THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF MECHANICAL ENGINEERING

Energy Usage and Literacy at Universities in the United States

EMMA LEMAY
SPRING 2022

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Mechanical Engineering
with honors in Mechanical Engineering

Reviewed and approved* by the following:

Dr. Jacqueline O'Connor
Associate Professor of Mechanical Engineering
Thesis Supervisor

Dr. Daniel Cortes
Assistant Professor of Mechanical Engineering
Honors Adviser

* Electronic approvals are on file.

ABSTRACT

Energy production and usage is a critical topic at universities in the United States as many top-level universities are looking to lead the way in applying research on renewable energy on their campuses. In 2008, 63% of incoming fist year students said they would like to have information on their universities' commitment to sustainable energy practices [1]. This thesis addresses the issue of how campuses across the United States share their energy practices as well as looking specifically at energy generation and usage at Penn State throughout the pandemic.

There is a lack of published material on how universities across the United States incorporate real time energy data from their campus into their curriculum for their students or as available resources for the students. Comparing public access information for universities in the United States, a study on how energy is generated, where energy is sourced from, and how available that information is (especially to students) is able to be done. Looking at universities on a similar level allowed a limited understanding of the national energy scene before discussing energy generation and usage at Penn State in particular. The generation of electricity and steam at various generation points at University Park are analyzed. Additionally, the usage of both electricity and steam are compared in terms of campus occupancy and temperature. These topics are then analyzed through the lens of the pandemic. The various impacts of phases of COVID-19 policies are explained. Finally, the renewable energy capabilities of Penn State are analyzed and compared.

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ACKNOWLEDGEMENTS

This thesis would not have been completed without the support from multiple people that I am eternally grateful for. First, I would like to thank Dr. O'Connor for her support and unending patience in completing this thesis. I am grateful for the guidance she has offered me as well as her kindness. I would also like to thank her for bringing me into her lab with such welcoming arms. Additionally, I would like to thank Dr. Cortes for his help in finding a research area to work on my thesis. I am also grateful for his support and assistance in completing this thesis.

I would like to thank my parents for their love and support while working through this thesis. I am also grateful that they have given me the opportunities to be at Penn State and in Schreyer. I am grateful especially to my mom for answering all my calls asking for reassurance and allowing me to talk through all the obstacles. I would also like to thank my siblings and friends for listening to me explain the same concepts over and over. I would like to thank my twin, Erin, in particular for staying up with me many nights to complete this thesis.

Chapter 1

Introduction

As the world continues to advance technologically, demands for energy have increased. Looking over the past 50 years, as the demand for energy has increased, technology has been developed to make power generation more efficient. 2019 and 2020 marked a change in the balance of energy consumption to energy generation in the United States. Energy production outpaced energy consumption in both years, though it was slightly less in 2020 than in 2019 [2]. As the world continues to demand more energy, countries have grappled with how to support economic growth while protecting the environment. Agreements such as the Glasgow Climate Pact [3] and the Paris Agreement [4] have been agreed to in order to prevent further damage to the environment while holding countries accountable. Countries across the globe have looked into how to reduce the impact of increasing power demands while being fair to developing countries.

Globally, reducing the environmental impact caused by power generation has been marked as an important issue. As recently as the Glasgow Climate Pact, agreed to in November of 2021, countries pledged to make a change. Climate agreements between countries started in 1995 with the first Conference of the Parties (COP) being held in Berlin [5]. This first meeting established broad goals for the original members to execute and demonstrated the global effort necessary to prevent climate change. The COP outlined the expectation that developed countries should bear the financial responsibility of climate change as developing countries did not have the financial opportunity and could not sacrifice their growing economies to achieve climate goals. Additionally, these developed nations were responsible for 79% of carbon emissions since the end of the industrial revolution [6]. Starting in the mid-1990s, the annual COP worked to establish an agreement for participating countries to sign. The Kyoto Protocol was the first agreement signed by the COP and has 192 participating countries [7]. The Kyoto protocol, which was signed in 1997, was fully in effect by 2005. From 2011 to 2015, the COP was used to establish the Paris Agreement. The Paris Agreement worked to focus the goals of the Kyoto Protocol while bringing more countries in on the agreement. The Glasgow Climate Pact, signed within the last year, affirmed that countries that are able to make bigger changes should to help countries that are unable. The pact specifically mentions how the pandemic hit countries disproportionately and how expectations for these countries to hit their targets are adjusted accordingly [3]. These agreements and the annual COP meetings demonstrate the global commitment to reducing environmental damage.

The pandemic had a global impact on how energy was consumed and produced. As many countries had to go into lockdown to prevent dangerous levels of transmission of COVID-19. Lockdown meant many people stayed in their homes all day, which increased the amount of electricity used in their homes but many office buildings, schools, and non-essential businesses had to be closed. As such, these buildings used no energy. Energy production, mainly coming from these types of energy plants in the United States, remained the same as it was considered essential to produce energy. Since energy was being consumed less than before the pandemic, generation also reduced during this time to prevent an abundance of energy being produced and not used.

In order to meet the goals agreed upon at the COP meetings, countries need to use various methods to holistically change their impact on the environment. For example, improving the energy efficiency within a building is a cost-effective way of reducing energy. Motion sensor lights, proper insulation, and use of natural lighting are common examples of improved efficiency. Improvements to the machines and systems that generate energy is another essential way to increase energy generation efficiency. Changes to existing machines and systems is especially important in developed countries as they have preestablished electricity grids and infrastructure. On an industry wide scale, improvements in the technology used for natural gas drilling has improved the efficiency of energy generation that has allowed energy generation to exceed energy usage. Additionally, there has been an increase in investments into renewable energy sources. Renewable sources of energy have steadily increased as a source of power in the United States and help limit climate change.

More locally, universities across the United States have worked to reduce energy consumption and improve their methods of energy generation. Their efforts are also ideological, as there is a push among students to have more sustainable campuses [8]. Some universities face geographical barriers in improving their carbon footprint. These obstacles have caused the universities to have innovative solutions to meet their environmental goals while still meeting the energy demand at their campus [9]. Some universities partner with local power generation sites by financially supporting the creation of renewable energy power generation sites [10]. Of these universities, this thesis takes a closer look at the Pennsylvania State University, specifically the University Park campus.

Many of these universities lacked public information on the energy policies they were following. While many had informative and easy to use websites or student involvement groups, they lacked an institutional involvement. Most notably, very few universities incorporated any of their energy usage into their curriculum, at least publicly. This thesis hopes to establish a way for

Penn State to incorporate real time data into its curriculum and increase student literacy around energy consumption.

The trends in power generation and energy consumption over the past couple of years at Penn State is studied. Data from the campus operations software used by the Office of the Physical Plant is analyzed from 2019 to 2021. During the time period studied there were improvements and changes made to the systems. The COVID-19 pandemic is also encompassed in the time period studied. The previous trends are analyzed in comparison to the pandemic timeline. As the campus has returned to normal operation of classrooms and shared spaces, the trends can be viewed from the beginning of the pandemic when campus was closed to students to normal operating conditions seen in the fall of 2021.

This thesis will first review the relevant literature necessary to establish a background in the topics of power generation and usage, especially at universities in the United States. Then provides a comprehensive analysis of designated Tier 1 Research Universities in terms of energy production, gas turbine usage, reusable energy, and student involvement. With a closer look at similar universities, the thesis will then delve into how power generation and usage is handled at Penn State University Park Campus. This chapter provides a more in depth look at the data specific for Penn State. After discussing the data for Penn State, the next chapter is an analysis of how the pandemic has affected power generation and power demands at Penn State University Park Campus. The final chapter includes recommendations for how Penn State can increase energy literacy at Penn State especially by including more relevant information into the curriculum as well as increasing student awareness.

Chapter 2

Literature Review

As discussed in the Introduction, tackling climate change is a global problem. Countries take different approaches to achieve similar global goals. Looking specifically at how universities in different countries have historically approached climate change is a good way to establish expectations for where universities in the United States should be. Additionally, case studies in other countries establish guides to include energy information into relevant curriculum. Since various methods of power generation are commonly used in universities, a discussion follows on the most common types of power generation. The goal of the discussion is to familiarize the reader with different resources available on campus. The last section describes the transition to renewable energy in recent years. The benefits behind this transition are explained, especially for universities in the United States.

The United States has access to energy information through the Energy Information Administration (EIA), which tracks and stores data about energy production at each commercial power production site in the country [11]. However, there is not much in the open literature about people using this data in their curricula, particularly at the college level. This disconnect makes it unclear what the best practices for doing so are. In Denmark, public access records of energy usage is used in secondary education curriculum [12]. Denmark's renewable energy initiatives at universities are second only to the United States. According to data collected in 2014, a new solar energy system was installed in the United States every two and a half minutes. This rate of installations has resulted in the United States having one of the largest installed solar PV and wind energy capacities in the world [13]. Despite the incorporation of renewable energy into universities, the United States universities may incorporate their knowledge and information of renewable energy systems into university curriculum but do not publicize this information unless renewable energy is the sole topic of study, such as a renewable energy engineering degree. This gap between technology and student awareness of energy usage and generation needs to be addressed through an increase in energy information in the core curriculum at universities across the United States.

Historic University Approach

Much of the published literature on energy literacy in students focuses on primary and secondary-school children. Case studies on the energy literacy of students based on knowledge, affect, and behavior were run in Taiwan and New York, USA [14][15]. Both papers found that an increase in knowledge increased student participation in sustainable behavior. Both papers also noted that an increase in age tended to be correlated with the impact of education. Older students who were educated were more sustainable in action than younger students, despite both groups committing to the same level of sustainability. DeWaters and Powers created a survey to measure secondary students' energy literacy [16]. This survey was able to measure baseline levels of energy literacy and determine the impact of educational intervention.

Universities are seen as examples of how the rest of the country should be in terms of energy performance [11]. In different countries, universities take a leading role in improving the climate change environment in the country, while in the United States initiatives are largely led by corporations [17]. For example, a study by Cotton et al. provides an outline of how higher-level educational institutions can lower their energy usage [18]. This paper discussed how different factors affected student awareness. As seen in Figure 1, the researchers identified a method to improving energy awareness among students based on their current level of knowledge. A paper from Milan Italy describes how engineering students led building refurbishment on two separate campuses as part of a lab course they were taking [19].

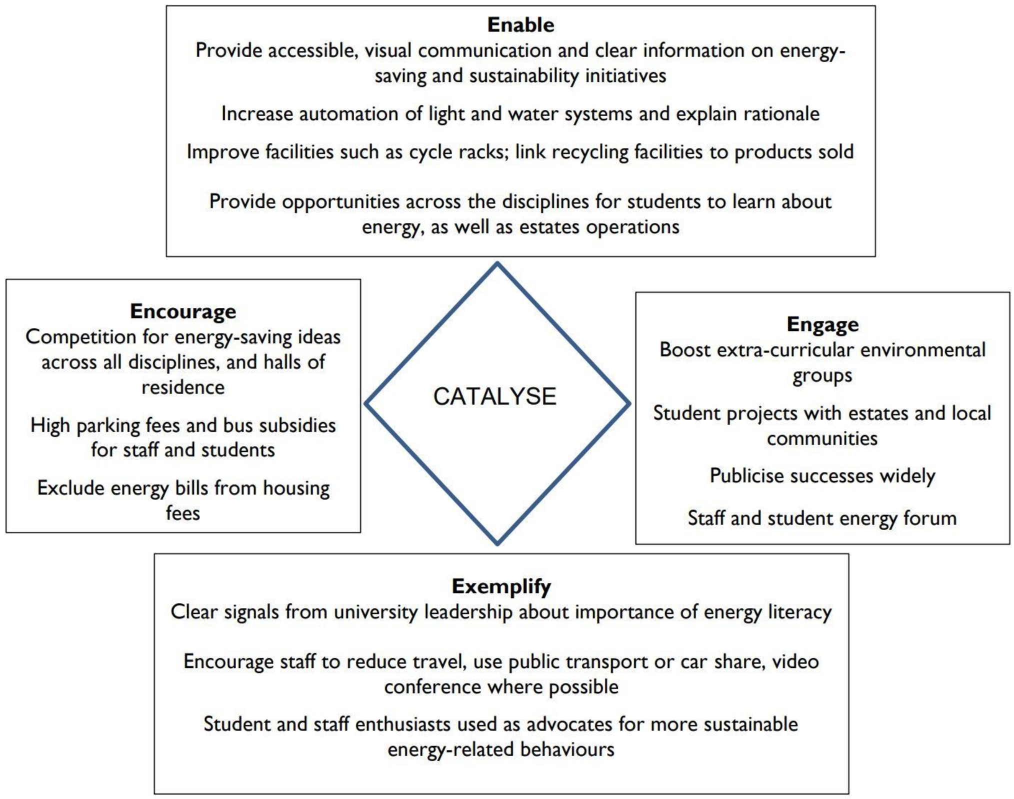


Figure 1 Methods used to increase energy literacy among students [18]. **Reprinted with permission from Emerald Publishing Limited.**

Universities in the United States tend to outperform other countries in terms of energy initiatives, with new programs incentivizing renewable energy or higher energy efficiency systems [20][17]. However, these U.S. universities also tend to have higher energy demands than universities in other countries. This higher demand results in only 13% of energy being used by the United States to come from a renewable resource [13]. U.S. universities also have excellent programs to study renewable energy and are consistently ranked among the top universities to study sustainability [13][21]. However, many universities fail to measure and publish how energy is included in their curriculum across degrees not specified as energy degrees. As the renewable energy sector increases, universities incorporate new majors tailored to energy efficiency and sustainability. But as renewable energy becomes critical in other industries, universities are lacking in incorporating energy information into more broad degrees. This gap in education is especially noticeable in engineering as many engineers are taught traditional energy generation systems that are not as prevalent as they once were [22]. Meanwhile, these students are not being taught the new systems that are becoming prevalent.

Common Power Generation Methods

Power generation is possible through multiple different methods. Across the globe, the most common resources used for electricity generation are coal, natural gas, and nuclear, in that order [23]. It is worth noting that 63.3% of electricity generation is produced by fossil fuels while 84.3% of total energy generation, including transportation, electricity, and heat, is produced by fossil fuels [23]. This trend is attributed to initiatives for clean energy usage in electricity generation. Additionally, the heat and transportation sectors are more dependent on fossil fuels, notably oil. The United States does not differ from the global pattern by much. The U.S. Energy Information Administration (EIA) notes that fossil fuels, including coal, natural gas, and petroleum, nuclear energy, and renewable energy sources are the three major categories of energy for electricity generation [24]. These are the same top resources used globally, but the EIA included natural gas and coal in the same category of fossil fuels.

In the United States from 1965 to today, coal has decreased by 49%, gas has increased by 419%, hydropower has increased by 44%, other renewables increased by 447%, oil decreased by

73%, nuclear increased by 20,432% [23]. Shown in Figure 2 is the distribution of sources used for electricity production in the United States in 2020. The graphic breaks down fossil fuels to show what percentage is natural gas, coal, and petroleum. Additionally, renewables are broken into smaller groups, displaying what percentage is from each source.

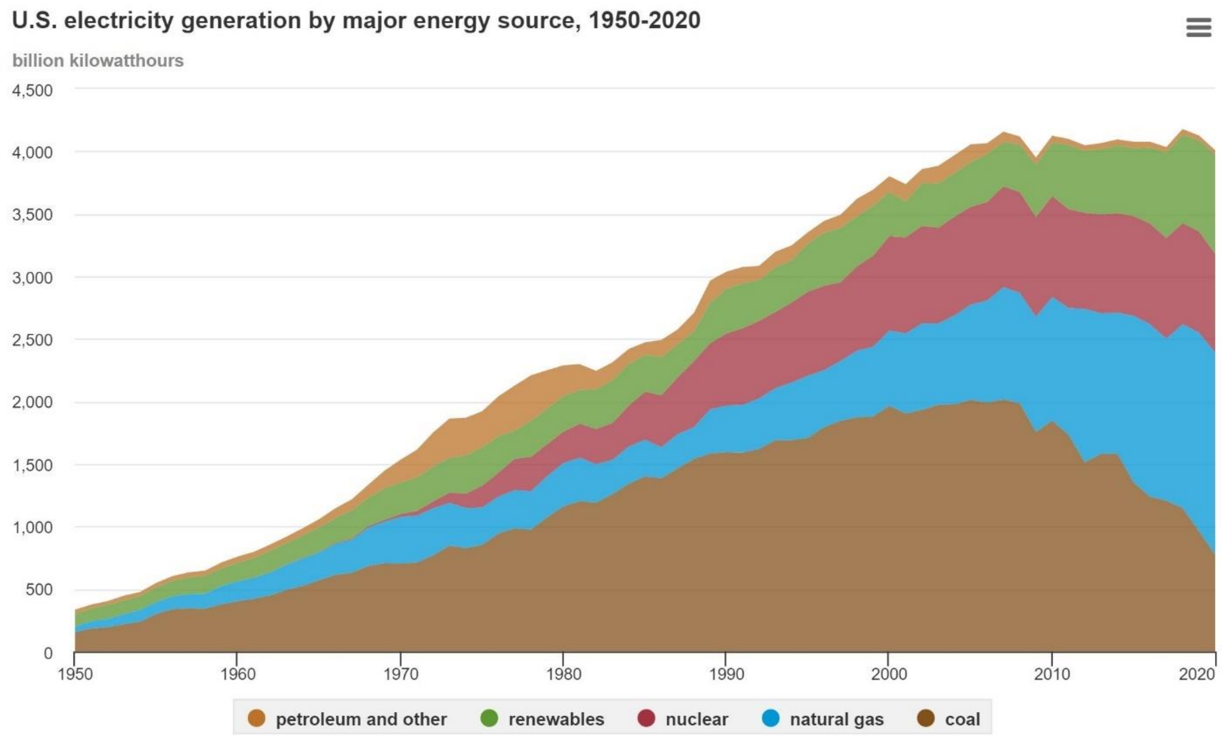


Figure 2 Distribution of electricity sources in the United States [24]

Steam turbines are the most common type of electricity generators in the country [1]. These turbines work by first burning natural resources, discussed earlier, or using nuclear reactions to create heat [25]. Water is then brought to a boil from the heat produced, which causes the water to transition to steam. The steam is converted into mechanical power by flowing through turbine blades as it cools down. The turbine is connected to a generator through an axle. The energy is produced by using a magnetic field that creates an electric current. Steam turbines have been increasing in their efficiency by improving the methods and designs used to produce electricity [25]. A key way steam turbines are being improved in is by incorporating the waste heat into the production process.

Another type of system that utilizes waste heat is a combined heat and power system. Combined heat and power (CHP) systems create the power using a steam turbine and gas turbine, then use the steam to then heat local buildings [26]. These systems are also known as cogeneration since the system is generating both power and heat at the same time. CHP systems are especially useful in areas that require a lot of heating as the more steam being used only improves the efficiency of the total system. These systems tend to be around 25% more efficient than traditional systems such as boilers for heat production and power plants for electricity [27][26]. CHP systems also limit geographic barriers that tend to prevent improvements to energy efficiency in urban areas. Another difference noted with CHP systems is they use a distributed system in comparison to a grid system [26]. A distributed system means that the generation source is closer to the buildings that are using the power and heat rather than needing to be transported.

Generally, electricity from the grid is produced by converting natural resources into mechanical energy. This energy is then transported to the areas that demand power. Power is transported to demand areas through an electricity grid, with both high-voltage transmission wires and low-voltage distribution wires. A major drawback of the electric grid is that energy is lost in transportation that reduces the energy efficiency of the whole system. Additionally, the electric grid is constantly monitored to ensure the production matches the demand as any electricity that is produced that exceeds demand will go to waste. Electricity is a commodity unlike physical items, once it is produced it must be used immediately or it will be lost.

Chapter 3

University Power Generation Study

*The contents of this chapter were published in the following work:

Winegardner, E., Lemay, E., Thole, K., Lynch, S., O'Connor, J., (2022) "Energy and the University: The Role of Gas Turbines in US R1 Universities and Strategies for Enhancing Energy Literacy" ASME Turbo Expo, Rotterdam, The Netherlands

Decarbonization is a focal point of global conversations because carbon dioxide has a significant negative impact on global temperatures relative to other materials [28]. Improving environmental standards is a global concern because it requires each country's commitment in order to be successful. Treaties such as the Paris Agreement and the Glasgow Climate Pact are important events that standardize what emission levels are acceptable for each country. The Paris agreement was widely signed in 2016 and has been ratified by 190 countries as of 2021 [29]. The Glasgow Convention, with 197 participating countries, finished in November and defined new goals to achieve [30]. As the world comes together on these goals, each country must look at its own use of technology and fuel sources to see where prevention of emissions and improvement of technology can be made.

The United States in particular emits 5.41 billion metric tons of carbon dioxide, placing it as the second largest carbon emitter in the world [31]. As a country, the United States has looked to improve technology to reduce emissions as well as researching new types of fuel that produce less carbon dioxide. The largest contributor to the carbon dioxide emissions is producing electricity by primarily burning coal [32].

One affordable and effective way to cut emissions on a local scale is to improve the efficiency and usage of energy. To this effect, many organizations focus on improving their existing buildings by installing smart technology. According to the International Energy Agency (IEA), "buildings were responsible for 28% of global energy-related carbon dioxide emissions in 2019” [33]. Motion sensor lights, effective insulation, and LED lights are easy methods to reduce energy usage. Individuals can help reduce energy usage in their daily habits by turning off lights when they leave a room or unplugging appliances that are not being used. The IEA noted that emissions were rising because the efforts for decarbonization were overcome by growth in demand for energy. Making individuals aware of their energy consumption is a key step in decreasing energy usage and gaining support for energy reduction initiatives. This global focus of decarbonization can be taken further, especially in the United States, by universities taking an active role in increasing student literacy on energy usage.

Universities have a considerable role in CO_2 emissions in the United States, accounting for nearly 2% of the national CO_2 emissions [34]. Universities across the country are aware of the conversation to reduce emissions globally and take an active role. Many universities have changed their source of fuel, improved technology, and increased efficiency of current buildings and systems to reduce their community’s carbon footprint. To give a sample view of how universities across the US are tackling carbon emissions, Tier 1 Research (R1) Universities were comparatively studied for their efforts. R1 institutions are defined as having the highest research activity (measured in research expenditures) and doctoral degrees conferred [35]. These universities were chosen because they are typically rather large, requiring dedicated sources of energy for power and heating, and have the research and educational influence to drive the decarbonization movement for universities. However, the largest impact these universities have on decarbonization is not in their improved technologies. It is instead in producing informed students with the tools and experience to decrease carbon emissions in all the parts of the world they go to next.

A common method of electricity generation on university campuses are combined heat and power systems. CHP systems, commonly run by gas turbines, can decrease the carbon footprint of a campus by using waste heat from a power source to produce steam for heating and cooling. As a result, the efficiency of a modern CHP plant is roughly 80% [27]. Investing in a CHP system is beneficial to universities for its increase of efficiency and reduction of emissions but also for the research opportunities it provides. For example, Texas A&M implemented a gas turbine run CHP that saves the university a third of the fuel that would typically be used for the same output of energy [36]. The installation of a CHP plant, along with other energy efficiency improvements, provided Texas A&M with $140 million in cost avoidance. On the other hand, Georgia Institute of Technology has one of the largest gas turbine research labs in the country, but campus doesn’t produce its own electricity. Clearly, the institution has the information and means to implement a CHP plant. However, they don’t have the space in midtown Atlanta to implement one that could provide electricity for the campus. A number of the R1 universities are heavily involved in gas turbine and CHP research but are unable to implement these systems due to geographical constraints as many of the campuses are in cities where all the surrounding land has already been developed. There is great incentive for universities to implement these systems but some may need partnership with industry to fully realize this potential.

University Energy Production

To compare energy usage and energy literacy at R1 universities, information on these topics had to be collected for each university. Questions relating to energy usage included if the university had a gas turbine, if it had a CHP system, and if it used renewable energy to power campus. Energy literacy was gaged by if the university had information publicly available to students on how the campus was using energy, referred to as “energy dashboards”. This information was gathered by searching the internet for news articles, open-source websites, and energy reports that answered these questions. Many R1 universities have sustainability websites that promote their decarbonization efforts. These websites highlight renewable energy usage and improvements to campus that reduce carbon dioxide emissions, such as implementing a CHP plant.

Additionally, a number of the universities self-reported their energy usage with the Sustainability, Tracking, Assessment, and Rating System (STARS). STARS is a program of the Association for the Advancement of Sustainability in Higher Education (AASHE) [37]. This program gives ratings to universities’ efforts based on all aspects of sustainability. It contained information on where universities acquired their energy, what renewable energy they invested in, and if they had a CHP plant to provide electricity to campus. Using these reports, and other sources listed above, some trends in both energy usage and energy literacy could be found among R1 universities. It should be noted that this information was gathered based off what was publicly available, mostly reported by the university or journals affiliated with the university. As such, if a university has not made information on its energy usage publicly available it may have been categorized wrong. As seen in Table 1, a little over 50% of universities have a gas turbine installed and roughly the same number have CHP plants. Around 82% of R1 universities produce electricity for use through some kind of renewable energy. Many of these universities use solar arrays and wind turbines to get renewable energy. Less than 60% of R1 universities have an energy dashboard available for their students.

Table 1 Number of R1 universities that use gas turbines, CHP plants, renewable energy, and energy dashboards

	Gas Turbine	*CHP*	*Renewable Energy*	*Energy Dashboard*
# Of R1 Universities that have the following	69	71	108	77
# Of R1 Universities that don't have the following	62	60	23	54
Percentage that has these systems	53.1%	54.2%	82.3%	59.4%

At many universities, students lead initiatives to reduce energy usage and their campus' carbon impact, despite having little access to information on energy usage at their campus. For example, a student movement at the University of Cincinnati pushed the university to pledge 100% renewable energy despite not having public information on the campus' energy usage available to the students [38]. At the University of Florida, another university without public access to energy information, student pushback caused the termination of a CHP plant run by gas turbines that was planned [39]. These students clearly show that there is a passion among today's students to make changes in how energy is used on their campus. If these students were informed by the universities on how energy is being used, they would be able to better advocate for their university. However, universities that publicly share their data can collaborate with students to implement an efficient system while reducing the campus carbon impact. University of Iowa has an energy control center that publicly displays data from the past 24 hours as well as the last month [40]. Additionally, they implemented a CHP plant that runs by gas turbine without student pushback. This CHP plant is unique as the University of Iowa uses a mixture of oat hulls and coal to run their CHP, greatly reducing their carbon consumption [41]. The oat hulls are a waste product from a Quaker Oats factory nearby. University of New Hampshire uses landfill gas to fuel their cogeneration plant [42]. They also provide their students with data on energy usage in residential halls, academic buildings, and campus buildings [43].

A trend found in comparing R1 universities across the country was that many southern schools did not utilize CHP plants. These southern schools seemed to rely primarily on the method of remodeling current buildings and implementing energy saving techniques without actually changing how they produced electricity or the fuel they used. This trend is not coincidental; in order for a CHP plant to make economic sense, a university must need the amount of steam for heating that is produced in waste from the production of electricity.

There are also several opportunities for universities to partner with industry in the power-generation space. The University of New Mexico is a primary example of how this can be accomplished. They are a warm climate school that uses gas turbines to produce electricity. In the winter, the excess heat is used to warm campus buildings. However, in the summer, the university uses the heat waste to drive chillers to cool campus buildings [44]. This technology is not widely used as many universities consider CHP plants when they require a lot of heating on campus. By utilizing the steam to cool the campus, southern schools would be able to improve their technology, especially for schools in urban settings that have less access to implement renewable energy alternatives.

Student Energy Literacy

The universities can further their impact on the energy transition by increasing student literacy of energy usage on campus. This requires the universities to monitor energy usage, make accessible dashboards, and include relevant material in the curriculum. By providing these resources to students already looking to make changes, as well as increasing the awareness of students not already involved, universities can increase their impact. A great way to increase awareness is to have publicly available data presented in a student-friendly format. Some universities have excellent dashboards. The University of California at Davis has optimized their reach to students by making an energy dashboard that is visually appealing while providing useful data [45]. The dashboard opens on an interactive map, Figure 3, that shows the buildings on campus as varying sizes of dots based on the energy use intensity of each building. The buildings are categorized as lab, office, housing, classroom, and community spaces. You can also view this interactive map based on the annual energy use of each building. By looking through the dashboard tab on the left of the screen, you can also look at data for total campus energy, central heating and cooling plant, energy saving projects, and energy and water challenges. Additionally, there’s a tool to download specific data and email it to yourself. This tool allows customization of what type of buildings you look at, the metric being measured, and the timeframe of data collection. This tool is a great example of how universities can give their students access to energy usage so that students are more informed on the initiatives they support.

The University of California at Davis has such an interactive and effective tool because they have invested resources into creating and studying what an energy dashboard should look like at a university. Researchers looked through multiple versions of their current dashboard and polled the community for ease of use, trust, interest, enjoyment, and engagement with each iteration [46]. Two primary styles that were looked into was a map-based dashboard compared to a bar graph style dashboard. Users found the map more interesting and enjoyable. Once these researchers had determined the best display for a dashboard, they conducted research on when a map-based dashboard should be used as well as how to best utilize the dashboard [47]. The second round of research included two experiments with over 830 participants using the map-based dashboard. This second study confirmed that the map-based dashboard was more effective at conveying energy information in an interesting way. They found that when geography plays a role, a map-based style can increase the usability of the dashboard.

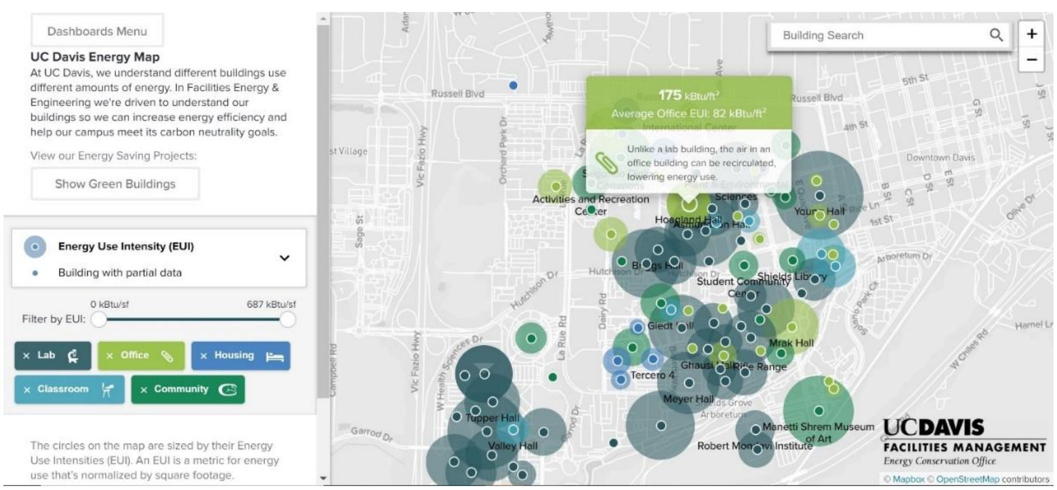
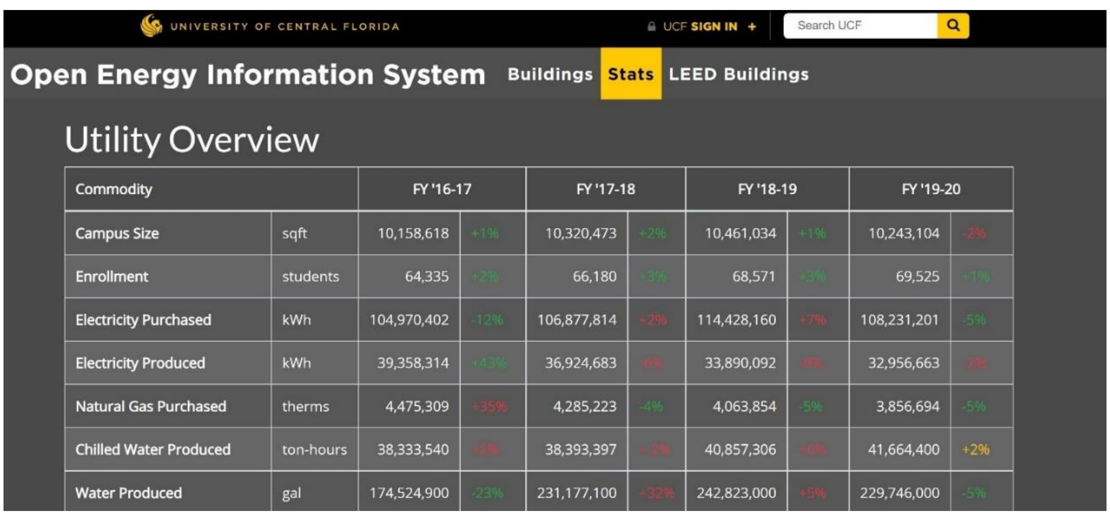


Figure 3 UC Davis energy dashboard [45]

The University of Central Florida has an energy dashboard, shown in Figure 4, that does not provide as much data but is a good format for students to make educated decisions on energy usage [48]. The home page provides information on the number of buildings on campus, energy used, and projects currently going on. Since the University of Central Florida implements solar arrays for energy, the dashboard also displays the current temperature and weather conditions. Below this information is two bar graphs, one showing energy use intensity from 2005 until 2021 while the other displays external utility cost over the same time period. From the main page you can navigate to pages focused on buildings, statistics, and LEED buildings. The buildings tab is a list of the buildings on campus categorized by type of building and energy use intensity. The statistics tab provides information on the campus such as square footage and enrollment for each year. The LEED buildings tab provides progress on LEED buildings on campus. The University of Central Florida additionally informs students on energy efficiency through 30 sustainability-focused courses offered [49]. A renewable energy specialized degree is available for students to pursue [50].



Commodity		FY '16-17		FY '17-18		FY '18-19		FY '19-20	
Campus Size	sqft	10,158,618	+1%	10,320,473	+2%	10,461,034	+1%	10,243,104	-2%
Enrollment	students	64,335	+2%	66,180	+3%	68,571	+3%	69,525	+1%
Electricity Purchased	kWh	104,970,402	-12%	106,877,814	+2%	114,428,160	+7%	108,231,201	-5%
Electricity Produced	kWh	39,358,314	+43%	36,924,683	-6%	33,890,092	-8%	32,956,663	-2%
Natural Gas Purchased	therms	4,475,309	+35%	4,285,223	-4%	4,063,854	-5%	3,856,694	-5%
Chilled Water Produced	ton-hours	38,333,540	+2%	38,393,397	+.2%	40,857,306	+6%	41,664,400	+2%
Water Produced	gal	174,524,900	-23%	231,177,100	+32%	242,823,000	+5%	229,746,000	-5%

Figure 4 University of Central Florida Public Energy Dashboard [48]

Campus Decarbonization

Decarbonization takes multiple approaches to be successful, and many campuses are using renewable energy to supplement the systems that cannot become more efficient. As many campuses reach peak efficiency in building infrastructure and system efficiency, they must look to methods to improve fuel sources. Popular at universities are solar, wind, geothermal, and hydro sources of energy. At the University of Connecticut, for example, students collected over 4,000 signatures to push the university to 100% renewable energy [51]. The university has a student group focused on climate impact. Cornell University uses a nearby lake for its cooling needs and was able to achieve 100% renewable energy usage with solar farms and a hydroelectric plant. Many schools in urban settings were unable to produce electricity from renewable resources on their own and instead purchased renewable energy certificates (REC) to counteract their carbon emissions. Improving the source of energy can further decrease the carbon footprint made by a campus.

Chapter 4

Penn State Power Generation and Usage

Electrical sources at Penn State University Park come from four main sources: the east campus combined heat and power plant, the west campus combined heat and power plant, the solar array, and power purchased from the electrical grid. The first three sources encompass the power generation capabilities at Penn State and can be seen in Figure 5. The CHP plants are also responsible for steam production that is used in heating and cooling across campus.

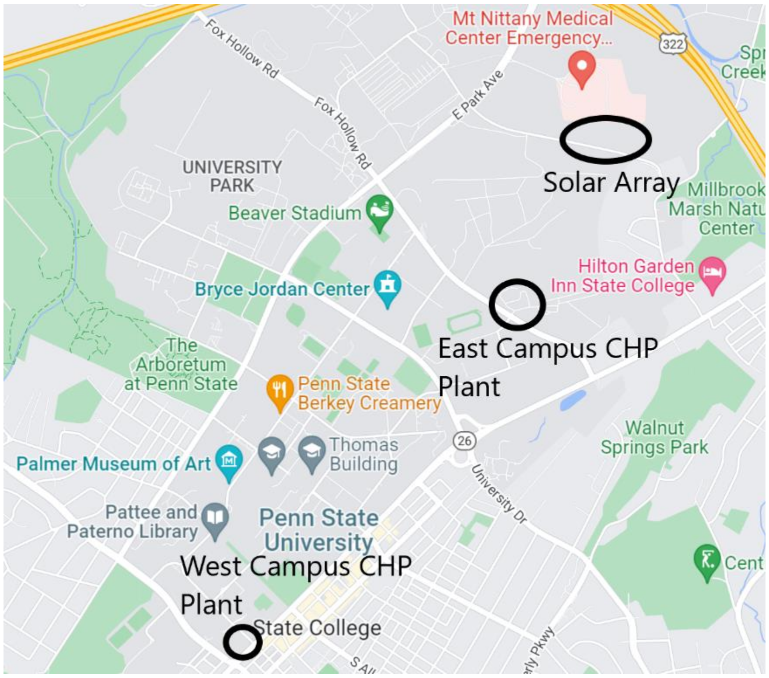


Figure 5 Energy generation sites on campus

On campus, power is primarily used for electricity to light buildings, HVAC, and power for computers, projectors, and other classroom technology [52]. Power is also used to run systems such as the solar array. Consumption of power is controlled by the campus by implementing automated systems. 350 buildings are equipped with lights that turn off after a set time, computers with sleep settings, and low power settings for when buildings are not being used. The data discussed in this chapter, power usage and generation as well as steam generation, are provided by the operations team at Penn State. The operations team uses an Enterprise Energy Management Suite called IceTec to compile and collect this data [52]. Data were collected at each of the power sources and usage was tracked across campus. Ranging from the beginning of January 2019 to the end of December 2021, the data were collected each hour. The amount of purchased electricity fills in the remainder of the power demands from campus and was also monitored.

The east campus CHP plant consists of a combustion turbine (a Solar Turbines Taurus 70 [53]) and heat recovery steam generator [54]. These systems are used to generate 7 MW of electricity and 117 kpph of steam. The electricity from the east CHP plant is used to meet the campus' energy needs. The steam is used for heating and cooling of buildings around campus. In the three years studied, the east CHP plant produced an average of 6,130.58 kW each hour. In 2019, a total of 199,000,000 MJ was produced for the year. In 2020 188,700,000 MJ was produced and in 2021 192,900,000 MJ was produced. These numbers reflect varying demands through the three years studied, especially as new energy saving systems were implemented. Additionally, with the CHP process an average of 60.12 thousand pounds of steam were produced each hour. This resulted in a total of 512,000 thousand pounds of steam being produced in 2019, 541,000 thousand pounds in 2020, and 528,000 thousand pounds in 2021.

The west campus CHP plant has three backpressure steam turbines rated at 6.8 MW capacity [54]. Recently, a Solar Turbines Taurus 60 combustion turbine was installed with a 5.6 MW capacity. The steam turbines and combustion turbine generate electricity to serve Penn State's emergency power needs. The west campus CHP plant produced an average of 3,766.52 kW each hour during the last three years. In 2019, a total of 48,000,000 MJ was produced by the three steam turbines as the combustion turbine was not installed until late 2021. In 2020, the steam turbines produced a total of 39,500,000 MJ. In 2021, the steam turbines produced a total of 47,600,000 MJ while the combustion turbine produced a total of 18,500,000 MJ in the last two to three months of the year. There are also two heat recovery steam generators with a combined capacity of 209 kpph. The heat recovery steam generators provide low-pressure steam to campus. Combined, the steam generators produce an average of 81.82 kpph. This resulted in a total of 782,000 thousand pounds in 2019, 656,000 thousand pounds in 2020, and 714,000 thousand pounds in 2021.

The solar farm produces less power than the CHP plants but is an important step in renewable energy sources used on campus. The solar array is specifically an important step because it is one of the only renewable energy sources on site at University Park. The solar array was intentionally planned to have a minimal negative effect on biodiversity of the area [55]. It has a nameplate capacity of 1.5 MW [56]. However, since the area has a lot of overcast days in the winter months, the system sometimes uses more energy to be run than what it is producing. The system was installed in the end of March 2019 and began generating power in April of the same year. Through the three years, the solar array averaged the production of 247.15 kW each hour. It should be noted that at night time the solar array uses about 3 kW each hour instead of generating electricity; this loss was calculated in the average production. In 2019, the array produced a total of 5,600,000 MJ of energy. In 2020, the number increased to 7,900,000 MJ as the system was running a full year. In 2021, 8,100,00 MJ were produced.

Despite Penn State's capabilities to generate power, the demand for power continues to exceed the amount generated each year. This gap is filled by purchasing electricity from the grid to ensure the demand for energy is met. Penn State purchases this electricity from multiple sources. A 25-year Power Purchase Agreement (PPA) with Lightsource bp provides 70 MW of solar power to the campus [57]. The 2 MW solar array on campus was possible because of a 25-year PPA with the Alternative Energy Development Group. A 10-year PPA with the Mahoning Creek Hydroelectric Company provides 6 MW of hydroelectric power. Annually about 725,000,000 MJ is imported to meet the needs of campus, which is roughly 899,000,000 MJ each year. In contrast with electricity, Penn State generates all its own steam needs with an average usage of 107.48 kpph and a production average of 141.94 kpph.

Throughout each year there are distinct periods where campus energy usage changes. Specifically, when students leave campus for breaks, the university changes its policies for maximum energy efficiency. During Thanksgiving break and spring break, the campus continues to generate energy and steam as usual. The demands for electricity are lowered during these one week breaks as students are not in the dorms and classrooms are not being used. Additionally, many faculty use these breaks to attend conferences and so are not on campus. There is a slight drop in electricity demands during the summer as students transition on and off campus for summer programs. Energy usage does not drop a lot during the summer as faculty mainly stay on campus and there are still students in certain dorms. Generation of electricity remains the same during the summer. Winter break, however, differs from the other breaks as there is a significant drop in electricity usage. This is due to Penn State policy where the heat is reduced in all buildings for at least a week during the break; in 2021, this time was extended to two weeks. During this time the campus does not maintain its operating electricity levels. This drop can be seen in Figure 6 which shows the noticeable drop in 2019. The effectiveness of this policy is clearly seen by the dramatic drop in energy usage and saves the university money that would have been spent on energy that was not needed.

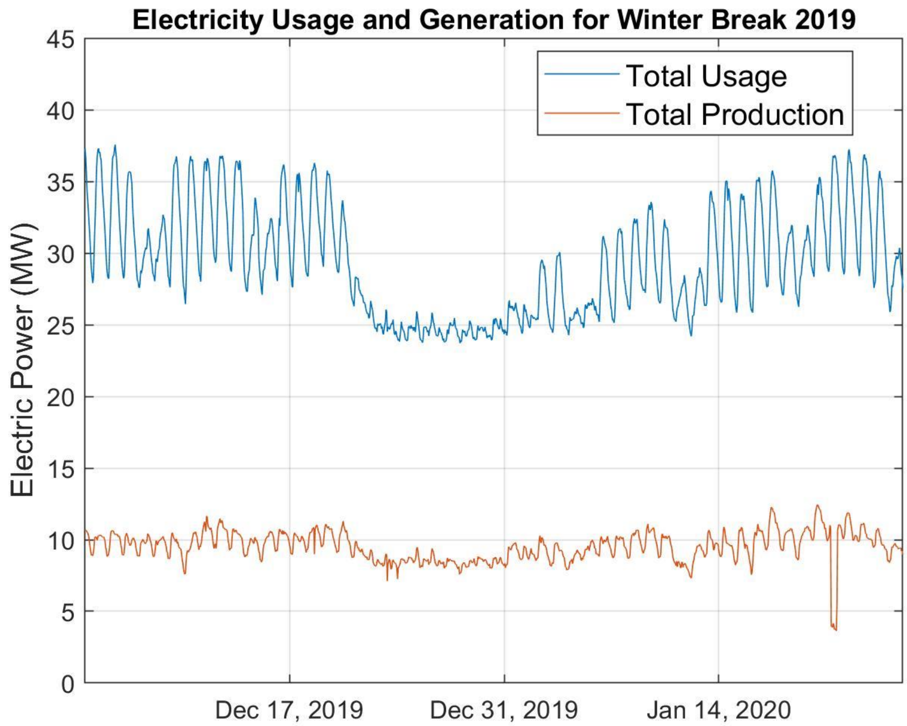


Figure 6 Drop in energy usage during winter break of 2019

Steam production on campus follows more seasonal trends. While steam is produced and used all year round, some seasons use more steam. When the temperatures are cold outside, more steam is produced to match the higher demands for heating of buildings around campus. In the summer months, steam is used to cool some of the buildings on campus. Figure 7 displays the steam trends throughout the three years studied. The trends for generation and production are extremely similar as Penn State produces all the steam that is used and so can produce almost exactly how much is needed. The trends follow a U-shape in the plots below as the summer months are in the middle of each plot. At the peak of steam usage, roughly in February of each year, the campus uses nearly 300 kpph of steam. Meanwhile less than 100 kpph of steam is necessary in the summer to cool the buildings. Worth noting is that each year the peaks are at slightly different levels. These changes reflect differences in the temperatures for that year, with lower averages creating a greater demand for steam.

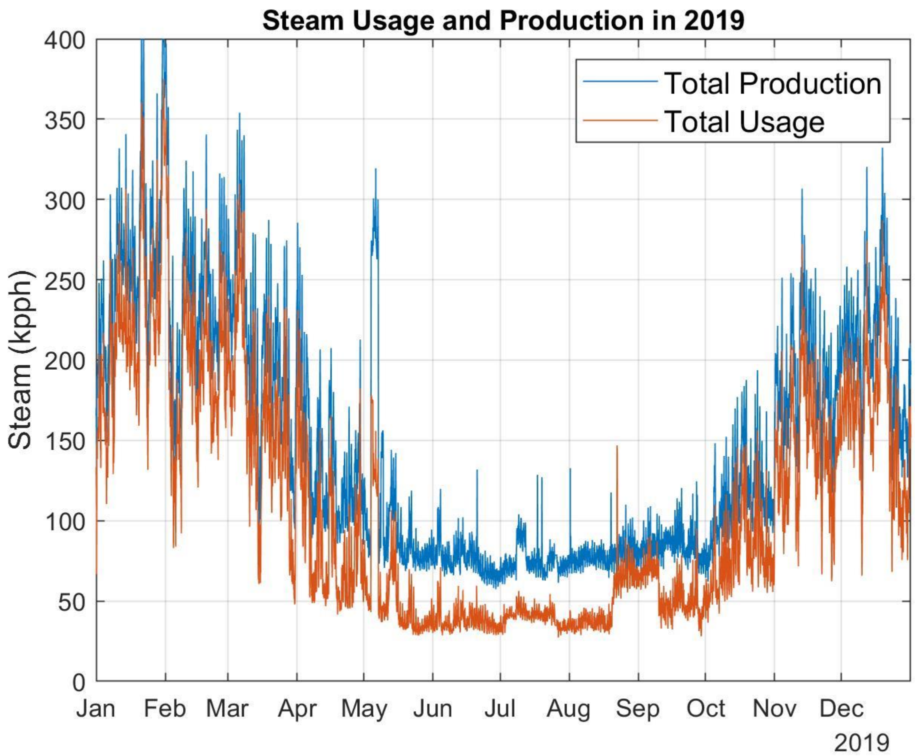


Figure 7 Annual steam usage and generation in 2019

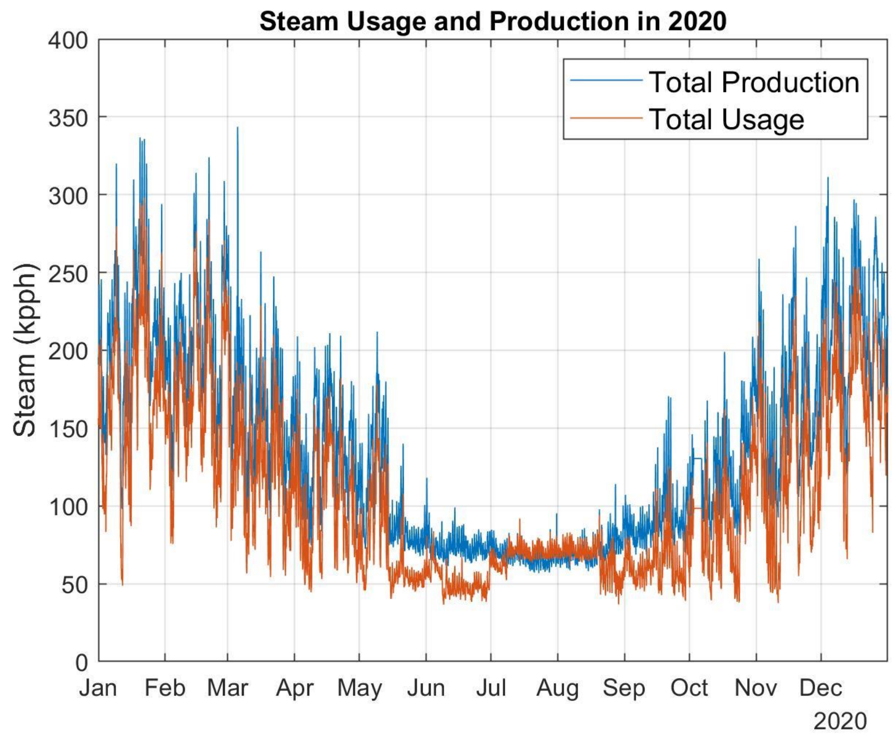


Figure 8 Annual steam usage and generation in 2020

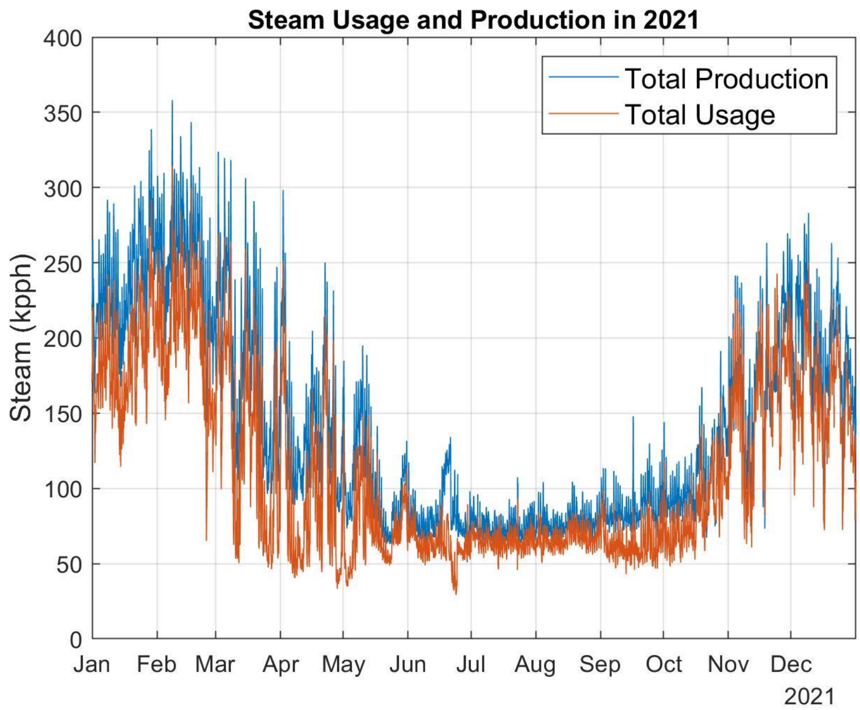


Figure 9 Annual steam usage and generation in 2021

The dependence that usage of steam and consequently steam production has on temperature was not reflected in electricity usage. A temperature study was completed to compare how the monthly temperatures affected steam usage and electricity usage. In February of 2019, the average temperature was 30.00 degrees Fahrenheit [58]. Also, during February 2019, an average of 195 kpph of steam was used. Compared to 2019 when the average temperature in February was 33.74 degrees Fahrenheit and 169 kpph of steam was used. The increase of average temperatures by almost four degrees decreased the demand for steam. In 2021, an average of 201 kpph of steam was used while the average temperature for the month was 29.86 degrees Fahrenheit. Electricity during these three months did not seem to change in correlation to the temperature.

Chapter 5

Effect of the COVID-19 Pandemic on Campus Power Usage and Production

The COVID-19 pandemic was defined by constant changes in how the world was reacting to the virus and what measures were being taken to avoid virus spread. This period of unprecedented times offered a unique opportunity to see how energy systems reacted to sudden changes. At University Park, the sudden removal of students and faculty from the campus as well as the gradual reintroduction gives insight to how energy usage and production on the campus were affected by shifting policies. Figure 8 shows a timeline of Penn State's response to the COVID-19 pandemic, focusing on policies that effected energy demands on campus. By looking at Figure 8 you can see the clear drop off in energy usage when students were removed from campus. You can also see that a lower level of energy usage is maintained as classes stayed online for the fall semester of 2020 and the spring semester of 2021. Since fall semester of 2022 was announced to be primarily in person, the campus was returned to "operating" standards. In the time the pandemic was taking place, the west campus combined heat and power plant had gone online, increasing electricity generation.

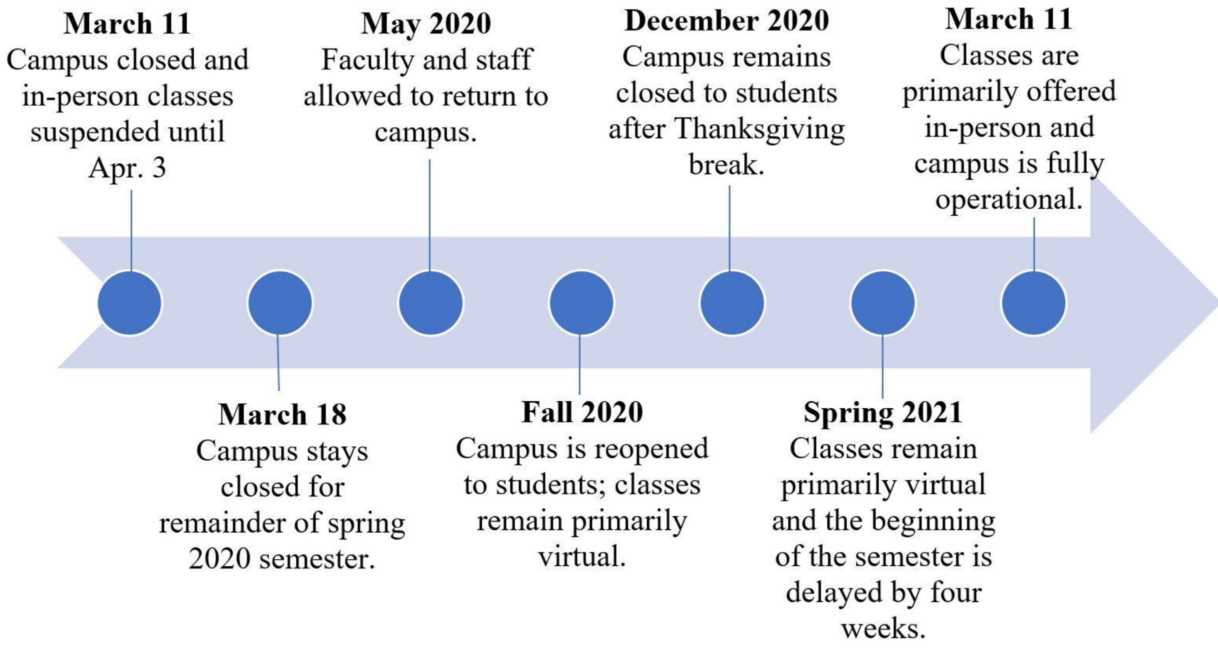


Figure 10 Timeline of Penn State's COVID-19 policies

The first case of COVID-19 was identified on January 7, 2020 in China [59] and by January 18, there was a confirmed case in the United States [60]. By January 31, both the U.S. Secretary of Health and Human Services and the World Health Organization declared a public health emergency. On March 11, the World Health Organization declared COVID-19 a pandemic. Also on March 11, 2020 Penn State announced that students would not be returning to campus until April 3 and in-person classes were suspended [61]. On March 13, President Trump declared a state of national emergency. One week after suspending classes Penn State announced on March 18 it would be extending the suspension of in-person classes for the remainder of the spring 2020 semester. Spring 2020 commencement was completely virtual. In June, Penn State announced it would be reopening campus to students in fall of 2020, but students would be primarily taking virtual classes. By September, Penn State announced classes would remain primarily virtual for the spring 2021 semester. During this academic year, sporting events were cancelled, campus remained closed after Thanksgiving break, spring break was cancelled, and the beginning of the spring semester was delayed by four weeks. Additionally spring commencement was held in Beaver Stadium [62]. In late February of 2021, Penn State announced plans to return to primarily in-person classes for the fall semester of 2021.

Data collected in 2019 and the beginning of 2020 give an image of what energy generation and usage was like before the pandemic affected campus operations. During 2019, the solar farm became operable and the west campus CHP plant had not yet installed the new combustion turbine. Before the pandemic, the campus generated about 10 MW of power daily. During the summer months, less energy was generated. This difference is partially because the steam turbines are more efficient in the winter as it is easier to remove excess heat in the colder weather [63]. During the beginning of May and end of June in 2019 there was a sharp decline in energy generation on campus. This was because the east campus CHP plant and the west campus CHP plant were shut down during these weeks. However, the production of electricity did not drop to zero because the solar array was still operable. The usage of electrical power on campus was steady before the pandemic with the only major drop occurring during winter break when campus shut down. This drop in electricity use can clearly be seen in the plot of Figure 9.

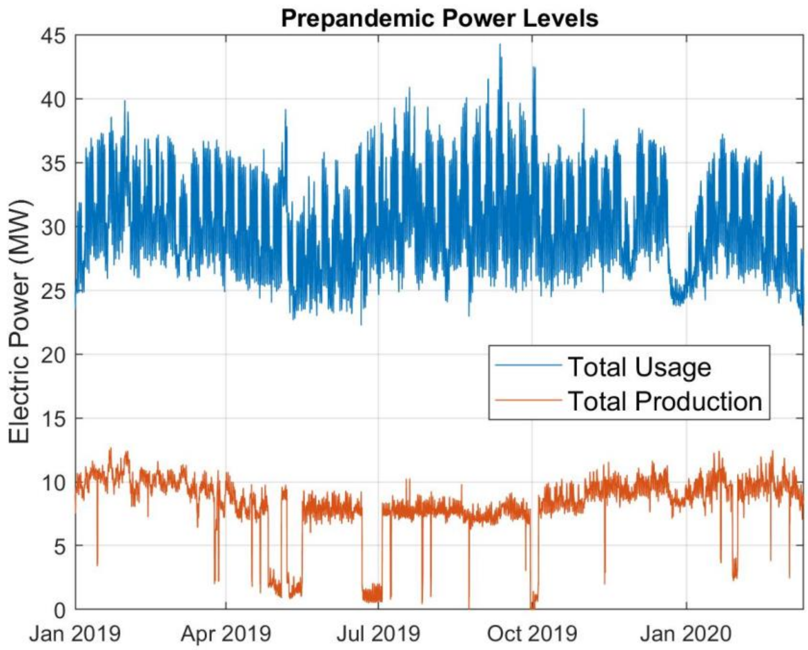


Figure 11 Electricity usage and generation on campus prior to the pandemic

Steam production and usage on campus followed the same trends as seen in Figure 10. Both generation and usage of steam were lower in the summer, as steam is not utilized as much during the warmer months. However, steam usage does not drop to zero during these months as the campus uses steam to cool some of its buildings. The difference between steam production and steam usage is also greater in the summer months. Since the campus meets 100% of its own steam needs, it can better control production to match the demand.

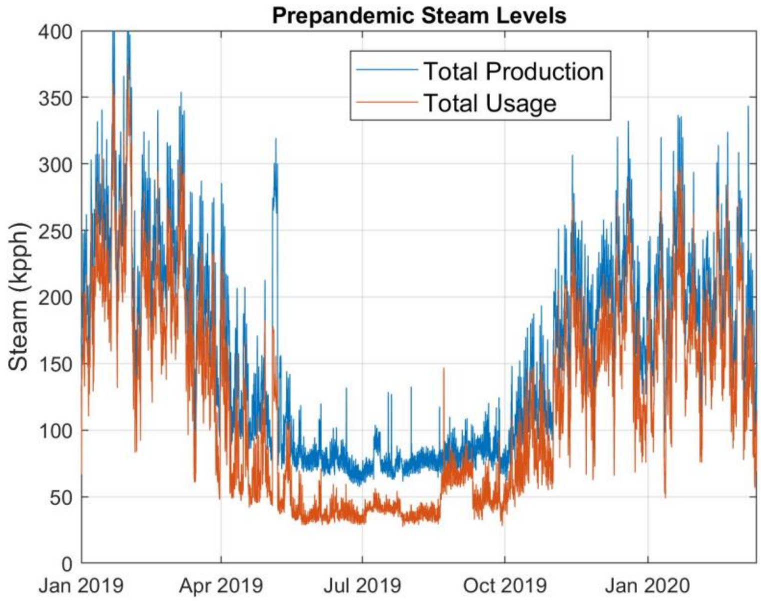


Figure 12 Steam usage and generation before the pandemic

March of 2020 caused a noticeable change in how energy was used and generated on campus. By looking specifically at the month of March, the transition from pre-pandemic levels to campus closure levels can be fully seen. Figure 11 shows the electrical demand and supply. The first week of March is the operational energy usage on campus. The second week is lower as students had left campus for spring break. During spring break, Penn State implements many energy saving policies that result in lower energy usage. The third week of March – when students were still expected to return – the campus maintained the energy policies used during spring break to most effectively keep campus running. By the last week of March, it was known that students and faculty would not be returning to campus for the remainder of the spring semester. The only faculty on campus at this point were those that ran studies involving live subjects such as animals, bacteria, or cultures. At this point the base level of energy needed to maintain campus – the lowest level since no students were on campus, was around 23 MW per day. The removal of students from campus did not interfere with the generation of energy on campus. This drop in energy usage was accommodated by the purchasing agreements Penn State University Park campus had signed previously. The steam levels of campus did not change by much. The lack of influence shut down of campus had on steam generation and usage on campus makes sense as steam usage and generation would already be on the decline post spring break as the weather begins to turn nice. The warmer weather requires less steam usage to heat and cool the buildings on campus.

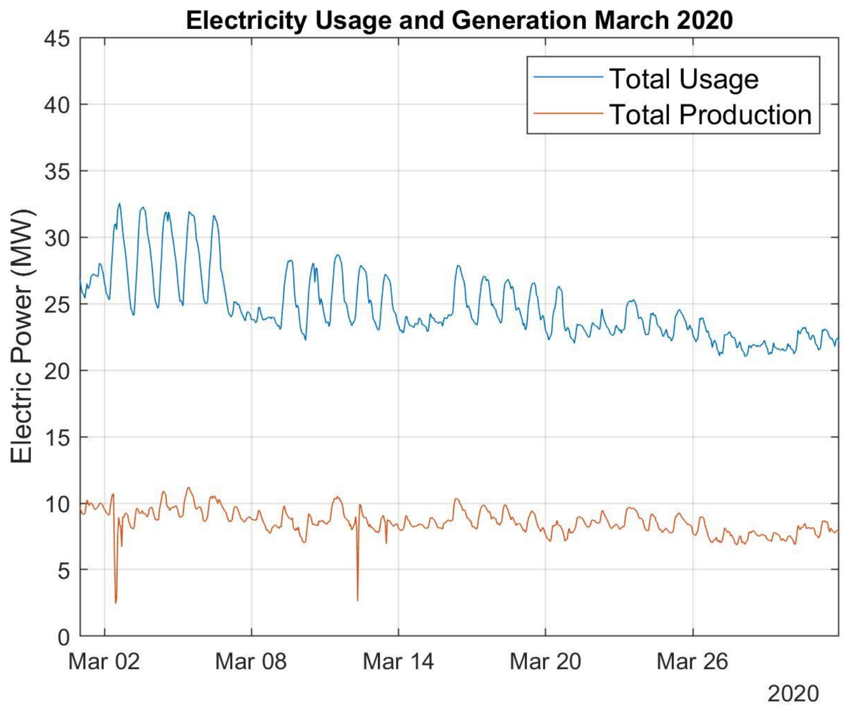


Figure 13 Progression of electricity usage in March 2020

Beginning in May of 2020, professors were allowed to return to campus in a limited capacity. As such, faculty and staff could return to their labs and offices. Students were still barred from being on campus and did not occupy the dormitories or the common centers. By allowing faculty back on campus, the base level of energy needed to return to "operational standards" was much different than before the pandemic. The operational level of electricity to properly run the campus was increased to around 26 MW daily. However, the steam production remained constant as heating and cooling needs did not change by a significant amount no matter how many students, faculty, and staff were on campus. The steam usage was affected much more by the temperature rather than by occupation of campus.

By the fall semester of 2020, students were allowed on campus to the extent of living in their dorm rooms and eating from campus dinery. However, Penn State continued to have primarily virtual classes with limited in-person opportunities. For both the fall 2020 semester and spring 2021 semester classes stayed primarily virtual with some in-person options. This shift in policy is especially crucial because it truly separates the energy usage of campus buildings such as the classrooms and offices from buildings such as the dormitories and common spaces. The electricity usage and generation during the 2020-2021 academic year can be seen in Figure 12. The base level of electricity used during these two terms was roughly 27 MW daily. In Figure 12 the period when students left campus again, from the end of November to the end of January, the electricity usage dropped to levels similar to the summer when only faculty were on campus. The winter break policy to effectively shut down campus can still be seen during the last weeks of December. The drop is not as drastic as it was in December of 2019. Steam production did not change by much. Again, the heating and cooling needs of the campus did not change much based on whether students and faculty were actively on campus or if they were anticipated to be coming back.

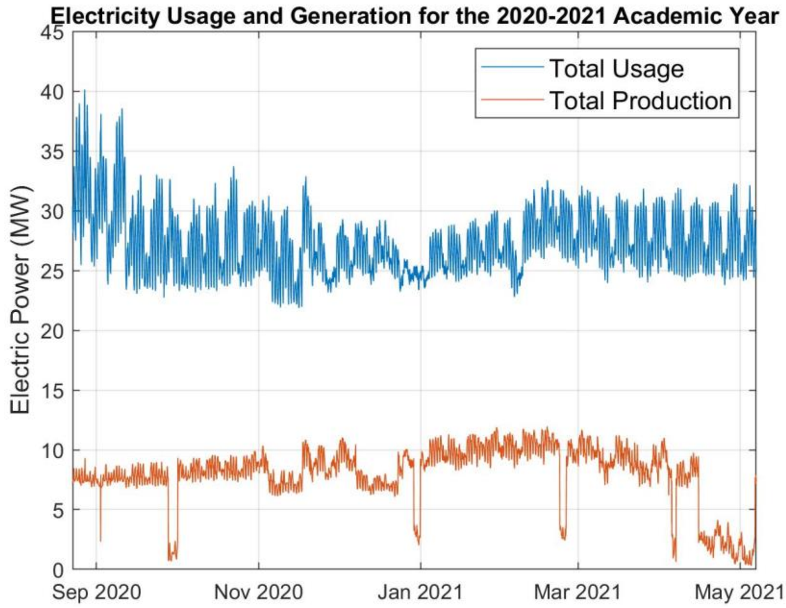


Figure 14 Electricity usage for the 2020-2021 academic year

The fall 2021 semester marked a major shift in campus policy as classes were offered primarily in person again. There was not a large change in energy usage but a slight increase can be seen in Figure 13 that shows all of 2021 electricity usage for easy comparison of the spring and fall semesters. A jump in energy usage is seen as the campus prepared for the return of students but the majority of the fall 2021 semester remained at about 30 MW daily. This operational level was below pre-pandemic levels. Even though this policy change was a major milestone for students and faculty on campus, it did not have a large impact in how campus was operating. Even when classes were virtual, students still occupied dormitories, classrooms for available for students to work in, faculty remained in their offices and labs. Students and faculty regularly meeting in classrooms, and more students deciding to live on campus had a slight impact but not nearly the change that could be seen when faculty returned to campus.

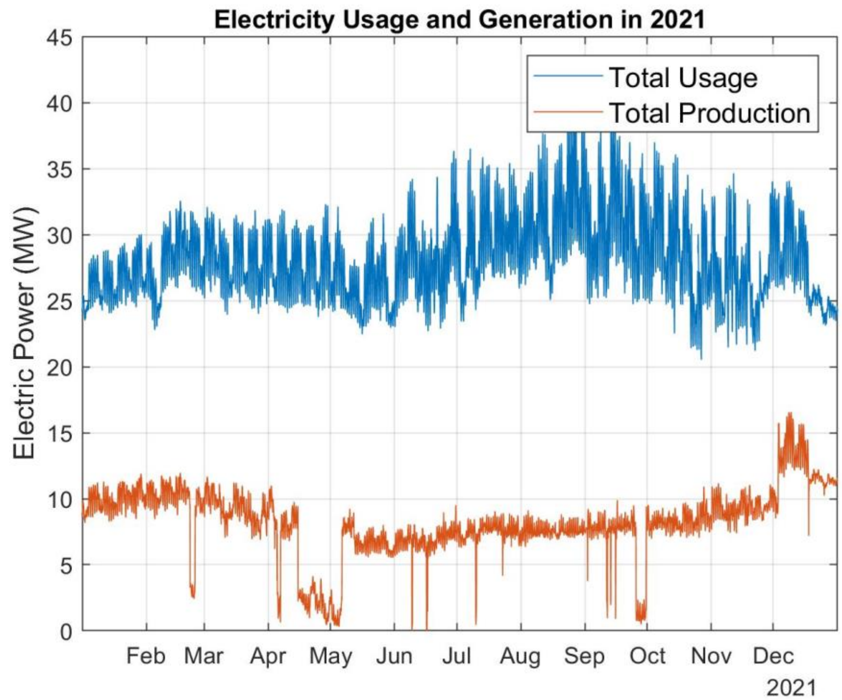


Figure 15 Fall 2021 semester compared to spring 2021 semester

Overall, energy usage on campus went through several phases as the pandemic progressed. Operational standards seemed to be heavily reliant on if there were people on campus more so than how many people were actually there. Bringing thousands of students back on campus had a much smaller impact than bringing back the initial round of faculty. Additionally, energy generation did not change based on the occupancy of campus. Especially, since Penn State only generates about 20% of its own electricity, it made sense to continue generating this amount as it was still below the amount of electricity used on campus. The steam usage and generation were not affected by the changing policies of the pandemic.

Chapter 6

Renewable Energy at Penn State

In recent years, Penn State has started to incorporate renewable energy sources on campus. The most notable is the solar array farm located on Orchard Road, as it generates electricity to be used on campus. There are a number of additional small scale solar panels located throughout campus that offset the energy needs of specific operations. A bus stop near Beaver Stadium has solar panels, the physical plant building has solar panels mounted on the roof, as does the MorningStar home, and the Center for Sustainability has some solar panels [64]. To date, all solar is the only type of renewable energy generated on campus and it is on a small scale.

To generate solar power on the scale of campus demands, much more space would need to be used on campus. Currently, the solar array is situated in a field away from campus. This area was chosen because it would have the smallest negative impact on the biodiversity of the area [55]. Since University Park is already developed, the largest place to install more solar panels would be the tailgating fields surrounding the stadium. Currently, the solar array uses about 780,000 square feet of land and produce 2.5 MW of power. 100% of campus electricity demands would be met at around 32 MW. Therefore nearly 75,000 solar panels would be needed to supply this demand. This number of solar panels would take up around 10,900,000 square feet or 250 acres. This is about 2.5% of campus space. Tailgating space, roughly around 500 acres, would need to be cut in half to accommodate this many solar panels. Figure

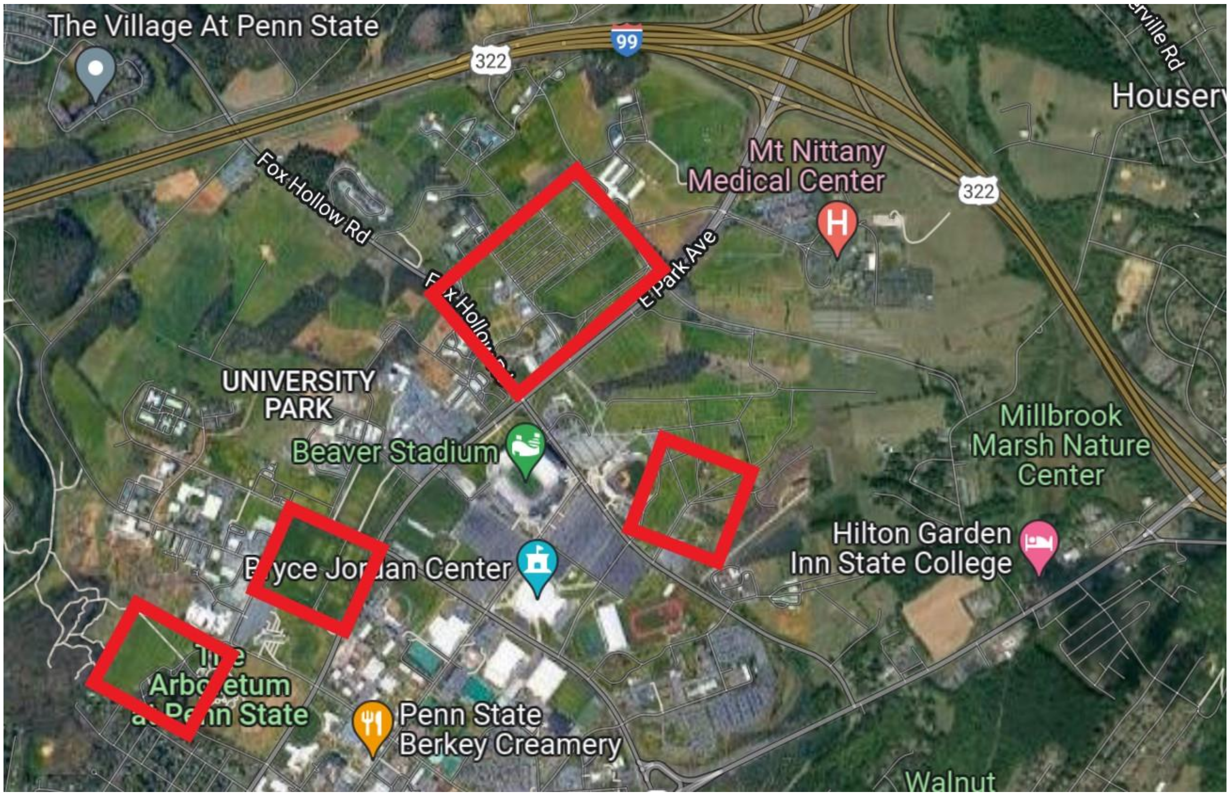


Figure 16 Tailgating fields that would be replaced with solar panels

Other forms of renewable energy could also be feasible. However, due to the geographical location of the campus (in a valley) wind power is not very feasible. Additionally, nuclear power is not feasible for the space provided on campus. Hydroelectric power could be accomplished on a small scale. A small scale hydroelectric energy source could be achieved with just two feet of water drop [65]. Since Penn State does not have a large water source or any waterfalls to naturally install a hydroelectric power generator, it would need to be artificial. This also limits the possibility of hydroelectric power to be on a smaller scale. It would also need to be a pumped-storage hydropower facility. This could be implemented in a way similar to the solar array where the amount of electricity produced is low but is a positive step in using renewable energy sources.

Chapter 7

Conclusion and Future Recommendations

As the world continues to progress in energy saving practices, universities have a unique opportunity to lead the way. Students across the United States have shown interest in changing policies at their universities to better suit environmental needs. These students have gotten involved by starting organizations, participating in best energy practice programs, and mobilizing students. Universities such as UC Davis, UNC, and University of Florida have taken advantage of student buy in to make positive changes on their campus. Furthermore, the students from these universities are being taught how to enact environmental change wherever they go.

At Penn State, energy is produced primarily through the east and west campus CHP plants. Since both plants have CHP capabilities, the plants can produce both electricity and steam, increasing the efficiency of the process. 100% of campus steam needs are met through generation at Penn State. The generated electricity met 26% of campus electricity needs in 2019. In 2020, that percentage increased to 28% and by 2021 it was up to 30%. This gradual but consistent increase in the amount of energy generated by Penn State is partially reflective of the improvements made to electricity producing systems on campus during the past three years. However, the increasing percentage is also a reflection of how the pandemic affected energy usage on campus.

The pandemic did not have much of an impact of electricity generation, steam generation, or steam usage as these metrics were not dependent on the number of people occupying campus or by what capacity campus was being used. However, changing pandemic policies had a profound effect on the levels of electricity usage on campus. Before the pandemic, campus needed a bit above 30 MW of electricity to operate on a day-to-day basis. During spring of 2020, when no one was on campus, barely 20 MW of electricity was being used daily. When faculty were allowed to return to campus in May of that year, operational levels returned to around 26 MW. Students returning full time and in-person in the fall of 2021 increased operational levels to a little less than 30 MW. The different phases had different levels of impact, as students returning virtually or in-person had a smaller impact than faculty initially returning to campus.

Renewable sources for energy at Penn State is an area of energy efficiency where Penn State has a lot of room to grow. Currently, the 2 MW solar farm near the hospital is the only renewable source of energy being used to provide electricity to the campus. Penn State needs to consider various logistical obstacles to implementing any new system, such as environmental impacts and teaching spaces. Due to these obstacles, there are certain options that are not as feasible, such as covering 50% of the tailgating fields with solar panels. However, Penn State could viably look into geothermal and hydroelectric power sources to help offset the lack of renewable sources currently being used by Penn State.

This data could be included in Penn State curriculum by taking the real time data and parameters of the electricity generation and incorporate it into sample problems or homework assignments in class. Additionally, these spaces could be opened up to students to learn more about energy production and transportation throughout campus. This would allow students to directly see where their electricity is coming from and the cost of producing electricity. Another way to incorporate student involvement is to include this data in more campus pamphlets. This would increase the information available to students when making decisions on campus about their electricity usage.

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ACADEMIC VITA

Emma LeMay

WWW.LINKEDIN.COM/IN/EMMA-LEMAY | EML5624@PSU.EDU |

EDUCATION

Bachelor of Science in Mechanical Engineering, May 2022
Schreyer Honors College
The Pennsylvania State University, University Park, PA

GPA:

Relevant Courses

Statics & Dynamics	Engineering Leadership
Thermodynamics (Honors) & Fluid Flow	Strength & Materials
MATLAB & SolidWorks	Engineering Design (Honors)

Study Abroad 2019
A two-week design course set in San Sebastian, Spain centered around a project focused on attachments for electrical scooters.

WORK EXPERIENCE

PPG INTERNSHIP —HARMARVILLE, PA —2020
Developed experiments to improve rheology on a previous product and presented findings to management.

PPG PRIMERS —PITTSBURGH, PA —2019
Explored the work culture at PPG by visiting sites and speaking to leaders in the company

PEGULA ICE ARENA —STATE COLLEGE, PA —2019-20

INVOLVEMENT

Penn State Club Crew Team 2018 -21
Women's varsity rowing program at Penn State.

Maker Ambassador 2019-21
Targeted to increase technical skills while providing women in engineering a gateway to the resource centers at Penn State traditionally occupied by men.

Society of Women Engineers 2019-21
A group that helps women in the college of engineering at Penn State to network, access opportunities, and provide a community for each other.

American Society of Mechanical Engineers 2019-21
Monthly meetings to network with other ME students and learn from professionals while building soft and technical skills.

Spark Program 2019
Weekly events with key speakers discussing opportunities in engineering and at Penn State. This also had a self-reflection aspect as to future ambitions.

HONORS

DEAN'S LIST FALL 2018, FALL 2020

PHI EPSILON DELTA HONORS SOCIETY 2019-20