDM.

Wind turbines are a critical player in the future of the world's energy mix. Their ability to be deployed both on land and at sea will prove pivotal for ensuring a smooth energy transition away from fossil-fuel based economies. During the summers of 2020 and 2021… During the summer of 2021, I [worked] in the generator design group for land-constrained wind turbines…on the topic of electrical discharge machining due to its widespread prevalence and critical nature. Studies have estimated that 58% of turbine failures on generators rated above 2 megawatts (MW) are due to bearing failures, [and] that figure jumps to 70% for generators rated between 1-2 MW. Although a perfect solution does not yet exist for detecting electrical discharge machining, there are several experimental attempts involving output frequency decomposition and neural networks….

My work in this capstone report provides the necessary background and discussion on electrical discharge machining [for] wind turbines.



↑ Schematic of a standard wind turbine showing the chain of devices from turbine blades connected by a gearbox to the generator rotor, converter, and transformer, which puts the electrical power at 60 Hz frequency and high voltage onto the electrical grid.

Building a circular economy: Plastics recycling in the United States

Rachel Chang '22

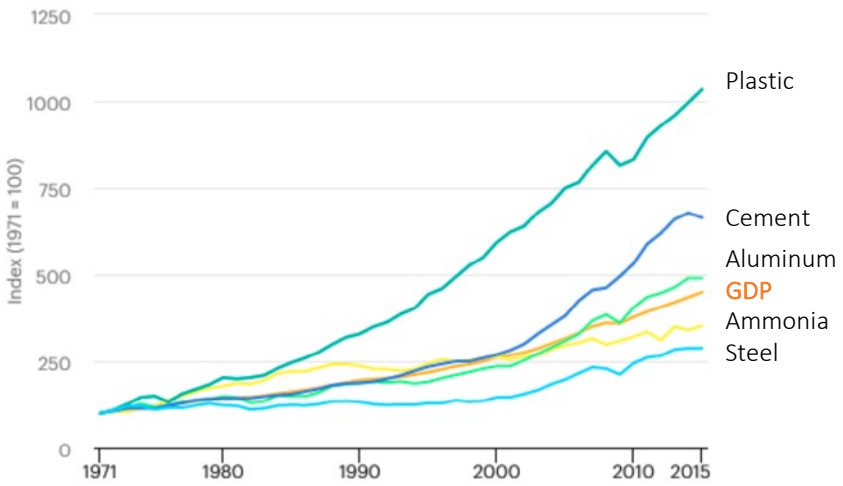
Branford | Environmental Studies | Political Science

According to the EPA in 2018, the US recycles only 8.7% of its plastic waste. Landfilling or incinerating our plastics creates public health crises that disproportionately harm low-income communities of color. Improving our plastic recycling rate and creating a circular economy will yield important benefits for mitigating climate change, reducing pollution, protecting vulnerable communities, and more. The US can replicate innovative, effective, and successful recycling policies from other nations to improve our own recycling rates…

I examine case studies to understand the successes and challenges faced by these nations to improve our policy implementation. Finally, I propose that minimum recycled content standards are the missing piece to an integrated recycling policy proposal. Combining these four policies creates a comprehensive and strengthened recycling approach. With this integrated platform, the US can close the loop on the plastics value chain and move toward a circular economy.

Legislative / Policy / Collection Service Element											
Widespread separate collection of key dry recyclable materials	✓		✓	✓	✓	✓	✓	✓	✓	✓	
Widespread separate collection of biowaste	✓		✓	✓	✓	✓	✓	✓	✓		✓
Landfill and/or incineration bans for some materials	✓	✓	✓	✓	✓		✓	✓			
Statutory recycling rate/separate collection targets	✓	✓		✓	✓	✓	✓	✓	✓	✓	
Restrictions on collection of residual waste e.g. fortnightly or less collections, restrictions on bin volume				✓			✓	✓	✓		
Variable-rate charging (e.g. Pay As You Throw)		✓			✓	✓	✓	✓	✓		✓
Extended Producer Responsibility scheme(s)	✓	✓			✓	✓	✓	✓			✓
Deposit Refund Scheme(s) for packaging	✓	✓	✓		✓	✓	✓	✓			✓

↑ Recycling policy across the highest-performing countries. Countries listed, from left to right: Germany, South Korea, Austria, Wales, Switzerland, Italy, Belgium, Netherlands, Slovenia, Singapore, Taiwan. Source: Eunomia



Drivers of petrochemical production growth, from 1971 to 2015. Source: IEA →

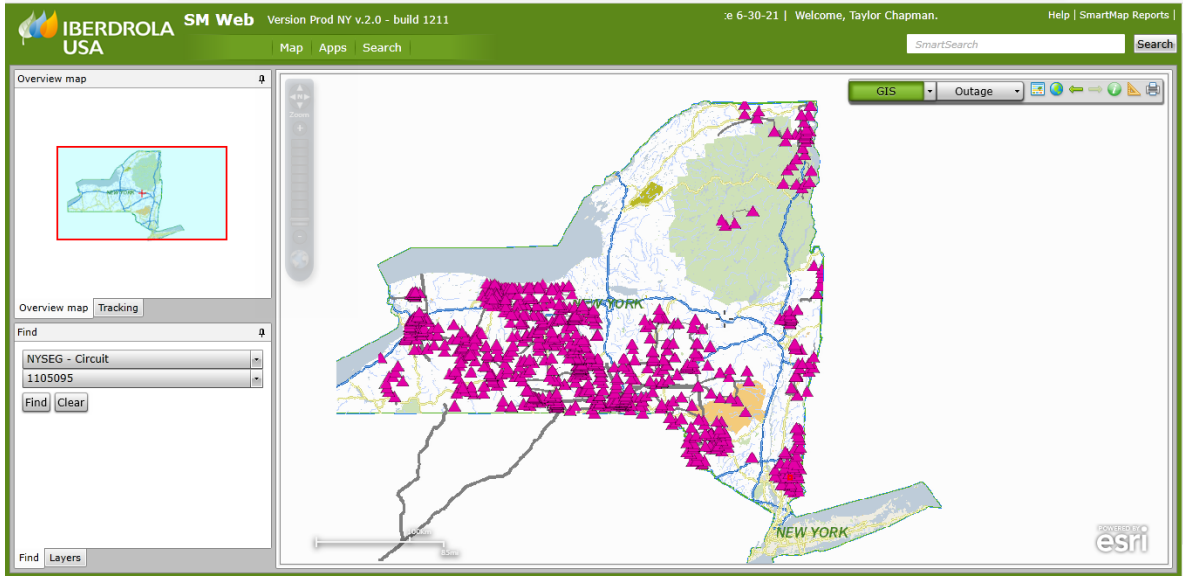
Smart Grid Innovation and Planning: An Internship at AVANGRID

Taylor Chapman '22

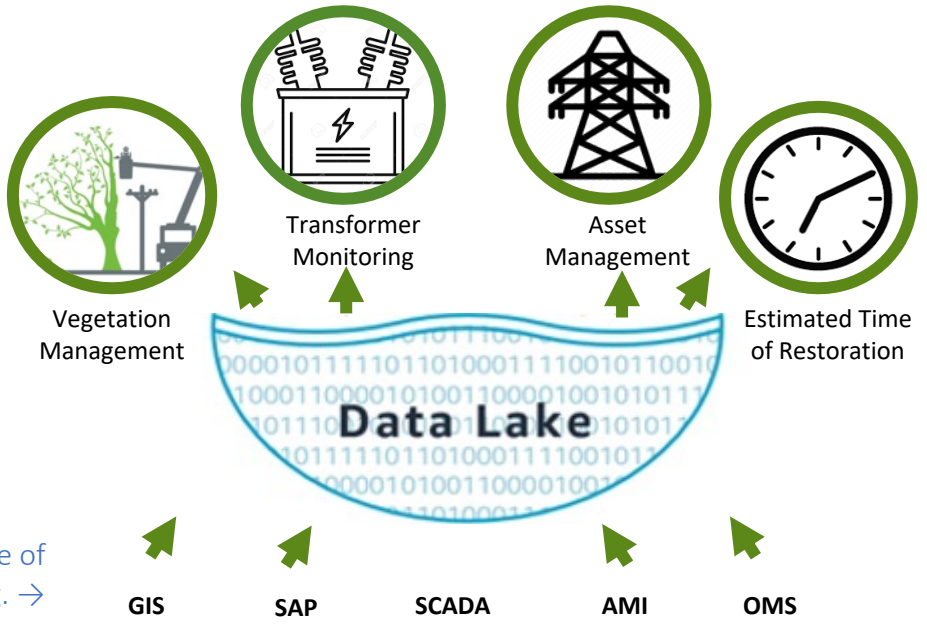
Grace Hopper | Electrical Engineering

This past summer I worked with AVANGRID, an electric utility company based in the northeast, on their smart grid innovation and planning team as an engineering intern. The smart grid team I was on is actively part of grid modernization efforts at AVANGRID. Grid modernization refers to upgrading technology and infrastructure on the grid and enabling it with smart technologies to improve resiliency, reliability, and flexibility. As the grid ages and becomes more decentralized with the proliferation of distributed energy resources, utilities need to… [continuously] monitor its far corners to ensure safety and reliability.

The projects I worked on relating to smart grids were in three major areas: data analytics, renewable energy demonstration projects, and advanced grid planning tools. Each of these topics are key areas of development in grid modernization.



↑ GIS map of suitable sites for a demonstration of new circuit control system called ANM Element (Smart Grid Solutions) with the unique capability of curtailing a PV systems power production should voltage in the circuit becomes too high. Sites were selected by providing specifications to the AVANGRID database.



Catalog for the AVANGRID data lake. Smart vegetation management is one of many examples harnessing the power of big data for decision making. →

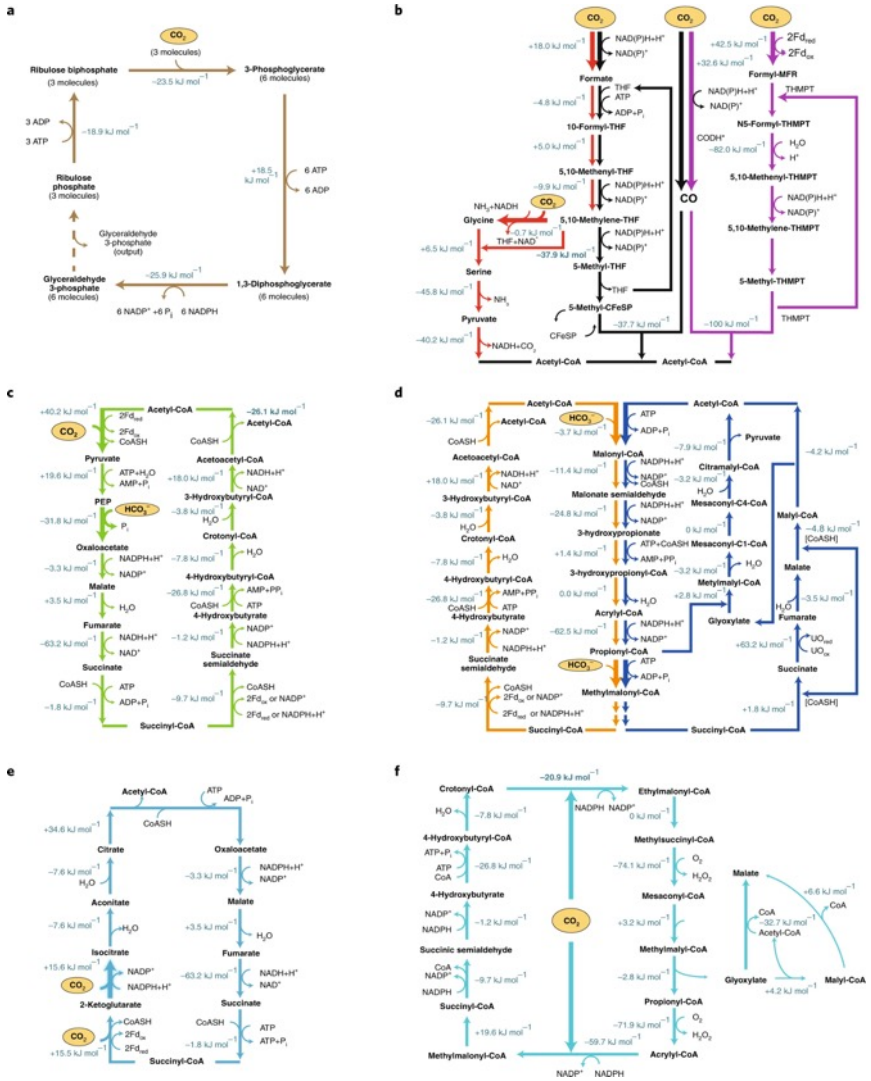
Syngas Fermentation by Acetogens via the Wood-Ljungdahl Pathway for Biorefinery

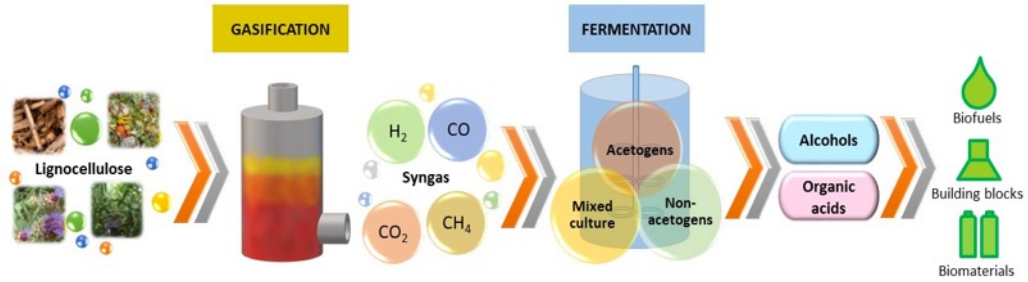
Lauren Delgado '22

Saybrook | Molecular Biophysics and Biochemistry

The rising concern of CO2 emissions from fossil fuel use has greatly increase the demand for low-carbon and carbon-neutral energy sources. Biofuels offer a renewable alternative for things that cannot be converted to electric energy sources. Though often associated with energy and land intensive practices, biofuels production from gasified biowastes, known as Syngas, with assistance from CO2 fixing microbial pathways provides a more efficient option with the opportunity to also produce valuable biochemicals sustainably.

The Wood-Ljungdahl pathway (WLP), present in acetogens and methanogens, is one such pathway that can be employed. This review gives an overview of the implementation of the WLP for syngas fermentation and details of the pathway. It also explores enzymes of importance, their mechanism, and opportunities for optimization.





↑ Graphical Abstract of Syngas fermentation for biorefinery. This proposed method utilizes biowastes for syngas production. From left to right the steps involved include the collection of lignocellulistic biomass, conversion to syngas, fermentation via acetogens and possibly other microbes, and separation of value-added products for further refinement. (Ciliberti et al. 2020)

← Known CO2 fixation pathways. A) CBB cycle. B) The WLP in acetogens (black) and methanogens (purple) and reductive glycine pathway (red). C) The DC/HB cycle. D) The HP/HB cycle (orange) and 3-HP bicycle (blue). E) The TCA cycle. F) The CETCH cycle.

Public Safety Analyses for Electric Operations at Con Edison: Report on an Internship

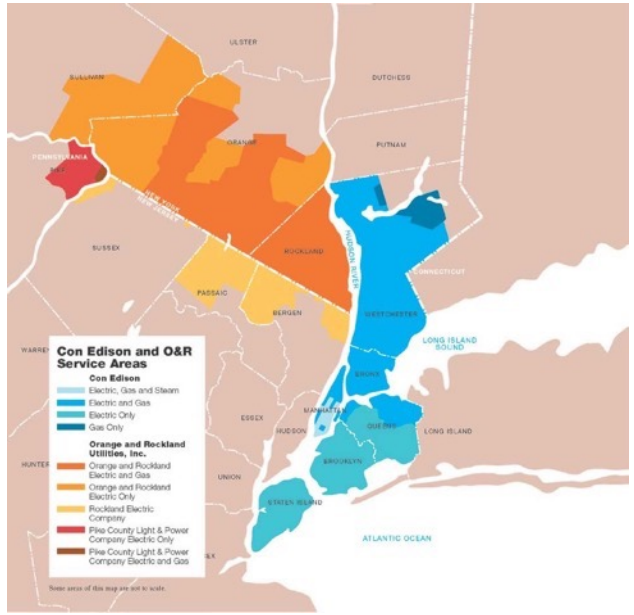
Lia Eggleston '22
Timothy Dwight | Computer Science

↑ Manhole explosions. One of the largest safety risks to the public from underground utility networks comes from explosions in manholes, which can send a manhole cover weighing up to 300 pounds rocketing into the air, literally over the tops of buildings. This infographic from the Con Edison website (coned.com) describes the sequence of events leading to an explosion, which starts with saltwater leaking through the insulation of power lines.

This capstone report concerns my co-op study at the energy company Con Edison, based in New York City. Founded in 1823 as the New York Gas Light company, Con Edison provides electric, gas, and steam for the 10 million people who live in New York City and Westchester County. It operates one of the largest energy delivery networks in the world. During my internship in the summer of 2021, I worked with the public safety engineering and analysis team.

The report starts with an overview of the energy infrastructure in the Con Edison network, introducing terms often used for electricity delivery operations, and then describes the data public safety team works with, including reports of safety incidents and faults.

My projects involved, first, building a risk index for pedestrian safety to highlight parts of the network posing the most risk to the public walking around the city and, second, analyzing the risks and impacts of road salt on the system & environment.

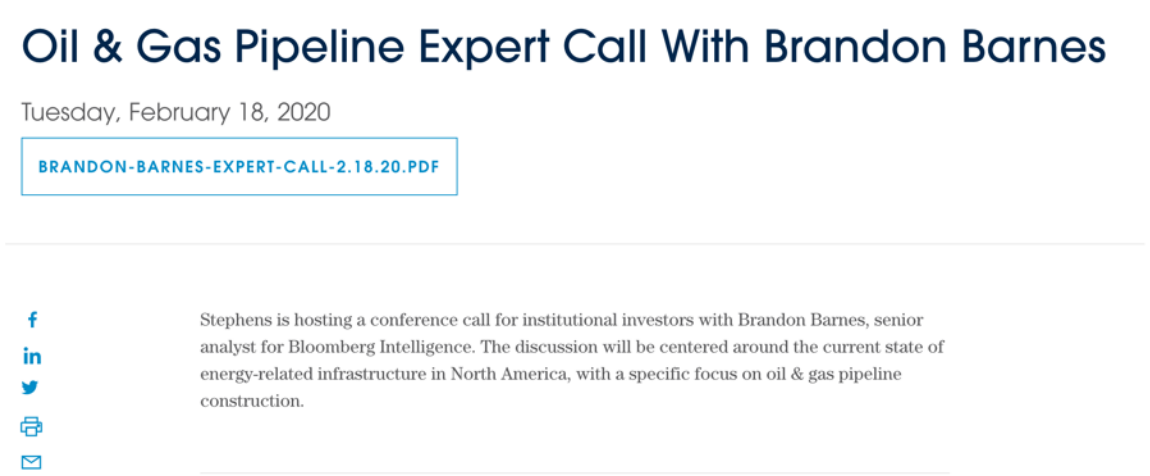


→ Map of the service area of Con Edison, Inc., which owns two energy business serving New York City: Consolidated Edison Company of New York (CECONY) and surrounding areas. and Orange and Rockland Utilities, Inc. (O&R). Source: New York Public Service commission Final Report and Operations Audit of Consolidated Edison Company.

Insight into an Investment Banking Internship in the Energy Sector

Freddie Elwes '22

Davenport | Computer Science



Oil & Gas Pipeline Expert Call With Brandon Barnes

Tuesday, February 18, 2020

BRANDON-BARNES-EXPERT-CALL-2.18.20.PDF

Stephens is hosting a conference call for institutional investors with Brandon Barnes, senior analyst for Bloomberg Intelligence. The discussion will be centered around the current state of energy-related infrastructure in North America, with a specific focus on oil & gas pipeline construction.

↑ Sample information event hosted by Stephens for institutional investors in the energy sector

Stephens Inc. is a privately held, independent financial services firm headquartered in Little Rock, Arkansas. Operating primarily in the US but also London and Frankfurt, the company offers well-established expertise in almost every form of financial service, including private equity, insurance, asset management, and investment banking.

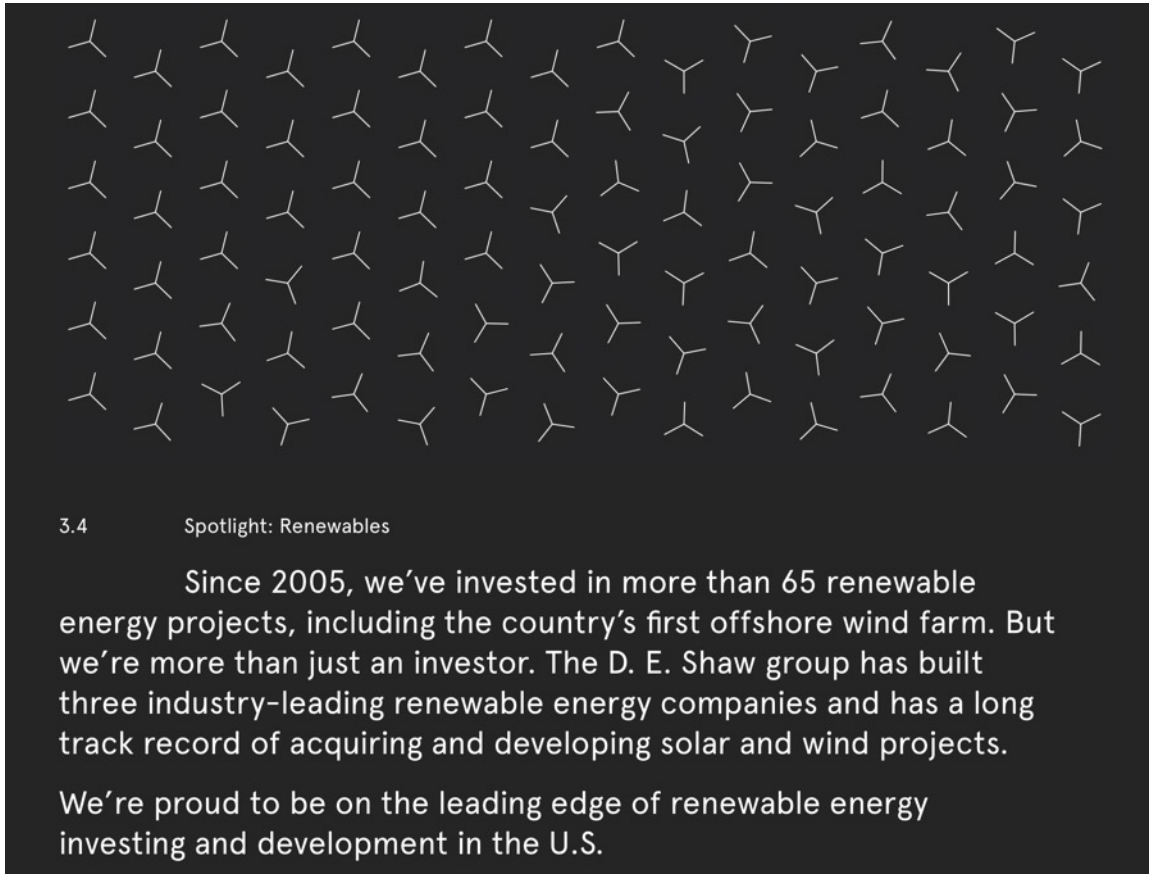
I joined the firm as an investment banking intern in September 2021 for eight weeks, spending the first four weeks with the Exploration & Production (E&P) team based down in Dallas and the final four weeks with the Alternative Energy team working out of New York. … I could not have chosen a better fit for my internship experience for three reasons: (1) the core values under which the firm operates, (2) the firm's unique position as an upper-middle bracket investment bank and (3) its far-reaching involvement within the energy sector. Stephens offered exposure to both the traditional and alternative energy sectors was truly unique and enlightening.

In the context of current media trends and a necessity to mitigate extreme climate change, many believe that an end-to-end energy transition is on the horizon where fossil fuels are filtered out of our energy systems entirely. This is naïve…

↑ Selected investments by Stephens with emphasis on the energy sector

Report on a twelve-month internship at D.E. Shaw Renewable Investments

Chris Fake '22
Trumbull | Engineering Science-Chemical



↑ D.E. Shaw Renewables investments in wind power.

The D. S. Shaw Group is a global investment and technology development firm, headquartered in New York City. Starting in 2020, I spent a twelve-month internship at the company, with their renewable investments (DESRI) development team, working on power purchase agreements for Ranger Power, a utility-scale solar company. This report gives a brief introduction to DESRI and my internship with the company.

There are so many different parts to a life of a renewable project – from development, to construction, to financing, to operations – with value to be created at every step in the process.

DESRI was focused on securing long-term power purchase agreements (PPAs) with credit-grade utilities, putting a high premium on risk mitigation.

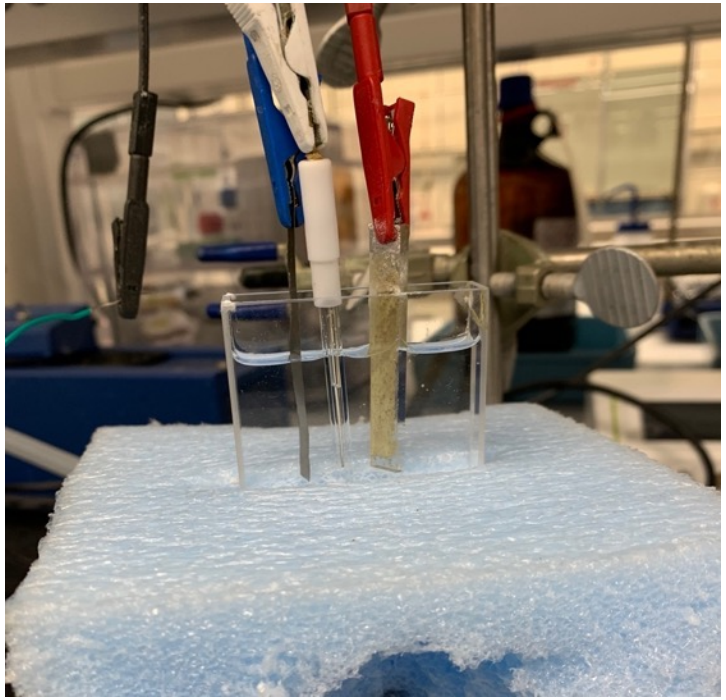
One of my projects was to develop a solar irradiance model for internal use at DESRI after questions arose about the accuracy of purchased software.

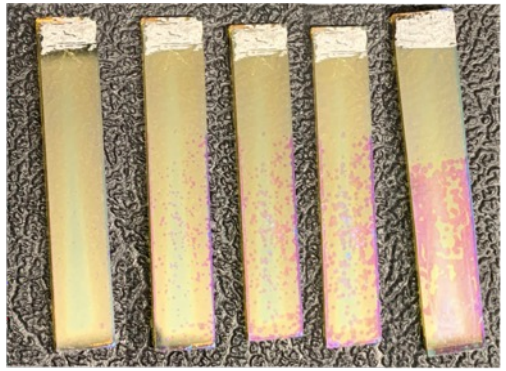
↑ Website of Ranger Power, a utility-scale solar company., focused on long-term PPAs.

Electrochromism for Energy Conservation

Ben Gibbs '22

Pauli Murray | Chemical Engineering





This summer I conducted research in the Hu Lab at the Yale Energy Sciences Institute under the supervision of Dr. Shu Hu…on a team preparing to finalize a multi-year project that would culminate in a presentation for the Navy and eventual publication. My task was to complete the remaining experimentation and convert raw data into presentable information.

Our project attempts to leverage electrochromism for commercial and military application. Electrochromic reactions are those which induce a color change due to a change in a species' oxidation state. Because these reactions are often non-spontaneous, they require an added driving force–in this case, applied potential is used to generate current flow and color change.

Electrochromic reactions are redox reactions, meaning electrons are exchanged between ionic compounds, changing the oxidation state of those compounds and shifting the wavelengths of light absorbed by the compound and altering its visible color…This project is multi-faceted in application—first as active camouflage for the Navy; second, in commercial energy-saving windows.

A manuscript describing the work carried out by the team during my internship is under review for publication in the journal Advanced Functional Materials.

← (TOP) Electrochemical cell configuration for testing electrochromic reactions. In this experimental cell, samples created by atomic layer deposition (ALD) are used as working electrodes with a silver (Ag/Ag+) non-aqueous reference electrode and titanium foil as a counter electrode. The counter electrode prevents significant current through the reference electrode. (BOTTOM) Progression of chromium oxidation at 3V after (left to right) 5, 30, 50, 75 and 120 minutes. Color change is due to a redox reaction occurring at the electrode surface.

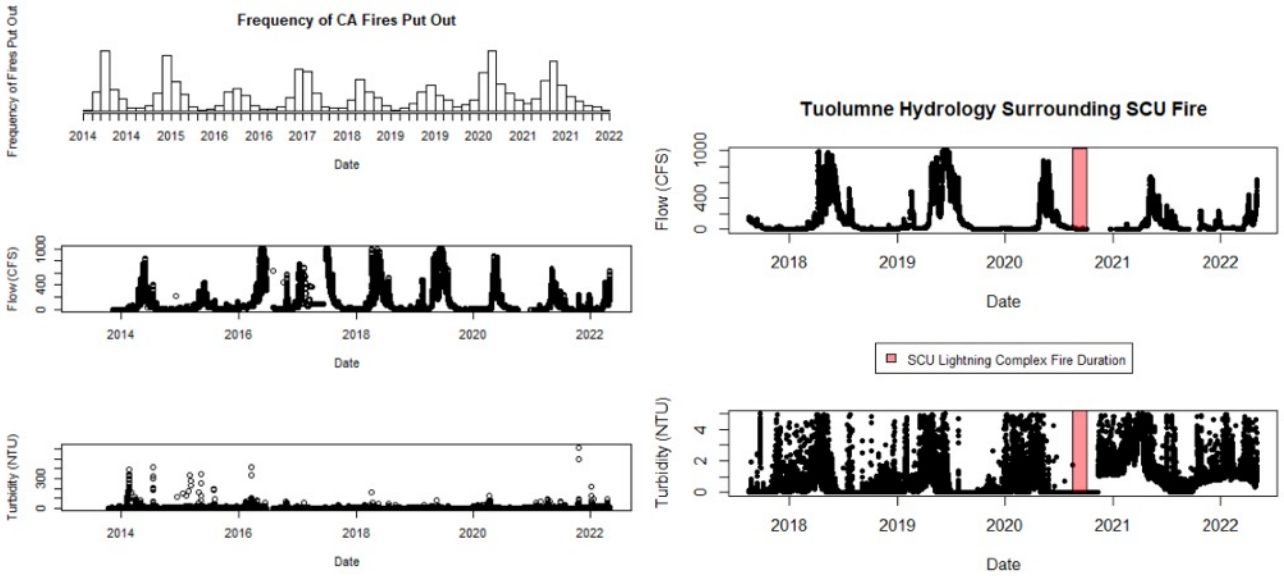
An analysis of the impact of forest fires in Yosemite Valley water systems

Harrison Gill '22

Benjamin Franklin | Statistics & Data Science

↑ Vernal Fall in Yosemite Valley viewed from along the John Muir Trail in early May 2019. Waterfalls are usually at their best in mid- late May. PHOTO www.nps.gov

This project takes a data-driven approach to analyze how Yosemite Valley water quality and quantity has varied over the past 10 years in relation to the pervasive forest fires of north and central California. Human activity over the past century that has accelerated climate change, and in addition to frequent human-caused ignitions, has led to an increase in the spread, magnitude, and duration of wildfires in California. Previous research has shown that in the wake of a forest fire, the burning of local vegetation pollutes water sources and leads to myriad short- and long-term water system issues (EPA). These negative consequences strain local ecosystems as well as municipal water resources.



↑ (LEFT) Flow (middle) and turbidity (bottom panel) of the Tuolumne River, one of the two main sources of for Yosemite Valley. Top panel shows the frequency of California wildfires. (RIGHT) Timeline of flow (top panel) and turbidity (bottom) of Tuolumne River in years encompassing the SCU Lightning Complex Fire which burned 400,000 acres in counties around Yosemite.

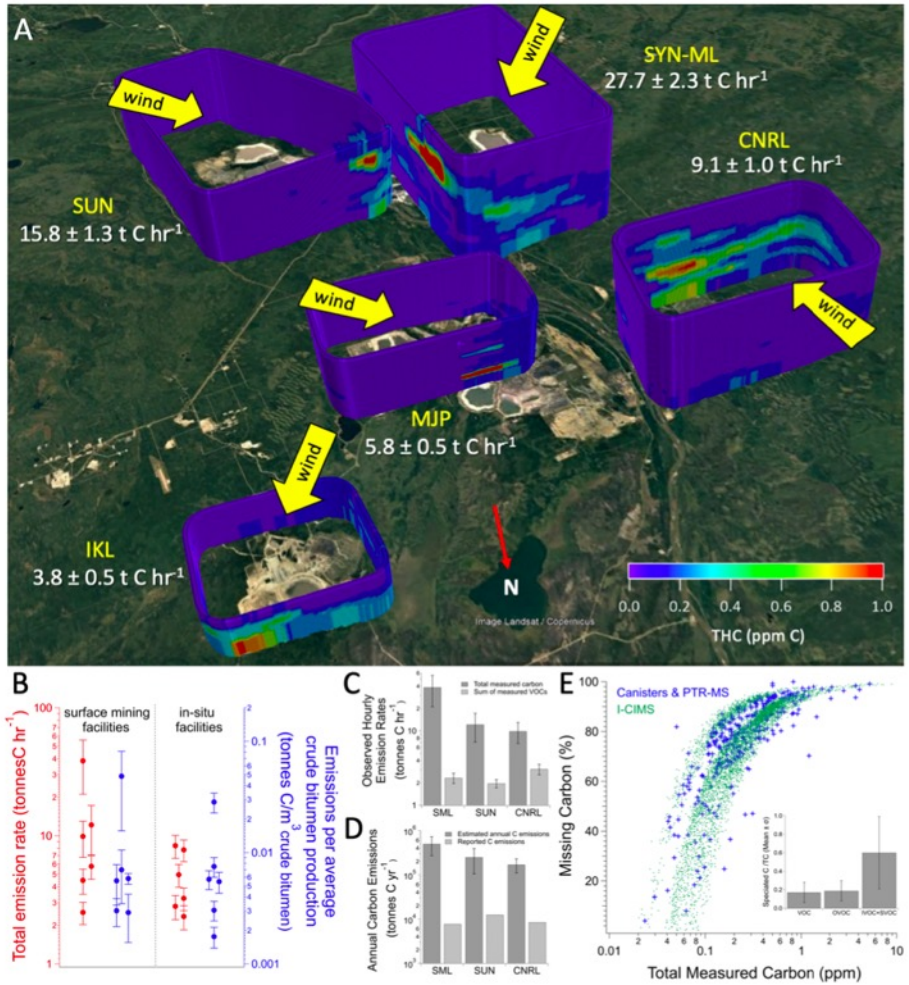
Airborne observations of "missing" reactive organic gas-phase emissions from oil sands operations

Megan He '22

Pauli Murray | Environmental Engineering | Global Affairs

The mining, extraction, and processing of oil sands deposits in Alberta, Canada constitute a major unconventional source of oil production. These operations also emit gas-phase organic compounds to the atmosphere, much of which has been previously unquantified... Here we use a novel combination of aircraft-based measurements (including of total carbon emissions) and offline analytical instrumentation to characterize the complex mixtures of hydrocarbons and their volatility distributions observed above Alberta oil sands facilities. Diverse distributions of hydrocarbon abundances are observed near and downwind of the facilities with enhancements in the C17-C22 range. We use laboratory experiments to assess possible emissions from oil sands mining waste processes.

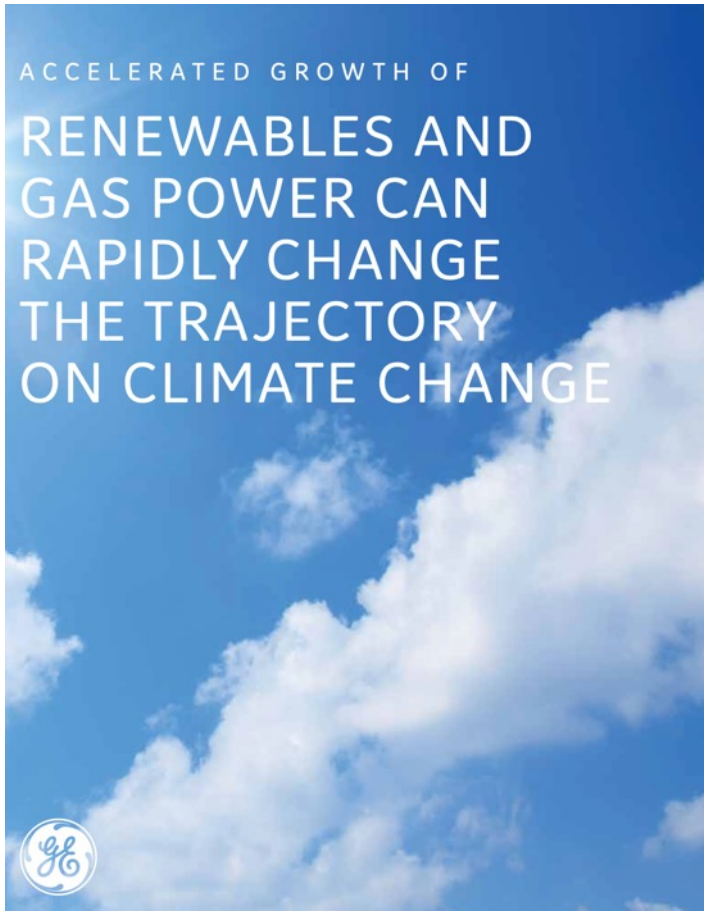
[Total] emissions far exceed industry reports, with around 1% of carbon extracted out of the ground at these facilities emitted to the atmosphere. The detailed chemical composition presented in this study reveals that the emissions pathways are oil sands-derived. In all, these results demonstrate the importance of holistic policies on fugitive emissions and waste management strategies from petroleum operations, and expanded monitoring of I/SVOCs.



← Observations of total hydrocarbons exceed reported emissions. (A) Box flights around the five largest-producing facilities show elevated downwind emissions using TERRA. (B) Hourly carbon emission rates and average monthly carbon intensities for surface mining and in-situ facilities. (C) Hourly measured emissions of THC from the flights, compared to the summed up hourly emission rates for the measured VOCs from both PTR-MS and whole-air samples together. Error bars reflect the standard deviation (STDEV) of the various flights and the propagated uncertainty from TERRA. (D) Annual carbon emissions compared to the reported carbon emissions (based on Canadian national inventories) for three major facilities. THC/NOx ratios are 24±11 (SML), 13±7 (SUN), 17±6 (CNRL), where NOx is represented as NO2. Error bars reflect the STDEV of the TC/NOx ratio used. (E) Carbon balance and missing carbon when only including I/SVOC observations in the top 75th percentile of THC data.

Building a World that Works? The Role of GE Gas Power and its Turbines in the Energy Transition

Sophie Isom '22
Saybrook | Engineering Science-Environmental



↑ GE whitepaper on the energy transition and climate change. ge.com

As climate awareness has grown and public opinion of fossil fuels has soured, GE Gas Power has put considerable effort towards publicizing their idea of the future of energy and role within it. Their education-focused campaign has included webinars, regional and technical white papers, a "Cutting-Carbon" podcast, and lobbying materials tailored to particular states.

As a marketing intern last summer, I worked closely with all of these. My takeaway of GE's current marketing strategy is that they are acknowledging the necessary shift away from carbon- intensive power generation, while simultaneously asserting that their turbines are compatible with this inevitable greener future. For my capstone project, I analyzed three elements of GE's public narrative: fuel switching (coal to gas), renewable capacity supported by gas, and decarbonization of gas turbines with hydrogen and carbon capture.

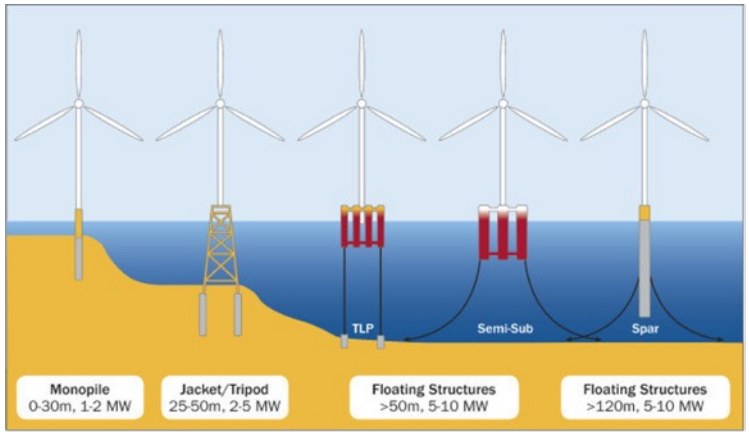
GE's longer-term vision for the future of energy (unlike China's) is renewables supported by gas. In their white paper titled "Accelerated growth of renewables and gas power can rapidly change the trajectory on climate change," GE Gas Power states: "GE believes that accelerated and strategic deployment of renewables and gas power can change the trajectory for climate change, enabling substantive reductions in emissions quickly, while in parallel continuing to advance the technologies for low or near-zero carbon generation."…

[T]hat said, gas-fired generation might not be the only solution. China, for one, is putting stock in nuclear energy to fill the same need. As evidenced by their massive buildout of nuclear capacity—and conservative buildout of gas—China does not seem to share GE's view.

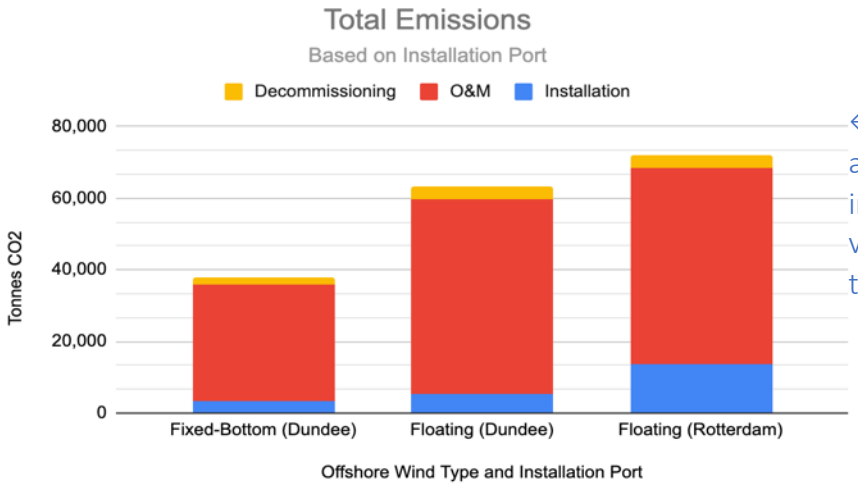
The Future is Floating: A comparison of direct emissions associated with fixed-bottom and floating offshore wind farms

Sarah King '22

Ezra Stiles | Environmental Studies



← Types of offshore wind platform foundations (Bailey et al. 2014)



← Emissions breakdown according to type of installation port for floating vs fixed-bottom wind turbines

This paper will investigate the carbon dioxide emissions associated with offshore wind farms during their life cycle, including the installation, operations and maintenance (O&M), and decommissioning phases. The main goal is to compare the emissions of fixed-bottom wind farms, a mature technology, with nascent designs of floating offshore wind farms, which will mature rapidly in the next decade.

First, an overview of the history of offshore wind as well as the present state and future projections of the global and U.S. markets will situate the research question in a background of knowledge. Then, the three main floating foundation designs will be described, along with the advantages and limitations of floating wind.

Market analysis will then provide a glimpse into the coming boom in floating wind-farm installations. In-depth descriptions of the installation, O&M, and decommissioning phases of both fixed-bottom and floating wind farms, as well as a case study of the Kincardine Floating Offshore Wind Farm, will contextualize the methodology.

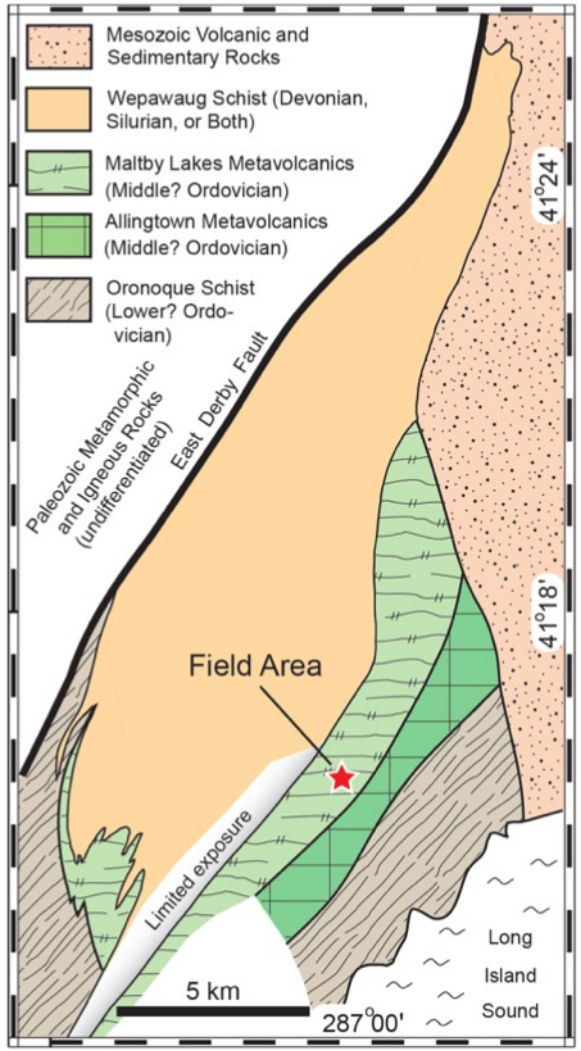
Tug supply vessels towing Kincardine floating wind turbine →

The Carbonation of Serpentinites in the Orange-Milford Belt, Connecticut, USA

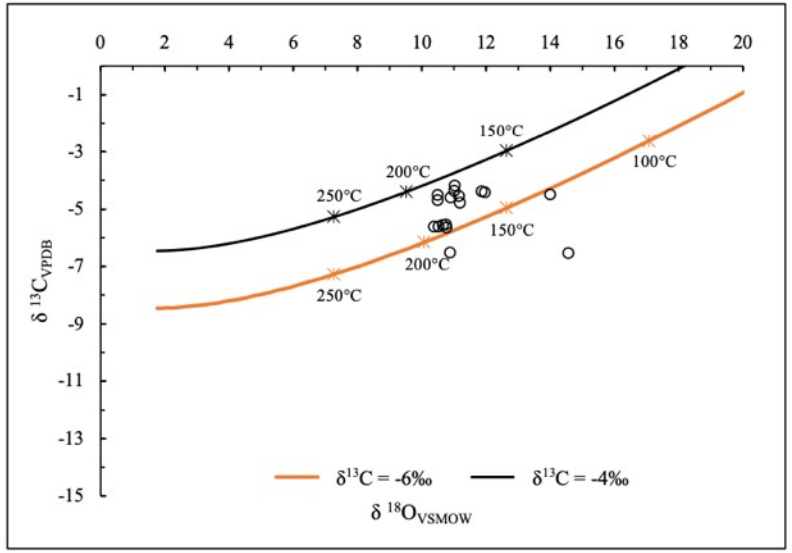
Sophie Lai '22

Jonathan Edwards | Earth & Planetary Sciences | Economics

The Orange-Milford belt of Connecticut contains carbonated serpentinites, or listvenites, that are characterized by a rich, olive-green color and cross-cutting yellow veins. They occur within the Maltby Lakes Metavolcanics (Ordovician). Previous research on their mineralogy suggests that the rocks were initially ultramafic in origin and had subsequently undergone hydration and carbonation in a pre-metamorphic event (Karsh, 1998). Currently, research is lacking on how the Orange-Milford serpentinites were carbonated, although there are several distinct possibilities: fluid rock interaction on the seafloor or during tectonic emplacement, or following emplacement and exhumation (Karsh, 1998). In this project, I examine the pre-metamorphic environment of the protolith and conduct an in-depth case study of carbon sequestration in ultramafic rocks through petrological analysis of thin sections prepared by J.J. Ague and stable isotope analysis of 13C and 18O along a profile extending across the carbonated serpentinites and associated metavolcanic rocks.



← Geologic map of the Orange-Milford serpentine belt which outcrops in southwestern Connecticut.

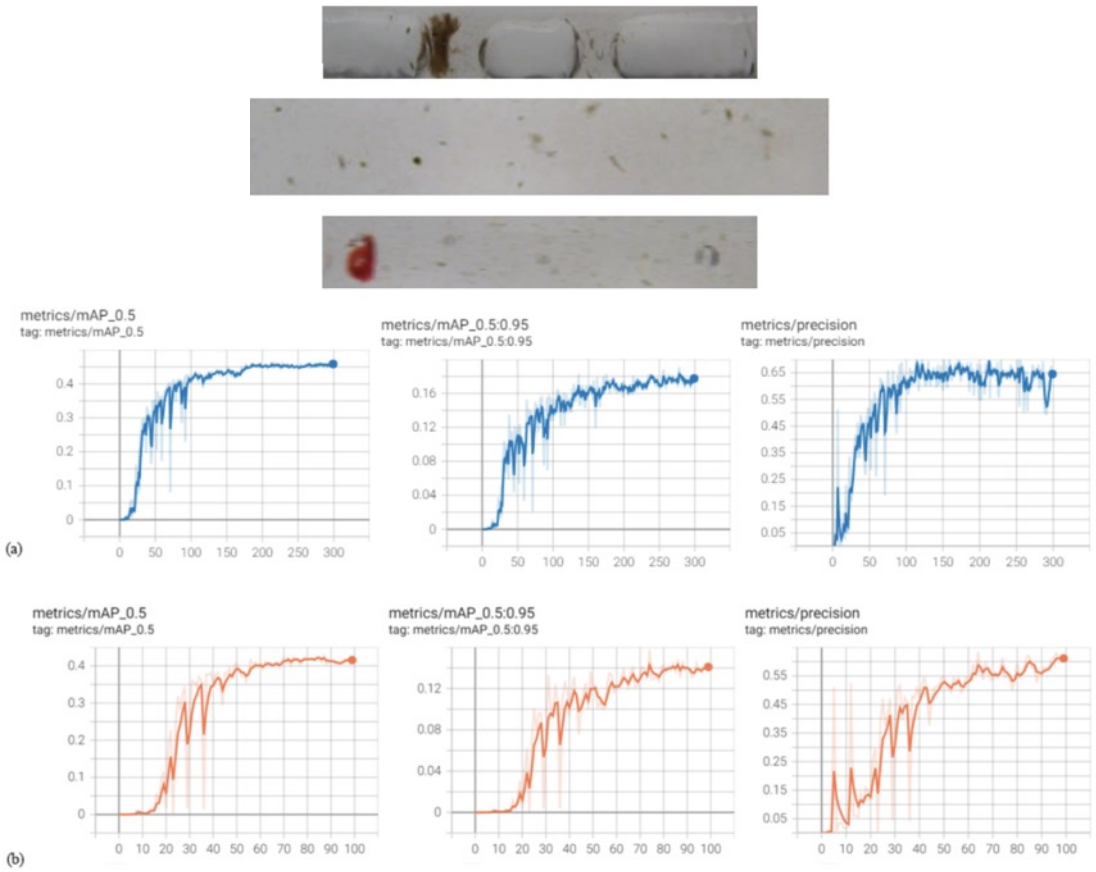


$\delta^{13}C$- $\delta^{18}O$ plot of the Orange-Milford listvenites located in the diopside zone and serpentinite regions. →

Lowering Energy Costs through Smart Filtration: An Internship at Phuc Labs, Inc.

Linh Manh Le '22

Branford | Chemical Engineering



↑ (TOP) Input images for analysis by neural network: sample with bubbles (upper panel); sample with small suspended solids (middle panel); sample with worms (bottom panel). (BOTTOM) Comparative performance of algorithm precision: (a) 300 epochs with a YOLO neural network algorithm (YOLOv5) and (b) 100 epochs with RSA-YOLOv5.

The project is inspired by the rising concern of water use in any industry, where massive amounts of energy and/or water are required in all stages of operation and wastewater treatment processes have not been optimized due to lacking financial incentives. Using advances in computer vision, I worked with the team at Phuc Labs, Inc., a Boston-based startup, to build a filter-less filtration system with fast-acting algorithms and tunable range to outperform state-of-the-art processes while reducing significant costs associated with chemicals consumption and energy use in a local water processing plant. This would further allow for real-time monitoring of particulates removal and obviate the need for traditional filtration media like membrane.

With experiences in the summer, I was able to extend my work to my final project for EENG 439: Neural Networks and Learning Systems, as well as combine it with my past research project with Professor Jaehong Kim at Yale. Future opportunities for such projects include optimizing the software-hardware-chemistry interdependency, locating applicability in fields not limited to wastewater treatment, and commercializing potential lab-scale demonstrations into end-use, customer-friendly products. I am further looking to see how this technology could empower smart cities in the developing world (i.e., Vietnam) where there is a huge demand for cost-effective and thermodynamically efficient water systems. While the same concept can be extended to fields such as but not limited to battery recycling, jet fuel filtration, and algae harvesting, this technology, as is, goes a long way in minimizing the footprint of energy-intensive industrial processes in the energy-water nexus.

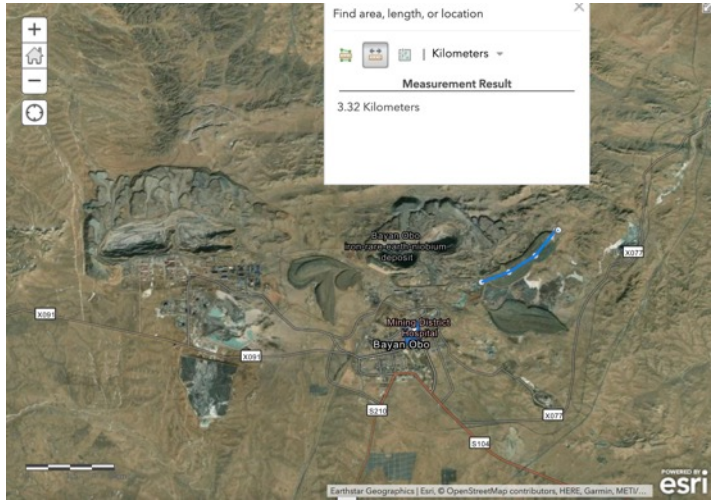
Illegal Rare Earth Element Mining: Southern China and Myanmar

Abigail Long '22
Jonathan Edwards | East Asian Studies
Honorable Mention for the Williams Prize Essay in EAS

There are few countries where [the] tension between global emissions mitigation and local level pollution is more visible than China. China faces some of the world's highest levels of local and regional level air, soil, and water pollution. China is also particularly vulnerable to the consequences of global climate change, such as rising sea levels, rising temperatures, and extreme weather…China has emerged as a leading producer and deployer of clean energy technologies.

However, continued reliance on highly pollutive inputs…complicates China's ambitious goals to construct an "ecological civilization" 生态文明. One such resource that is crucial for clean energy technologies, but has substantial potential for local pollution, is rare earth elements 稀土元素(REEs). In recent decades, China has established a virtual monopoly over the REE supply chain, meaning that mining and processing burdens from the world's growing demand for REEs are concentrated in China's industrial mining hubs, such as Baotou 包头市.

This paper brings the local environmental degradation imposed on Baotou as a result of the REE industry into conversation with China's national climate concerns and commitments.



↑ (LEFT) Map of Zomia, a rugged swath of Asia, including southern China and Myanmar where rare earth elements (REEs) are illegally mined.

(RIGHT) Large-scale legal REE mining at Bayan Obo mine near the city of Baotou in Mongolia. At more than 50 years old, with a collective length of 12 kilometers and area of 11 square kilometers, Bayan Obo's tailings are the world's largest "稀土胡"(rare earth lakes). Tailings hold a total of 1.73 million tons of earth. The northeastern tailing with the blue line is measured at 3.32 kilometers long for reference.

↑ Examples of environmental damage associated with REE mining in Southern China and Myanmar

Weather satellites for wildfire tracking: Mapping burned area in near-real time using geostationary satellite data

Danielle Losos '22

Saybrook | Environmental Studies

↑ Visible spectrum maps of the Whitney Fire burn perimeter, located at 47.71°N, 118.26°W in eastern Washington. The top row (a, b) is MODIS imagery while the bottom row is GOES-R imagery. Pre-fire unburned imagery is on the left; post-fire unburned imagery is on the right . In the center is the burned area perimeter from the MODIS global burned area product.

America's geostationary weather satellite mission, GOES-R, delivers multispectral images of the United States every five minutes. Together, these highly frequent images form a detailed time-series of surface reflectance which can be used to monitor wildfires in near-real time. Conventionally, polar-orbiting satellites like Landsat and MODIS are used for mapping burned areas at high spatial resolution. Yet reliance on these high-resolution images often comes at the cost of time. Days or weeks may pass before polar-orbiting satellites get a clear view of the burn scar unobstructed by clouds or smoke. During these delays, the unstable post-fire zones are vulnerable to flash floods and debris flows, threats which forecasters can only predict with burn severity images.

This study explores whether GOES-R, despite its low spatial resolution, could provide burned area maps that would improve the timeliness of post-fire risk warnings. The GOES-R near-infrared and shortwave infrared channels are used to compute the Normalized Burn Ratio (NBR) spectral index, the industry standard for monitoring burn severity…I modeled GOES-R time-series for 132 wildfire events with harmonic functions to estimate midday NBR before and after each fire. GOES-R measured midday NBR as consistently as MODIS.

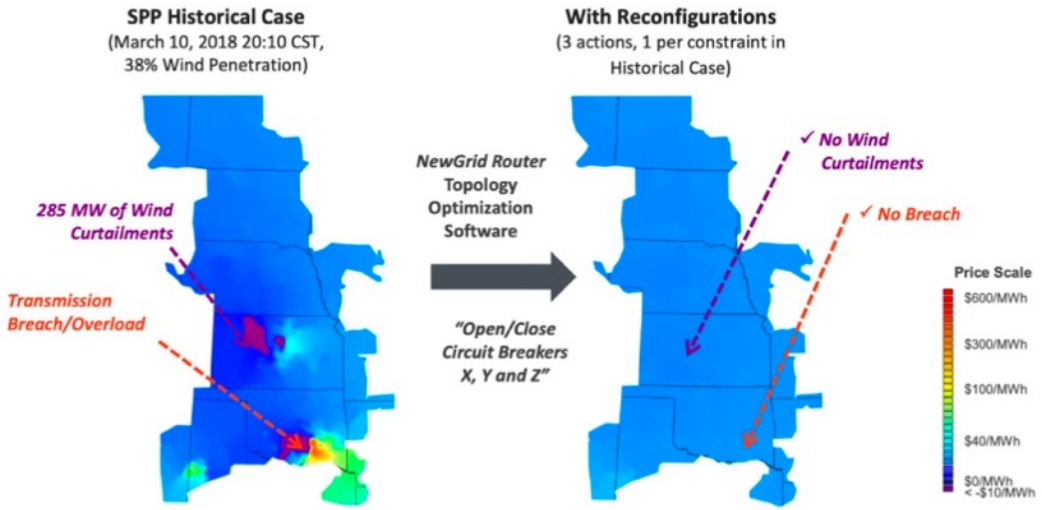
The NBR values were correlated strongly (r = 0.90), though GOES-R overestimated MODIS NBR by a factor of 1.4 …The daily NBR amplitudes significantly increased due to wildfire, meaning that post-fire areas exhibited a wider range in reflectance throughout the day than unburned areas…In summary, geostationary satellites show potential for near-real time monitoring of land surface disturbance, with burned-area mapping at the forefront of their capabilities.

A Techno-Economic Analysis of Grid Enhancing Technologies: the Path Forward for America's Energy Infrastructure

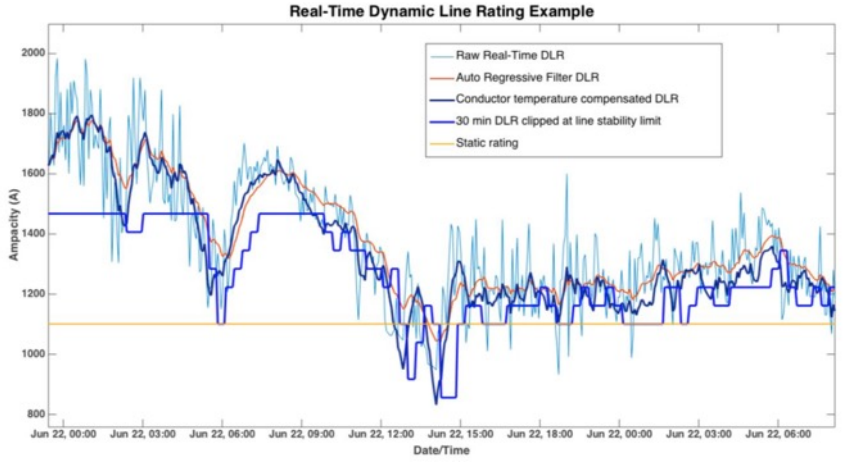
Diego Meucci '22

Grace Hopper | Environmental Studies

Given the average age of American electrical infrastructure, traditional modes of the generation and distribution of electricity are beginning to clash with modern technologies and renewable energy sources. Electrical infrastructure is aging and inefficiencies in transmission are preventing the cost of electricity from falling, while preventing large-scale integration of renewable energy technologies into the transmission network… [T]o perform a large-scale transition from fossil fuels to renewable energy generation, these constraints must be eliminated. In order to do so in a time-effective manner, grid enhancing technologies must be employed at large-scales. Grid enhancing technologies (GETs) present low-cost transmission upgrades with multiple benefits, including improving the transmission capabilities of existing infrastructure.



↑ Visualization of topology optimization software solving the issue of renewable energy curtailment and transmission overload in the SPP. Topology optimization completely removes the transmission overload and eliminates excess wind curtailments through more efficient use of pre-existing transmission infrastructure. Source: The Brattle Group.

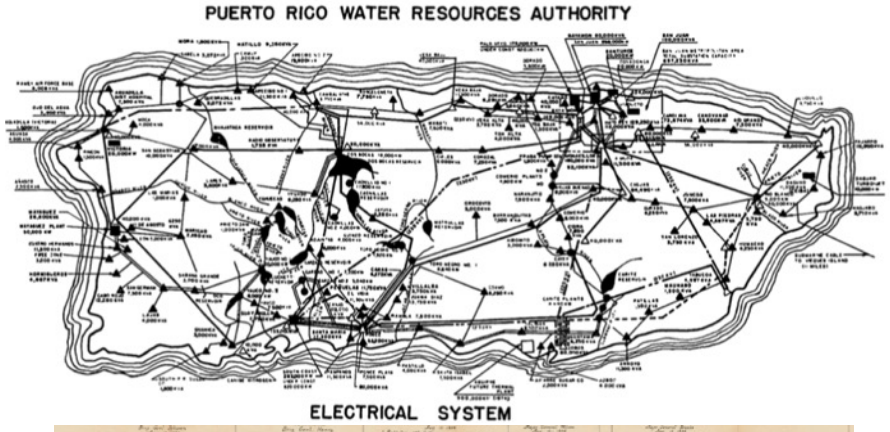


↑ Graph of the real-time transmission capacity compared to the static capacity rating. The static rating, while beneficial for safety reasons, is significantly less than the real-time rating. Dynamic line rating systems (DLRs) effectively allow for grid operators to set what the line rating should be for any given minute, depending on the weather or line conditions. Source: The Brattle Group

Operation Bootstrap—Industrial Conquest and U.S. Colonial Expansion in Puerto Rico, 1930–1980: Focus on Energy Infrastructure

Liam Muldoon '22

Davenport | Economics | History



← Map of the electrical grid of Puerto Rico made in 1970 by the Water Resources Authority, illustrating development of the island's electrical system under Bootstrap

← Map of Puerto Rico drawn by the United States military during its invasion in 1898

This paper focuses specifically on the developments that occurred in Puerto Rico under Operation Bootstrap—a program started by Luis Muñoz, the island's first governor, for creation of an economic revitalization targeting the high unemployment, low wages, and stagnant GDP growth that the island had faced in the years before its consolidation as a U.S. commonwealth in 1952.

Emphasis is on how Operation Bootstrap represented an extension of American colonial power. By analyzing the initial history of U.S. involvement on the island at the end of the 19th century, and by studying the ways in which American presence evolved over the 20th century, this essay will show how the rise and fall of Operation Bootstrap solely benefited American enterprises— while paradoxically providing no sustainable improvements for Puerto Ricans.

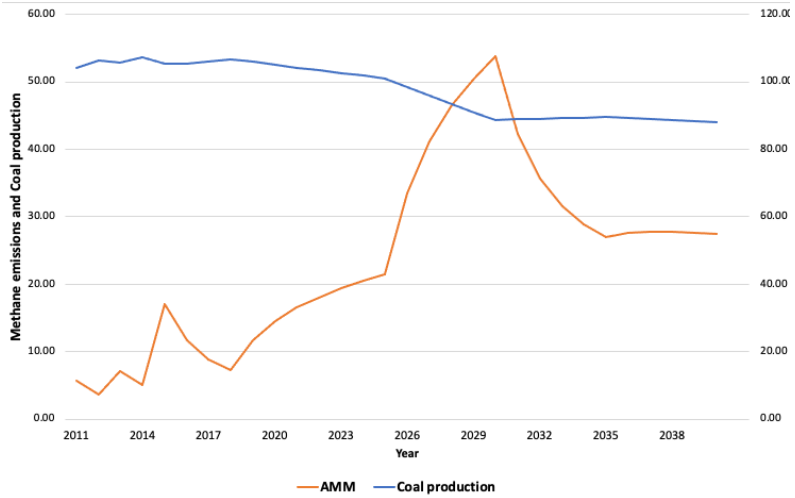
While Bootstrap is recognized as having occurred from the 1950s to the 1970s, this paper covers the period from 1930 to 1980 in order to contextualize the political nuances that paved the way for its industrial projects. Furthermore, the expanded time frame is used to show how the failures of the program by 1980 devolved into long-term issues the island continues to face, particularly when focusing on its energy grid.

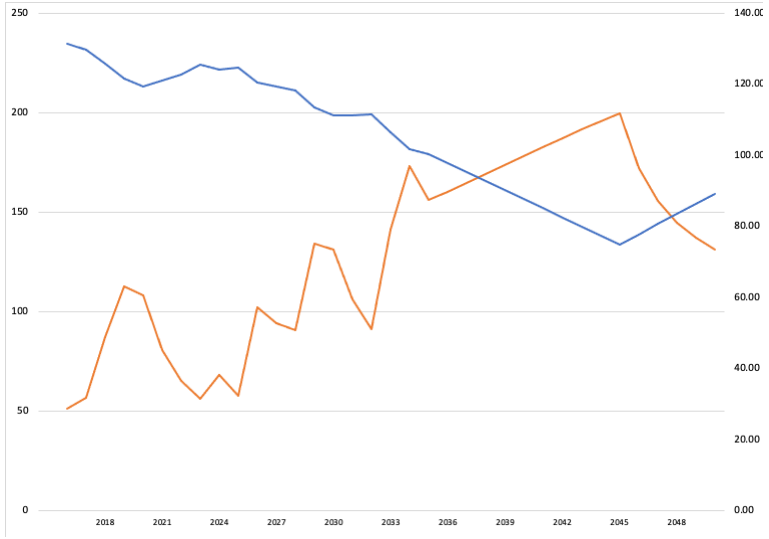
The colonial legacy of Operation Bootstrap will therefore be discussed through the ways in which it brought about political suppression and partisanship on the island, attracted American capital by subduing local Puerto Rican businesses, and led to infrastructure development and energy imports that supported U.S. trade, while damaging the island's environment in the process.

Evaluating the potential of abandoned coal mine methane development in South Africa

Wanjiku Mwangi '22

Saybrook | Engineering Science-Environmental | African Studies



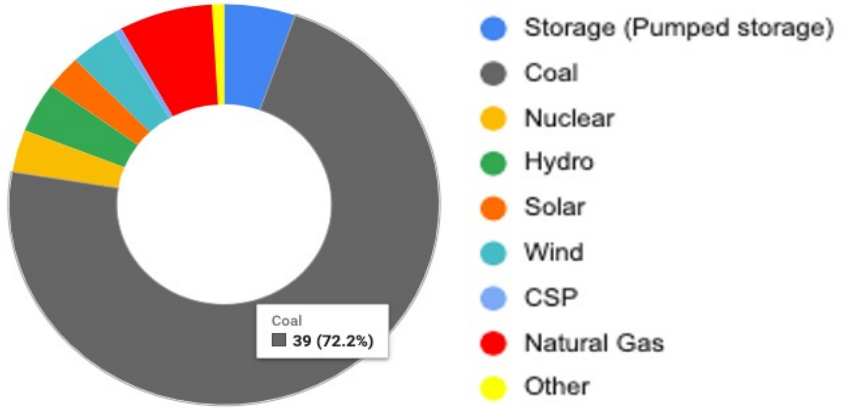


← Abandoned mine methane (AMM)—emissions from abandoned coal mines calculated by the author's model under two different coal production scenarios.

(TOP) IEA Stated Policies Coal Production Scenario.

(BOTTOM) Coal produced scenario in the emissions reduction pledge by South Africa (or NDC, for nationally determined contribution) under the Paris Agreement

South Africa is a coal intensive economy that produces the most greenhouse gas emissions in Africa. Greenhouse gas emissions are responsible for climate change which poses serious systemic risks worldwide. Because of the transboundary nature of climate change, it can only be addressed through collective action. Consequently, there has been an international shift from fossil-based systems of energy production and consumption to renewable energy sources. South Africa plans to implement its' Just Energy Transition plan to shift most of its coal-fired electricity production from to renewables by 2050. However, the country has a poor record of rehabilitating abandoned coal mines which continue to release methane despite halting mining operations. This paper seeks to propose the further evaluation of the potential of developing projects to capture methane at abandoned coal mines given South Africa's decommissioning plan. The goal of this research is to incentivize the South African government to incorporate better planning for abandoned coal mine methane into its long-term emissions mitigation commitments.



↑ Electricity mix of South Africa in 2019. Source: iEA

Biden Goes Nuclear: An SMR moonshot project for the United States and the world to achieve a zero-carbon future

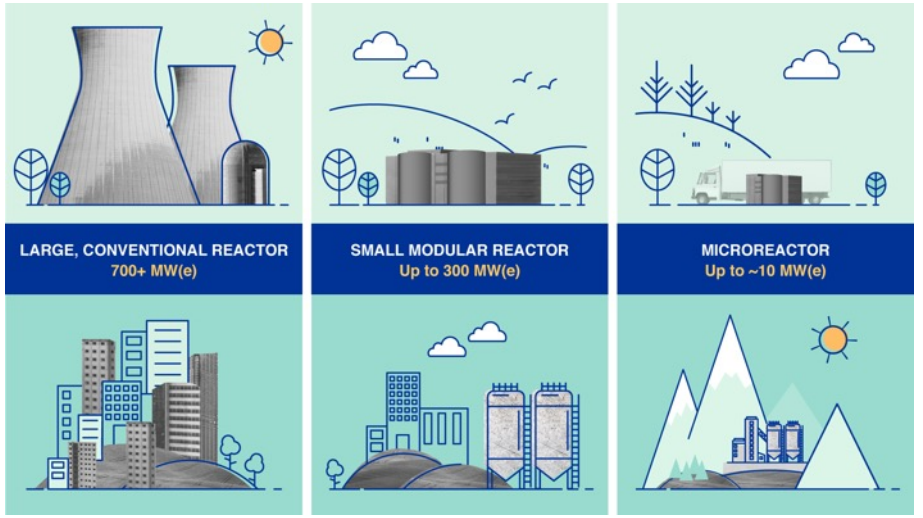
Wyatt Nabatoff '22

Morse | Engineering Science-Mechanical

1938: Nuclear fission discovered
1942: Manhattan Project launched in secret to create the first nuclear weapon
1946: Atomic Energy Commission created
1951: First experimental reactor produces power (US)
1952: First small reactors built
1953: Eisenhower's Atoms for Peace speech
1954: Atomic Energy Act
1957: Price Anderson Act
1957: Shippingport Nuclear Plant goes online, first fullscale nuclear power plant
1959: Dresden-1 goes online
1960: Golden Age of Nuclear begins and lasts until Three Mile Island meltdown
1963: Oyster Creek Nuclear Plant goes online
1973: Arab Oil Embargo
1973: A record 41 nuclear plants ordered
1974: Nuclear Regulatory Commission created
1979: Partial meltdown at Three Mile Island (12 days after release of *The China Syndrome)*
1980: Electricity demand contracts. Nuclear growth begins its long stagnation.
1986: Chernobyl Plant Meltdown (USSR)
1989: 20% of US electricity comes from nuclear
2011: Meltdown at Fukushima (Japan)
2013: Virgil C. Summers Plant construction begins
2016: Watts Bar Nuclear Plant completed
2017: First US SMR Reactor Certified (NuScale)

↑ Timeline of Nuclear Power

If the trend of nuclear power's decline continues, there will be very few, if any, operating US nuclear power plants in 2035. That same year the country pledges to have an electricity sector that produces zero emissions. Currently, the United States produces more electricity from nuclear power than all the other carbon-free energy sources combined. These two trends are incompatible and only first has the potential to change. Understanding that conventional nuclear power plants are no longer economically viable due to delays and cost overruns, this paper explores what it would take to ignite the widespread reintroduction of the nuclear power though Small Modular Reactors (SMRs). These reactors are based on proven nuclear technology and are much safer and more cost-effective than their large-scale counterparts. This paper examines why SMRs are needed, how public support for SMRs is growing, and what government actions are required to stimulate the growth of the much-needed industry.

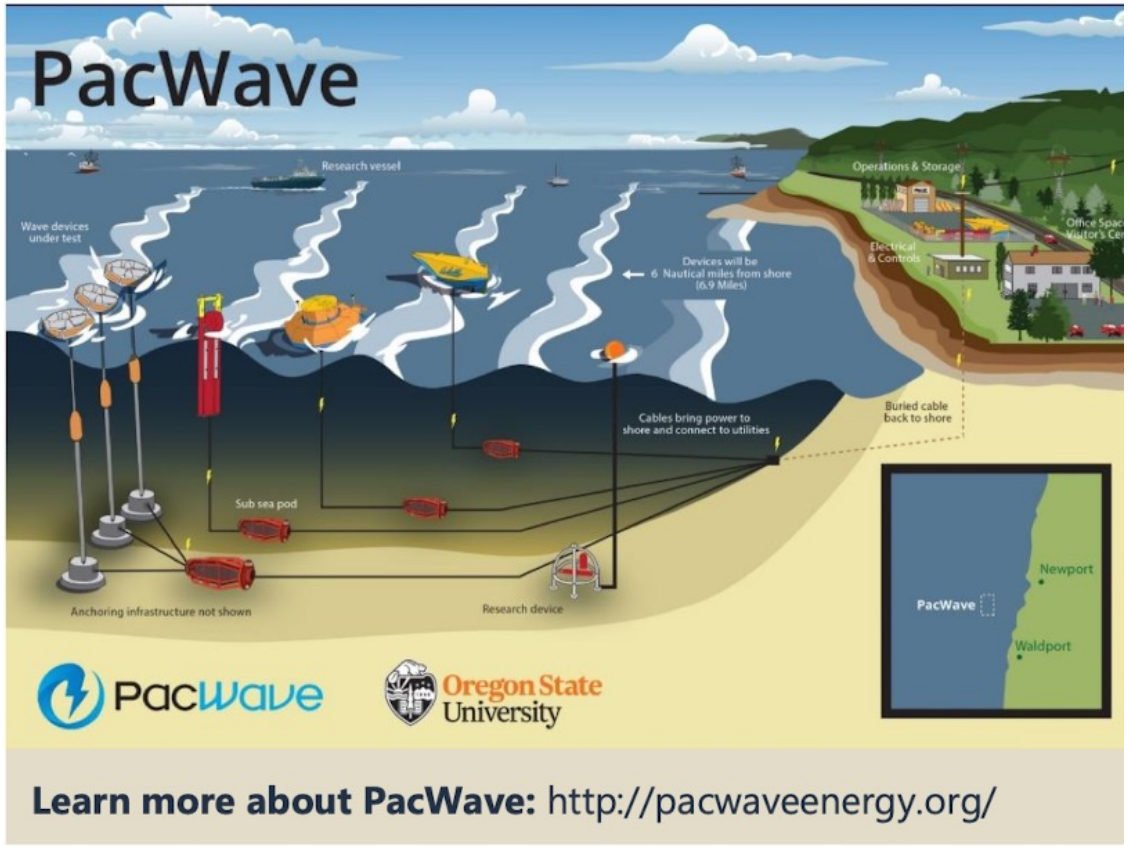


↑ Classification of nuclear reactors, including SMRs and micro-reactors. Source: IAEA

Marine Renewable Energy in Oregon

Bea Pickett '22

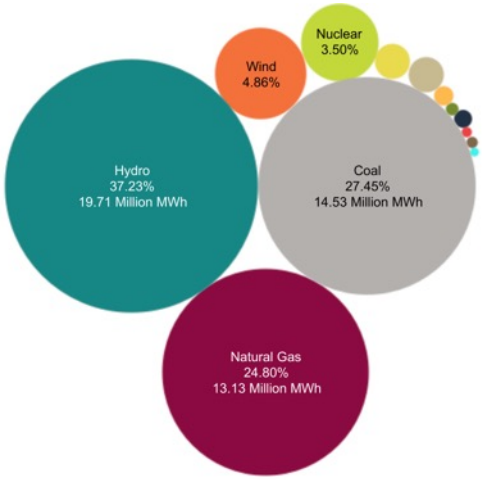
Berkeley | Environmental Studies | Political Science



↑ >Testing ocean wave energy generation in Oregon. PacWave is an open ocean wave energy testing facility consisting of two sites, each located just a few miles from the deep-water port of Newport, Oregon. pacwaveenergy.org

As humanity confronts imminent catastrophic climate change, an energy transition towards renewable sources becomes increasingly urgent, galvanizing a need for creativity and ingenuity in harnessing the planet's natural resources sustainably. For this, we must look to the ocean and tap into the abundant and fully renewable energy created through natural oceanic processes. Wave movement, tidal fluxes, and oceanic currents create a plethora of opportunities to convert marine energy into renewable power. Though marine renewable energy is a relatively nascent field compared to other renewable energy sources such as wind and solar power, it holds great potential and promises to play a critical role in the decarbonization of the world's energy.

The state of Oregon in particular boasts a promising landscape for the development of marine renewable energy, given its abundant wave energy resources. Oregon is thus advantageously poised to lead the United States in the development and deployment of marine renewable energy capture systems. Marine renewable energy development can play a key role in decarbonizing Oregon's electrical grid and enabling Oregon to export more energy to other states.



Energy mix for electricity generation in Oregon. ↑
Source: Oregon Department of Energy

The Waymaker: A Breakthrough Strategy to Tackle Climate Change

Jack Pleasants '22
Grace Hopper | Political Science

U.S. Carbon Advantage Over Key Trading Partners By Sector

	USA	Brazil	Canada	China	EU	India	Mexico	Russia
Chemicals & pharmaceuticals	1.0	0.9x	1.5x	2.6x	0.8x	2.1x	1.2x	5.5x
Rubber and plastic products	1.0	0.9x	1.0x	2.7x	0.7x	2.1x	1.1x	2.9x
Basic metals	1.0	1.3x	1.0x	1.8x	0.9x	2.7x	0.7x	3.7x
Fabricated metal products	1.0	1.3x	0.9x	3.1x	0.9x	6.1x	1.4x	4.8x
Computer, electronic and optical products	1.0	2.5x	2.3x	5.7x	2.1x	8.0x	3.4x	7.4x
Electrical equipment	1.0	1.5x	1.2x	3.1x	1.0x	3.9x	1.4x	4.8x
Machinery and equipment	1.0	1.0x	0.9x	2.8x	0.8x	4.0x	1.2x	4.5x
Motor vehicles and trailers	1.0	1.2x	0.9x	2.4x	0.7x	3.5x	1.0x	3.6x
Economy-wide	**1.0**	**1.1**	**1.3**	**3.2**	**0.9**	**3.8**	**1.4**	**4.2**

U.S. Carbon Advantage (foreign competitors less carbon efficient)
U.S. Carbon Disadvantage (foreign competitors more carbon efficient)
U.S. Carbon Efficiency or Equivalent

Source: MacroDyn Group calculations based on data from the International Energy Agency, the World Input-Output Database environmental accounts and the Global Trade Analysis Project.

↑ Table comparing the carbon efficiency of US compared to its trading partners, overall and in key economic sectors.

To begin, we must take a birds-eye view of the human story. Henry Elkus, thinker, former student here at Yale, and the founder of Helena.org, gave an inspiring TEDx Talk in October 2018. The central premise of his talk is that the defining feature of humanity to date has been reactivity – solving problems after they become problematic. Elkus makes the case, however, that the 21st century will be defined by our ability – or inability – to become a civilization that proactively solves problems.

I agree with Elkus and will add the specification that proactively solving collective action problems will define the 21st century. The most prominent example of such a problem right now, quantified by the vote of the millennial inhabitants in 186 countries, is climate change. However, in order to maintain brevity and establish a comprehensive argument, we must narrow the scope of the problem.

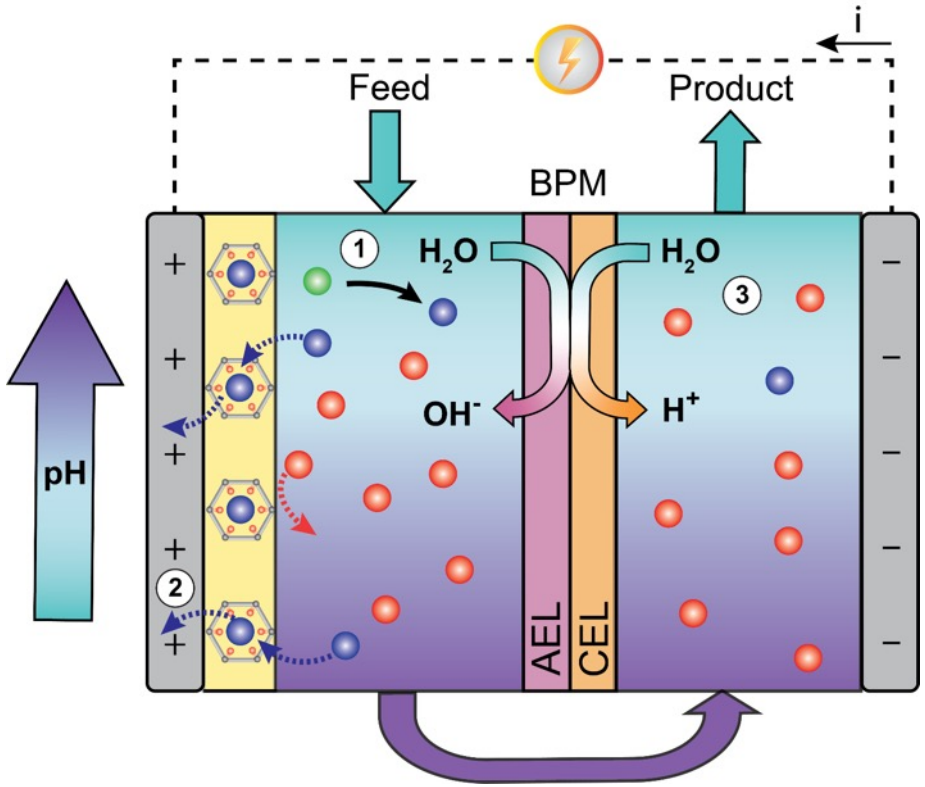
There are multiple policies, technologies, and actions we need to tackle climate change effectively, hence the recent emergence of the idea of a "silver buckshot" rather than the familiar "silver bullet" approach. More specifically, in this essay we will taper the climate problem to a manageable size and argue that the United States needs a sufficient, revenue-neutral, border-adjustable carbon tax as a "Waymaker" for our silver buckshot.

Let's discuss first principles. The main reason climate change is unresolved is that the energy system overhaul is happening too slowly. But why? The simple answer is that current incentive structures are flawed.

Bipolar Membrane Assisted Electrosorption for Boron Removal and Recovery

Alex Saczawa '22

Benjamin Franklin | Engineering Science-Chemical



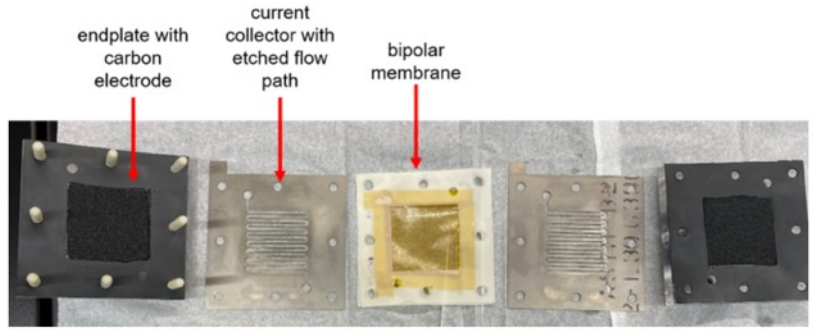
↑ Bipolar membrane boron electrosorption process. The basic conditions on the anode side (feed) allow for the conversion of boric acid to borate ion. Boric acid is represented by green spheres while borate ion is represented by blue spheres. The functionalized anode on the feed side selectively electrosorbs borate ions over chloride ions, depicted as red spheres. The basic effluent solution is then neutralized on the cathode side. Water electro-dissociation at the membrane is also depicted at the BPM.

There is a rising global need to remove and capture boron from water supplies. While boron is an essential nutrient to plant life, in high concentrations is can be toxic for certain plant species and has the potential to be harmful for humans. This is especially true for drinking water supplies. The current two-pass reverse osmosis method for boron removal requires high energy, chemical, and cost inputs, and a new method for removal must be attained to address these shortcomings. Furthermore, due to the utilization of boron in many industrial applications, there is great value in recapturing the boron removed from water samples.

Capacitive deionization is a technology in which ions can be selectively electorsorbed. A bipolar membrane, which contains two ion- exchange layers, can be used for adjusting pH levels to a desirable level for ion synthesis.

The novel boron removal and recovery method proposed in this research utilizes a combination of capacitive deionization and a bipolar membrane for selective electrosoprtion of boron, in the form of boric acid, in saltwater samples.

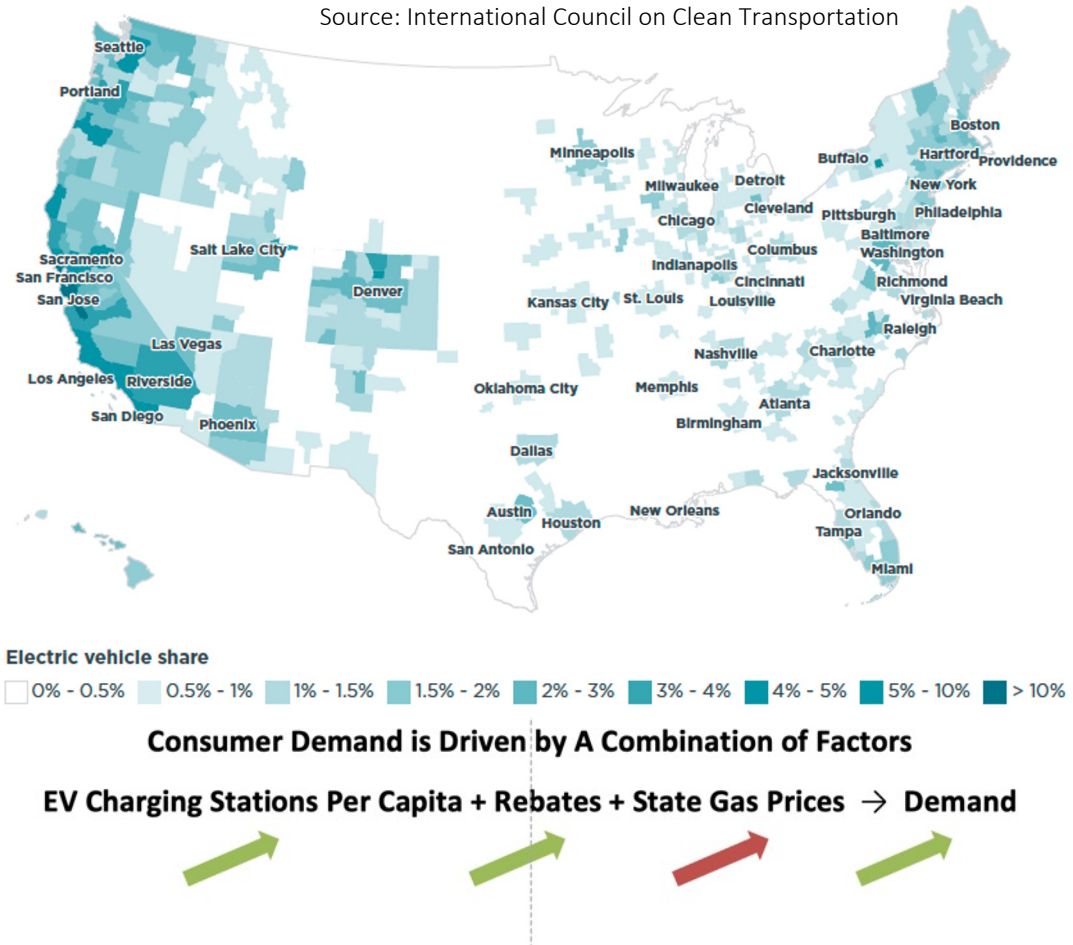
Bipolar membrane electrosorption setup. Activated carbon cloth electrodes, at both ends of the electrochemical flow stack, have high surface area from high porosity which allows electrosorption of ions on the charged surfaces. Carbon cloth is stored in acid solution to increase electrosorption. →



Analysis of the Market and of Grid Capacity and Resilience for EV Charging in the U.S.

Andrew Song '22
Pierson | Global Affairs

Source: International Council on Clean Transportation



↑ TOP) EVs as share of new 2019 vehicle registrations by metropolitan area.
(BOTTOM) Model of consumer demand for EVs and trends in each factor.

In 2021, I participated with a team of students from Yale College, Yale School of the Environment, and Yale School of Management in a research project on electric vehicle (EV) charging and grid infrastructure. The project was supported, in part, by ADS-TEC Energy, Inc., a newly listed public company developing advanced technology for ultrafast (15 minute) charging of EVs using a large-scale batteries connected to the grid.

One part of the project looked at the market size, including:

- *Assessment of projected EV sales in the U.S. on a regional basis, including a breakdown of types of vehicles and settings (urban, suburban, rural);*
- *Analysis of charging patterns and locations (home, work, public charging stations at parking locations);*
- *Research into existing surveys of consumer preferences for charging times*

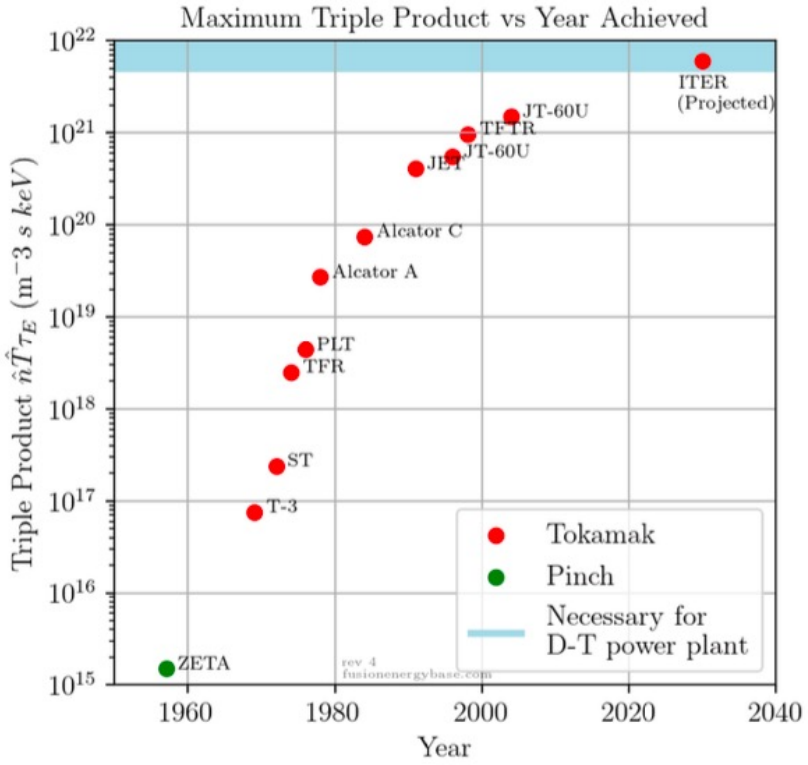
A second part of the project conducted research on limitation that today's electrical grid places on EV charging including:

- *Evaluate the lack of infrastructure in parts of the US and understand level of difficulty to implement ultra-fast charging within cities;*
- *Consider implications of peak demand by region/city;*
- *Consider limitations on power attributable to the grid;*
- *Identify the impediments—technical, economic, and regulatory–in deploying a fleet of ultra-fast charging stations at the density needed to support full electrification of transport in the U.S.*

Nuclear Fusion: A Primer

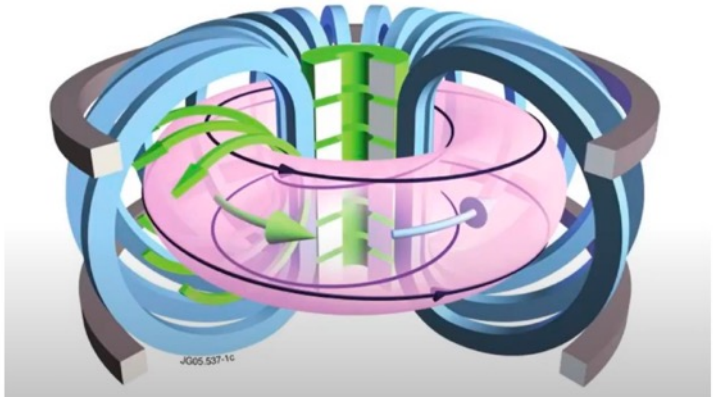
Will Strauch ’22

Grace Hopper | Earth & Planetary Sciences



↑ Measuring progress toward practical fusion. The fusion triple product is figure of merit for plasma which accounts for density (n), temperature (T), and confinement time (τE). Raising the temperature of a plasma increases the likelihood of a collision between nuclei resulting in a fusion reaction. Raising the density of a plasma increases the rate at which these collisions occur. The confinement time is the average time it takes for a unit of energy to leave a plasma..

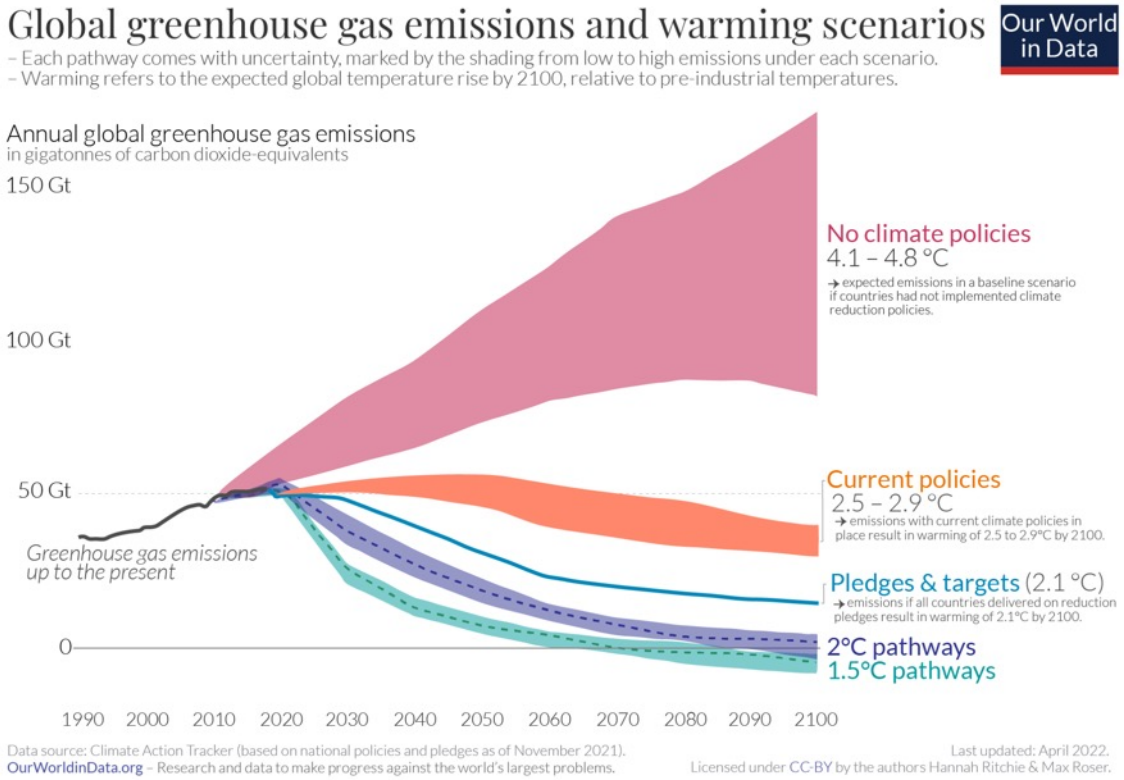
Fusion energy has seemingly been ‘right around the corner’ for almost sixty years now. Many have lost faith that a viable fusion reactor design will ever be developed. However, a surge of private funding has sparked renewed public interest in the potentially unlimited energy source. While the emergence of a private fusion energy industry may be bringing a long-overdue wave of fresh ideas and new perspectives, it has only increased the opacity of the industry from an outsider's perspective. With multiple ventures claiming breakthroughs and milestones, it is difficult to gain an accurate understanding of the development without a detailed understanding of the requirements for fusion. This thesis is an attempt to demystify a complex science and undercover some of these requirements. With a better understanding of the physics behind fusion energy development, time and resources might be directed towards the ventures that have the highest potential for success.



↑ Schematic of the Joint European Torus, the most promising type of fusion reactor. D-shaped coils (blue) looping around the torus are electromagnets, which create magnetic field lines (black) guiding charged particles in spirals. A torus-shaped reactor is the simplest way of closing magnetic field lines to confine a plasma (UK Atomic Energy Authority).

The Tides Are Turning: If & How to Navigate the Climate Tech Wave: A White Paper on Climate-Tech Investing

Nico Trigo '22
Davenport | Economics

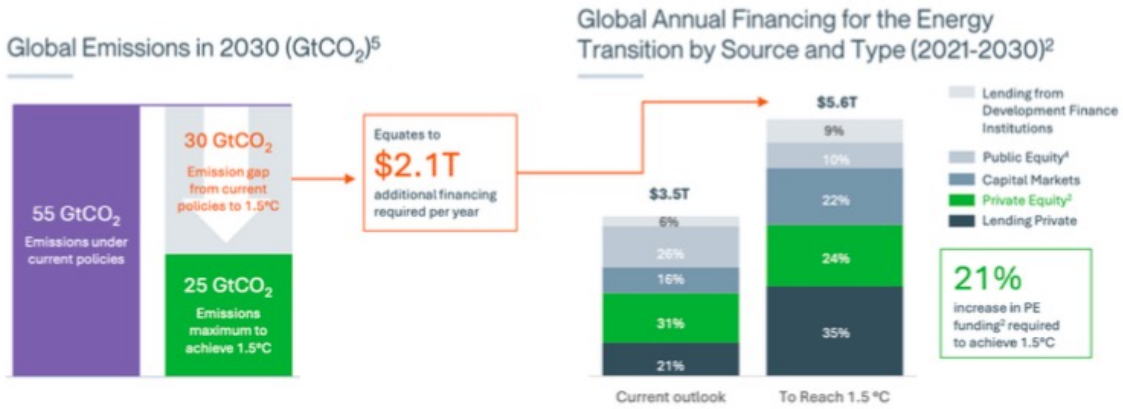


↑ Greenhouse-gas emissions trajectories and implied global warming. ourworldindata.org

Today, we are faced with an objective unlike any from our past. As we gear up to address climate change and the unprecedented impacts it can and will have, we must remember the evolution of the instruments and processes we have designed, built, and normalized that put us where we are today. Climate technology will be the steamboat, the steel mill, and the personal computer of tomorrow.

This paper's scope is limited to early-stage investments in climate technologies. In this context, early-stage investments refer to conventional venture and growth stage private equity investments. This paper covers climate technologies as an asset class with the goal of understanding, primarily:

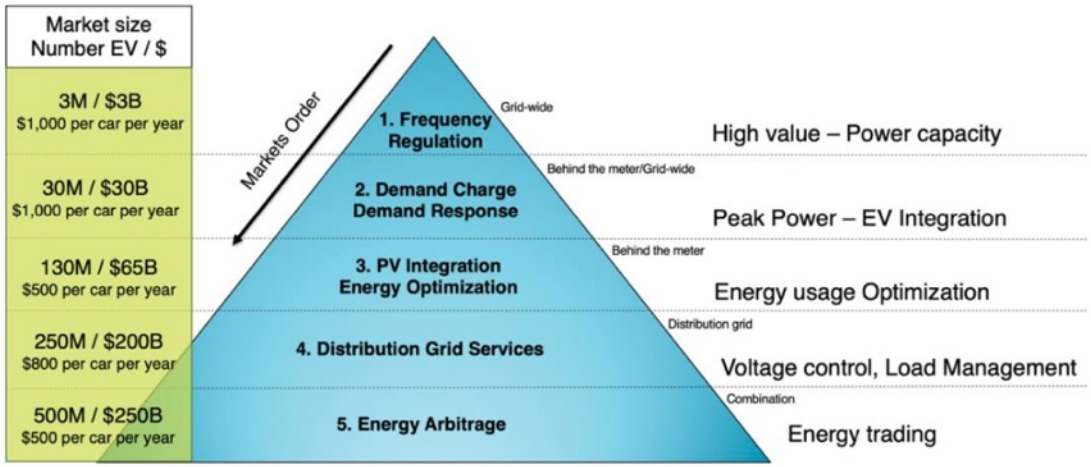
- *Historical progression and momentum of climate-tech investments*
- *Aggregated and segmented returns and expectations*
- *A comprehensive market mapping of the investment opportunities in climate technology*
- *Thematic insights for an early-stage climate tech investor*
- *The relationship between invested capital and progressive climate impact, and how to maximize impact accordingly*



Estimate by Silicon Valley Bank of investments needed to be a reasonable pathway by 2030 to limit global warming to 1.5°C. →

Energy Storage in the United States: Trends and Investment Opportunities

Alex Urbahn '22
Saybrook | Economics



↑ Investment opportunities in V2G. Vehicle-to-Grid (V2G) is a concept for integrating electric vehicles (EVs) as energy storage devices in the electrical grid. V2G takes advantage of low vehicle utilization, providing storage capacity when not in use. Benefits are the same as traditional standalone battery storage. Some studies demonstrate that intelligent V2G services can even extend the life an EV's battery. Source: Nuvve Corp. (nuvve.com)

Global average surface temperature has increased by over 1°C since 1880, with two thirds of that warming occurring since 1975.1 Fossil fuel combustion and the associated Greenhouse Effect have been the principal cause of this change. The electricity sector is the second largest source of emissions in the United States; 62% of supply comes from fossil fuels, namely natural gas, and coal.2 With this understanding and the threats posed by climate change, shifting electricity generation to renewable sources has become an integral component of sustainability. Grid decarbonization is projected to be the single largest pathway for reaching net zero by 2050 (36% of emissions reductions).

As such, renewable energy has been the fastest growing energy source in the United States. Renewables as a percent of electricity generation have increased 90% between 2000 and 2020.4 Wind and solar have been particularly favorable. Total annual electricity generation from wind has increased from 6 billion kilowatt-hours ("kWh") in 2000 to 380 billion kWh in 2021, corresponding to a 22% compound annual growth rate ("CAGR").5 Solar generation has grown from 0.5 billion kWh in 2000 to 91 billion kWh in 2020, corresponding to a 30% CAGR.

This paper will review the benefits of storage, technologies offered, and market growth factors. This will be accompanied by an investment recommendation. The viability of energy storge necessitates significant capital allocation from both retail and institutional investors; this paper seeks to identify key trends and opportunities to close information gaps for said parties.

A Dammed Existence: the Ranganadi Dam's impact on the reshaping of riverine communities of the fisher and the fished

Elizabeth Van Ha '22
Benjamin Franklin | Ecology & Evolutionary Biology

↑ Outward-facing view of the Ranganadi Hydro Power Station.
Source: North Eastern Electric Power Corporation Limited.

This paper will highlight the case study of the Ranganadi Hydropower Electric Plant (RHEP)—operated by the private organization North Eastern Electric Power Corporation Limited (NEEPCO)—on the Ranganadi river and its effect on downstream communities, particularly the village fishers and their relationship to the water and the fish they commercially and traditionally consume.

We will first look at what elements contribute to the dams and entangled rivers, then examine who controls the river, and how the river is controlled through situating ourselves in the particular social, historical, environmental, and political context of the dam. Then, we will look more closely at the impact and changing relationship with the downstream inhabitants of the dam, particularly examining ties seen between the endemic fish populations of these rivers and the humans who interact with them.

The effects of hydropower projects at the turn of the 21st century contain universal issues of environmental justice, but they cannot be understood without assessing the local environmental, political, and social contexts that formulate the specific experiences of individuals downstream of the dam. In a local analysis of the impacts of the dam, particularly in the fish and fishing community, one will see how physical changes and more abstract political, post-colonial public, and private stakeholders further destabilize the human and nonhuman livelihoods and shift the ecological and socionatural baselines that were already in place.

The story of the Ranganadi dam [teaches] us that the attempts to control never goes to plan, as the river creates ways to resist and flow beyond the preset limitations…

Development of geothermal district heating systems in the United States

Paulina Wells '22

Jonathan Edwards | Environmental Engineering

↑Geothermal District Heating in Iceland. Reykjavík District Heating system (now known as the Reykjavík Energy) is today the largest geothermal district heating service in the world. Over 97% of the inhabitants of the capital city of Reykjavik are connected to the system. Overall, in Iceland, 57% of the population enjoy the benefits of geothermal district heating.

Yale University is drilling test wells to evaluate the feasibility of replacing the heating and cooling of main campus—which today comes from waste heat generated by the university's two natural-gas power plants—with a geothermal district heating system.

Buildings account for 36% of the global final energy demand and 39% of energy and process-related CO2 emissions, thus play a major role in climate change mitigation. However, efforts in energy efficiency have been hindered by the growing energy demand for space and water heating. In 2015, space and water heating accounted for 62% of household energy. consumption. Recent data suggest that space heating accounts for about 42% of energy use in U.S. residences and about 36% of energy use in U.S. commercial buildings.

This essay looks at the feasibility of using geothermal energy at the community scale to decarbonize heating in residential and commercial buildings. Geothermal energy uses natural low-grade heat flowing from Earth's hot interior to the surface. On average, temperature within the Earth increases by about 25°C for every kilometer of depth in the crust. These higher temperatures at depth can be exploited by technologies such as heat exchangers and heat pumps to satisfy the heating (and cooling) needs of buildings.

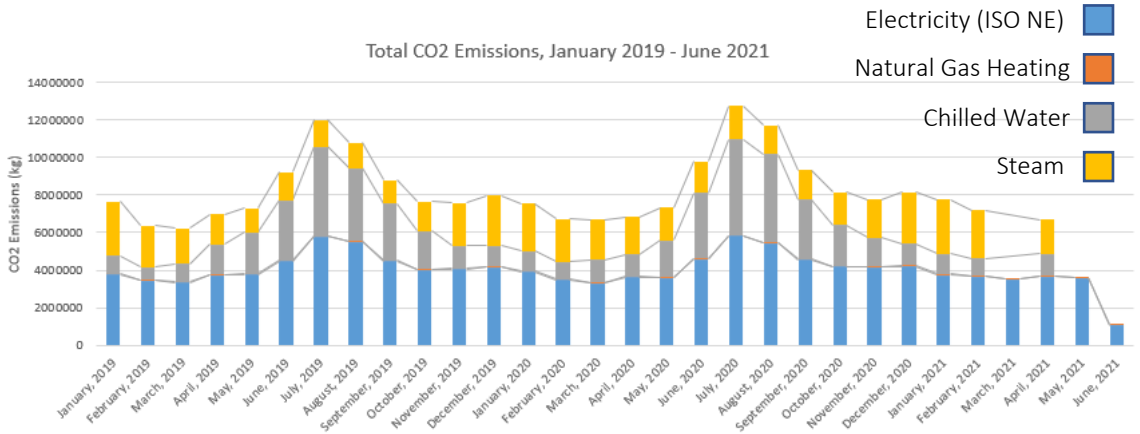
Geothermal district systems (GDS) are networks that provide temperature regulation to multiple consumers from a single well or from multiple wells or fields. These systems are mostly used for district space heating. With rising global temperatures, the demand for district cooling is growing at a tremendous rate. Space cooling loads are not discussed in this paper because construction of a district geothermal "cooling" system is difficult to justify economically….

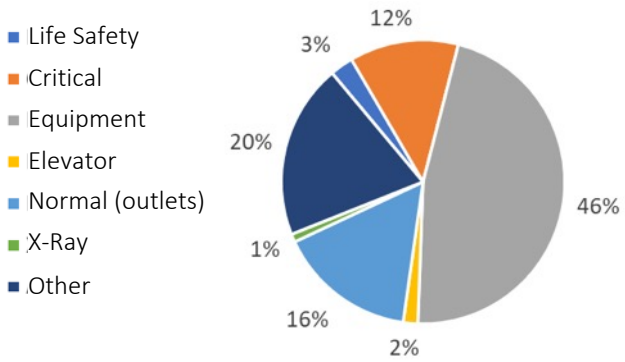
With lessons learned from developing and developed GDHS, the United States can facilitate reaching its goal of decreasing CO2 emissions and preventing further global warming through the development of geothermal district heating systems.

Carbon Dioxide Emissions Caused by Electricity Usage in Healthcare: Case Studies of the Yale New Haven Health System

Alex Wynn '22

Timothy Dwight | Environmental Studies





↑ (TOP) Total CO2 emissions for all five hospital campuses in the YNHHS from January 2019 through June 2021.
(BOTTOM) Emissions by type of service at Yale New Haven Hospital.

There is a revolution in the global healthcare community to push for rapid net-zero as a sector. Climate change has harmful effects on public health that are only set to increase as greenhouse gas (GHG) emissions rise (USGRP 2016). Increasing global temperatures and extreme weather events are causing illness, disease, and even death (Schwartz et al. 2015). As proved by this essay previously, the emissions from buildings operations contributes greatly to the changing climate.

Healthcare buildings are no different from those in other sectors in that they all produce greenhouse gas emissions. In 2013, the United States' healthcare sector contributed 10% of national greenhouse gas emissions (Eckelman and Sherman, 2016). When treating patients with illnesses and disease, the healthcare system consumes electricity and fuel, generating CO2 and other greenhouse gases and, thus, contributing to future health damages that will be caused by climate change. To fix this paradox, emissions caused by healthcare services must be reduced.

To reduce the use of electricity in healthcare buildings and its associated GHG emissions, it is necessary to know where usage is highest, and how the electricity is generated, to understand where the largest potential for reduction lies. This essay provides guidance to Scope 2 emissions in healthcare buildings, through a series of case studies on Yale New Haven Healthcare System (YNHHS)—a non-profit healthcare system that operates five large hospitals in Connecticut and Rhode Island and includes Northeast Medical Group, a collection of medical practices that is comprised of more than 130 providers.

Desert Shores Hot Spring Spa (Salton Sea): Design for Sustainability

Hannah Yi '22
Benjamin Franklin | Architecture

Desert Shores Hot Spring Spa is located at the shores of the Salton Sea: a shallow, landlocked, highly saline body of water in southern California that is well known for being an ecological disaster. Once a booming tourist attraction, the lake has since been abandoned due to its toxic waters. My project aimed to aid in the city's relief efforts by constructing a sustainable hot springs spa drawing water and steam from the nearby sea and bringing tourism back...

The spa spirals around the body of the hot spring; its construction takes inspiration from the volcanic mudpots...scattered around the site as well as from the experiential qualities of water: its three-dimensionality, dynamism, [and] scalelessness... Guests at the Desert Shores Hot Springs Spa are able to fully experience living in a waterscape while bathing in the many pools that flow out of the hill's peak, where the water bursts out and eventually collects throughout the landform's dips and terraces.

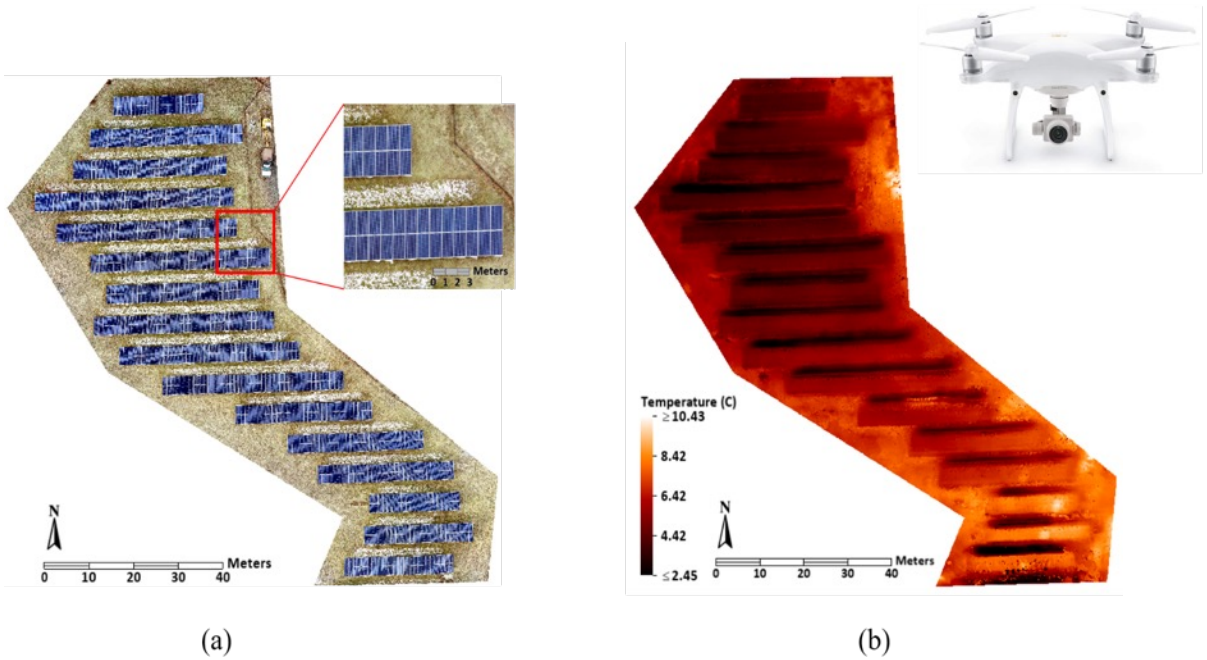
↑ Model | *Cotton and yam on carboard and wire frame*

Section showing relationship to the hot spring →

Photovoltaic Solar Panel Identification and Fault Detection Using Unmanned Aerial Vehicles: Case Study of a 0.5 MW PV System

Raymond Zhao '22

Saybrook | Earth & Planetary Sciences



(a) (b)

↑ Orthomosaic images of the solar array at Bishop's Orchards. (a) This image contains the first three bands, DJI-RGB, of the 4-band orthomosaic. It looks pixelated but that is due to the linear patterns within the panels. A zoomed-in view of the panels is depicted by the red box. (b) The thermal band is the fourth band of the 4-band orthomosaic. Its DN values have been calibrated. Inset at upper right shows the DJI Phantom 4 Pro Quadcopter used to collect the data.

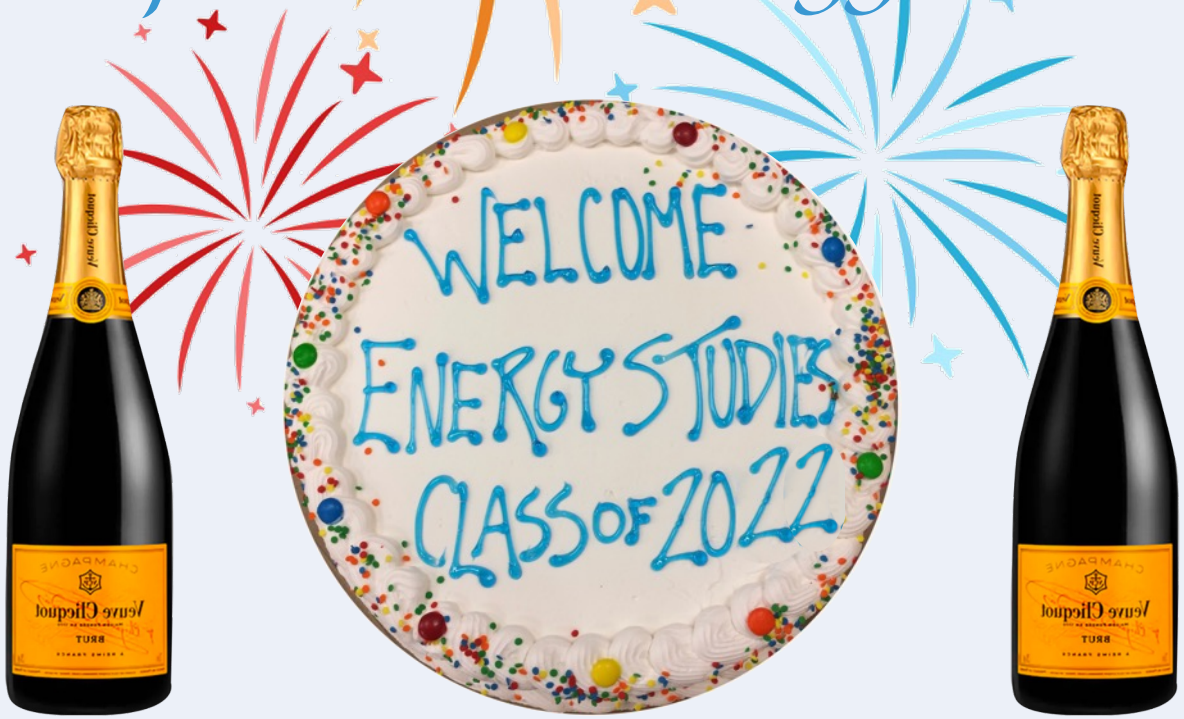
Performance monitoring of individual PV modules in utility-scale solar farms can be a difficult undertaking due to the issue of scale. Since most PV systems are placed in-line and series connected, panel-specific granularity is costly, and most systems monitor performance up to the inverter level. Because faulty PV modules are higher in temperature relative to the neighboring modules, unmanned aerial vehicles (UAVs) can play an important in this field because it can survey large areas within the RGB and infrared radiation (IR) wavelengths in a convenient and low-cost manner.

In this study, we developed a workflow to capture UAV images, process the data, and perform panel identification and fault detection in the PV systems. We found that including a RGB dataset can greatly improve panel identification results since our algorithm utilizes ISODATA unsupervised classification. All of the 1048 panels were successfully identified, parsed, and turned into polygons. Moreover, our fault detection algorithm, using two spatial autocorrelation techniques, was able to detect 4 out of 6 faulty panels within our region of interest (ROI).

Data validation was performed, and we found that instantaneous mean temperature measurements did not have an intuitive relationship with energy output—positive relationship with an r-squared of 93%. It is very likely that poor temporal resolution of the orthomosaic influenced instantaneous temperature measurements and temperature sensitivity to environmental factors like sunlight and cloud coverage. These results suggest that spatial information is quite important and should receive sizeable weight in fault detection techniques to determine clusters and outliers.

To the Energy Studies Class of 2022, 33 newly minted Yale Energy Scholars:
May you never lack the energy to pursue your dreams. And:
May your dreams change the world.
But most important: May your dreams change your world!
All the best. Keep in touch!

Class of 2022 Yale Energy Scholars



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