Here Comes the Sun:
Solar Siting for Williams' Clean Electricity Needs

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I. Introduction

In 2021, Williams College completed the installation of over 400 DC kW of solar photovoltaic (PV) systems in Williamstown. These projects added to a portfolio of arrays on campus and a share in the Farmington Solar Project in Maine which provides the school with another 8.6 MW of clean energy capacity. In addition to its infrastructure investments, the College has made forward-looking commitments to renewables. In its all-encompassing Strategic Plan released in 2021, Williams listed “securing 100 percent renewable purchased electricity and continuing to increase on-campus solar generation” as two of its action items for promoting institutional sustainability. Furthermore, during the 2019-2020 school year, the College engaged the Integral Group, a sustainable engineering consultancy, to envision pathways for the institution to become carbon neutral by 2050 and began purchasing carbon offsets in 2020 to neutralize existing emissions.

Taking into consideration all past investments, the College’s Sustainability Working Group recommended in its 2019-2020 report that Williams reduce campus emissions by 15-30% by 2035 compared with 2022 emissions to remain on track with its carbon neutrality goals. To meet these goals, Williams is in the process of formulating a Climate Action Plan[1] and Energy and Carbon Master Plan and there are currently several solar PV system installation projects underway. The Zilkha Center for Environmental Initiatives alongside the Office of Planning Design & Construction are especially interested in opportunities in new solar installations on campus or on College-owned land.

[1] The Climate Action Plan can be found here: https://docs.google.com/document/d/1rbF3knDxPEw-2yPk4AetG3urH1HSvTh8HBPmXtgTJYQ/edit#heading=h.ympdy6we0762

II. Project Goals

This project and report were both completed as a part of Professor Gardner's Fall 2022 section of ENVI 402: Environmental Planning Workshop: Community-Based Project Experience. This course is an opportunity for upperclassmen Environmental Studies majors, Environmental Studies concentrators, and other interested students to apply knowledge and experience from previous courses while engaging with community organizations and local governments to solve real-world problems. As students in this course, we were paired with clients Tanja Srebotnjak and Jason Moran, who were interested in identifying opportunities for Williams College to increase its renewable energy production potential by installing additional solar PV systems.

Tanja Srebotnjak is the current Director of the Zilkha Center for Environmental Initiatives at Williams. Jason Moran is Williams College's Assistant Director of Energy and Utilities. Together, they have asked us to identify the most promising properties for additional solar PV systems both on Williams College's campus and on College-owned off-campus buildings and lots. As the clients are open to all types of solar installation, including rooftop, ground-mounted, carports, agrovoltaics, and others, we evaluated the hundreds properties that the College owns. The primary objective of this project is to locate, rank, and recommend the best opportunities available for expanding Williams' onsite solar generation where it is not already being considered.

III. Procedure

During the early stages of our project, our team researched what factors needed to be considered when identifying a good site for solar PV systems. In addition, we sought to understand what kind of solar installations would be best for Williams College given its set of goals and circumstances.

In our research process, we first spoke in depth with our clients about which factors (e.g., economic benefit or feasibility, educational opportunities, electricity generation potential, physical feasibility, ability to own the system, etc.) were the most important to them and to the College. While we learned through these conversations that all such factors were to be considered to some degree, generation potential and physical feasibility were the most significant, as much of the effort to install solar panels is driven by the College's desire to reduce carbon emissions at low cost. Our rationale behind the criteria we ultimately used is discussed further in Section IX: Evaluation Matrix Mechanics.

Following our conversations with our clients, we began our interview process with a wide range of solar power industry professionals and industry-adjacent researchers, consultants, and project leaders. In addition, we reviewed published literature, industry reports, and relevant internet posts on emerging solar photovoltaic technologies, the carbon sequestration potential of grasslands, and ecosystem services of land under different uses. All of these sources informed our final conclusions.

After understanding the opinions of our interviewees and learning from relevant resources, we focused on the second stage of our project: identifying and surveying all of the existing on-campus and college-owned sites that could potentially host a PV system. First, we completed an initial review of the list of college-owned rental properties, aerial maps of campus, lists of off-campus College-owned land, and a list of on-campus buildings, all of which were provided to us by our clients. We then used the available data to create Google Earth maps of all on-campus and college-owned properties, and these maps served as references as we evaluated each site based on our final criteria.

IV. Literature Review

Emerging Technologies

The technological landscape of solar electricity generation is changing quickly. Driven by investment in research and development, the levelized cost of electricity for utility scale solar has dropped from $359/MWh in 2009 to $36/MWh in 2021, moving from the most expensive to the cheapest source of electricity analyzed by Lazard in just 12 years, as seen in Figure 6 of the Appendix. Similar cost reductions have been observed for other technologies related to photovoltaics, making the technology easier to install in previously inaccessible locations or alleviating intermittency issues. Some of these new technologies could impact new solar installations at Williams immediately. Others are not yet cost effective, but may still have application potential in the future. In this section of our Literature Review we analyze noteworthy developments.

Battery Storage

Battery storage has been a closely tracked technology over the last decade because it has the potential to solve the intermittency problem of renewable energy sources. Li et al. (2020) describe the problems preventing universal solar adoption and categorize them into two bins: (1) “strong diurnal and seasonal periodicity” and (2) “strong volatility and randomness.” Periodicity refers to the fluctuations in solar electricity generation that we can predict. Diurnal periodicity occurs because the sun rises and sets daily, and seasonal periodicity occurs because the amount and directness of sunlight changes over the course of the year. Both are problematic if a home or business is relying on solar power to handle all of its electricity needs. Daily generation differences are problematic because electricity must immediately be used or stored at the time of production, and solar production does not perfectly align with usage throughout the day. Peak production happens around noon, but peak usage is reached at about 9 PM, when virtually no solar power is being generated (Kosowats, 2018). Furthermore, a company sizing a system to its power usage that consumes the same amount of power in all months of the year will either be producing too much power during the winter or not enough during the summer as the amount of sunlight changes throughout the year.

Volatility and randomness refer to the fluctuations in solar electricity generation that are unpredictable. While there can be randomness in any generation source if it breaks down, solar is particularly volatile because it is exposed to changes in the weather. More power is generated on a sunny day than on a cloudy one, but people and businesses need power regardless of the weather outdoors. Consequently, solar still needs support from other generation technologies, even though it is sometimes cheapest at the point of generation.

These issues can be solved if the electricity generated at peak hours on good days could be stored for use later. Kosowats (2018) explains how battery storage can ease these challenges. Specifically, he examines the “California Duck Curve” (Figure 8 in the Appendix), a colloquial term for the graphical representation of the mismatch between renewable energy production and overall electricity consumption that arises in areas with high solar penetration, including California. In California, solar electricity can even be wasted by curtailment, which is the shutting down of solar PV systems when they are producing more power than is demanded by electricity users. According to Kosowats (2018), battery storage can help with both problems because it can provide “both supply and load.” That means that it can shift the release of electricity to the grid so that it happens more uniformly and does not require energy intensive ramp-ups, and it can also absorb the excess power generated on sunny days at peak hours so it is not wasted. Additionally, power provided from batteries is immediate, whereas gas fired peaker plants can take ten minutes to come online (Kosowats, 2018).

According to our client Jason Moran, Williams is not yet in danger of experiencing a Duck Curve-like situation. The College is such a large user of electricity that production from all solar PV systems on and near campus collectively is dwarfed by the amount of electricity used by its buildings. That said, if the College eventually meets its sustainability goals, it will encounter such issues. It should therefore consider the addition of battery storage to its new solar projects, but it does not need to do so if the economics are unfavorable. The cost of installing battery storage is considerable but improving fast. Lazard (2021b) estimates that for commercial and industrial systems (the scale at which Williams installs solar), output from storage costs between $235 and $335 per MWh. To give a sense of scale, suppose a solar developer that made a project proposal to the College offered to sell it power at $0.173 per kWh and estimated that it already buys power at $0.176 per kWh. These figures translate to $173 and $176 per MWh, respectively. Therefore, Williams would have to pay between 136 and 194 percent of the cost of power to store each additional unit of electricity, on top of the price it already pays for electricity.

That said, the situation is somewhat more nuanced. According to our client Tanja Srebotnjak, battery storage offers savings in a few ways that can offset these higher upfront costs. Having battery storage on site can be economically beneficial in three ways – by supporting utility demand response, by qualifying for the Clean Peak Standard, by reducing capacity tag charges. Utility demand response allows electric consumers to save by selectively reducing their usage at peak usage times, which the utility compensates them for (Department of Energy, 2022). The Clean Peak Standard is a Massachusetts incentive for clean energy technology – including battery storage systems – that helps reduce electricity usage at peak times (Commonwealth of Massachusetts, 2022). Capacity tag reduction allows electricity customers to save because they are charged in part based on the maximum amount of energy they demand from the grid at specific times (National Grid, 2017). Savings from demand response and the Clean Peak standard only occur when demand is high, so they do not contribute consistently to savings, but capacity tag charge reduction offers a significant financial opportunity. The opportunity is significant enough that proposals for storage that the College has previously received have been economically net positive over their ten to twenty-year contract lives.

We recommend that the College inquire about battery storage for each new project that it considers. Furthermore, it should periodically check on the cost of storage and on legislation that makes it even more competitive. The economic viability of energy storage systems could change, for instance, as a result of the recently passed Inflation Reduction Act (IRA). The IRA extends the federal Investment Tax Credit (ITC) for 10 years for projects with solar and storage, and for the first time offers the tax credit for standalone battery storage projects (Buchalter, 2022). In the near term, this tax credit would essentially give a 30 percent discount on the capital costs of any project, and Wood Mackenzie Power and Renewables estimates that storage deployments could increase by a quarter as a result of the law (Buchalter, 2022). The combination of this legislation and the corresponding cost reductions from use could bring the technology closer to economic viability at the commercial and industrial scale.

Photovoltaic (PV) Glass

Todd Holland, a senior mechanical design engineer at the University of Massachusetts Amherst, informed us during a presentation to the ENVI 402 class that his institution is installing PV windows in one of its new buildings. This presentation led us to investigate the prospect of using PV windows in new buildings or retrofitting old ones as methods to boost renewable energy production without sacrificing aesthetics. Photovoltaic glass, a type of building-integrated photovoltaic system, works by absorbing wavelengths of light outside of the visible spectrum (including ultraviolet and infrared) while letting through the light we can see. The technology is in its incipient stages, and there are significant trade-offs between transparency and panel efficiency (Wheeler and Wheeler, 2019).

When we asked Mr. Holland about the windows, he said that they were not cost competitive with roof-, ground-, or carport-mounted panels. Preliminary research indicates that his assessment was likely an understatement. Very little information has been published in academic journals regarding cost comparisons between conventional and photovoltaic windows, but a blog post in Understand Solar makes a rough comparison. Based on the post's information we calculate that PV windows are over 48 times more expensive per Watt than traditional panels (Austin, 2018). The gap may close slightly if you consider the foregone cost of the window, but PV windows are unsurprisingly many times more expensive than regular windows as well. Since Williams' goal for installing additional solar is to reduce carbon at low cost, and not to educate its students on emerging technologies, we do not believe that this is a technology that the College should consider at this time.

Current Use of Lands

Through our correspondences with local land stakeholders and our conversations with Professor Gardner, it has become apparent that in order to recommend solar sites that would truly benefit Williams and its surrounding community, it is necessary for us to adopt a more holistic evaluative approach, particularly for off-campus properties. We learned that many existing sites – though they may initially show promise for solar – currently provide important ecosystem services that would be subdued by the installation of solar PV systems on them. In this section of our literature review, we cover what we have learned about the value of off-campus College-owned land as they stand today.

Carbon Sequestration

While it is often thought that trees and forests are the main actors when it comes to carbon sequestration by natural ecosystems, grasslands are estimated to store around a third of global terrestrial carbon stocks (White et al., 2000). With the increasing frequency and intensity of forest fires in the past decades, perennial grasslands, such as those Williams owns, have been garnering attention because they are particularly reliable and resilient carbon sinks. Unlike trees, which store much of their carbon above ground in their woody biomass, grasslands store much of their carbon underground. Therefore, grasslands release less carbon back into the atmosphere than forests in the event of a fire.

A study completed by Dass et. al. (2018) at the University of California, Davis modeled and compared how grasslands and forests in California might fare as carbon sinks under the projected climate changes of coming decades. Their models indicated that grasslands were more reliable in the long run particularly due to the increasing threat of wildfires. While wildfires are admittedly a much more imminent threat in California than in the Berkshires, meteorological trends in past years have proven that forest fires are threats that Williamstown should not ignore. During the summer of 2022, the entire state of Massachusetts received a designation of moderate drought or worse for the first time in 20 years, and severe drought covered 94% of the state. The summer months were some of the driest ever recorded near the Boston area. Furthermore, closeby mid-Atlantic states are known to usually have relatively wet, humid summers, yet New Jersey experienced a massive wildfire this past June which grew to cover over 13,500 acres in Wharton State Forest. This was the largest wildfire to occur in New Jersey in the past 15 years, and the state has seen a shift in its fire season from seasonal to year-round. Given the increasing threat to forests as reliable carbon sinks, it is vital to protect the carbon sequestration capacities of the grasslands that remain.

While many studies have shown that solar fields reduce atmospheric carbon emissions more efficiently than grasslands and forests of the same size (the magnitude of this difference depends on the sources of electricity that the solar fields are replacing), we believe that the College should explore purer ways to reduce its carbon emissions. Putting solar arrays on grasslands is at best a one step backward, two steps forward approach, which we believe to be sub-optimal. It is also important to recognize that the value of grasslands and hayfields do not stop at carbon sequestration.

Ecosystem Services

Perennial grasslands are essential components of the existing natural and economic ecosystem of the Berkshire region. While they are relatively under-researched, Bengtsson et al. (2019) found that grasslands provide many non-agricultural ecosystem services. Aside from carbon sequestration, the authors list water supply and flow regulation, erosion control, climate mitigation, and pollination as some of the services provided by grasslands around the world.

Needless to say, grasslands are also invaluable sites for local agriculture at a time when agricultural land in Western Massachusetts is depleting quickly and under intense pressure to develop. According to *Farms Under Threat: A New England Perspective*, a report released by the American Farmland Trust (AFT), Massachusetts has lost the third highest percentage of its agricultural land between 2001-2016 to urban and highly-developed use across all states in the US. In “Solar Siting Guidelines for Farmland”, also released by the AFT, the need to prioritize agriculture and protect farmland was emphasized. They recommended that brownfields, rooftops, and solar canopies were first considered for solar developments before farmland.

Given the existing research and published best practices, along with our conversations with local farmers, farmlands and grasslands were not placed at the top of our recommendations for potential solar sites, even if they fit the topographic requirements.

Legislation

While the federal and state governments provide incentives for developing solar arrays, the most significant guidelines on what development is permitted comes from local governments. The state encourages local governments to make rules which encourage the development of solar arrays and prohibits any restrictions on solar PV systems. The state law negates any local laws where, “any provision in an instrument relative to the ownership or use of real property which purports to forbid or unreasonably restrict the installation or use of a solar energy system… or the building of structures that facilitate the collection of solar energy" (M.G.L. ch. 184 § 23C).

Williamstown permits the development of solar in most zones, particularly if it is a roof- or canopy- mounted PV solar system (Williamstown Code 70-3.3). While zoning laws allow rooftop and carport systems to be installed anywhere, the town evaluates ground-mounted systems based on their size (Williamstown Code 70-3.3). A small-scale solar PV system is a ground-mounted system where the combined area of the panels is less than 1,000 square feet (Williamstown Code 70-9.2). A medium-scale system is between 1,000 and 20,000 square feet and a large-scale system is greater than 20,000 square feet (Williamstown Code 70-9.2).

The areas of Williams campus being considered for ground-mounted solar are zoned as General Residence (Williamstown Assessor Map). This category means that small systems can be built, while medium systems need Planning Board approval and large systems are prohibited. On GoogleEarth, the size of the Greylock lot is around 23,000 square feet. However, the lot size is not what is in consideration, the combined surface area of the panels is. Given spacing between rows, the system would likely fall under the 20,000 square foot limit. However, it would still require the approval of the planning board. Denison Park is a much larger lot, totaling around 71,000 square feet. Given zoning restrictions, any approved project would not be able to take advantage of the whole lot, only around 28 percent of it. Even with a limited system size, there would still have to be planning board approval.

Off-campus properties are either zoned as Rural Residence 2 or Upland Conservation (Williamstown Assessor Map). The areas considered for Mt Hope and Pine Cobble are both in Rural Residence 2 zones, meaning that any size of solar system is allowed (Williamstown Code 70-3.3). Berlin Mountain has significant chunks zoned as Upland Conservation, which would require special approval by the Planning Board (Williamstown Code 70-3.3). This zoning law syncs with the clients' desire and our recommendation to not clearcut any land for solar development.

National Environmental Protection Act (NEPA) is a federal regulation that requires agencies to assess the environmental impacts of their proposed actions. This review looks at environmental, social, and economic effects of proposed action, as well as soliciting public feedback. If the effects of a project are uncertain, the lead federal agency must prepare an Environmental Assessment (EA), which means the review process must include "public involvement to the extent practicable," as dictated by 40 CRF 1501.5 (e). If the project is suspected to have major impacts, the lead agency conducts an Environmental Impact Statement (EIS), which must follow the regulations for public involvement and disclosure set by the Council of Environmental Quality. A particularly important part of this consultation is outreach to tribes to understand the impact these projects may have on cultural land.

This group encountered NEPA in correspondence with the Stockbridge-Munsee of Mohican Indians' tribal council. While NEPA will likely not apply any solar projects Williams will undertake- it would take a utility-scale project on federal land to involve a federal agency- the College should still take the logic of NEPA and make significant outreach efforts to the Stockbridge-Munsee tribe whenever considering building ground-mounting off-campus PV systems. Our group, as well as the College, acknowledges that Williams is built on their ancestral homelands. In an effort to build a more inclusive and equitable space for all, we want to ensure that development on a specific plot would not further any injustices against the Stockbridge-Munsee tribe. As part of our evaluation, we tried to request information about the significance of sites like Mt Hope, but were informed that without a specific project design, the council cannot comment on any potential impacts. While it may not be required by law, this group emphasizes that the College should always solicit input from the Stockbridge Munsee community when building ground-mounted projects.

V. Preliminary Site Visits

On Monday, October 17, Jason Moran took the project group members on a set of site visits so that we could better understand the physical components that need to be considered when surveying potential ground- and roof-mount PV systems and why they were important. In Figure 1 in the final section of the report, we have included a photo that was taken of one of the several electrical poles outside of the Williamstown Landfill Solar Array. Jason informed us that these were needed in order to connect solar array systems further away from Williams onto the National Grid system. We also visited Kite Hill, where he mentioned that the existing electrical poles would not be able to handle a large PV array's volume of generated electricity. He informed us that if an array were to be installed there, significant upgrades would need to be made and additional electrical poles would need to be installed.

Figures 2, 3, and 4 show the electrical room inside of Horn Hall, which Jason gave us access to on our site visit. He explained that Horn Hall was built anticipating solar installation, so it was a "best case scenario building" for solar. Conduits from the roof were built into the walls of the building so that they could reach the electrical room in the basement, which allowed the panels on top to function without wires running along the outside. He also showed us how spacious the room was and told us that when surveying potential buildings to host roof-mounted systems we should consider whether or not their electrical rooms had space for such large electrical equipment.

VI. Completed Interviews

Interviews comprise a large portion of our base of knowledge collected for the report. This is the case for a few reasons. First, there are some limitations to academic literature in this field since much of the current work is in the private sector where information moves quickly and is not as often published publicly. Therefore, speaking with people involved in the industry can give us a picture of what is important currently. For example, information on the recently passed Inflation Reduction Act (IRA) is yet to be reflected in articles much more substantial than blog posts simply because so little time has elapsed since the bill was passed into law. People in the solar industry whose businesses will be greatly affected by the bill will likely have the most up-to-date information.

Second, interviews can give us a more local perspective on the problems we could face in siting. The fact that a solar carport has been successful at Michigan State may tell us little about whether or not one could be successful at Williams. Energy prices, state incentives, electric grid structure, local attitudes, and other factors influence viability. Speaking with professionals and members of local organizations in Western Massachusetts and Berkshire County can help us better understand those forces in ways that experts based out of other regions of the United States cannot.

Third, interviews can lead us to information and resources that we did not initially know could be helpful in our evaluation in ways that are less common in literature. This is the case because businesspeople, community organization members, and academics often maintain networks of connections with others with tangential expertise. Those that we interview may be able to point us in the direction of other resources or people that help us broaden and sharpen our evaluation. Put another way, we can ask people questions, but we cannot ask questions to papers.

Consequently, we structured our interviews to cover all parts of our initially intended evaluation characteristics and allowed the interviewees to have input on the attributes we will evaluate. The larger categories we were assessing for each site are (1) Economic/Avoided Emissions, (2) Technical, (3) Community, and (4) Other/Cobenefits. Based on our conversations, we narrowed down our final evaluation characteristics to only Economic/Avoided Emissions and Technical. Below we have listed each interview we performed, the questions we asked, and the insights we gained.

Zac Bloom, VP and Head of Sustainability and Renewables at Competitive Energy Services — October 19, 2022

Description: Our client, Jason Moran, connected us with Zac Bloom. He, with Competitive Energy Services, had previously worked with Williams College as a consultant on the Farmington Solar Project in Maine. We spoke virtually for an hour.

Purpose: We sought to learn more about the economic and technical criteria that should be included in our evaluation matrix and how the recently passed Inflation Reduction Act (IRA) would influence the economics of projects in the next decade. We also wanted to hear some of his insights from the Farmington Solar Project on how to best site for solar.

Questions:

- What sorts of things were you looking for when choosing the Farmington site, and how might these considerations translate into smaller sites?
- Have you found that certain management practices/structures are optimal for projects of this size?

- Are there any factors that immediately disqualify a site from being viable for solar development?

<u>Insights</u>

- The location and orientation of trees and buildings near the panels could significantly impact shading and energy production potential.
- Communication with our clients about their priorities is essential: projects that are "out of the money" (that would likely cost the client more for electricity than it would have without the system) and thus not viable for some could be viable to an educational institution with pressure and a mandate to reduce emissions. For Williams specifically, poor economics may not necessarily be a reason to disqualify a project.
- It is impossible to recommend a single management structure to all clients; this decision is ultimately made after bids are submitted for the project, so whether Williams wants to engage in a power purchase agreement (third-party ownership structure) or not should be decided on a case-by-case (project-by-project) basis.
- In the IRA there are specific incentives for using different types of labor. Interconnection costs will now also be eligible for investment tax credit (ITC) benefits while they hadn't before.
- The interconnection piece (along with the more generous ITC benefit in general) could make projects that were previously not likely to be built because of economic hurdles become realistic. He said these changes will also change the RFP process as hiring union labor becomes a priority for developers trying to capture the full scope of the IRA's incentives.

Dwayne Breger, Professor and Director of the Clean Energy Extension at the University of Massachusetts Amherst — October 19, 2022

Description: Meaghan Boehm, who has been working closely with our client Tanja this semester, connected us with Professor Breger due to our interest in learning more about his main research area: agrovoltaics. We spoke with him for an hour virtually.

Purpose: We aimed to inform our evaluation of community support of cobenefits of new systems on College property, so we spoke to Professor Breger, whose research area is in agrivoltaics (or in Massachusetts law, dual-use solar). Broadly defined, agrivoltaics combines agriculture and PV systems on the same plots of land. We were initially interested in this variety of PV since we thought it might provide a path to ease the tension between community stakeholders and the College as we consider solar on its off-campus land. We felt that community members that would be against turning an open space or potentially productive farmland into a solar field would be more receptive if the community saw agricultural co-benefits.

Questions:

- What process did you use to survey the suitability of the agricultural land used for your dual-use (agrivoltaic) solar installations?
- Can you explain the costs of implementation/maintenance?
- How do you prevent electrocution from interaction with inverters and connectors?
- How important are Massachusetts Department of Energy Resources grants for this project? Could you have done it without the grants?

Insights:

- Current systems are heavily reliant on Massachusetts state subsidies, which have highly specific eligibility requirements.

- A project that qualified under the strict guidelines of "dual-use" solar in Massachusetts law could expect to receive a price of electricity about 50% higher than normal tariff rates for solar electricity.
- The incentives are the sole reason that any developer would take on a dual-use project at this point in time; other costs for dual-use solar installation are much higher than they are for normal solar installation. The spacing between panels needed to allow for agriculture diminishes the possible electrical output of the system. Since the laws are written with farming in mind, no more than 50 percent of the total land can be shaded by panels. Furthermore, the panels have to be raised eight to ten feet off the ground, requiring more steel and leading to higher costs.
- In order to qualify for the incentives, the land on which dual-use solar is developed needs to be already productive farmland.
- Farmland is under threat in Massachusetts and decreasing its productivity through agrivoltaics would be difficult to justify in most situations.
- The details about dual-use in Massachusetts made this style of PV seem like an unlikely fit for Williams.

Jay Galusha, Local farmer at Fairfield Dairy Farm in Williamstown, MA — October 24, 2022

<u>Description:</u> Professor Gardner spoke on our behalf with Jay Galusha, a farmer who manages much of the College's farmland.

<u>Purpose:</u> We wanted to further inform our decisions regarding land use and community/stakeholder opposition to repurposing farmland.

<u>Questions:</u>

- What problems are associated with converting productive farmland into a solar field?
- How do farm-connected stakeholders react to proposals for renewable energy on land they have used for farming?

Insights;

- Fairfield Dairy Farm (one of Jay Gelusha's properties), would be strongly opposed to the College making changes to the current use of fields which the farm currently hays.
- If he lost any of the hayfields that the College owns, he would have to significantly reduce his cattle operation due to insufficient availability of hay for feed.
- He has recently invested in large harvesting equipment that would be incompatible with dual use solar.
- If his opinion is representative of others in the community (in particular the local farming community) it seems that agrivoltaics will face strong opposition due to its negative effects on the local farm economy.

Rebecca Martin and Hannah Poplawski, VP and Project Manager at Berkshire Photovoltaic Services — October 27, 2022

Description: We virtually interviewed two solar industry professionals working at a local developer and installer, Berkshire Photovoltaic Services (BPVS). BPVS is one of the longest running companies in the Berkshire County renewables space.

Purpose: We aimed to gain economic and technical knowledge about the development and installation of new solar systems. Additionally, we asksed for more insight on what makes a good or bad system and why to understand what to look for in a potential project site.

Questions:

- Could you walk us through a standard project from when your team joins to when it leaves? What kinds of regulatory or permitting costs are involved in the process?
- Are you ever asked to build projects that you cannot? If so, why?
- How much say does the developer or installer have in where a system goes? Will a customer ask for solar and let you take care of the rest or can they say they only want it on a certain part of the house or building, letting BPVS propose a design?
- What elements are most likely to break down in a system? How often do those breakdowns occur?
- What does the maintenance process look like for replacement? Who's responsible?
- Are some types of systems more prone to failure than others?
- What specific factors do you suggest that we look for (e.g. roof material, roof slant, slope of the site, etc.) to avoid future complications as much as possible?
- What factors make for a productive and hassle-free system?

Insights:

- An entirely unproblematic roof-mounted system has a roof oriented south (though east and west-facing roof orientations are also acceptable), has no structural or electrical upgrades required, and is low to the ground for easy access
- For ground-mounted systems, sites are ideally on non-rocky environments
- Slate roofs, old electric meters near to the ground, and old fuse boxes are not ideal since they usually require upgrades.
- If an old roof is going to be replaced, the customer should make the roof replacement before the PV system is installed.

- Although their experiences were mostly in residential systems, they seemed confident that the same factors and challenges would similarly apply to larger systems.
- Collaboration with the customer is key, and special requests about where the system should be located could always be considered, but additional costs may be associated with making changes and these costs should be communicated.
- Inverters are most likely to break down, but all of the parts could be covered by warranties and responses to claims usually occur in less than a month.
- BVPS has existed for a long time, so it seems likely that they will continue to do business and maintain their systems into the future; signing on with a risky installer that goes out of business within a couple years can lead to a much bigger headache later on when their responsibilities with the system have to be replaced.
- OpenSolar, a resource they often use, could help us visualize potential systems later on in our process.

Jeremy Burdick, Architectural Trades Manager at Williams College — October 28, 2022

Description: To best understand the architectural challenges of adding solar panels to a building, we spoke with Mr. Burdick for an hour.

Purpose: We met with Mr. Burdick in hopes of acquiring information about on-campus buildings' roof materials, age, load, and slope.

Questions:

- Do facilities have a consolidated document that contains information about roof age, load, material, and slope to help with our evaluation of properties for on-campus solar siting?
- If there is no consolidated document, what is the ideal building type to add solar onto?
- One of our clients proposed adding solar onto faculty rental housing. What are your thoughts on the feasibility of that endeavor, and do you have any examples of prime locations for such a project?

Insights:

- Understanding the potential for solar installation on past buildings will require data on roof material, age, slope, and ability to carry the additional load of a PV system.
- Williams does not have documented information on the factors we asked for.
- After consulting with Jason Moran to understand the electrical constraints of a building, he can make recommendations based on visual inspection of the building, looking at roof material, slope, and available area.
- Preliminary recommendations include the Spencer Studio Art Building, Mission Park, Wachenheim, and the South Science building.
- In addition to his list, Mr. Burdick will review any additional sites we discover through our review using Google Earth.
- While not directly prompted by a question, Mr. Burdick was concerned at community reaction to the aesthetic effect solar panels would have on buildings. He was also concerned about creating punctures in roofs from adding solar panels.

Anne O'Connor, Member of the Williamstown COOL (CO_2 Lowering) Committee — October 31, 2022

Description: Professor Gardner connected us with Anne O'Connor, a current member of the Williamstown COOL Committee and former Select Board member. We spoke with her at the Class of 1966 Environmental Center for one hour. The COOL Committee is a body of representatives from Williamstown, Williams College, and the town government that works to promote sustainability at the town and individual levels. In particular, the COOL Committee focuses on retrofitting buildings and increasing local renewable energy sources in order to lower Williamstown's carbon emissions.

Purpose: We aimed to better understand how the larger Williamstown community has responded to solar developments in the past and how we could successfully and thoughtfully balance stakeholder opinions.

Questions:

- What type of role do you see additional renewable developments in Williamstown playing in its transition to net zero?
- Are the arguments against land-mounted solar (especially when they're on undeveloped lands) mostly environmental or are there other philosophical arguments that are made?
- How closely does the town work with the College in making decisions about/financing new renewable energy projects?

Insights:

- Anne expressed her strong opposition against virgin land-based renewable energy development.

- Because the COOL Committee has positioned itself as being pro-renewables, she imagines that in the future the tension between renewable energy development supporters and conservationists like her could become more pronounced, but she remains hopeful that the COOL Committee has the potential to move forward as a unit, while remaining cognizant of current land use.
- There is a distinct discomfort with being accused of "NIMBY-ism" in communities that have opposed solar developments for conservation reasons.
- She emphasized that the College has already contributed significantly to deforestation in the name of renewable energy as a participant in the Farmington Solar Project.
- In order to work through these tensions, she believed the College should maintain open lines of communication with community members if it plans to develop solar projects off-campus.
- Based on her experience, she felt that there was consistent dialogue between the town, College, and utilities about renewable energy projects as a function of the town being so small and close-knit, but that it sometimes felt as though Williams made decisions in a bubble.

Jamie Pottern, New England Program Manager at the American Farmland Trust - November 1, 2022

<u>Description:</u> Jamie Pottern visited our class to discuss the importance of retaining and growing available farmland. As American Farmland Trust's Program Manager for New England, they are an advocate against using productive agricultural land to generate solar unless it is the only option available.

Purpose: We hoped to better understand how to weight agricultural value and current use in our evaluations of Williams' productive hayfields, and gauge the potential for agrivoltaics on these hayfields.

Questions:

- Is there any situation for which agrivoltaics could work symbiotically with a productive hayfield?
- If agrivoltaics are not possible, how should the College approach meeting its renewable energy target through ground-mount solar generation?

Insights:

- Massachusetts has a relatively high rate of farm loss, at about 8.7 percent each year.
- Part of this loss comes from competition with solar developers.
- Siting solar on rooftops and brownfields will be insufficient to meet renewable energy needs, so the state needs smart solar siting.
- Smart solar siting:
    - First, develop rooftops, brownfields, and solar canopies.
    - Second, if it's necessary to site on farmland, locate panels on marginal or unproductive land.
    - Third, only develop agricultural land with carefully monitored dual-use solar.

Todd Holland, Senior Mechanical Design Engineer at the University of Massachusetts Amherst — November 2, 2022

Description: Todd Holland visited our class to present about his experiences as a design engineer at Williams College, Hampshire College, and UMass Amherst. In these roles, he has been responsible for installing solar on several college campuses. We asked him questions based on his presentation at the end of the session.

Purpose: We aimed to learn about the process of developing a solar project on a college campus, the challenges that could be faced, and the creative ways to overcome those challenges.

Questions:

- Why do carports have to be as high up as they are (they seem taller than cars)?
- Does the foregone snowplowing from a carport installation save any money?
- How do PV windows compare production- and cost-wise to traditional rooftop solar?
- What problems did you have with the power purchase agreement (PPA) you signed at Hampshire College?

Insights:

- Williams College uses a very large amount of energy per capita compared to other institutions in Western Massachusetts.
- EUI stands for energy use intensity; it is a metric used to rate the efficiency of buildings.
- Solar glass can now appear transparent on windows.
- In Massachusetts, 60 thousand acres of land are needed to fit enough solar to meet our state's climate goals. This translates to about one percent of the total land area. Solar already covers about six thousand acres, or ten percent of the goal area.
- "Citizens who fight against everything" are a major hurdle for progress, even when well intentioned
- Black fencing looks much nicer than gray metal fencing.
- Regulations require that around a solar field, fencing must be six feet high topped with barbed wire or alternatively at least seven feet high.

- Raising the bottom of a fence six inches can allow wildlife to move freely into and out of the solar field.
- Pollinator friendly plants can be planted in a solar field.
- It is easiest to install solar on standing-seam metal roofing.
- Large snow plows need to fit under carport systems.
- Foregone costs from plowing are not significant.
- Problems with a PPA mostly have to do with who is on the other side of the contract; In their case, Tesla was not a good partner.

Milo Becker, Connecticut College Recent Graduate — November 3, 2022

<u>Description:</u> Milo Becker is a recent Connecticut College graduate who performed an analysis similar to the one we are undertaking as an independent study project during his senior year. Cole interviewed him over the phone to ask about his experience.

<u>Purpose:</u> We hoped to gain insights from someone with experience writing a solar siting report for a NESCAC college.

<u>Questions:</u>

- What was the scope of your independent study? What were your deliverables?
- How did you deal with NIMBYism challenges or community opposition?
- What recommendations do you have about formatting the report?
- Did you use any external tools to create deliverables for your report? If so, which ones?
- Do you have any other insights learned during the process that we could benefit from knowing?

<u>Insights:</u>

- The scope of his project was very similar to ours; he met with Connecticut College's facilities department, collected data on existing utility usage, and evaluated potential sites for solar based on characteristics including size, shading, and aesthetics.
- He used the SolarEdge and PVWatts tools for modeling and production calculations for potential projects
- He confirmed our thought that large, flat roofs are best for solar, but agreed that carport projects have potential.
- To capture community support, he included a section for each site for qualitative in addition to quantitative analysis; the quantitative section was mostly potential production statistics, but the qualitative section included information about what each space was used for informally (e.g., open field used for ultimate frisbee club practice).
- He recommended that we be wary of surveys and ensure that ours were simple.
- He included an appendix with a mock up model and production estimates for each site he analyzed.

VII. Solar Modelling Estimations

To evaluate the sites for their feasibility and generation potential, we used two online tools for system mockups and generation estimates. The first tool is OpenSolar, which was recommended to us by BPVS, which uses the tool in its regular business operations. The second is PVWatts, which one of our group members, Cole Whitehouse, had used while interning for a solar developer and was recommended by Milo Becker. OpenSolar was used primarily for our reported statistics, and PVWatss was used by our group to check the accuracy of the estimates and make calculations for our final presentation. We generally found that PVWatts estimates tracked relatively closely with OpenSolar's estimates.

OpenSolar

OpenSolar is a solar estimation and system price tool. Its main benefit is its ability to create model mockups to represent how the PV system would look if installed. They are not transparent about how the factors inputted are used for calculating the final generation potential or system cost. The tool asks for the address of the building or open plot and building or topographic details of the site. The panel OpenSolar uses for its estimates is the Solaria PowerXT-370R-PD. It is difficult to identify areas of uncertainty because there is no detail provided about how these estimates are calculated. Consequently, we used it primarily to create mockups and system sizing but relied on PVWatts for generation estimates.

PVWatts

PVWatts is a solar estimation tool created by the National Renewable Energy Laboratory (NREL). This tool was used as a second solar estimate, to give an idea of the uncertainty in final system size, particularly because of the lack of clarity in how OpenSolar is reaching its estimate.

The user enters information about the DC[2] system size, module type, array type, system losses, tilt, and azimuth (direction relative to poles). The settings we use to calculate this estimate are: standard module type, fixed array type, and 14.08 percent system losses. We estimated a tilt of 10 degrees for flat rooftops and 20 degrees for ground mounted systems based on Cole Whitehouse's experience working for a solar developer. The tool uses several models to estimate

[2] This stands for direct current, as opposed to alternating current (AC). Solar panels produce power in DC watts, but as energy passes through an inverter to become appropriate for use (AC), it decreases in wattage.

hourly simulations of the performance of different parts of a PV system. The hourly electrical output of the system is calculated using the following factors. First, the tool calculates the hourly plane-of-array (POA) solar irradiance using the horizontal irradiance, latitude, longitude, and time in NREL's solar resource data, and the user-entered array type, tilt, and azimuth inputs. Solar irradiance data comes from hourly diffuse horizontal irradiance (DHI) and direct normal irradiance (DNI) data in NREL's weather file for the location, looking at the position of the sun and the orientation of photovoltaic modules in the array. Then, the effective POA irradiance is calculated to reflect the losses from the reflection of the module cover; this calculation depends on the solar incidence angle.

To calculate the PV's DC output, PVWatts first estimates the PV cell temperature using the array type, POA irradiance, wind speed, and ambient temperature; this model assumes that fixed, roof-mounted systems have a module height of five meters and have an installed nominal operating cell temperature (INOCT) OF 49° C, and assumes good airflow, and thus cooling, and an INOCT of 45° C for all other system types. After the tool has an estimate of cell temperature, PVWatts uses a reference POA irradiance of 1,000 W/m² and assumes a cell temperature of 25°C, and temperature coefficient of power of -0.47% °C for the standard module type, -0.35% °C for the premium type, or -0.20% °C for the thin film type, to calculate DC output of the system. Finally, PVWatts calculates the AC output using the DC output and accounting for system losses and nominal inverter efficiency input, using 96 percent by default due to empirical measurements by NREL of inverter performance. These calculations are based on the fact that there are 8,760 hours in a year. The system's developers emphasize that these assumptions are appropriate for flat-plate PV systems with crystalline silicon or thin film modules, not for systems with concentrating collectors or other types of new technology.

Limits to estimation accuracy arise from weather variability, system design and operating conditions, module choice, and energy value. Solar radiation also varies year-to-year. PVWatts states that, based on 30 years of historical weather data for Massachusetts, a fixed PV system has a 90 percent chance of generating at least 96 percent of the estimated "typical year" production. It has a 10 percent chance of generating more than 102 percent of the "typical year" production. Generally, PVWatts cautions that a system's monthly output can vary by ±30 percent and yearly output can vary by ±10 percent from the provided estimated long term value. PVWatts also emphasizes that a PV system will underperform its estimate if it meets any of the following conditions: nearby objects shade the modules, annual soiling or snow cover losses exceeding 5 percent, or the system performance degrading (a PV system may degrade as much as 1 percent per year). PVWatts was used primarily to create annual generation estimates.

VIII. Evaluation Matrix Categories

As this group is considering three types of solar generation—roof-mounted, carport, and ground-mounted—on sites that are both on and off the Williams campus, the evaluation matrix is divided into two sheets subdivided by the type of solar considered. One sheet is for on-campus properties and the other is for off-campus parcels because off-campus sites must first be considered on vegetation and agricultural land use. The sheet is then subdivided into three groups, each containing the different factors needed to evaluate a site for the type of solar considered. As mentioned later on in the report, potential systems are considered against other systems of the same type, so for instance an off-campus ground-mount system will not be evaluated under the same criteria or listed in the same ranking as an on-campus roof-mounted system.

The following matrix categories were chosen after gathering information from the interviews described above. Each factor for the specific property is color-coded in green, yellow, or red to reflect the relative rating/outcome of the finding. These categorizations can be found in the "Properties Under Consideration" and the "Evaluation Matrix with Weightings" spreadsheets found in the Appendix.

When evaluating solar potential, the system size must be a minimum of 50 kW; this is a standard that was explicitly stated to us by our clients as a minimum for material contributions to carbon reduction on campus.

Example of On and Off Campus Matrix Sheet

Roof Mounted
Property
Technical
Roof Angle/Style
Roof Material
Shading/Sun Exposure
Orientation towards Sun
Economic / Avoided Emissions
OpenSolar Estimated Size
PVWatts Estimated Annual Output (kWh/year)
Carbon Emissions Avoided (tons/year)
Other/Comments
Carport
Property
Technical
Shading/Sun Exposure
Economic / Avoided Emissions

OpenSolar Estimated Size
PVWatts Estimated Annual Output (kWh/year)
Carbon Emissions Avoided (tons/year)
Other/Comments
Ground Mounted
Property
Technical
Topography
Shading/Sun Exposure
Economic / Avoided Emissions
OpenSolar Estimated Size
PVWatts Estimated Annual Output (kWh/year)
Carbon Emissions Avoided (tons/year)
Other/Comments

Roof-Mounted PV

After meeting with Jeremy Burdick and Jason Moran, a common concern we identified for roof-mounted PV was the ability of the roof to hold solar panels. The main factors impacting this ability are material and slope. The ideal roof is made of asphalt or metal and somewhere between flat and slightly pitched. The final factors consider the sunlight that the roof receives by accounting for any shading created by neighboring buildings or trees. We also look for the potential to add south-facing panels because in the northern hemisphere, the sun moves along the southern part of the sky, so south-facing panels receive the most direct sunlight.

The economic considerations for roof-mounts look at the size of system (kW), number of estimated kilawatt-hours per year (kWh/yr), and avoided carbon emissions (ton/yr). System size is an important consideration because it allows us to compare generation potential across sites.

That measure is then used to calculate the kilawatt-hours per year of that system. This measure lets one calculate the avoided carbon from using this system each year.

Other is a category for this group to leave notes about the property that do not fit within the options previously mentioned.

Carport

Similarly to roof-mounted systems, shading is considered for a carport's technical feasibility.

The Economic/Avoided Emissions considerations are the same as for roof-mounts, however, as solar potential will again be evaluated using the tools PVWatts and OpenSolar. We rely primarily on estimates from OpenSolar because they come directly from the mockups we made of the systems, and we used PVWatts for reality checks on system production numbers. We do not include the estimated system cost created by OpenSolar because costs are rapidly changing, we do not know if it will be accurate enough to be helpful, and it does not account for different financing options that could be available to the College.

Ground-Mounted PV

Since it is desirable to have a relatively flat piece of land to site solar on, the topography category will indicate the change in elevation of a given plot of land. The other technical consideration is the shading of the area from trees, buildings, or other objects.

IX. Evaluation Matrix Mechanics

A key feature of our evaluation matrix will be our color-coding of each cell within the technical considerations, which is a strategy we chose to employ at the request of our clients. We plan on coloring each criteria for each site either green, yellow, or red, to reflect whether the data entry is favorable, acceptable, or unacceptable, respectively. The possible data entries and their respective colorings are shown in the table in Appendix TBD.

We believe these colors are appropriate for our matrix in two ways. First, they allow for quick overviews of the data, as a simple survey of the colors under a site can more-or-less communicate whether it is an ideal or unfeasible site. If there are an overwhelming number of greens and no reds, we can quickly understand that the site has many favorable qualities, making it a top choice. Second, it will allow us to compare evaluations of different criteria against each other even if they use different units of measurement (i.e. it allows us to consider a large number of tons of CO_2 emissions avoided to an ideally sloped roof).

We chose a non-numerical matrix because some sites will have disqualifying characteristics. If a site has many favorable characteristics and just one disqualifying characteristic, it could still be ranked highly in a purely numerical ranking system. In our alternative coding system, it can be eliminated. Therefore, we will have a more holistic view of the sites we evaluate and will not be tied to somewhat arbitrary numbers that interact with one another in ways that are impossible to capture in a matrix.

Before properties being considered for ground-mounted systems are ranked based on technical factors or system size, the consideration of Human Interest is prioritized. One of these factors is whether or not the site is important to the Stockbridge-Munsee Band of Mohicans. Our group, as well as the College, acknowledges that Williams is built on their ancestral homelands. In an effort to build a more inclusive and equitable space for all, we want to ensure that development on a specific plot would not further any injustices against the Stockbridge-Munsee tribe. This category has to be evaluated on a project-by-project basis as the Tribal Council cannot comment on the cultural significance of general areas like Berlin Mountain. Therefore, it is outside the scope of this report to comment on the cultural significance of a site because that requires a project design. We include this category in the matrix to emphasize the importance of considering and prioritizing the history of injustice written into much of Williamstown land.

The second factor included in our Human Interest considerations is the Current Land Use. Based on several interviews and our literature review, there is very significant value to forested and agricultural land. Therefore, the first line catalogues any agricultural use of the land. An ideal, green-ranked, site would have been previously disturbed land and a poor, red-ranked, plot will be used for current agriculture where the crops are incompatible with agrivoltaics and/or the farmer currently renting the land does not desire adding solar. The yellow for this factor represents when the farmer wants to host solar on their land. The second line looks at the current vegetation of the plot. A site is marked as red if it is forested because of the important carbon sequestration happening from those trees or a wetland or floodplain, as it is illegal to build a solar site on these spots. A green site is open land that only has grass. Yellow reflects that there is some significant recreational use of the land. Given the strong ties that people develop to an area, we do not think we can adequately capture the community impact of transitioning a light-use recreational site to a solar field through the medium of a matrix. Any sites that have light recreational use will be starred to indicate that we recommend the College engage in meaningful community outreach to understand the real impact of transitioning that land if it is eventually considered as a site for solar.

Procedure for Incorporating All Considerations

Given these preliminary considerations, our evaluation moved forward to incorporate both the system type-specific technical considerations and estimated system output/avoided carbon emissions. The following subsection describes the general procedures we followed to evaluate each site across the relevant Technical considerations, and by our Economic/Avoided Emissions criteria.

Ranking 1 (Technical): Based on the specifications in Appendix A, we immediately disqualified any sites that have red in any category. Then, we will come up with a ranking of all remaining sites (now with only green or yellow cells) based on the percentage of green evaluations they received. Higher percentages of greens receive higher rankings.

Ranking 2 (Economic/Avoided Emissions): In addition to technical considerations of a hypothetical site, we have heavily weighted Economic/Avoided Emissions factors, namely the expected size of a system. Because Williams' solar projects are above all driven by the College's commitment to institutional sustainability, the size of a site is among our most important considerations. Therefore, we created a second ranking based purely on the size of the system, i.e., the kW rating obtained from the OpenSolar estimates. Readers may note that kWhs and avoided carbon emissions (tons/yr) are included within the Economic/Avoided Emissions section of our matrix, but not used to rank systems in the future. Since avoided carbon emissions overlap with some of our technical considerations, particularly orientation, shading, and more, if this metric was weighted against the technical side, it could result in double-counting of certain property benefits.

Aggregate Ranking: We will then combine those two rankings (estimated system production and technical considerations) into one overall score for the site that can be compared to any other site. As our clients expressed desire to manipulate the percentage weight of technical versus estimated capacity, this report will later list our top sites we found by size and by technical ranking. We also later highlight a few sites that stood out in both respects. However, the following is an explanation of the mechanism of the spreadsheet so that, when our clients decide to use the it to create a ranked list, there is an explanation of how it functions.

Spreadsheet Ranking System

The spreadsheet functions as follows. Each kW of generation capacity for system estimated generation potential is converted into a point. The largest system we estimate that could be connected to the Williams electrical distribution system would be given a "full" amount of points for the 50 percent of points awarded for estimated production. For example, if we estimate that the largest system would be rated 100 kW of electricity, it would receive 100 points.

Additionally, that 100 points would represent the maximum value of points for technical considerations. If that site or a different site had entirely "green" rankings for technical considerations, it would be awarded another 100 points. "Yellow" rankings do not contribute to points. Therefore, a system with all "yellow" rankings would be given zero points for its technical portion. The two-point totals could be added together to holistically rank sites. That is done by choosing percentage weightings in the designated area of the spreadsheet. Giving each a 50 percent weight would multiply the scores for sizing and technical by 0.5 and then adding them together, for example. "Red" rankings because any ranking of "red" completely disqualifies a system from consideration.

We want to emphasize that rankings should depend on the array type. Each type of system, roof-mounted, carport, and ground-mount, will bring its own cobenefits to a project that cannot be easily evaluated against each other. Carports provide cover from rain and snow, have the ability to install charging stations, and make the College seem sustainable because it is a relatively new development in solar technology. However, if the College wanted the project to be visible, a rooftop mounted solar system could be better suited because most student activity concentrates around academic buildings and dorms. While not applicable to any of Williams' current land holdings because of their use as productive hayfields or forests, ground-mounted systems have the potential to agrivoltaics systems, which are innovative and could potentially provide both solar and food. Furthermore, ground-mounted systems are usually the largest, so they could have the most significant impact on carbon emissions. Without knowing more about the College's priorities (outside of the facilities department), we feel that it is only appropriate to rank systems within type.

The qualities that lead to "green," "yellow," and "red" rankings for each technical consideration are listed in the chart below.

X. List of Evaluated Sites

Below is a list of all on-campus and off-campus sites evaluated. This list corresponds with our Google Earth maps included with the report that show the location and evaluation status of each site. The rightmost column indicates whether the site was immediately disqualified or not based on factors such as size (it was evident that any system it would host would fall below the 50 kW threshold), roof (if we observed that the site had a slate roof), or shading (if we observed complete shading). The first table directly below lists only on-campus sites, listed by site type (rooftops for roof-mounted systems, open spaces for ground-mounted systems, and parking lots of carports).

On-Campus Sites			Immediate Disqualification (X)
Rooftops			
1	Fort Bradshaw	Housing, graduate student	X
2	Agard House	Housing, student	X
3	Thompson Health Center	Student services	
4	Garfield House	Housing, student	X
5	Fellows Hall (CDE)	Housing, graduate student	
6	Center for Development Economics	Academic	
7	Miller House	Administrative	
8	Austen House	Housing, rental	X
9	McGinnis House (CDE)	Housing, rental	
10	South House West	Housing, rental	X
11	Wood House	Housing, student	X
12	South House East	Housing, rental	X
13	North House West	Housing, rental	
14	Perry House	Housing, student	X
15	Weston Hall	Administrative	X
16	Temporary Modular Faculty Office	Administrative	
17	Bascom House	Administrative	X
18	Modular Classroom	Academic	X
19	Carlton House	Housing, rental	X

20	*Unknown*		X
21	*Unknown*		X
22	Leigh House	Housing, rental (TA)	X
23	*Unknown*		X
24	Brinsmade House	Administrative	X
25	Johnson House	Administrative	X
26	*Unknown*		X
27	Gavitt House	Housing, rental	X
28	Horn Hall	Housing, student	
29	Chadbourne House	Housing, student	
30	Jewish Religious Center	Religious	X
31	Brooks House	Housing, student and administrative	X
32	Spencer House	Housing, student	X
33	Milham House	Housing, student	X
34	ABC House	Academic	X
35	Lambert House	Housing, student	X
36	Doughty House	Housing, student	X
37	Susan B. Hopkins House	Housing, student	X
38	Oakley Center	Academic	
39	Weston Team Center	Athletic	
40	Williams Inn	Commercial	
41	Facilities Service Building	Administrative	
42	Towne Field House	Athletic	
43	College Bookstore	Commercial	
44	The Log	Commercial	
45	Lansing Chapman Rink	Athletic	
46	Heating Plant	Service	X

47	Facilities Service Center North	Administrative	
48	Spencer Studio Art Building	Academic	
49	*Unknown*		
50	*Unknown*		
51	Driscoll Dining Hall	Student dining	X
52	Prospect House	Housing, student	
53	Fitch House	Housing, student	
54	Currier Hall	Housing, student	
55	East College	Housing, student	
56	Fayerweather Hall	Housing, student	
57	Lawrence Hall	Academic	
58	Williams College Museum of Art	Arts and administrative	
59	Chandler Athletic Center (1/2)	Athletic	
60	Chandler Athletic Center (2/2)	Athletic	
61	62-64 Spring St.	Commercial	
62	*Unknown*		
63	*Unknown*		
64	Adams Block	Commercial	
65	Chandler Commercial	Commercial	
66	Lasell Gym	Athletic	X
67	Simon Squash Center	Athletic	
68	Goodrich Hall	Student union	X
69	South Science Building	Academic and administrative	
70	Morley Science Laboratories/Schow Library	Academic and administrative	

71	Thompson Biology	Academic	X
72	Thompson Chemistry	Academic	X
73	Thompson Physics	Academic	X
74	Wachenheim Center	Academic	
75	Clark Hall	Academic	X
76	West College	Housing, student	X
77	Jesup Hall	Academic	X
78	Morgan Hall	Housing, student	X
79	Gladden House	Housing, student	
80	Carter House	Housing, student	
81	Mark Hopkins House	Housing, student	
82	Bryant House	Housing, student	
83	Greylock Hall	Student dining	
84	’62 Center for Theatre and Dance	Auditorium, theater	
85	Faculty House	Specialty event space	
86	Woodbridge House	Housing, student	X
90	Class of ‘37 House	Administrative	
91	Vogt House	Administrative	
92	Mears House	Administrative	X
93	Mears West	Administrative	X
94	Williams College Children’s Center	Administrative	
95	President’s House	Housing, other	
96	Paresky Center	Student union	
97	Sage Hall	Housing, student	X
98	Williams Hall	Housing, student	X
99	Chapin Hall	Auditorium, theater	

100	Bernhard Music Center	Academic	
101	Hollander Hall	Academic	
102	Schapiro Hall	Academic	
103	Lehman Hall	Housing, student	X
104	Hopkins Hall	Administrative	X
105	Thompson Memorial Chapel	Religious	X
106	Griffin Hall	Academic	X
107	Mason House	Academic	X
108	Wild House I,II	Housing, rental	X
109	Quinn House I,II	Housing, rental	X
110	Sawyer Library	Academic	
111	Class of 1966 Environmental Center	Academic	
112	Sewall House	Housing, student	X
113	Goodrich House	Housing, student	X
114	Dodd House	Housing, student	
115	Dodd Annex	Academic	X
116	Hubbell House	Housing, student	X
117	Parsons House	Housing, student	X
118	*Unknown*		
119	Treadway House	Housing, rental	X
120	Mission Park	Housing, student	
121	Thompson Hall	Housing, student	X
122	Chaffee Tennis House	Athletic	X
123	Tyler House	Housing, student	X
124	Tyler Annex	Housing, student	
125	Poker Flats	Housing, student	

126	Facilities Barn	Administrative	
127	Cold Field House	Athletic	X
128	Cold Field House Shed	Athletic	
Open Spaces			
1	Denison Park		
2	Greylock Field		
3	Tennis Court Field		
Parking Lots			
1	Lamb Field Parking		
2	Towne Field House Parking		
3	Greylock Parking Garage		
4	Lehman Parking Lot		
5	Thompson Parking Lot		
6	Sawyer Library Parking Lot		
7	Poker Flats Parking Lot		

The second table lists off-campus sites. In this table, sites (namely open spaces) can be immediately disqualified due to Human Interest considerations (e.g. productive farmland, heavily recreational use, forested, etc.). At the end of this second table, we have also included a miscellaneous category that lists a proposed boathouse and a newly on-the-market dirt lot that we also evaluated at our client's request.

Off-Campus Sites			Immediate Disqualification (X)
Rooftops			
1	224 Pine Cobble Rd	Housing, rental	

2	261 Pine Cobble Rd	Housing, rental	
3	290 Pine Cobble Rd	Housing, rental	
4	340 Pine Cobble Rd	Housing, rental	
5	350 Pine Cobble Rd	Housing, rental	
6	380 Pine Cobble Rd	Housing, rental	
7	401 Pine Cobble Rd	Housing, rental	
8	510 Pine Cobble Rd	Housing, rental	
9	540 Pine Cobble Rd	Housing, rental	
10	730 Pine Cobble Rd	Housing, rental	
11	735 Pine Cobble Rd	Housing, rental	
12	*Unknown*		
13	Beals House	Housing, rental	
14	Brown House East	Housing, rental	
15	Brown House West	Housing, rental	
16	Cable Mills Apartments	Housing, rental	
17	Caretaker’s House	Housing, other	
18	*Unknown*		
19	Chaucer House	Housing, rental	
20	Clark House I-II	Housing, rental	
21	Danforth Block 1-4	Housing, rental	
22	Danforth Block 5-8	Housing, rental	
23	Dickens House	Housing, rental	
24	Fisher House 1-4	Housing, rental	
25	Friedrich House	Housing, rental	
26	*Unknown*		
27	Grundy’s Garage	Service	
28	Hawthorne House I	Housing, rental	

29	Hawthorn House II	Housing, rental	
30	*Unknown*		
31	Hewat House I-III	Housing, rental	
32	Rosenburg Center	Academic	
33	Jerome House I-III	Housing, rental	
34	Lamphier House E	Housing, rental	
35	Lamphier House W	Housing, rental	
36	*Unknown*		
37	Williams College Library Shelving Facility	Academic	
38	Marcus House I-II (CDE)	Housing, rental	
39	Mason House Apartment	Housing, rental	
40	Maxcy House	Housing, rental	
41	McGinnis House I-II (CDE)	Housing, rental	
42	Melville House I	Housing, rental	
43	Melville House II	Housing, rental	
44	Messer House	Housing, rental	
45	Morey House A	Housing, rental	
46	Morey House B	Housing, rental	
47	Million Dollar Cow Barn	Housing, other	
48	Mt. Hope Inn A-D	Housing, rental	
49	North House West, East	Housing, rental	
50	Orwell House	Housing, rental	
51	Park St Condos 2,3,5	Housing, rental	
52	Patrie House East	Housing, rental	
53	Patrie House West	Housing, rental	
54	Pratt House	Housing, rental	

55	Quinn House I-II	Housing, rental	
56	Roberts House I	Housing, rental	
57	Roberts House II	Housing, rental	
58	Rogers House	Housing, rental	
59	Royal House	Housing, rental	
60	Ruland House I-III	Housing, rental	
61	Sherman House I-IV	Housing, rental	
62	*Unknown*		
63	South House West	Housing, rental	
64	South House East	Housing, rental	
65	Southworth Schoolhouse	Administrative	
66	Stocking House 1	Housing, rental	
67	Stocking House 2	Housing, rental	
68	Taconic Golf Club	Athletic	
69	The Knolls I-III	Housing, rental	
70	Thoreau House	Housing, rental	
71	Tower House	Housing, rental	
72	*Unknown*		
73	Verizon Equipment Building	Service	
74	Wharton House	Housing, rental	
75	Whittier House	Housing, rental	
76	*Unknown*		
77	*Unknown*		
78	Woodworth House I-III	Housing, rental	
79	Onota Boathouse	Athletic	
80	Mt Hope Shed 1	*Unknown*	
81	Mt Hope Shed 2	*Unknown*	

Open Spaces		
1	Pine Cobble Development (forested)	X
2	Cluett Drive	X
3	Hopkins Memorial Forest (forested)	X
4	Wire Bridge Farm	X
5	Berlin Mountain	X
6	Mt Hope Farm Lawns	
7	Mt Hope Inn Lawns	
8	Taconic Golf Club Greens	X
9	Mt Hope Farms	X
10	Pine Cobble Development (cleared field)	
Parking Lots		
1	Williams Inn Parking Lot	
2	Southworth Schoolhouse SE Lot	
3	Southworth Schoolhouse NW Lot	
4	Spring Street Parking Lot	
Miscellaneous		
1	Planned Onota Boathouse	
2	US Route 7, Pownal, VT Dirt Lot	

XI. Scoring of Sites

As explained in Section X (Evaluation Martix), sites were scored by both technical suitability and size. Furthermore, we determined that some site characteristics could immediately disqualify a site from further consideration. To evaluate sites, we first combed through our lists to determine which potential sites had these characteristics.

On Campus

For on campus sites, including rooftop, ground mount, and carport, we created a Google Earth file containing all potential sites. This included 130 significant buildings, seven parking lots, and three non-athletic or recreational fields. These sites were labeled with blue markers. The rooftop sites were labeled with a house icon, the parking lots with a fortress icon, and the fields with a campsite icon. An image of the map before disqualifications were made is included as Figure 10.

To disqualify sites, first, we looked for sites that already had solar installed. This accounted for 14 sites, which were labeled with green markers and are shown first in Figure 11. We assume here that these sites will not be candidates for more solar PV since their potential has already been taken advantage of by the College.

Second, we disqualified sites based on the concept of "Zones of Uncertainty" which we discussed with our clients. Zones of Uncertainty are areas for which there is not 25-30 year certainty about the existence of the sites in the same form as they exist today. These sites were drawn based on a preview of insights from the Campus Framework Plan that is expected to be presented to the Board in the near future. This is important in the context of solar PV installations because 25-30 years is the expected life cycle of panels produced today. Consequently, generation assets installed would not be able to achieve their full value. We agreed with our clients that these areas should therefore be avoided. There are four such Zones, the area near Towne Fieldhouse, Greylock Quad, Mission Park, and Dodd Neighborhood. Together, the zones account for 18 buildings and one significant parking lot. The zones are marked with red borders and shading and disqualified buildings and parking lots are marked with red icons in Figure 12.

Third, we disqualified sites based on the suitability of roof material. Based on our conversations with Williams Architectural Trades Manager, Jeremy Burdick, we are considering slate roofs unsuitable for solar PV at this time. There were 24 such additional sites which are labeled with red icons in Figure 13.

Finally, we disqualified sites based on a number of other lumped criteria including unusual or interrupted roof shape, proximate expected building demolition date, southern tree shading, or small roof size. Any of these characteristics would make a building unsuitable for solar PV at this time. Unusual or interrupted roof shape includes buildings with rooftops that are not flat or consistent enough to accommodate solar panels. This includes but is not limited to buildings with a large number of dormers or ornamental spires on the roof. Proximate expected building demolition date includes buildings that are expected to be demolished in the near future. Southern tree shading includes buildings or other sites that experience significant shading from trees from the southern direction, where they would otherwise experience the most direct sunlight. Since the College's primary goal of installing solar is to reduce the net carbon emissions of the campus, removing trees to install solar would run counter to the objective because of their carbon storing properties. We consider small roof sizes as roofs that we expect could not host 50 kW of solar capacity. We agreed on this size with our clients because systems below that size would not make immediate material impacts on overall campus power usage. This does not necessarily mean that they are unsuitable or should not eventually be considered for solar, but for the purposes of this project they do not make sense to evaluate further. We determined roof size by mocking up satellite images of the rooftops using the OpenSolar online tool for sites where the size appeared to be near 50 kW. These additional sites are marked in red on Figure 14.

The 17 remaining building sites were mocked up to find their expected power rating using the OpenSolar online tool, which was recommended to us by BPVS. Since the purpose of the project was to find rough estimates, we did not change the advanced parameters on the site and mocked up sites by filling open areas on the rooftops and other sites with panels. Further correspondence with BPVS informed us that panels should be set back from the edge of the roof or obstances by enough space to walk around them, or two feet in their experience, that panel configurations are cheapest in parallel rows, and that shading of over roughly 30 percent in any area is a reasonable cutoff for panel suitability. These mockups produced the power ratings included in our Properties Under Consideration list.

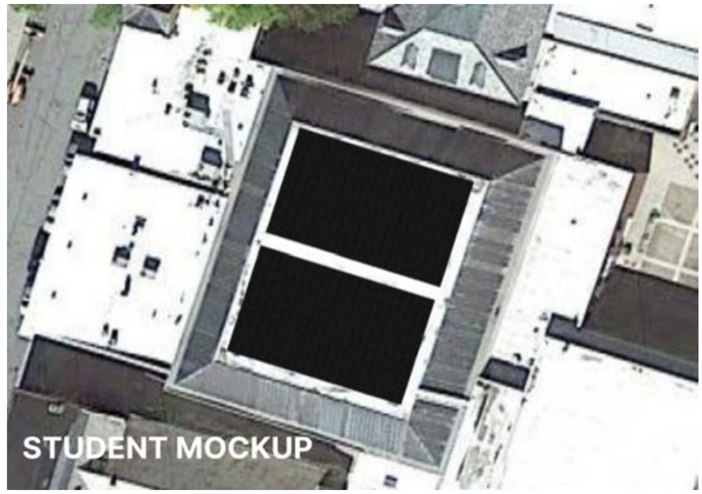
XII. Top Sites

We have listed the top sites separately for each type of installation considered because the type of installation pursued may depend on the College's priorities. Mockups for these sites are included and were made using OpenSolar. The selected sites for on-campus are presented in no particular order but are included because they are both sizable opportunities for solar and would be technically easier to install. We also include lists of potential sites ranked by size that include information on technical ease of installation (Appendix ???).

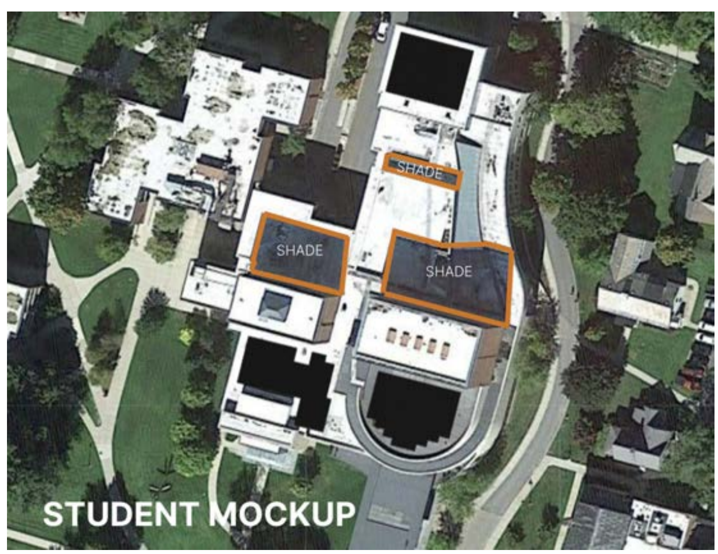
On Campus – Rooftop

Chandler Athletic Buildings (33 Spring St)

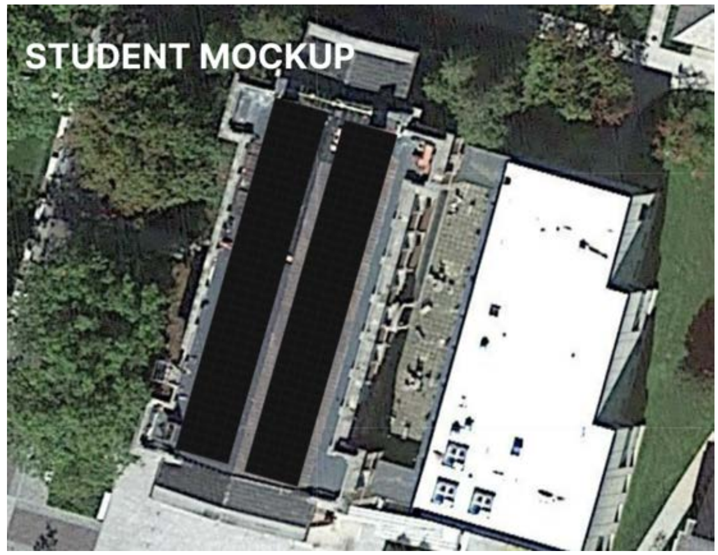
Potential Size	133.2 kW
Roof Angle	Flat
Roof Material	EPDM
Shading	None
Orientation	~ South
Rooftop Units	None
Other considerations	None



’62 Center for Theatre and Dance (1000 Main Street)	
Potential Size	156.9 kW
Roof Angle	Flat
Roof Material	EPDM
Shading	Some from other parts of roof
Orientation	~ South
Rooftop Units	None
Other considerations	Shading not visible in GoogleEarth not considered; system

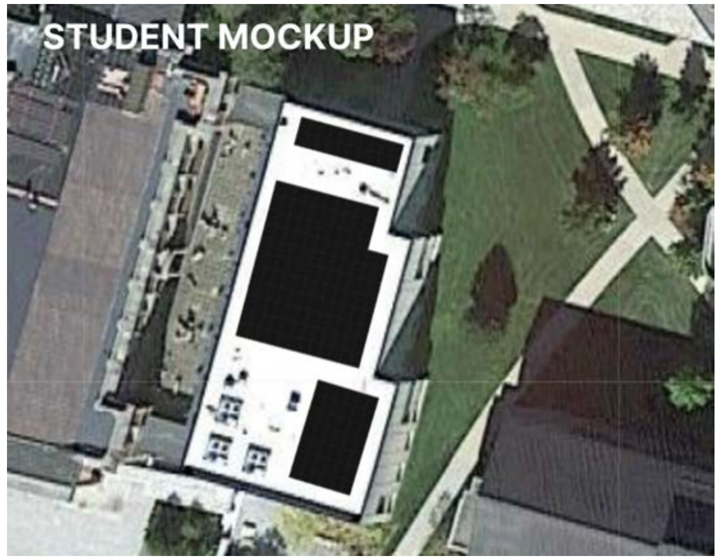


	is disjointed with far away parts	

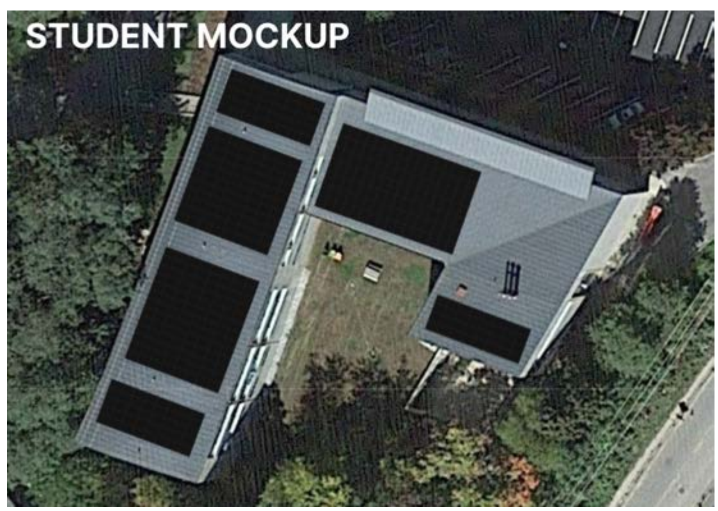
Chapin Hall (62 Chapin Hall Dr)		
Potential Size	106.6 kW	
#Roof Angle	Slightly pitched	
Roof Material	Standing-seam metal	
Shading	Little to none	
Orientation	East and West	
Rooftop Units	None	
Other considerations	Historical building; could be installed alongside Bernhard Music Center	

Bernhard Music Center (54 Chapin Hall Dr)

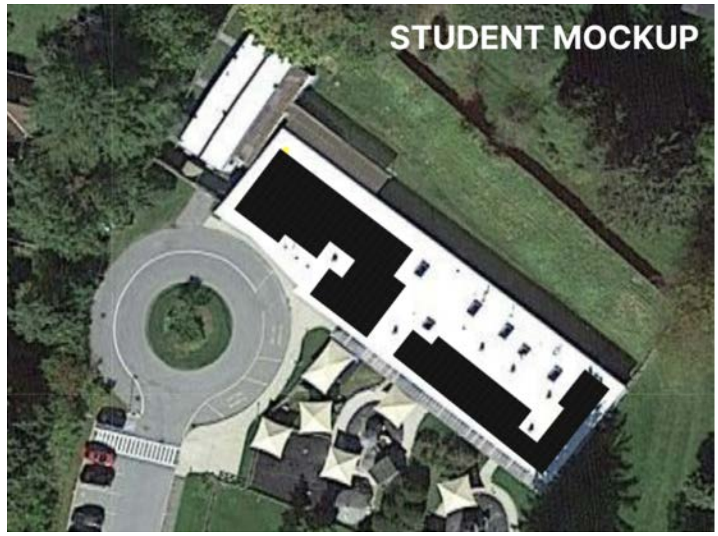
Potential Size	69.6 kW
Roof Angle	Flat
Roof Material	EPDM
Shading	None
Orientation	~ South
Rooftop Units	3 that take up space; can be worked around
Other considerations	Could be installed alongside Chapin Hall



Spencer Studio Art Building (35 Driscoll Hall Dr)	
Potential Size	153.9 kW
Roof Angle	Slightly pitched
Roof Material	Sarnafil
Shading	None
Orientation	South, East, West in different sections
Rooftop Units	None
Other considerations	Standing-seam metal appearance is artificial; largest roof section (east-facing) is a barrel roof, which BPVS says is very unusual but possible to install solar on

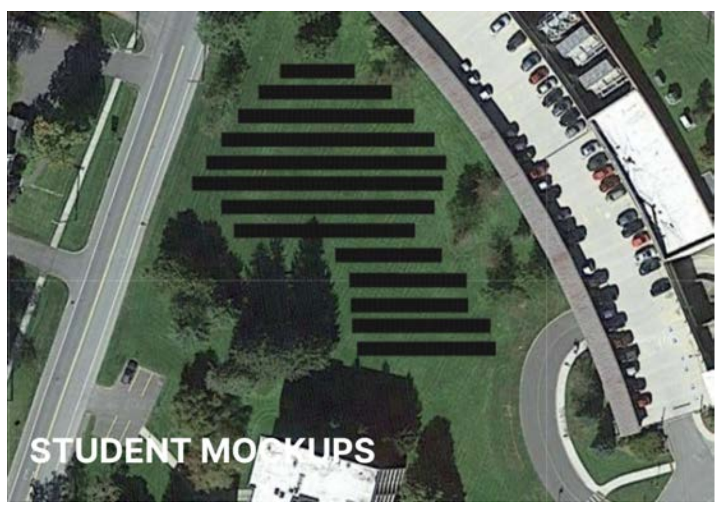


Williams Children's Center (44 Whitman St)	
Potential Size	98.8 kW
Roof Angle	Flat
Roof Material	EPDM
Shading	Little to none
Orientation	~ Southwest
Rooftop Units	Few potential skylights; lots of room to spare
Other considerations	Would not connect to Williams campus grid



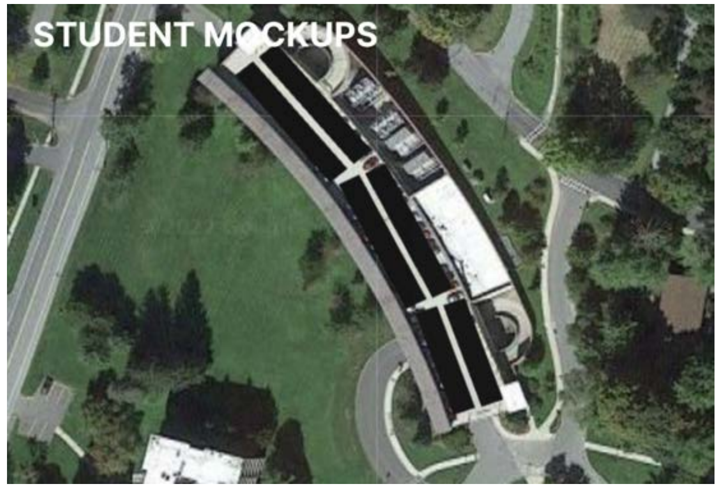
On Campus – Open Space

"Gladden Field"	
Potential Size	291.6 kW
Topography	Mostly Flat
Shading	Minor shading in South
Other considerations	



On Campus – Parking Lots

Greylock Parking Lot

Potential Size	287.1	
Shading	No shade	
Other considerations		

Off Campus – Rooftop

Grundy's Garage		
Potential Size	164.3 kW	
Roof Angle	Flat	
Roof Material	EPDM	
Shading	No Shading	
Orientation	South, East, West	
Rooftop Units		
Other considerations		

Off Campus – Parking Lots

Spring St Parking Lot

Potential Size	552.8 kW	
Shading	No shade	
Other considerations		

XIII. Recommendations

Our research has led us to four overarching recommendations for the College.

1. Increased transparency about undeveloped college land

One of the biggest logistical challenges of this project was figuring out which properties the College owns. The College's facilities website lists 231 buildings currently owned by Williams. While this number is slightly higher than the real number of structures owned because apartments within the same building are listed individually, Williams still owns a very large number of buildings. This amount of property is even more considerable when including the lands Williams owns which do not have buildings on them. The facilities list only contains the buildings the College owns, meaning that sites like Hopkins Forest, Berlin Mountain, and portions of Pine Cobble are not listed publicly as college holdings. It is not that the College tries to hide that they own these sites – HMF has its own website – it that there is no comprehensive list of all the land that Williams owns.

One way to see how much land the College controls is to look at the Town Assessor's map. As seen in Figure 17, Each blue pin on the site represents a parcel of land owned by the College. These pins reveal that Williams owns a significant portion of Williamstown. The college also owns land outside of the town and state limits; HMF stretches into New York and Vermont.

Williams should be transparent about how much property it owns because that reflects how much land it is managing. The College chooses how a significant portion of land in Williamstown and beyond is used. As it commits to make Williams a sustainable place, the success of these measures cannot be fully understood without examining how Williams manages its land.

2. All new buildings should have solar installed, baring technical infeasibility

This recommendation arose after seeing plans for the new Onota boathouse, which is proposed under development, meaning that it may be built soon, but there is no guarantee of this outcome. The boathouse has the ideal conditions for solar siting, with two south-facing roofs made of standing seam metal with no shading of the building. While the head coaches pushed to add solar to the building, adding solar would have added a large cost to the project which already had to cut amenities like showers in the locker rooms to stay within budget.

At a college that has both a significantly higher endowment and energy usage per capita than comparably sized institutions, Williams should be looking at how to reduce its footprint. An excellent way to achieve this goal is solar siting on all new buildings. The point of this suggestion is not to place blame on those involved in the planning process for the boathouse, but rather to highlight that there is no standard or fund or other enabling factor to add solar to buildings right now. The main exception to this rule is when the College decides it wants to achieve a certain building standard, which usually requires the addition of solar.

At a minimum, the College should design every new building so that it has the possibility of hosting a PV system in the future. This approach is equivalent to the argument for electrification: it is an investment in the possibility of clean energy, rather than choosing a building design that makes hosting solar an impossibility.

However, when the College passes up a chance for local energy generation, it must also consider the equity impacts of this choice. On average, non-Western countries are paying the cost of other countries' historical emissions, including the United States. An undeniable benefit of adding solar to every new building is that it demonstrates a commitment to generating energy in the same area that it will be used.

3. Prioritize current use of the land

When the College is looking to develop ground-mounted solar systems, it should look for previously disturbed land because of the agricultural and ecological benefits this report has found for most of the College's existing land holdings. A prime example of an ideal site for a ground-mounted PV system is a site our clients found, a gravel pit just over the Vermont border along Route 7. This 110 acre site has 40 acres of previously cleared land from the gravel extractions, as can be seen in Figure 18. The site is sloped towards the South and would receive minimum shading, making it an ideal site when looking at the technical considerations. Using the ratio of acreage to system size from the Farmington Solar Project, this site could host between 6 and 17 MW of solar. Preliminary research did not find any zoning restrictions on siting this project.

The other option the College has to reduce its impact on productive land is to consider investments in wind power. Wind turbines disrupt much fewer acres than solar panels, allowing existing vegetation to remain relatively undisturbed. While a common complaint against turbines is that they are noisy, new turbines' have much longer blades that move slower, making them quiet (GE, 2014). Additionally, wind turbines can generate much more power than solar panels: one wind turbine can generate the same amount of kWh as thousands of solar panels (Nextamp, 2021). As Williams owns parcels of land along the Tatonic Crest which has been studied as a potential site of wind since the 1980s, using local wind generation could be a more favorable alternative to solar (Augenbraun, 2009).

4. Strongly consider installing solar on the top evaluated sites

The most direct way for Williams to lower its on-campus emissions is to make investments in on-site renewable energy. Our report identifies over a dozen sites that are suitable – and even ideal – locations for solar. These sites may even have the potential to save the institution money on electricity in the long run because of improvements in solar technology and incentives at the state and federal levels. The benefits of adding solar appear to outweigh the costs, so it would behoove the College to contact consultants or developers about the prospect of installing systems. Williams will then have the option to move forward with projects if they prove to be boons for its energy usage and its social impact.

XIV. Future Research Recommendations

During the course of this project, we encountered a number of gaps in information that fell outside the scope of our research but that we believe would be beneficial to examine in the future. We have listed some ideas for continuations of our efforts below.

Survey Data

Our clients were especially curious about opinions regarding where and how solar should be implemented at Wililams, and we believe a survey could help capture these opinions. Additionally, the client wants to learn about any co-benefits the Williams community may find in various types of solar projects. Ideally, this survey is conducted across students, faculty, and staff.

Roof Age and Load Data

As Williams does not store this data, it will take a structural engineer coming in to evaluate these factors of the roof. Roof load will tell us if the building can physically hold the system. Roof age is important because if a roof is going to be replaced in the next decade, there is no sense in adding a solar system that will have to be replaced in 25 to 30 years.

Grid Connection Information

The College is continually communicating with National Grid to understand the capacity of the grid. As Williamstown is at the end of the grid, there is limited available capacity for new energy generation. A large solar project that could not connect to Williams' campus grid could mean that the College would have to pay between half a million to one million dollars to upgrade the utilities' hosting capacity. An investment of this size would make the economics of such a project unfeasible.

Ownership Structure

Either Williams or a development company can be responsible for the cost, operations, and maintenance of the installed panels. There are costs and benefits to each approach, which is why Zac Bloom of Competitive Energy Services emphasized that it should not be considered until there is an actual system plan.

Size of Electrical Room

In order to use the generated electricity, the building must have space in its electrical room to add a weather station, and additional space on the electrical breaker for an inverter. Due to the security of the spaces, it fell outside of the scope of work and is to be investigated on a case by case basis as the College continues evaluating its next locations for solar.

XV. Bibliography

American Farmland Trust, 2020, *Solar Siting Guidelines for Farmland*, https://s30428.pcdn.co/wp-content/uploads/2020/01/AFT-solar-siting-guidelines-Jan-2020.pdf.

Austin, Ryan. "Solar Windows Cost - Are They Worth It?" *Understand Solar*, 21 Nov. 2018, https://understandsolar.com/solar-windows-cost/.

Augenbraun, JJ. "Wind Power for Williams College: A Feasibility Study." *Williams College*, 2009.

Bengtsson, J., et al. "Grasslands-More Important for Ecosystem Services than You Might Think." *Ecosphere*, vol. 10, no. 2, 2019, https://doi.org/10.1002/ecs2.2582.

Buchalter. “Inflation Reduction Act Set to Boost Standalone Energy Storage.” *JD Supra*, https://www.jdsupra.com/legalnews/inflation-reduction-act-set-to-boost-1821618/.

Commonwealth of Massachusetts. “Clean Peak Energy Standard.” *Mass.gov*, 2022, https://www.mass.gov/clean-peak-energy-standard.

Dass, Pawlok, et al. “Grasslands May Be More Reliable Carbon Sinks than Forests in California.” *Environmental Research Letters*, vol. 13, no. 7, 2018, p. 074027., https://doi.org/10.1088/1748-9326/aacb39.

“Decarbonization.” *Sustainability*, https://sustainability.williams.edu/uncategorized/decarbonization/.

Department of Energy. “Demand Response.” *Energy.gov*, 2022, https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid/demand-response.

Diflippo, Dana. “Illegal Campfire Started N.J.’s Largest Wildfire in 15 Years, Fire Official Says.” *New Jersey Monitor*, 21 June 2022, https://newjerseymonitor.com/2022/06/21/illegal-campfire-started-n-j-s-largest-wildfire-in-15-years-fire-official-says/.

Eliasen, Terry. “94-Percent of Massachusetts Now in 'Severe' Drought, 39-Percent 'Extreme'.” *CBS Boston*, 18 Aug. 2022, https://www.cbsnews.com/boston/news/massachusetts-drought-severe-extreme-report-update-august-18-2022/.

“How Loud Is a Wind Turbine?” *GE News*, 2 Aug. 2014, https://www.ge.com/news/reports/how-loud-is-a-wind-turbine.

Kosowatz, John. “Energy Storage Smooths the Duck Curve.” *Mechanical Engineering*, vol. 140, no. 06, 2018, pp. 30–35., https://doi.org/10.1115/1.2018-jun-1.

Lazard. *Lazard’s Levelized Cost of Energy Analysis—Version 15*. Oct. 2021, https://www.lazard.com/media/451905/lazards-levelized-cost-of-energy-version-150-vf.pdf.

Lazard. *Lazard’s Levelized Cost of Storage Analysis—Version 7*. Oct. 2021, https://www.lazard.com/media/451882/lazards-levelized-cost-of-storage-version-70-vf.pdf.

Li, Wei, et al. “Key Operational Issues on the Integration of Large-Scale Solar Power Generation—a Literature Review.” *Energies*, vol. 13, no. 22, 2020, p. 5951., https://doi.org/10.3390/en13225951.

National Grid. “National Grid Method for Estimating ICAP for ISO-NE Reporting.” 2017, https://www1.nationalgridus.com/files/InformationAndForms/ICAP%20Tag%20Update%20for%20New%20PWR%20Yr.pdf

Pottern, Jamie B., and Laura N. Barley. American Farmland Trust, *Farms Under Threat: A New England Perspective*, https://farmlandinfo.org/wp-content/uploads/sites/2/2020/10/AFT_NE_FUT-10_14_20_rev.pdf.

“Solar vs. Wind Energy: Which Is Better for Powering Your Home?” *Nexamp*, 15 Jan. 2021, https://www.nexamp.com/blog/solar-power-vs-wind-energy.

Wheeler, Lance M., and Vincent M. Wheeler. “Detailed Balance Analysis of Photovoltaic Windows.” *ACS Energy Letters*, vol. 4, no. 9, 2019, pp. 2130–2136., https://doi.org/10.1021/acsenergylett.9b01316.

White, Robin P., et al. Grassland ecosystems. Washington, DC, USA: World Resources Institute, 2000.

United States, Town of Williamstown, Planning Board. *Article IX*.

United States, Town of Williamstown, Planning Board. *70-3.3 Use Regulation Schedule*.

XVI. Appendix

Figure 1. Electrical poles outside of the Williamstown Landfill Solar Array. Several poles are necessary to feed such a large volume of generated energy into the electrical grid.

Figure 2. Transformers in the Horn Hall electrical room.

Figure 3. Inverters and transformers for solar systems in the Horn Hall electrical room.

Figure 4. A diagram of the electrical components for the rooftop solar system outside of Horn Hall.

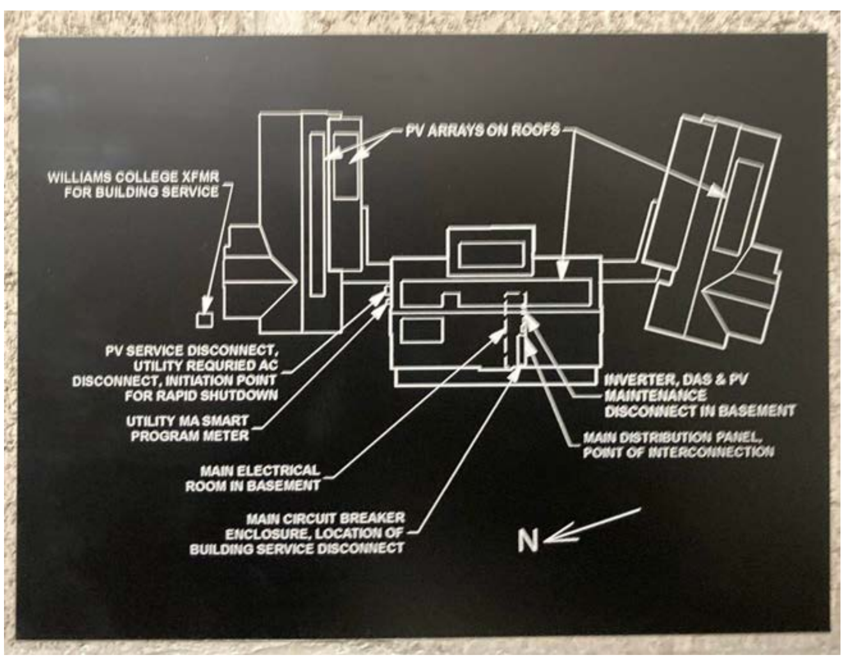


Figure 5. Levelized Cost of Energy Comparison for Selected Technologies since 2009 (Lazard, 2021a)

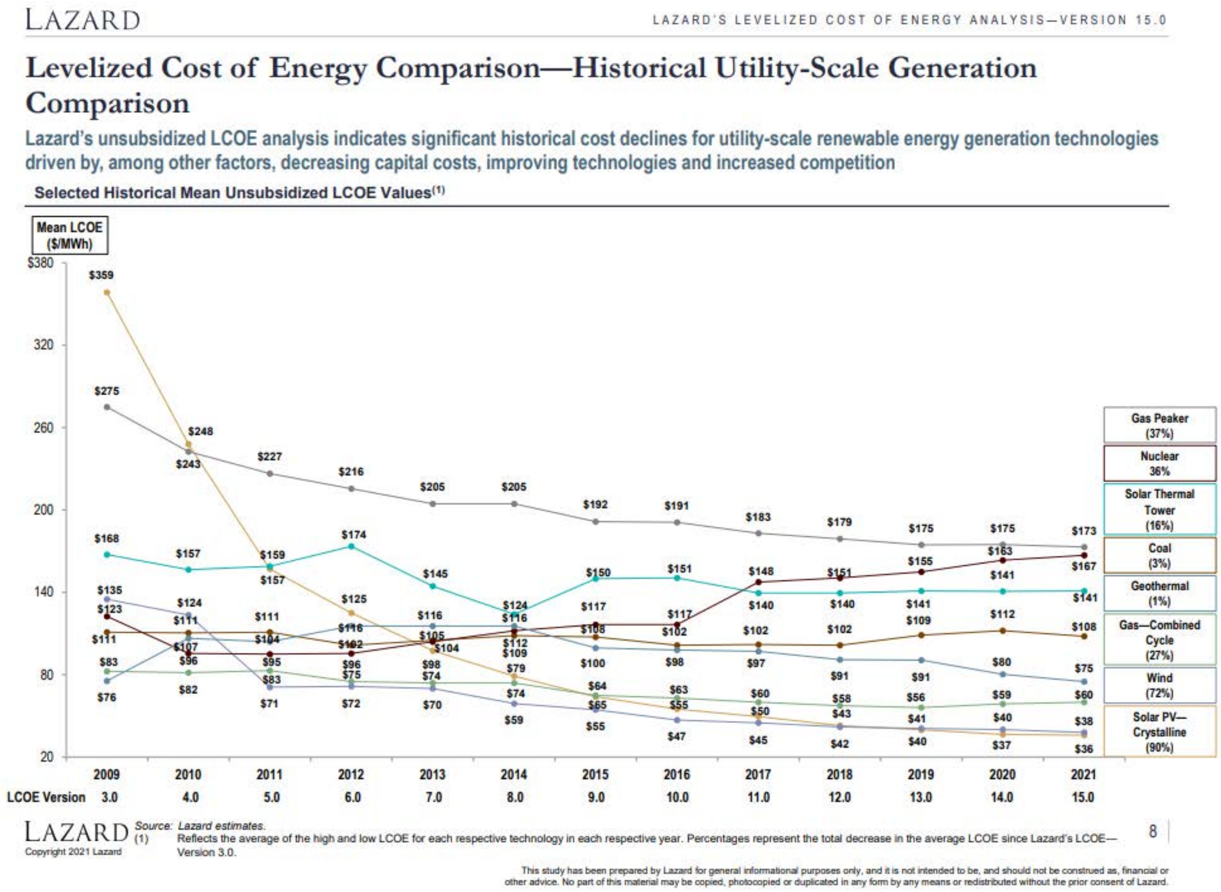


Figure 6. Levelized Cost of Storage Comparison between Selected Technologies as of 2021 (Lazard, 2021b)

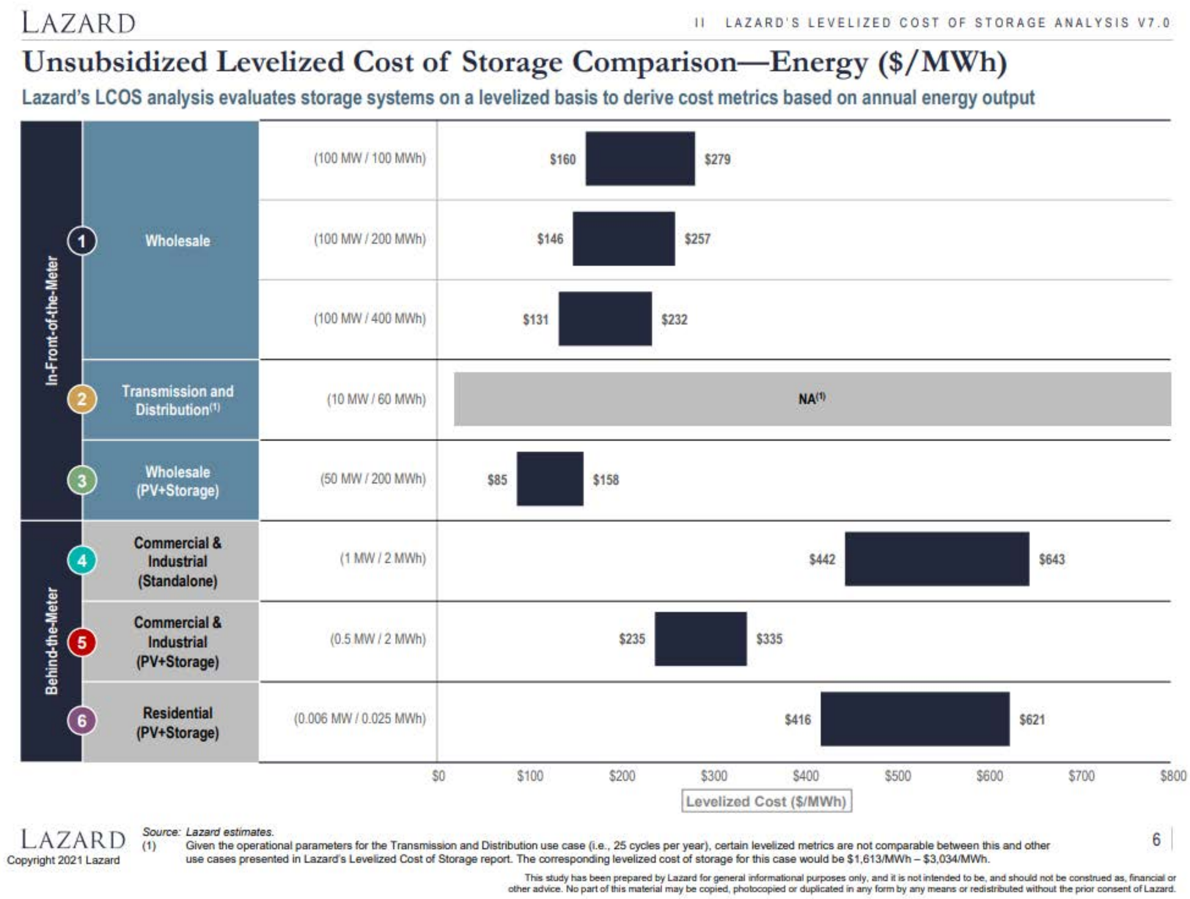


Figure 7. The California Duck Curve (Kosowats, 2018)

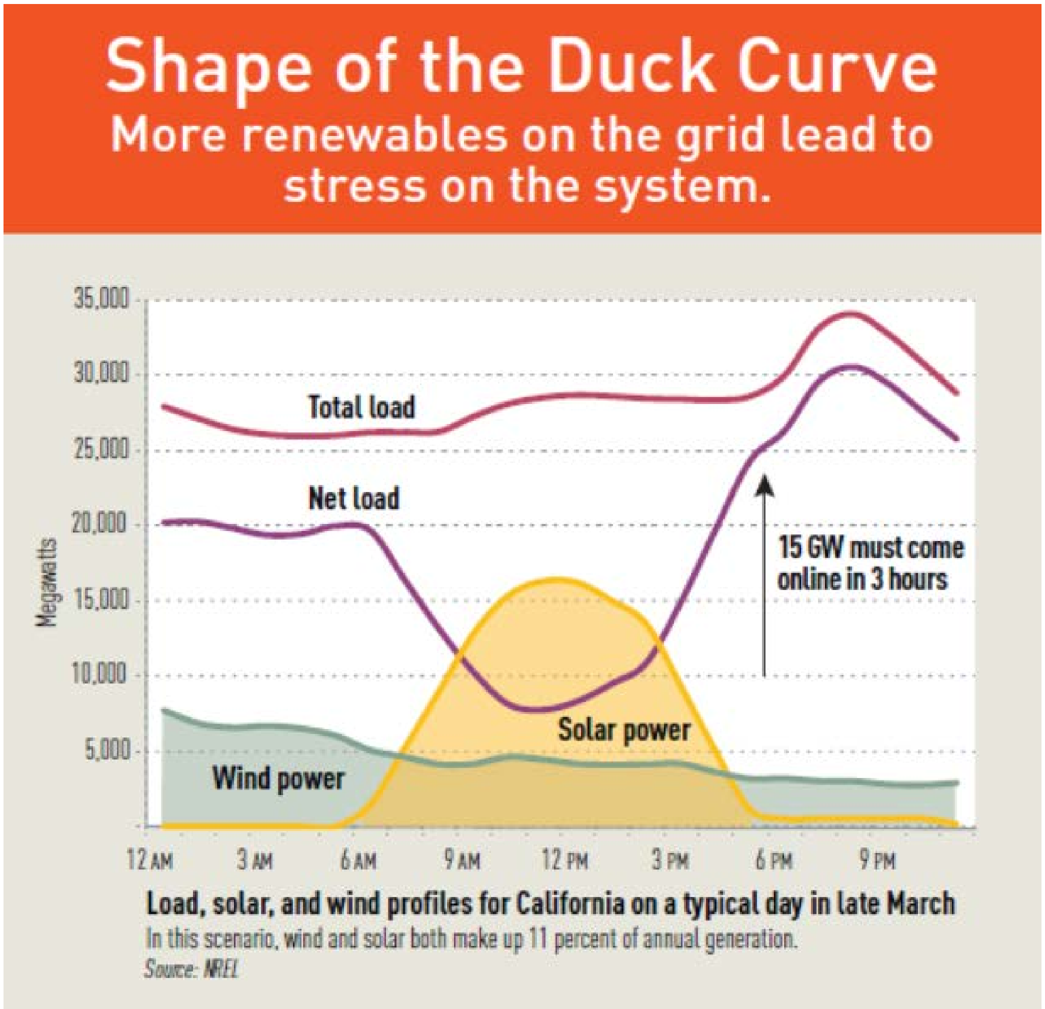


Figure 10. A map of all existing buildings, non-athletic or recreational open spaces, and significant parking lots on campus. (Created with Google Earth)

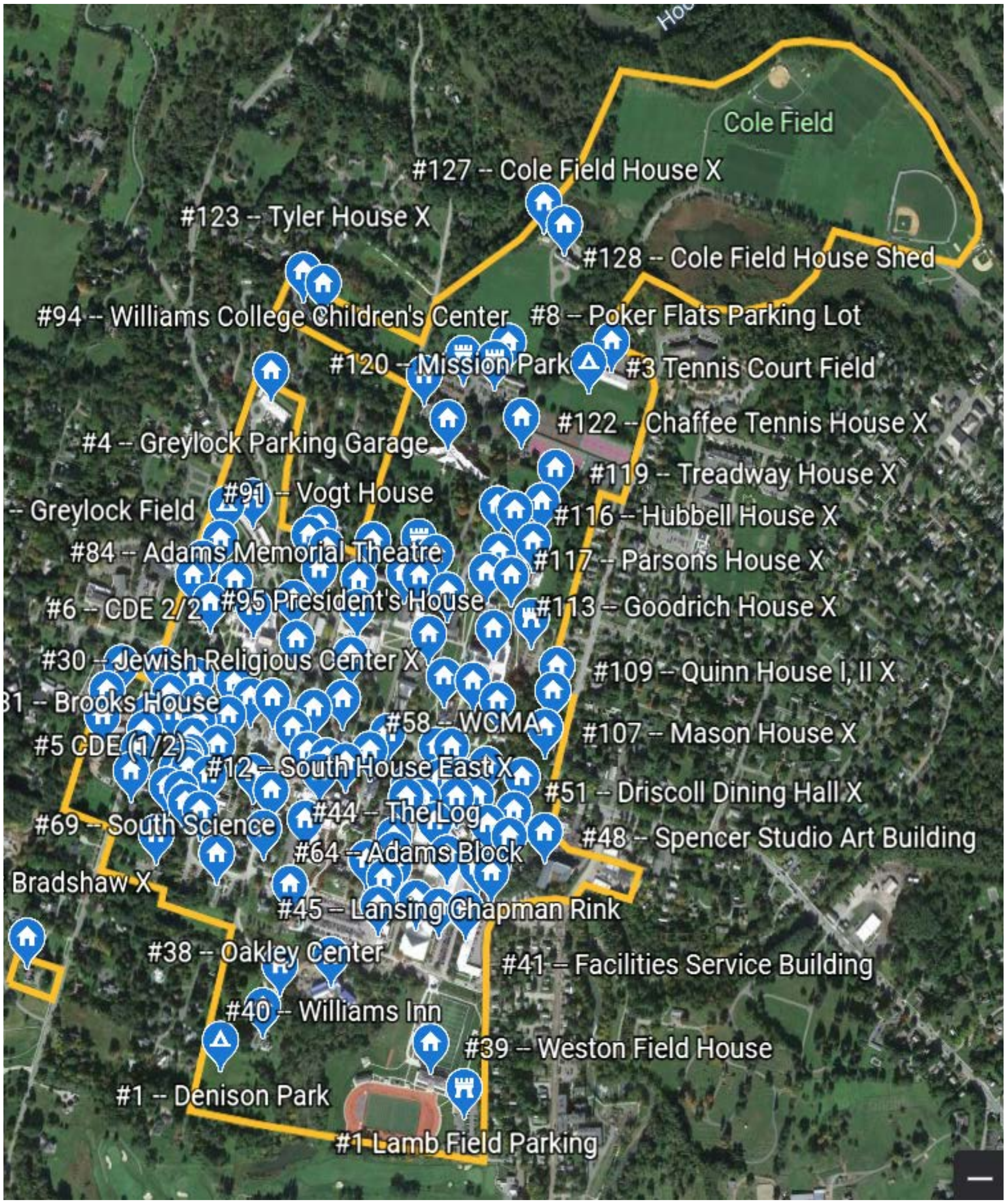


Figure 11. A map of all existing buildings, non-athletic or recreational open spaces, and significant parking lots on campus, updated to reflect sites that already have solar on them, are in the process of having solar installed on them, or have plans to add solar to them in the near future. These sites account for 14 buildings, 0 open fields, and 0 carports, and are labeled in green. (Created with Google Earth)

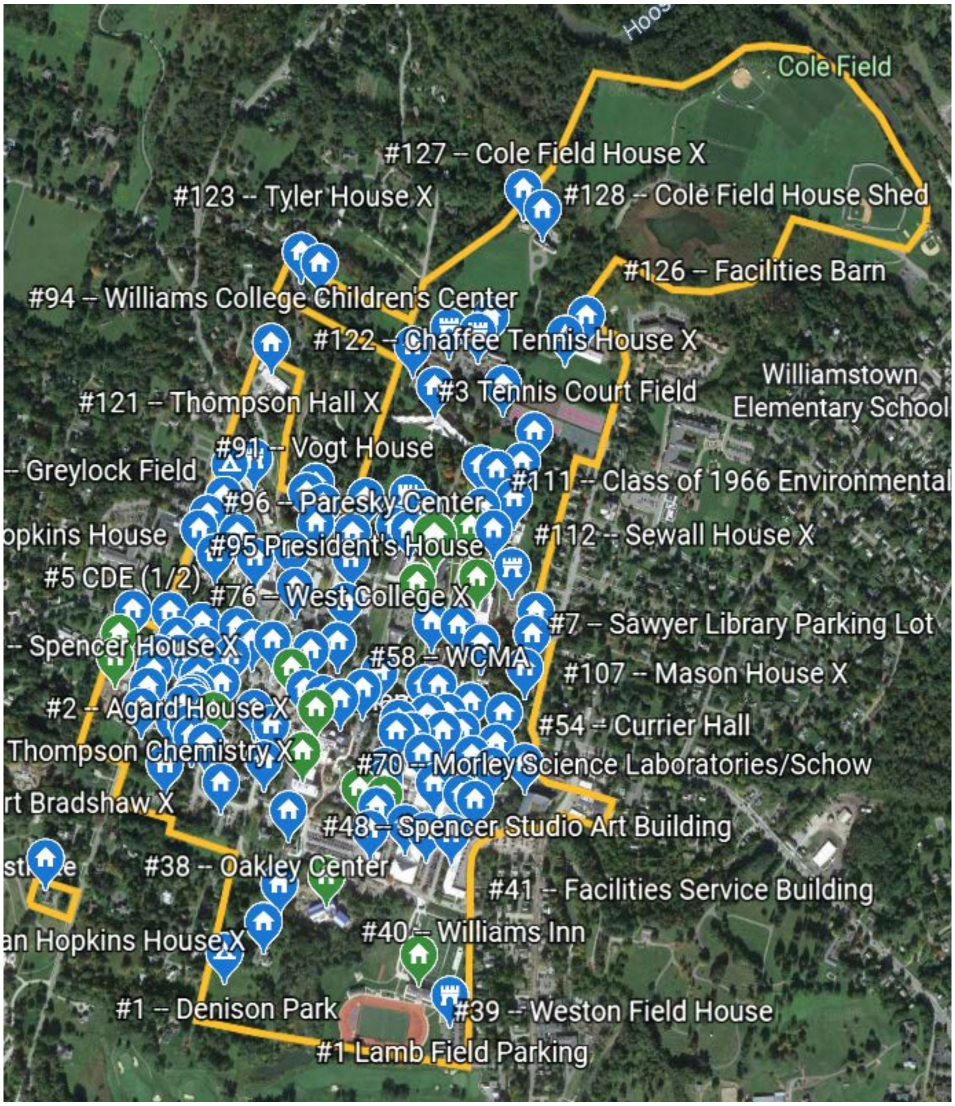


Figure 12. A map of all existing buildings, non-athletic or recreactional open spaces, and significant parking lots on campus, updated to reflect "Zones of Uncertainty" as determined with clients. These zones are not certain to exist in the same physical form for the next 25-30 years (expected useful life of a solar PV system) based on the Campus Framework Plan which will be presented to the Board in the near future. There are four such zones (Hockey Rink Neighborhood, Greylock Quad, Mission Park, and Dodd Neighborhood) which account for 18 additional buildings and one parking lot. They are outlined in red and the buildings and parking lots are labeled with red icons.

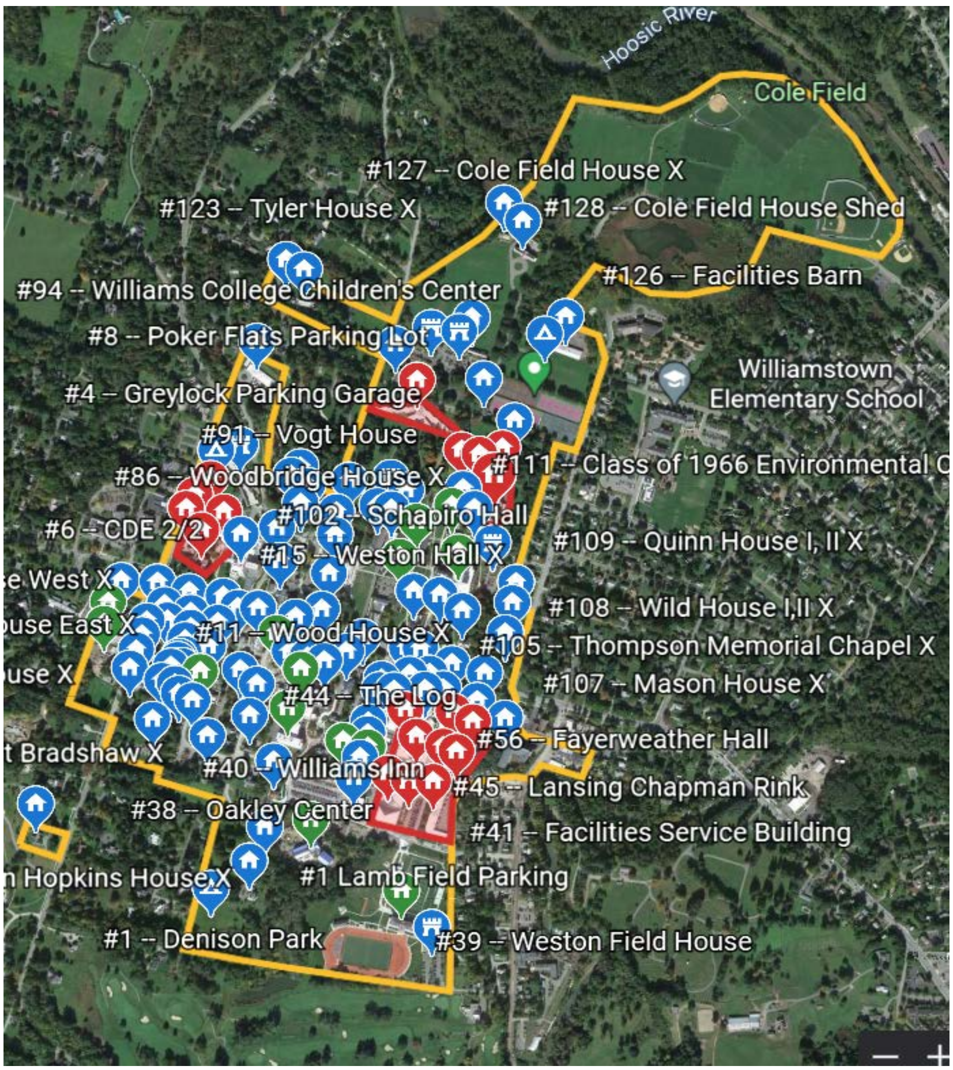


Figure 13: A map of all existing buildings, non-athletic or recreational open spaces, and significant parking lots on campus, updated to reflect buildings with slate roofs that are therefore unsuitable for solar. These sites account for 24 additional buildings, and are marked with red icons. (Created with Google Earth)

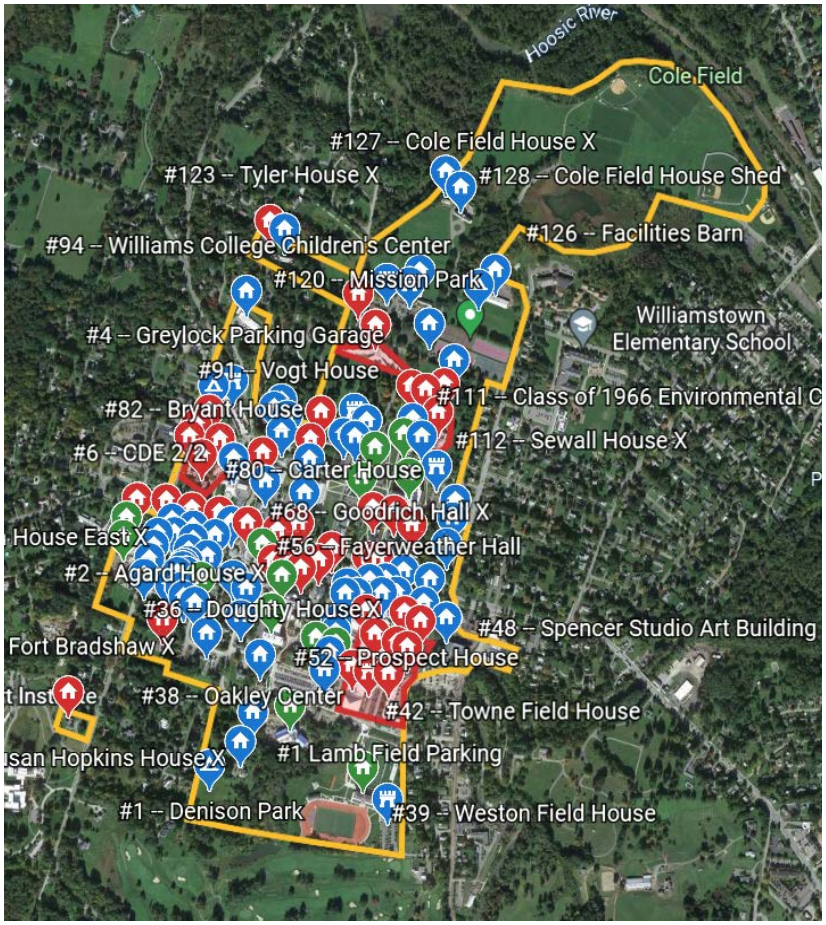


Figure 14: A map of all existing buildings, non-athletic or recreational open spaces, and significant parking lots on campus, updated to reflect sites that have southern tree shading, have oddly shaped roofs, are slated for demolition, or could not fit the agreed-upon minimum of 50 kW of solar PV on the sites. These sites are not suitable for solar at this time. This accounts for 57 additional buildings, which are marked with red icons.

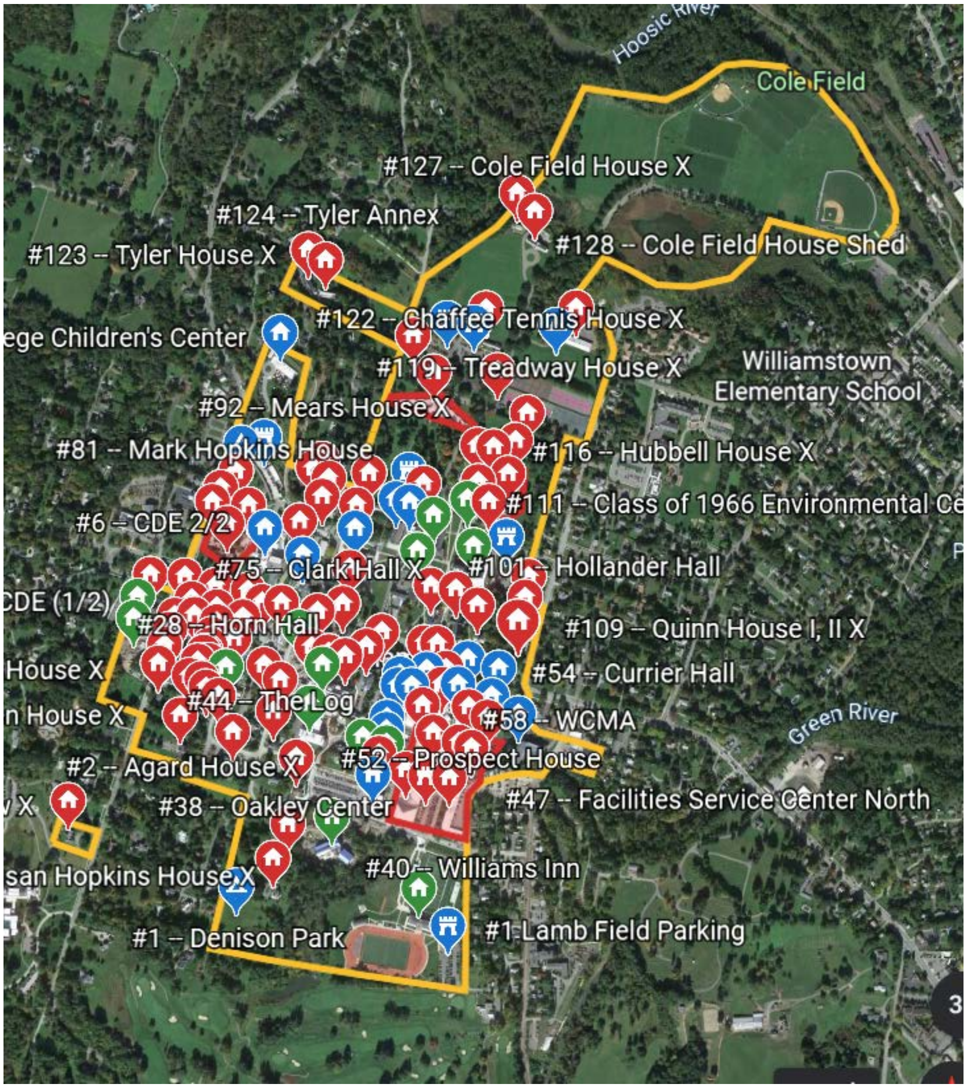


Figure 15. A working map of all College-owned properties (both buildings and open spaces) that are off-campus. (Created with Google Earth)

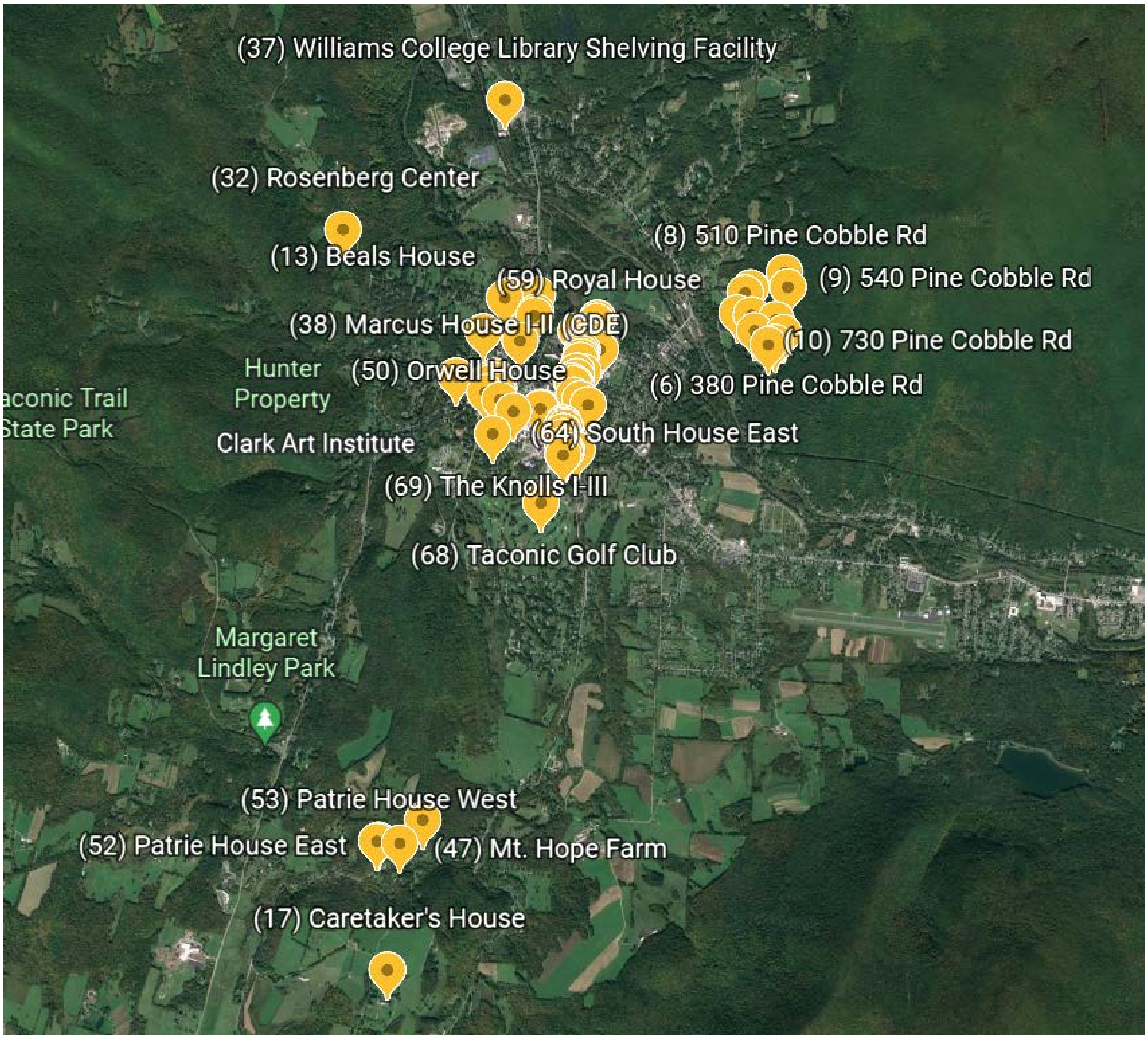


Figure 16.

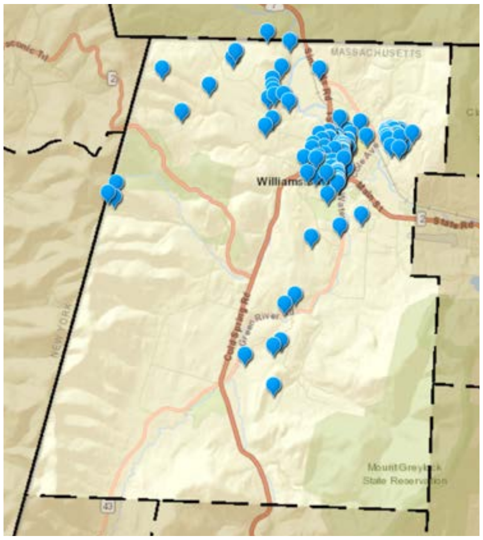


Figure 17.

Table 1. Evaluation of Technical Characteristics

Technical Considerations: Explanation of Colorings				
	Red	Yellow	Green	Data Source
Roof-mount systems				
Roof Age	Being replaced in the next decade	Unsure of replacement timeline	Just replaced or reasonably confident that it is new or scheduled to be replaced in the next three years	Jason Moran (Assistant Director for Energy and Utilities) and Jeremy Burdick (Architectural Trades Manager)
Roof Angle	Unusual slope (ex. Mansard, seawave, etc.)	Extreme slope	Flat or shallow sloped roofs	GoogleEarth and site tour
Roof Material	Slate	Anything else	Metal, asphalt shingles, or EPDM[3]	GoogleEarth and site tour
Size of Electrical Room	Too small	N/A	Large enough	Site tour with Jason Moran
Surrounding Building Orientation or Shading of Area	Complete shading	Some shading	No shading	Site tour
Orientation Towards Sun	North	East or West	South	GoogleEarth
Carport systems				
Surrounding Building Orientation or Shading of Area	Complete shading	Some shading	No shading	Site tour
Ability to Connect to Grid	No (either feasibility or prohibitively high costs)	Moderate costs	Yes (no or minimal costs)	Outreach to National Grid or other applicable utility

[3] Stands for ethylene propylene diene monomer, and describes a type of synthetic rubber used in roofing.

Ground-mount systems				
Topography	Requires clear-cutting, wetland, in a floodplain, or other prohibitive ecological factors	Any slope	Flat with no sediment issues	Site tour
Surrounding Building Orientation or Shading of Area	Complete shading	Some shading	No shading	Site tour

Table 2. Rankings by Size: On Campus – Rooftops

On-Campus: Rooftop	Production	Technical				
Site	kW rating	Roof Age	Roof Angle	Roof Material	Sun Shading/Exposure	Oreintation towards Sun
62 Center for Theatre and Dance	156.88	Unclear	Good	Good	Mediocre	Good
Spencer Studio Art Building	153.92	Good	Good	Good	Good	Good
Chandler Athetic Center	133.2	Unclear	Good	Good	Good	Good
Chapin Hall	106.56	Unclear	Good	Good	Good	Mediocre
Paresky Center	99.9	Unclear	Good	Good	Mediocre	Good
Williams College Children's Center	98.79	Unclear	Good	Good	Mediocre	Mediocre
Chandler Commercial and Adams Block	71.41	Unclear	Good	Good	Good	Good
Bernhard Music Center	69.56	Unclear	Good	Good	Good	Good
Lawrence Hall	66.6	Unclear	Good	Good	Good	Mediocre
Fayeweather Hall	61.05	Unclear	Good	Good	Mediocre	Good
Faculty House	55.5	Unclear	Good	Good	Mediocre	Good
Danforth Block	54.76	Good	Good	Good	Good	Good
East College	53.28	Unclear	Good	Good	Good	Good
B&L Building	51.06	Unclear	Good	Good	Good	Good
Currier Hall	51.06	Unclear	Good	Good	Mediocre	Good
Simon Squash Center	50.69	Unclear	Good	Good	Good	Good
Fitch House	50.32	Unclear	Good	Good	Mediocre	Good

Table 3. Rankings by Size: On Campus – Open Spaces

On-Campus: Grount Mount	Production	Techical	
Site	kW rating	Sun Shading/Exposure	Topography
Denison Park	642.3	Mediocre	Mediocre
Greylock Field	291.6	Mediocre	Good

Table 3. Rankings by Size: On Campus – Parkings Lots

On-Campus: Carport	Production	Techical
Site	kW rating	Sun Shading/Exposure
Lamb Field Parking Lot	448.4	Mediocre
Greylock Parking Garage	287.1	Good
Sawyer Library Parking Lot	233.8	Mediocre
Lehman Parking Lot	109.5	Mediocre

Table 4. Rankings by Size: Off Campus – Rooftops

Off-Campus: Rooftop	Production	Technical				
Site	kW rating	Roof Age	Roof Angle	Roof Material	Sun Shading/Exposure	Oreintation towards Sun
Grundy's Garage	164.3	Unclear	Good	Good	Good	Good
Cable Mills Apartments	123.6	Unclear	Good	Good	Good	Good
Verizon Equiptment House	113.2	Unclear	Mediocre	Good	Good	Good
Caretaker's House	77.33	Unclear	Good	Mediocre	Mediocre	Good
Taconic Golf Club	64.38	Unclear	Good	Good	Mediocre	Good
Onota Boathouse (Future)	-	Unclear	Good	Good	Good	Good

Table 5. Rankings by Size: Off Campus – Open Spaces

Off-Campus: Grount Mount	Production	Techical	
Site	kW rating	Sun Shading/Exposure	Topography
US Route 7, Pownal, VT Lot	6000000	Mediocre	Mediocre
Mt Hope Farm Lawns	*Unknown*	Good	Good
Mt Hope Inn Lawns	*Unknown*	Good	Mediocre
Pine Cobble Development (cleared field)	*Unknown*	Good	Mediocre

Table 6. Rankings by Size: Off Campus – Parking Lots

Off-Campus: Carport	Production	Techical
Site	kW rating	Sun Shading/Exposure
Spring St Parkng Lot	552.8	Good
Southworth School NW Lot	191.3	Mediocre
Williams Inn Parking Lot	68.82	Mediocre