Sociotechnical Synthesis

(Executive Summary)

Behind the Meter: Implementing Distributed Energy Technologies to Balance Energy Load in Virginia

Universities and higher education institutions across the country are often seen at the forefront of social and environmental change, the catalysts for the rest of the country. Universities such as Stanford and Cornell are the leaders of this environmental change, making solid and proven steps toward carbon neutrality. The University of Virginia has also made steps toward net zero emissions, but still have some work to do. Both of my projects focused on what methods these universities are using to reach their emission goals, and how these strategies can be implemented at the University of Virginia. For the technical project, my team and I used the Tools for Energy Modeling Optimization and Analysis (TEMOA) to predict when peak energy demands occur at UVA and to understand how interventions, such as heat recovery chillers and thermal storage tanks, might be used to balance load and also scaled these strategies to the whole state of Virginia.

In my STS research, I go in depth into my finding when studying the strategies of decarbonization for Stanford University and Cornell University. I chose these two universities because from they are rated in the top three institutions across the country that lead the way in carbon neutrality, according to the sustainability tracking, assessment and rating system (STARS) produced by the Association for the Advancement of Sustainability in Higher Education (AASHE). For both Stanford and Cornell, I study their sustainability offices' climate action plans and compare their emission goals and how they are achieving those goals. I also take into account the cost effectiveness of the methods and study how they could be applied to the University of Virginia.

The technical portion of my thesis analyzed how energy load-shifting technologies could be scaled to larger universities such as UVA by focusing on the Fontaine Research Park. Using the predictive TEMOA model along with institutional energy data, my team studied how application of distributed energy technologies in the state of Virginia and at UVA could have an effect on the grid's ability to apply these methods. Our research and models showed that on a state-scale level, balancing energy loads had a minimal effect. However, for individual institutional use, it could prove to be a helpful resource in lowering energy use and demand as well as reducing cost. My research and work with my team inspired my STS research to continue to study other ways universities and institutions of higher education can lower carbon emissions in an efficient and cost effective way.

Undergraduate Thesis Prospectus

Getting to Neutral – Designing a Zero-Carbon Emissions Plan for UVa and Virginia

(technical research project in Civil Engineering)

Going Neutral: How Universities are Making Strides Toward Carbon Neutrality

(sociotechnical research project)

by

Harrison Hurst

November 2, 2020

technical project collaborators:

Nina Mellin
Bailey Thran
Chloe Fauvel
Daniel Collins
Thomas Anderson

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.
Harrison Hurst

Technical advisor: Andres F. Clarens, Department of Civil/Environmental Engineering

STS advisor: Peter Norton, Department of Engineering and Society

General Research Problem

How Can Universities Reduce Their Energy Usage?

According to the University of Virginia's Office of Sustainability (2017), in 2017 the university emitted 274,246.4 metric tons of carbon dioxide equivalent (MTCDE); the average annual emissions at U.S. institutions of higher education was 52,434 MTCDE (UVA Office of Sustainability, 2017). Each year, universities across the United States account for approximately 2% of greenhouse gas (GHG) emissions (Parikhit et al., 2010). While this may seem like a small contribution, 2% of the United States' total GHG emission in 2017 (5.1 billion) was 102 million metric tons of energy-related CO_2. How are U.S. universities pursuing carbon neutrality?

Getting to Neutral – Designing a Zero-Carbon Emissions Plan for UVa and Virginia

What strategies can UVa implement to shift energy usage behind the meter?

This capstone project seeks to find realistic tools to reduce carbon emissions and have carbon neutrality within reach for UVa. This will be pursued alongside Nina Mellin, Bailey Thran, Chloe Fauvel, Daniel Collins, and Thomas Anderson, supervised by Professor Andres Clarens (Civil/Environmental Engineering). Geographically the boundary lines of the project are within the Fontaine Research park electrical microgrid, specifically at the Research Park's electrical substation. Within the site the existing buildings include clinical buildings, medical research buildings, parking structures, office buildings, academic buildings, and soon a new data center. The technology of distributed energy solutions that this project recommends must contribute to UVA's carbon neutrality energy plan. The viable possibilities of implementing distributed energy at Fontaine include rooftop solar, thermal energy storage, harnessing heat energy from the data center, and using an electric fleet of buses as electrical storage batteries.

The main constraint is to find a solution that provides a stable source of electricity and a favorable cost. A possible solution could be shifting load demands from the peak time at the middle of the day to nighttime to level out the demand curve. These factors create many considerations when thinking about transitioning the Fontaine Microgrid to renewable energy sources and zero carbon emissions.

Battling Within: How Universities are Split on Carbon Neutrality

How are participants within universities advancing their agendas with respect to carbon neutrality?

Climate change is quickly becoming the most pressing problem for our generation. In the last 50 years, global atmospheric carbon dioxide has risen from approximately 325 parts per million (ppm) to nearly 415 ppm (Lindsey, 2020). Universities would like to be at the forefront of progress when it comes to reducing carbon emissions, but the question is how to get there. In considering means of reducing GHG emissions, universities must consider their costs. In 2007, more than 450 universities signed onto the Presidents' Climate Leadership Commitments, a project designed to help universities take the lead in climate action. However, only seven universities have claimed they have achieved carbon neutrality, and many won't reach it until 2050. Experts at Dickinson University in Pennsylvania believe that there is a "symbiotic relationship" between environmental and financial sustainability, citing a project that led them to full carbon neutrality by 2020 (Dickinson University, 2020). However, every claim is a claim, not a fact, as the best measures are not a matter of agreement.

Two participant groups are pressuring universities to reach their carbon neutrality goals: advocacies not affiliated with universities and student groups. One of these advocacies is Second

Nature, led by Tim Carter who states that “we actually want schools to reflect that commitment…not just because they signed a piece of paper 10 years ago” (Earls, n.d.). Students are demanding carbon neutrality sooner (Villarreal, 2020). At Johns Hopkins University, HEAT (Hopkins Energy Action Team) is demanding that the university adopt the Responsible Energy Policy of 2015, which would assist in neutralizing carbon emissions (Perazzoli, 2007). The University of Michigan’s Climate Action Movement student group was joined by 31 other student organizations to write an open letter to the university’s presidential commission on carbon neutrality, expressing serious concerns regarding the “scope, pace, and efficacy of progress the commission has made” on their goal to become carbon neutral (Slagter, 2019).

Universities are primarily pursuing carbon neutrality through alternative energy sources and through carbon offsets. An example of this is at University of Georgia, who just recently invested in 33 electric buses to be in circulation by 2021 to use for student transportation (Major, 2020). Colgate University, however, favors carbon offsets to “eliminate remaining emissions from Colgate’s operations” (Colgate University, n.d.).

Environmental America, an initiative to get universities to move to 100% clean, renewable energy through solar panels argues that the price for solar installations has dropped by 70% between 2010 and 2018, and often it is cheaper than fossil fuels. A study on solar PV as a mitigation strategy for the US education sector found that solar panels could provide 100 TWh of electricity annually, meeting 75% of the current consumption, reducing health, environmental, and climate change damages by nearly $4 billion per year (Azevedo et al., 2019). Solar panels can markedly reduce grid power consumption, but they are generally too expensive to serve as the primary path to carbon neutrality. The other option is a reduction in energy in general, and offsetting any energy usage through the purchasing of carbon offsets. Carbon offsets would allow universities to help fund projects that reduce GHG emissions in order to 'offset' their own GHG emissions. Duke University has invested in carbon offsets in order to reach a goal for carbon neutrality by 2024, and are expected to offset 73,000 metric tons of carbon dioxide per year.

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Going Neutral:
How Universities are Making Strides Toward Carbon Neutrality

A Research Paper Submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia – Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

By

Harrison Hurst

Spring, 2021

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Signed: ____________________ Date May 5, 2021
Harrison Hurst

Approved: ____________________ Date ____________

Kathryn A. Neeley, Associate Professor of STS, Department of Engineering and Society

Introduction

Climate change is quickly becoming the most pressing problem for our generation. In the last 50 years, global atmospheric carbon dioxide has risen from approximately 325 parts per million (ppm) to nearly 415 ppm (Lindsey, 2020). The effects of carbon dioxide and thus climate change is very pressing. An increase in carbon dioxide levels means higher global temperatures, which in turn means shrinking glaciers, changing seasons and habitats for plants and animals, changes in precipitation patterns, more intense weather events, and sea level rise. Action needs to be taken quickly and effectively to halt climate change and to begin to reverse the effects. Higher atmospheric concentration levels not only affect nature, but also directly affects human health with side effects such as "inflammation, reductions in higher-level cognitive abilities, bone demineralization, kidney calcification, oxidative stress and endothelial dysfunction" (Jacobson et. Al, 2019).

The focus of this paper remains on universities and how they specifically can contribute to the mitigation of climate change and increasing carbon dioxide levels. Universities are the focus because very often in society they are the drivers and stewards of change; seen as the innovators for social and environmental change. Universities would like to be at the forefront of progress when it comes to reducing carbon emissions, but the question is how to get there. In considering means of reducing GHG emissions, universities must consider their costs. In 2007, more than 450 universities signed onto the Presidents' Climate Leadership Commitments, a project designed to help universities take the lead in climate action. However, only seven universities have claimed they have achieved carbon neutrality, and many won't reach it until 2050. Experts at Dickinson University in Pennsylvania believe that there is a "symbiotic relationship" between environmental and financial sustainability, citing a project that led them to full carbon neutrality by 2020 (Dickinson University, 2020). However, every claim is a claim, not a fact, as the best measures are not a matter of agreement. Only nine universities across the United States have reached carbon neutrality. That is a little over 0.1% of the universities across the country (Wise, 2020). Clearly, there is still a great amount of unknown when it comes to decarbonizing higher institutions of education.

Defining the Problem: The Gap Between Knowledge of Issues & Knowledge of the Solution

Each year, universities across the United States account for approximately 2% of greenhouse gas (GHG) emissions (Parikhit et al., 2010). While this may seem like a small contribution, 2% of the United States' total GHG emission in 2017 (5.1 billion) was 102 million metric tons of energy-related CO2. How are universities across the country working to lower this number?

Stanford is leading the way when it comes to universities decarbonizing. Stanford is a large university – it hosts nearly 17,000 students each year and has more than 1,000 buildings on its campus. This contributes a good amount of energy and thus carbon emissions; in 2017 Stanford emitted 65,519.68 Metric Tons of CO2 equivalent. However, in 2011, Stanford emitted 202,688.07 Metric Tons of CO2 Equivalent – nearly a 68% decrease in carbon dioxide emissions over a span of only six years (STARs, 2017). In order to accomplish this, Stanford has used three main principles to guide their decarbonization: Minimizing energy demand in new buildings, reducing energy use in existing buildings, and focusing on green energy supply (Sustainable Stanford, 2017).

For minimizing energy demand in new buildings, focus has been placed on energy and water usage reduction targets. The university made a goal in 2015 that all new buildings would be 30% more efficient than what was required by building codes. Stanford set out the guidelines for their buildings to reduce total energy consumption and lower the peak electrical demand, reducing air pollution, slowly reducing the use of fossil fuel reserves, and achieving energy cost and related savings due to new infrastructure.

As far as reducing energy use in existing buildings, Stanford has sought to do this through conservation, improved efficiency, and renewable power generation. Stanford's suite of energy-saving programs target large-scale building retrofits and small-scale retrofits, including heating, ventilation, and air-conditioning (HVAC) controls, as well as user programs. One of these projects is the ICAP (Integrated Controls and Analytics Project) from 2017. With this project, Stanford executed over 35 building upgrade projects. One of their success stories came from Wallenberg Hall which reduced energy usage by 40% in the first year. Using software analytics like fault detection, predictive maintenance, and performance optimization, the ICAP has saved over $100,000 in energy savings for some buildings on the campus. In order to reduce greenhouse gas emissions, Stanford also introduced the Stanford Energy Systems Innovations Project (SESI), which converted gas-powered steam boilers to a campus heating and cooling system utilizing Heat Recovery Chillers (HRCs). Two retrofit programs were also introduced, the Whole Building Energy Retrofit Program (WBERP) and the Energy Retrofit Program (ERP) which has saved Stanford $6.5 million and year and cut energy use by 24%. Figure one gives an illustration to show all the methods that were employed at Stanford.

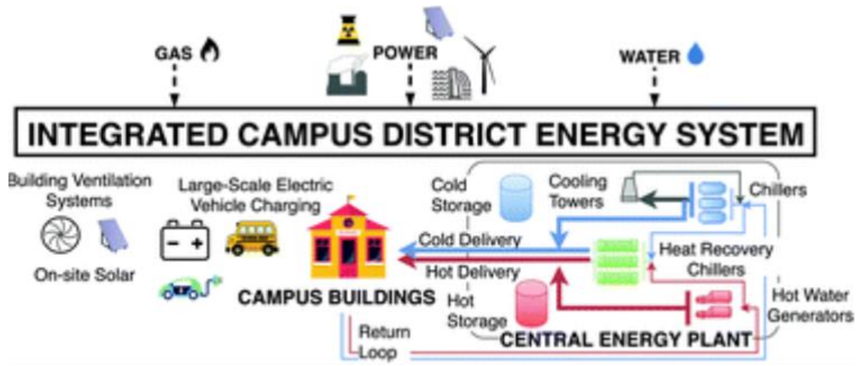

Figure 1: Mapping of methods Stanford employed to lower emissions

Following Stanford University, Cornell University was studied for the purposes of this research given that it is also one of the highest-rated universities when it comes to sustainability, and to give a different perspective since it is on the east coast in New York rather than in California like Stanford. Cornell hosts nearly 24,000 students each year and has 260 major buildings on 2300 acres for their campus (Cornell University, 2021). For the STARs emissions tracking, the performance year of 2019 was compared to a baseline year of 2004. In 2019, Cornell University emitted a total 149,053 Metric Tons of CO2 Equivalent. In 2004, they emitted a total of 250,702 Metric Tons of CO2 Equivalent (STARs, 2020). That is nearly a 41% decrease over the span of 15 years. So, how did Cornell University achieve this?

Seven neutrality key actions are outlined in Cornell's climate action plan: complete the Energy Conservation Initiative (ECI), integrate Building Energy Standards and energy modeling into building design, review, and approval process, optimize the campus Heat Distribution System, capitalize on university-owned biomass to generate renewable energy through CURBI (Cornell University Renewable Bioenergy Initiative), eliminate the use of fossil fuels for campus heating by developing an Enhanced Geothermal System (EGS) hybridized with biogas, support the expansion of wind power, and implement carbon management strategies such as forest management, carbon capture, and community projects to offset university emissions. Figure two below shows the potential impacts of these methods.

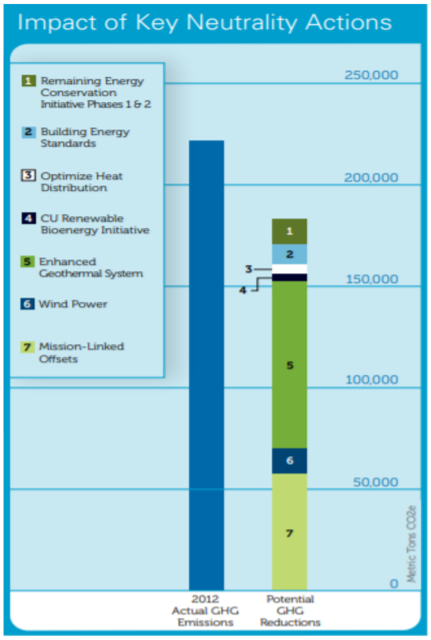

Figure 2: Potential GHG reductions with seven neutrality key actions: Energy conservation, building energy standards, heat distribution, bioenergy, geothermal energy, wind power, and mission-linked offsets.

Methods for Reduction of Emissions

The SESI project at Stanford costed $485 million (Benson et. Al, 2019). This project switched the campus district energy system from gas-based to electricity-based while meeting much of the heating and cooling loads from large heat recovery chillers, which are heat pumps that store lost heat in a water loop that can then be used later. The SESI project resulted in an overall reduction of annual carbon emissions by 65%. Figure two shows practically how these HRC's work throughout a full year.

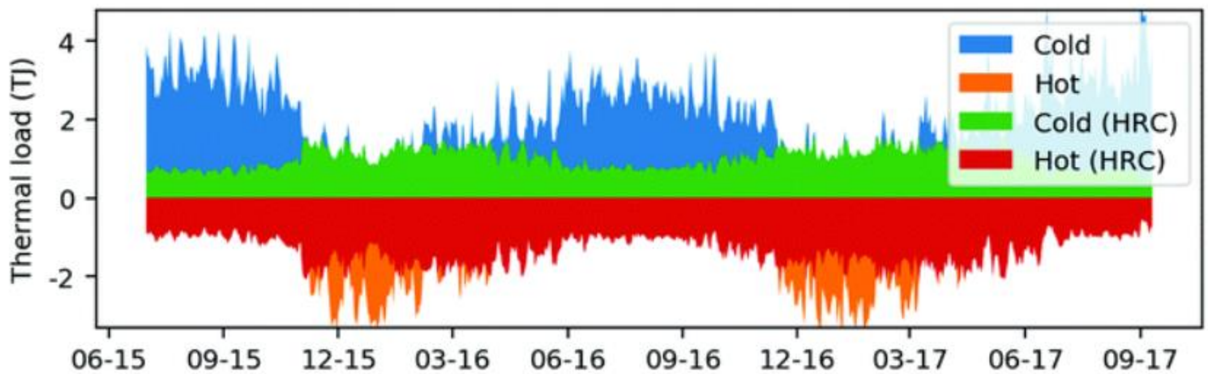

Figure 3: The red and green areas are the amount of heating and cooling loads than can be met by heat exchange using the heat recovery chillers.

Throughout two years, 51% of cooling and 90% of heating loads were met using the heat recovery chillers. Different designs were considered before the one above was employed, as this one was the lowest cost option at $1.3 billion between 2015 and 2050. Another method that Stanford was able to use to cut emissions was power and energy scheduling. In the summer and winter, much of the heating and cooling loads were fulfilled by the heat recovery chillers. The storage tanks allowed the university to shift energy consumption throughout the day, so then the chillers would produce the most at night when the demand and thus the price of electricity were at the lowest. Because of this, during peak energy hours throughout the middle of the day, Stanford is able to use energy that is already generated and stored. A graph of this is shown below.

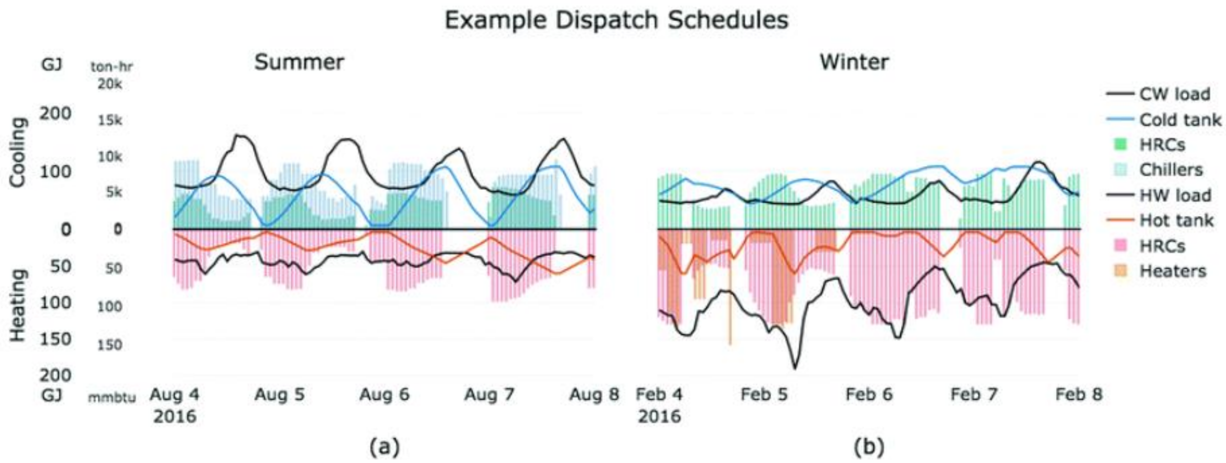

Figure 4: This graph illustrates how systems coupling heating and cooling streams can follow the highs and lows of demands and loads throughout the day. For 2016, 50% of cooling and 89% of heating loads were met by the HRCs, with the remainder being met by chillers and heaters in order that electricity is the main input and gas consumption is at a minimum.

For Cornell, the first key method is completing phase one of the Energy Conservation Initiative (ECI) and to initiate phase two. The goal is to complete retrofit, replacement, and weatherization projects in buildings on campus meant to reduce the amount of energy lost by buildings. Other retrofits also include reducing maintenance costs. Phase 1 is meant to reduce university emissions by about 11,800 metric tons of CO2 annually and reduce utility costs by $3 million per year (Cornell Sustainability Office, 2013).

The second key action is to adjust building energy standards. The goal is to establish lofty goals but to make them into contractual obligations for architectural and engineering agreements. This could help the university reduce emissions by over 10,000 metric tons of CO2 per year. Energy Use Intensity (EUI) goals are now incorporated into agreements for buildings, with each building having a unique EUI dependent on how large it is and how it will be used. For example, laboratories use much more energy than typical buildings, so a lab would have a larger EUI.

The third key action is to optimize the heat distribution system, which is very similar to the strategies employed by Stanford. Around 15% of the heat energy used at Cornell is lost in the distribution system. By fixing this problem, Cornell could reduce the university's emissions by about 6,500 metric tons of CO_2.

The fourth action is to utilize biomass for renewable energy. By using wood-based organics, organic waste, or used vegetable oil, these products are then combusted, converted, or digested in order to make heat, syngas, biogas, effluent, or biodiesel which can then be sold for profit. CURBI is currently not in full implementation but it has the potential to remove about 3,000 metric tons of CO_2. However, cost estimates for CURBI are nearly $12 million, with the basic research aspect being only $6 million.

The fifth action is to enhance the geothermal system. The goal of this project is to construct a demonstration project and determine the feasibility of implementing a full-scale project that could allow Cornell to heat and cool using only renewable resources or stored heat. This project could cause nearly 82,000 metric tons of CO_2 to be taken out of Cornell's carbon footprint each year.

Action six is to support the expansion of wind energy by obtaining electricity for facilities from outside sources, boosting the region's renewable generation potential as well as the renewable energy sector. This could provide 11,900 metric tons of CO_2 equivalent of annual carbon abatement.

Finally, action seven is to implement broad carbon management strategies such as forest management, carbon capture and sequestration, and community projects to offset the unavoidable emissions that Cornell produces. Currently, Cornell owns around 14,000 acres of land that sequester nearly 11,000 metric tons of CO_2 per year. By continually planting new trees and managing the existing one, these offsets could account for annual carbon abatement of 59,000 tons of CO_2 equivalent per year.

Results

Overall, Stanford's methods for reducing energy usage and carbon emissions were and have been very effective. Shifting loads to reduce operation costs, decreasing carbon emissions due to less carbon intensity of electrical grids, and storage methods to allow for energy demand and price flexibility have lowered emissions while keeping costs low. Peak demand is lowered from 40 to 34 megawatts, annual cost savings are $770,000, and the amount of electrical chillers needed drops from 7 to 3. The systems that Stanford employed are not only applicable to universities, but also to hospitals, industrial campuses, and any sectors that use similar technology. However, these improvements do not come without barriers. The key obstacles are more political and social than technical or economic. Retrofitting existing systems with heat recovery and distributed energy had the lowest cost, even lower than the business-as-usual scenario. Including these systems in new construction as well as retrofits are very feasible and cost-friendly, but most of the costs are upfront, so it is hard for communities and institutions to get on board with plans that don't have immediate benefits. Another barrier that is not represented well with the example of Stanford is the fact that the university is in California, and California already has a strong framework for carbon neutrality of its electricity grid through the Renewable Portfolio Standard, so the incentives and benefits are larger than what would be in other states or cities. Typically, the energy culture of the state in which the university is located plays a decisive role in shaping the energy conservation strategies an institution undertakes.

Cornell has also made great progress with the reduction of carbon emissions. To date, Cornell has decreased emissions by at least 36% from 2008 (Sustainable Campus, 2021). The

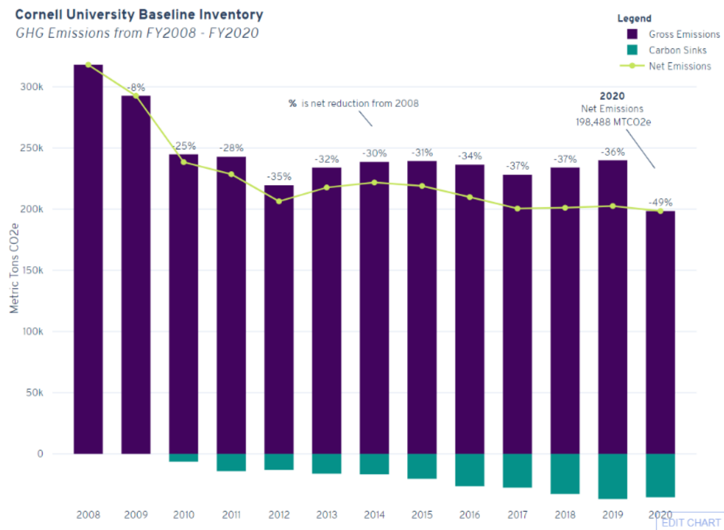

Figure 5: Net carbon emissions 2008 - 2020

figure above shows these reductions. The teal at the bottom of the graph represents renewable energy certificates, offsets, and exported electricity. Cornell has already made great reductions in their emissions, but plan to do more. Recently, they came out with the goal to reach carbon neutrality by 2035. Building off of the methods stated before, by 2022 they would like to complete their project of ESH (Earth Sourced Heat), by 2027 they would like to have fully implemented a campus heating solution as well as advancing other carbon reduction efforts, and by 2035 want to have net carbon emissions down to zero (O'Connor, 2017). However, Cornell might face some opposition to their aspirations in earth-sourced heat as it involves drilling. The community in Ithaca, NY is concerned about how this will affect them.

So, after studying Cornell University and Stanford University and looking at the ways that they have seen success in the reduction of carbon emissions, what is UVA currently doing and what changes do they need to make? In 2009, UVA emitted 285,917.60 metric tons of CO_2 Equivalent. In 2016, they emitted 244,229.10 metric tons of CO_2 Equivalent. Between 2009 and

2016, that is only a reduction of 14.6% (STARs, 2020). While reduction is progress, it is nowhere near the progress that Stanford and Cornell have made.

In 2011, UVA's Board of Visitors passed a resolution to reduce GHG emissions 25% by 2025 (Pettit, 2019). In their plan, UVA broke up a summary of their GHG emissions into a few sectors: energy generation, renewable energy, existing buildings, green labs, new construction and renovations, transportation, awareness and individual effort, and green IT. By making modifications in each of these areas, they hope to reduce total emissions by 130,000 metric tons of CO2 Equivalent.

UVA is looking more into pursuing reduction strategies such as heat recovery technology, renewable, and a sustainable transportation plan (Anderson, 2019). UVA also recently released a ten-year sustainability plan which is to "be carbon neutral, reduce water use by 30%, and reduce the university's nitrogen footprint by 30% in the next ten years. It also wants to increase the use of local, sustainably grown food and reduce waste" (Wyant, 2020). They also have the goal to be totally fossil fuel-free by 2050. University of Virginia is utilizing their students in these efforts, as they are exploring the possibilities of converting buses from diesel to electric and implementing more solar rooftops.

Conclusion

Overall, UVA is making improvements in reducing emissions, but they still have a ways to go. A reduction of a little over 10% in carbon dioxide emissions in the past decade is progress, but other schools are developing much faster. Cornell and Stanford are leading the way in their reduction efforts, dedicating funds to large upfront costs that payoff quickly. Climate change is a long-term problem, so it requires investment in multiple methods. UVA can improve their climate action plan by imitating the methods that Stanford and Cornell have pursued.

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