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Enlightened Education: Solar Engineering Design to Energize School Facilities

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Enlightened Education: Solar Engineering Design to Energize School Facilities

Abstract: This paper explores the potential for universities, colleges, and K-12 schools to implement solar electric infrastructure projects on their campuses that not only provide financial savings, but also provide learning environments and instructional opportunities for students. A recent case study at Madison College is presented for a 1.85 MW photovoltaic system that is the largest solar rooftop installation in the State of Wisconsin. The system was designed with several unique features to facilitate public access, provide students with hands-on interaction, and compare and contrast several different types of solar equipment. Special engineering design considerations should be made when installing solar on schools, and recommended practices from the Madison College experience are detailed. Madison College completed a Solar Roadmap in order to prioritize and sequence investment in solar across the multiple buildings and campus locations operated by the college. The featured installation was the first project within that plan. A ten-step guide on how to create a solar roadmap is shared, so that other schools can learn from Madison College's experience and replicate the process for their own institutions.

Introduction - The Opportunity for Schools to Pursue Solar Energy

The past two decades have seen massive growth in renewable energy while aging and obsolete coal fired electrical plants are increasingly being retired. This is illustrated in Figure 1 by the growth in global installed solar capacity [1]. This trend is mirrored in the workforce, and solar photovoltaic (PV) installation has been one of the fastest growing occupations in the nation in recent years [2]. This growth is driven by dramatic reductions in the cost of solar technology and solar PV installations today cost less than 10% of what they cost twenty years ago [3]

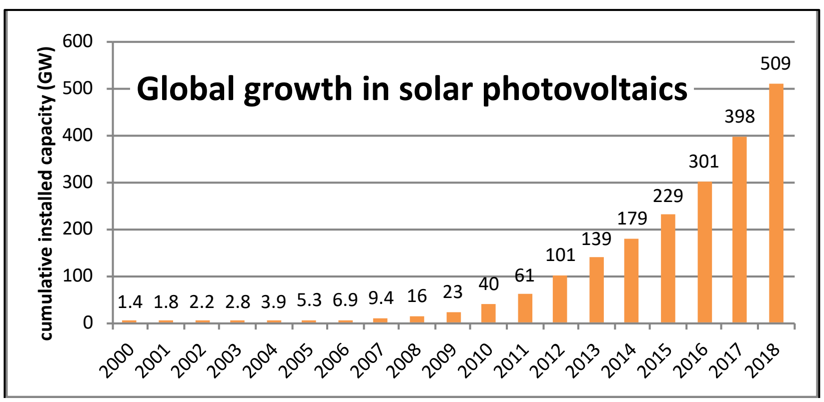


Figure 1. Global solar energy growth since 2000

The transformation of the solar industry has created an exciting new opportunity for schools to pursue solar developments for their facilities. At a time when many students have been involved in environmental activism and climate strikes, installing solar is a way for schools to demonstrate a commitment to the students that they serve and fulfill a moral obligation to future generations. Solar PV systems also help to lower ongoing operational costs for schools by reducing utility bills. Moreover, solar facilitates cost hedging by providing budgeting certainty for future electric costs. It is not uncommon for schools to have significant restrictions on their annual operating budgets. Thus, there is an opportunity to use capital expenditures for solar PV systems to reduce energy related operational costs and address budget gaps. Today, for many parts of the U.S., solar photovoltaic systems can provide energy at a levelized cost of electricity that is well below the retail rate charged by electric utilities. As a result, schools pursuing solar PV systems can achieve both financial and environmental sustainability.

Schools are long term public investments, and school buildings often last 50 to 100 or more years. As such, decision makers at schools have much longer time horizons than owners of residential homes or commercial buildings, who may be reluctant to invest in solar if they are uncertain about how long they will continue to occupy a given structure. Typically, a school's electrical load is largest during the day, at times when electricity rates are at their highest. This synchronizes well with the daily solar cycle, and thus makes solar an ideal energy source for schools. Investing in solar PV systems also represents good stewardship of taxpayer dollars, since the reduction of electrical costs allows for the money saved to be focused on things that directly impact student learning (e.g. more teachers, smaller class sizes, new instructional materials, and technology investments). All of these factors have led to the concept of what one solar designer and engineer has called "The Inevitable Solar School" [4].

The Madison College Solar Experience

In 2019, Madison College commissioned the largest rooftop solar PV system in Wisconsin at its Truax Campus (see Figure 2). Comprised of over eight acres of solar panels, the system is rated at 1.85 MWdc. When skies are clear, the system is capable of providing all of the electricity needed to operate the one million square foot facility for several hours throughout the day. After factoring in cloudy days and nighttime building operations, when averaged over the entire year the system offsets about 25% of the building's electric bill.

Figure 2. View of the 1.85 MW solar PV system at Madison College's Truax Campus

The Truax solar PV system was a culmination of effort that spanned several years. The college installed its first solar PV system in 2002. By comparison, that system was only 1.2 kW in size, and the installed cost per Watt was nearly ten times greater than it is today. The college has had a Renewable Energy academic program in place since 2005 and over 600 students have completed coursework through the program. In 2017, the college formed a team to create a Solar Roadmap that examined all of its campuses and buildings for their solar potential. These potential projects were then evaluated for inclusion in the college's future facilities plan. The college worked with the Midwest Renewable Energy Association to develop the roadmap, prioritizing projects based both on their potential energy savings and the educational benefit to students. The effort was funded by the Department of Energy Solar Energy Technologies Office and engaged colleges and universities from across the United States in an online course and direct technical assistance to advance large-scale solar PV projects.

Since the Truax building is the largest energy consumer in the college's portfolio and this facility serves the largest number of college students, the Truax rooftop solar PV system received the highest priority in the college Solar Roadmap. Portions of the Truax building are over 30 years old, so the solar installation was executed in coordination with a roof replacement project. Planning for the project took place throughout the latter half of 2017, and construction initiated immediately following final exam week in spring of 2018. Construction proceeded throughout the summer and fall, although several delays were encountered due to unforeseen complications in the roof replacement and an unprecedented amount of fall rain events. Construction was slowed during the winter of 2018-2019 due to inclement weather, but a ribbon cutting event was held in January 2019 as two-thirds of the system was commissioned and brought online. The solar installation was completed in spring and the system has been fully operational since June 2019.

Solar Engineering Design for Energy Production

Solar developers will design a solar PV system for their client. If a school's solar team is capable of completing some preliminary design work internally, this can save some cost by focusing the scope of the developer's work. In addition, assembling a knowledgeable solar team for the school also provides more confidence in the recommendations they might receive from a solar developer.

The ideal time to consider a solar installation is during the construction of a new building. In this case the solar PV system can be included in the upfront design of the building and can be most easily integrated into the electrical system. However, most general contractors are not very knowledgeable in solar energy. It may be desirable to contact a solar specialist ahead of time to assist with the preparation of calls for bids for new construction, and to incorporate solar energy into the request in the beginning stages.

If the planned solar installation is intended for an existing building, then there are several initial site assessment screening considerations that will determine if the location is suitable for solar. The site assessment should begin with an examination of the building's structure to determine the type and design of the roof and possible weight and wind load limitations. The age and condition of the roof should also be considered. Ideally, solar installation on existing buildings should be aimed at roofs that are less than five years old. Thoughtful planning can also be used to schedule a targeted solar project to coincide with the replacement of an old roof. If obstacles are discovered in the roof analysis, then it might be prudent to instead consider a ground mounted solar array.

An analysis of the “solar window” should also be conducted to determine the amount of shade (if any) that falls on the planned solar installation location and which sections of the roof are affected. Cutting down trees to eliminate shade is usually not advised, since trees benefit the atmosphere and the shade helps to reduce building air conditioning loads. However, tree removal may be warranted in cases where a tree is already compromised due to disease or structural issues, and in the case of undesirable invasive or nuisance tree species.

When designing a solar PV system for energy production, it is also advisable to assess the building’s energy use and load profile/patterns. Schools are very different from residential homes in that they are primarily used during the day. They also tend to have peak loads that coincide with daytime hours when solar energy production is at its maximum. However, schools can vary considerably. For example, universities, colleges, and high schools typically have much higher nighttime energy consumption than elementary schools. This is especially true for technical and community colleges that tend to offer a large number of night classes for working adult students. Seasonal differences in energy consumption should also be examined. Colleges and universities that offer summer terms may see fairly high energy consumption during this time of year, whereas most K-12 schools are out of session and may have reduced electric loads compared with the academic year. A trend among many newer buildings is to provide heating and cooling using geothermal ground source heat exchange systems. Schools with geothermal systems will have very different electric loads than those that heat with fossil fuels. With geothermal, electricity is used to provide space heat, which greatly increases the winter electric load.

In addition to understanding the building’s electric load, it is also necessary to understand how the school is billed for electricity. Electric billing for a commercial building such as a school can be considerably more complex than that for a typical residential home. In the U.S. most residential homes are billed a “flat rate” for the energy consumed. The national average for 2019 was $ 0.130/kWh. When considering the average rate for each of the 50 states, the lowest rate was in Louisiana at $0.094/kWh and the highest rate was in Hawaii at $0.327/kWh. Even within a given state, rates can differ significantly from one electric provider to another [5].

By comparison, commercial buildings will typically see lower overall rates for the energy they consume (measured in kWh). However, they may be subject to aggressive Time of Use charges that greatly increase the cost of energy during times when the electric grid has the highest load, which is typically during the day. There may also be seasonal charges to adjust for times when the electric grid has the largest electrical demand. For example, summer air conditioning or winter heating, depending on the regional patterns of climate and predominant HVAC practices. In the case of Madison College, the rate for energy consumed between 1 and 6pm in the summer is roughly double the rate for energy consumed at night after 9pm.

Commercial buildings such as schools will also usually have a demand charge, which is determined by the peak power consumption of the building, measured in kW [6]. Demand charges are typically assessed for the highest average power measured over a 15 minute interval (see Table 1). For large buildings such as schools, there frequently is a demand charge issued for that month, as well as an additional demand charge issued based on the maximum 15 minute demand observed over the prior year. It is not unusual for the demand charges for a school to account for as much as 40% of the monthly bill. Understanding these calculations is key to modeling the financial benefit of a proposed solar PV system (see Table 2).

	summer	winter
Fixed meter connection and customer service charge (per day)	$14.50	$14.50
Energy charges (per kWh)		
Base Energy all kWh	0.04930	0.04930
Distribution Charge all kWh	0.01022	0.01022
On-peak period 1 adder (10am-1pm)	0.02802	0.01747
On-peak period 2 adder (1pm-6pm)	0.04595	0.01596
On-peak period 3 adder (6pm-9pm)	0.02668	0.02270
Power demand charges (per kW per day)		
Maximum monthly on-peak 15-minute demand	0.45203	0.37362
Maximum annual 15-minute demand (measured over the past 12 months)	0.10600	0.10600

Table 1. Electric rate structure for Madison College's Truax campus. Note lines for the 15-minute demand charges, and the various time of use energy rates

Month	Electric Energy Use (kWh)	Power Demand (kW)	Total Cost (energy and demand) ($)	Demand Charge Costs ($)	Demand Portion of Electric Bill %
Jan	789,141	1,903	$81,534	$28,173	34.6%
Feb	801,113	2,041	$83,354	$28,642	34.4%
Mar	904,385	1,957	$94,063	$32,728	34.8%
Apr	799,171	2,327	$86,518	$31,608	36.5%
May	806,414	1,966	$85,924	$30,841	35.9%
Jun	801,865	1,911	$93,663	$36,080	38.5%
Jul	891,694	2,022	$100,050	$36,908	36.9%
Aug	943,859	2,436	$112,563	$42,692	37.9%
Sep	954,393	2,671	$96,267	$46,623	48.4%
Oct	857,718	2,512	$93,292	$34,726	37.2%
Nov	836,776	2,146	$88,663	$31,856	35.9%
Dec	847,756	2,029	$89,805	$33,602	37.4%
Annual	**10,234,285**	**2,017**	**$1,075,697**	**$414,478**	**35.8%**

Table 2. Madison College's electrical consumption prior to the installation of the solar system. Note the higher total electrical costs and higher demand costs that occur in the summer months, corresponding to high air conditioning loads.

Teams developing solar projects for a university, college, or K-12 school will benefit from using multiple models to predict the expected solar performance of the system (see Table 3). There are a variety of tools and calculators available to determine the maximum possible size of a solar array for a given roof or ground surface area. These tools also adjust for panel tilt angle (slope) and for panel orientation relative to due south. The models predict system output based on local historical weather patterns, account for electrical efficiency, shading, soiling, and snow cover losses, and approximate the effects of equipment degradation over time. Many of these tools are available online for free including PV Watts [7] and the System Advisor Model [8], both of which were developed by the National Renewable Energy Lab. Using multiple models to estimate system performance can allow a team to explore the effects of different input parameters, and consistent results from multiple models lends confidence to the analysis.

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)
January	2.35	115,372
February	3.32	144,642
March	4.18	196,416
April	5.06	225,339
May	5.92	261,578
June	6.47	268,497
July	6.73	183,242
August	5.96	148,786
September	5.29	220,146
October	3.79	168,709
November	2.58	118,645
December	2.02	96,111
Annual	**4.47**	**2,349,485**

Table 3. A sample energy output model generated for the Madison College solar system using the PV Watts tool developed by the National Renewable Energy Lab.

When using models, it is important to understand the primary benefit of a solar PV system is energy (kWh) reduction. Although a solar PV system can also provide some reduction in the peak demand (kW) charges assessed on a building's maximum power consumption [9], it is wise to be conservative when estimating these benefits. Demand is usually billed based on 15 minute intervals. A single cloud event, happening at the wrong moment, might account for the peak demand for that entire month - or depending on the rate structure, possibly for the entire next year (see Figure 3). For this reason, the decision to pursue solar energy at Madison College was made solely on the basis of energy (kWh) production, and the resulting electric bill savings. Hence, any reductions in peak demand (kW) that might result from the solar PV system will simply provide additional financial benefits above and beyond what was included in the project budget.

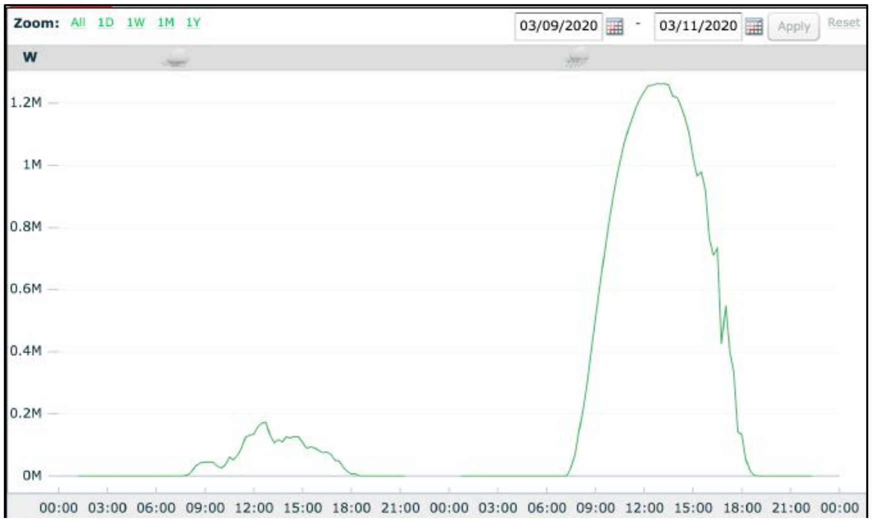


Figure 3. Variability in power production for the Madison College solar PV system between a cloudy and clear sky day in March 2020. For this reason, it is advised to be conservative when estimating demand charge savings from solar installations.

When estimating the financial benefit of a solar PV system it is also critical to understand the utility policies toward net-metering of the solar generation, and to know the buyback rates paid for any solar electricity that is produced in excess of the building's consumption. In many parts of the U.S. buyback rates for solar electricity have been reduced in recent years. If a school is trying to maximize the financial benefits of a solar PV system, it may be desirable to size the system so it meets the buildings daytime load, and rely on the utility for energy supplied at night. Schools may also wish to make use of the free SolarProjectBuilder [10] financial modeling tool developed by the Midwest Renewable Energy Association. The tool models installation, operations, maintenance, and decommissioning costs, to visualize the cash flow for the life of a project. The tool also determines financial metrics such as the simple payback period, net present value, internal rate of return, and levelized cost of electricity for the lifetime of the solar PV system.

Alternatively, if the goal of the school is to strive for net-zero carbon emissions from electricity, then it will likely need to overproduce solar energy during the day to offset nighttime electrical consumption. In these more ambitious cases, battery systems can be considered to store the excess daytime electrical energy. However, battery systems add significant cost and complexity to a solar project. Batteries also require very sophisticated controls systems and a much more detailed understanding of the building's electrical load to extract the maximum benefit from the storage system. Schools considering solar + storage systems and those pursuing net-zero buildings should allow for extra planning and design time to accommodate the additional work that will be required to design and install these systems. Even if the upfront cost prohibits inclusion of energy storage in the initial project, it may be of interest to design the solar PV system to be "storage ready" so that battery storage can be added in the future if economic conditions become more favorable. The National Renewable Energy Lab offers the free Re-Opt Lite software tool for sizing a solar + storage system, along with a more robust paid version intended for more complex projects [11].

Solar Engineering Design for Educational Purposes

Most solar developers and contractors do not have extensive experience designing for or working in school environments. For that reason, schools must be prepared for additional work on engineering design and be ready to advocate for what they need to get the best educational benefit from the product. Finding the right solar developer to partner with can greatly facilitate this process. By planning ahead schools can strategically design requests for proposals for solar construction projects to ensure that all of their interests are accounted for in the bidding and procurement process.

Schools - a special subcategory of the Commercial Solar Building Sector

There are several aspects to solar development at school locations that make these projects different from conventional commercial and industrial solar projects. The decision making process for educational institutions is usually much longer and more involved than typical businesses. Projects usually pass through several stages of review before various faculty, staff and administrative committees. Budgeting for school based solar projects is also more involved and will likely require significant financial review to ensure good stewardship of taxpayer dollars. Most large colleges and universities operate with some type of shared governance system, so decisions to proceed with solar development may need to pass through various committees overseen by faculty and staff. They then proceed to a fiscal team for financial analysis, followed by approval at the executive level, and may ultimately require the consent of a governing board. Furthermore, most schools have specific procurement policies for large construction projects that require public notice, solicitation of bids, and competitive award of contracts. These processes lengthen the time to complete the solar project and may create frustration or friction with solar developers who are not accustomed to working with schools.

The solar construction and installation process at school based sites can also differ from other commercial and industrial locations. Unless the proposed location is a new construction site, it is likely that the solar installation will happen while the building is occupied and in use. Projects of this nature can be quite disruptive to the school learning environment, so thoughtful planning with the school, the solar developer, and any subcontractors will be necessary. If the students are not in attendance during the summer months, it may be desirable to schedule the bulk of the installation work during that time. This can minimize or eliminate the impact on student instruction, restricting the disruption to faculty and year round staff. If solar construction must be done while school is in session, modifications to work practices can help to minimize the impact on students. Rooftop construction can be noisy, so impacts will largely be concentrated on those occupying the uppermost floor of the building. Class scheduling to move operations away from areas under construction can help. Strategic timing of various installation job tasks can also provide benefit. For example, restricting the use of various types of rooftop power tools to early morning, afternoon, or weekend hours when classes are not in session. Since parking and transportation can be limited at school campuses, scheduling of deliveries and of rooftop crane access will also likely require special considerations to minimize the disruption to students and school personnel. For this reason, the role of project manager for school based solar installations takes on a heightened importance. When considering prospective solar developers, schools may wish to tailor their procurement processes to seek out and retain developers who have prior experience in this arena.

Designing Solar PV Systems for Educational Benefit

In most commercial and industrial solar installations, systems are designed to operate "invisibly" once the installation is complete. The owners of the building are not expected to interact with the system. In most cases the only information that they seek is the financial impact of the solar PV system on their monthly utility bill.

The situation for schools is different from other commercial and industrial solar customers. Almost all schools will want to have some type of educational activity integrated with the solar PV system. This may take the form of public awareness campaigns, museum-like interpretive displays, open house events and tours, classroom instruction on solar principles, or even hands on learning for STEM students in aspects of solar installation, operations, and maintenance. For this reason, it is critical that schools plan ahead to design a solar system for educational access. Educational access will likely require design considerations and expenses beyond that of a conventional commercial solar installation. Educational access may also require additional technical experts or sub-contractors to work on the design and installation of the system. Engagement of the school's facility managers and faculty members early in the process is essential. Dialogue between these parties and the solar developer can maximize the educational benefits of a solar installation.

Potential Educational Audiences

When designing solar PV systems for educational use, the first step is to consider who the intended educational audience(s) might be. A possible list of educational activities organized from the most general to the most specific includes: tours for the general public, open houses for prospective students, field trips for students from other educational institutions, outdoor classroom instruction for students in science courses, system performance and data analysis for students in engineering and mathematical programs, and hands-on installation work for students enrolled in renewable energy or solar specific programs. Each of these activities requires different levels of access to the solar PV system. Thus, it is necessary to make design considerations to accommodate these users and to minimize the risk of injury to any students or staff who intend to use the solar PV system for educational purposes.

Public Access to the Solar System

The first consideration to make regarding public access is whether the planned system will be roof or ground mounted. If the system is ground mounted, it almost certainly will require perimeter fencing in order to protect individuals from walking unaccompanied into the area of operating electrical equipment. The size and type of fence will need to be considered. In some cases, it may be desirable to also exclude wildlife from the solar array. And in urban locations, it may be desirable to have solid fencing that blocks visual views of the system to discourage potential vandalism.

If the array is mounted on the rooftop, fall hazards and roof safety are of concern. Flat roofs are more conducive to educational use, whereas sloped roofs are very difficult for hands-on instruction. If the solar PV system is going on a new construction site, designs that incorporate flat roofs with taller parapet walls can add significant safety advantages. Strategic placement of the solar array with larger setback distances from the building walls and inclusion of guard rails to restrict student access help define the outdoor workspace to a safe limit. The structural capacity of the roof must also be considered. The size of potential user groups, and the combined weight load of people plus solar equipment must be accounted for in the design.

Whether the system is ground or roof mounted, it is also important to consider the accessibility of the solar PV system for all types of users and to comply with local guidelines for emergency exits and fire safety, as well as requirements specified by the Americans with Disabilities Act [12]. This will impact design specifications for things like the sizing of doors and gates, placement of wheel chair accessible ramps and thresholds, and the selection of ground or roof surfaces. For ground mounted systems, it may be desirable to have poured concrete or asphalt surfaces within the array rather than the more customary gravel, crushed rock, or grass ground cover. For roof mounted systems, this likely will guide the installation of abrasive grit or raised ridge walkway treads to provide traction on what can otherwise be slippery footings of Ethylene Propylene Diene Monomer (EPDM) rubber or Thermoplastic PolyOlefin (TPO) polymer roof surfaces. For both ground and roof mounted installations, it is likely desirable to provide some type of marked walkways to guide visitors to certain areas of the installation that are deemed to be safe, and to restrict activity from areas of greater risk such as roof edges or high voltage connection points. Another key difference from commercial and industrial installations is the consideration of space allocation for educational solar PV systems. In most solar installations the solar modules and associated hardware are closely spaced to contain the installation in as small of an area as possible. For educational uses, it is desirable to space this out over a much larger footprint. This is especially true if the school plans to use the system to host tours or field trips, since it will be necessary to provide sufficient space to accommodate larger groups.

Figure 4. The 10 kW instructional subarray for the Madison College solar PV system.

The solar PV system at Madison College was designed with these considerations in mind. The building at Madison College consists of over a dozen different sections and elevations. One of these was specifically selected to host a 10 kW solar sub-array intended for educational use. The chosen roof section was at a lower elevation relative to the surrounding sections, making it impossible for users to near the roof edge on three sides (see Figure 4). To contain users on the fourth south facing side of the roof section, a guardrail was installed to restrict users to a safe area. As shown in the photo, this location was also designed with ample space outside of the solar array and the roof surface was outfitted with grey walkway treads. The roof structure of this section is formed by six inches of reinforced concrete decking overlaid with sheathing, installation and TPO membrane, and the location can easily accommodate groups of over 100 individuals for tours and open house events. An ADA compliant doorway and ramp were also installed to provide access to the roof, as shown in Figure 5.

Figure 5. Observation viewing deck, roof access door, and ADA compliant ramp for the student instructional subarray for the Madison College solar PV system

Education for the General Student Body

School personnel will likely want to consider several additional methods to enhance the educational value of the solar installation. The simplest of these is creation of a fact sheet or brochure to profile the solar PV system. These are helpful in educating the general public, and also help to prepare college students and personnel to lead public tours and open house events. The solar developer can help in the creation of the fact sheet, providing important specifications and details to help explain the system design and performance. In many cases, schools will also want to create a museum-like interpretive display. Figure 5 shows the interpretive display that was created at Madison College. The large windows provide a viewing area for users to observe the outdoor solar system from indoors during times of inclement winter weather. The exhibit includes examples of the hardware components, descriptions of their function, photos of the installation taken during and after construction (see Figure 6), and additional signage explaining the function and performance of the solar PV system. A smart screen kiosk, shown in Figure 7, is also included that presents a monitoring dashboard showing the real-time power output of the system and the lifetime energy production. At Madison College, the solar PV system has been used by students in classes including Environmental Science, Weather and Climate, and various Mathematics and Statistics courses. The students are able to see and tour the working system, access the energy production and weather data sets, and use the data for instructional exercises teaching skills such as spreadsheet manipulation, data visualization, trend analysis, and fundamental statistics.

Figure 6. Photo of the Madison College solar PV system installation in progress

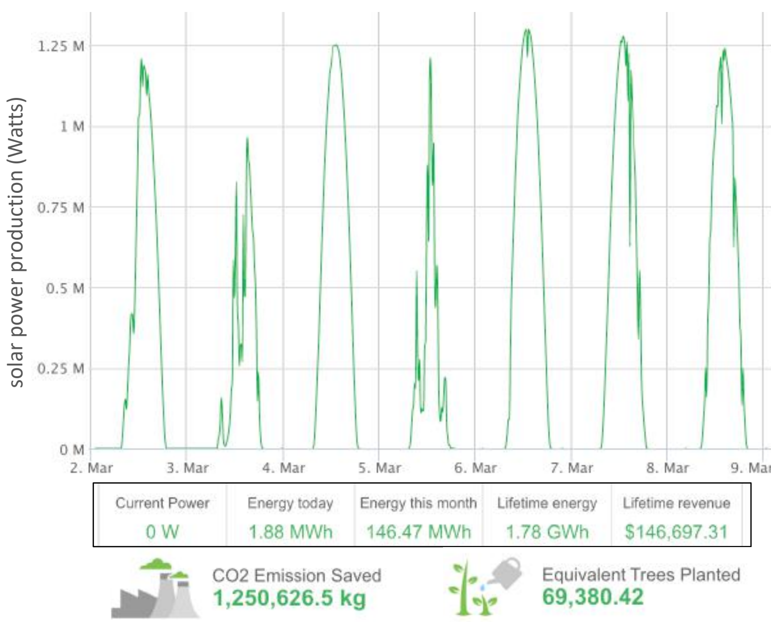


Figure 7. Public kiosk display for the Madison College solar PV system. The graphic represents the power output over a week in March 2020. The metrics below show daily, monthly, and lifetime energy totals and environmental benefits.

Education for Renewable Energy Students

Additional considerations will be necessary if the solar PV system is to be used for teaching students in renewable energy programs. Students in the Madison College Renewable Energy Program complete several courses in solar and renewable energy that are making use of the new solar PV system. Students in the program learn to design, specify, and model performance for various types of solar installations. They also learn to estimate the effects of shading, module soiling, and snow cover. Most importantly, they learn hands-on installation skills that include basic construction, workplace safety, solar assembly and wiring, electrical safety, code compliance, safe commissioning and system verification practices.

The college's system is comprised of several sub-arrays, each of which is connected to one of seventeen DC to AC inverters. The sub-arrays include ballast mounted panels in both south-facing (see Figure 8a) and east-west facing rack designs (see Figure 8b). This includes panels placed on a conventional black Ethylene Propylene Diene Monomer (EPDM) rubber roof, as well as panels placed on a white Thermoplastic PolyOlefin (TPO) membrane roof, and students can compare the thermal profiles of these two roof surfaces and quantify the impact on solar energy production. The system also includes a subarray composed of modules fastened to a standing seam metal roof deck (see Figure 8c), which provides yet another thermal environment for solar panel operation. Schools that are considering ground mounted systems might want to consider different types of ground cover for the same reason. For example, comparing panels mounted over a black asphalt parking area, those mounted over white crushed rock, and those located over a grass covered surface. For the system at Madison College, module level power electronics are incorporated in the system that allow for detailed monitoring of the system's performance. Each panel in the system has its own unique hardware ID number, and DC optimizers located on the back of the modules allow for the independent operation and metering of each individual solar panel. The optimizers send a communication signal back to the DC to AC inverters which is then uploaded to the cloud via an Ethernet connection in real time. This allows for large data analytics to compare panels installed in various locations and racking orientations. It also allows students to learn about advanced Supervisory Controls and Data Acquisition (SCADA) systems, which can be programmed to provide alerts when system performance deviates from expectations. This type of SCADA monitoring can detect early indicators of component degradation, allowing for better scheduling of system maintenance, and reduction of system downtime in the event of necessary repairs [13].

Solar electric systems are capable of producing dangerous electric potential and current. If the system is intended for hands-on educational use, it is recommended to locate power disconnect devices near the system array so that it can be de-energized and taken offline for instruction with students. The system at Madison College was designed with a separate inverter and DC disconnect for the 10 kW instructional sub-array. This is used by faculty and students for teaching lock-out tag-out procedures for safe electrical work. The 10 kW instructional sub array can be taken offline for teaching. Meanwhile, the larger majority of the system can continue to function, providing uninterrupted power to the campus. The sub-array is also located close to classrooms and a storage area that is used for STEM classes, so there is easy access to tools and equipment. The ADA accessible ramp and roof access point also facilitate transport of rolling carts to haul tools and equipment out to the roof for lab classes. An outdoor Wi-Fi access point was also installed for the area so that instructors and students can access the real-time data of the system while outside on the roof.

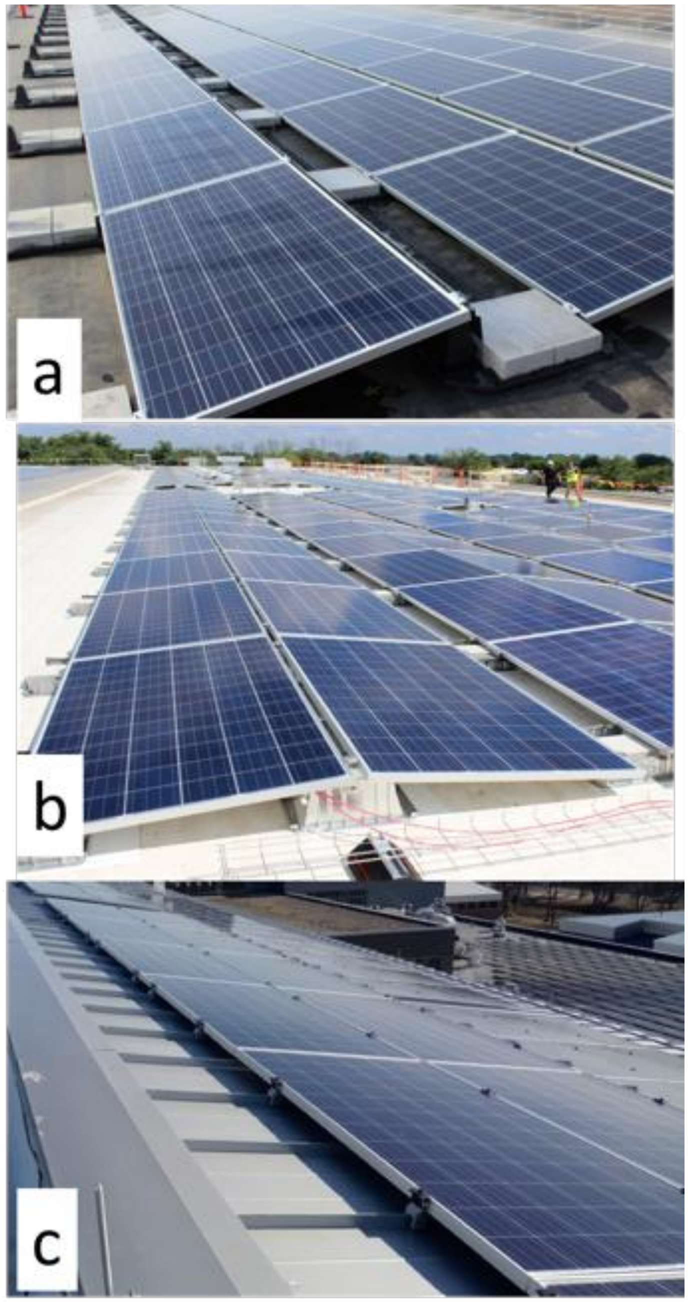


Figure 8. Variations in racking for the Madison College solar system include a) south facing ballast mounted panels over black EPDM rubber roof membrane, b) east-west mounted panels a white TPO membrane roof, and c) south facing panels mounted on a standing seam metal roof

The bulk of Madison College's 1.85 MW system has an open "solar window", so the panels do not experience any shading throughout the year. However, shade analysis is one of the key concepts that solar students must learn. For this reason, the college intentionally positioned the panels for the 10 kW instructional array in a location that receives a couple hours of shade in the late afternoon. Students are able to use shade analysis tools to measure the expected shade of the location and then predict the resulting power reduction over the course of a year. Students also have access to the historical data archive, so they can apply data analytics to confirm if the actual power production is consistent with the shade modeling predictions. The system also includes two weather stations that monitor ambient temperature, wind speed and direction, rainfall, and irradiance in the plane of the solar array. Students can apply data analytics to compare performance on sunny versus overcast days, to quantify the effects of snow cover (see Figures 11, 12, and 13), and to explore the relationship between solar panel soiling and the frequency of rainfall events.

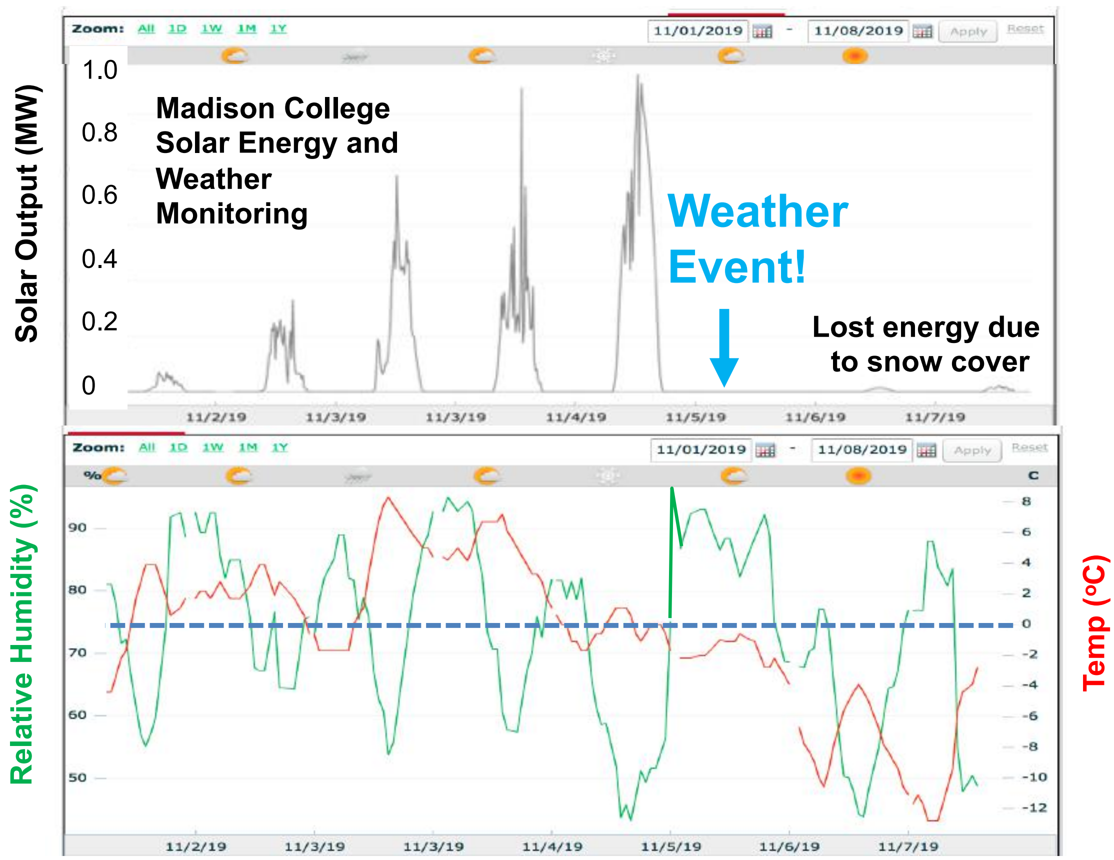
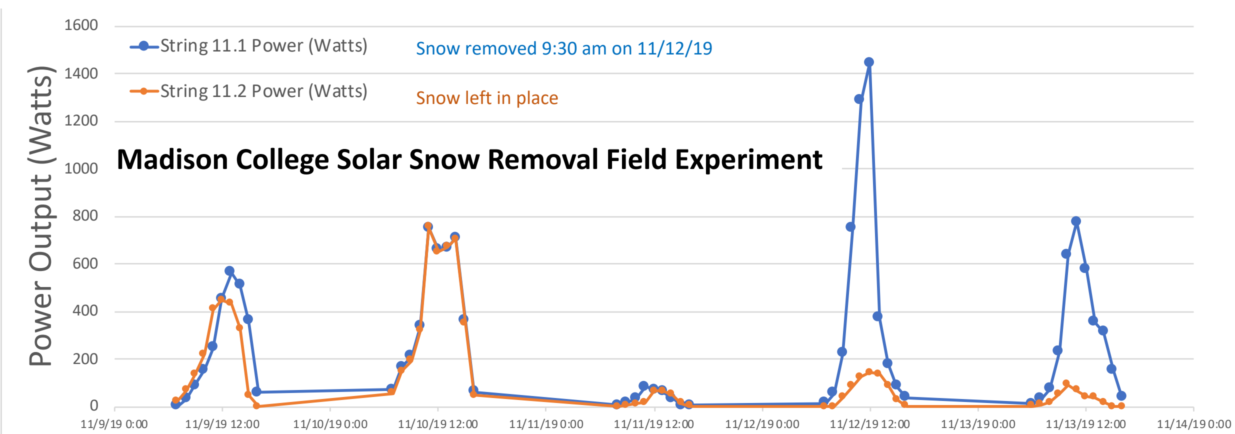


Figure 11. Weather station data for Madison College for Nov 2-7, 2019. Note that the temperature drops below freezing and the relative humidity hits 100% on Nov 6, corresponding to the first snowfall event of the winter.

Figure 12. Students at Madison College clear snow from the instructional subarray to assess the costs and benefits of solar operations and maintenance.



Daily Energy Output in kiloWatthours									
	11/9/12		11/10/12		11/11/12		11/12/12		11/13/12
String 11.1	2.41		3.97	Overnight	0.28	Snow Removed	4.39		3.14
String 11.2	2.07		3.88	Snow	0.21	Snow Left in Place	0.62		0.33

Figure 13. Student generated data quantifies the gains provided by cleaning solar panels to remove snow cover.

Engaging Students in Hands-on Installation Work

Many schools are interested in the idea of engaging students in the installation of solar PV systems. In practice however, there are several potential issues that may preclude this. Safety is a primary concern considering that the installers will be working with potentially lethal voltages/currents. In most states or municipalities there are also regulatory restrictions that specify who can conduct electrical work, usually requiring specialized training to earn an electrical license. At Madison College , the solar foreman was a graduate of the college's electrical program, and several members of the crew were current electrical apprenticeship students (See Figure 14).

Figure 14. Madison College alumni work on the rooftop solar installation.

For schools that do not have electrical training programs, this likely precludes students from being involved in much (if any) of the electrical work. Depending on the local regulatory status, it may be possible for students to be involved in the layout and racking of solar panels, as long as there are workplace restrictions that isolate them from the electrical installation. If this is a goal of the solar project, then it should be included within the request for solar proposals/bids and be negotiated up front with the solar contractor. Solar installations usually come with a workmanship warranty, which may require additional consideration if students are to be involved in the project. Another opportunity to involve students might be in the commissioning and verification of the solar installation, engaging students in analysis of the system power output to see if it meets manufacturer specifications, and matches energy modeling predictions. Few solar contractors will be accustomed to working with students on a job site. Thus, it is imperative for the school and developer to have these discussions early in the planning process, and to negotiate and document any special educational accommodations that are agreed to. After the installation is complete, students could also be involved in the ongoing operations and maintenance (O&M) activities such as performing annual system inspections and diagnosing production issues using a string analyzer. If the school intends to sign a maintenance contract with the solar developer, then student based O&M activities should also be discussed and negotiated ahead of time.

A Ten-Step Guide to Creating a Solar Roadmap for Educational Institutions

In the past year, Madison College has provided a large number of tours to visitors from other schools, colleges and universities. The most common questions that are asked are some variation of "How did you manage to do this?", and "What can I do to encourage my school to consider a solar project at my campus?" In order to address this, we created a ten-step guide to help other schools create a Solar Roadmap. The steps are not necessarily sequential, and in practice many of these activities may take place simultaneously as a given project is executed. The ten steps are organized below to illustrate a logical progression that will facilitate potential projects from conception to implementation.

1. Identify Team and Articulate Purpose: Assemble a team of individuals that represent key groups including a facilities operations manager, renewable energy faculty, institutional financial officer, and students. It is important to have representation from each of these parts of the institution, because they will all be affected by the roadmap. Equal representation on the team ensures valuable input from multiple perspectives. It is also helpful to define the scope of the roadmap planning process at this stage, so that everyone agrees on the goals and understands the intended outcome. It is also necessary to address the foremost question, "Why do we need a Solar Roadmap?" The most straightforward response is that most school districts, colleges, and universities operate more than one campus location and more than one building facility. It is not feasible to engage in multiple construction projects all at the same time, so it is necessary to prioritize. Creating a Solar Roadmap facilitates the planning process and ensures sound use of limited school resources.

2. Motivating Objectives: Once the team is assembled, use a method to identify what the institution's primary reason(s) are to pursue solar energy. Objectives may include ambitions such as cost savings, energy budget certainty (cost hedging), learning opportunities for students, social and environmental goals, energy resilience for critical electrical loads, and "green" visibility. Objectives should be ranked or weighted to assess potential solar projects. The team may wish to have individual members rank priorities to capture the point of view of various constituents, and then use some method of averaging to arrive at a consensus (See Table 4)

What do you feel are the most important reasons for Madison College to "go solar"	Rank	Rank	Rank	Rank	Rank	Average Rank
cost savings	2	1	2	4	4	2.6
learning opportunities for students	1	4	3	2	3	2.6
energy budget certainty (cost hedging)	3	2	4	1	5	3.0
social and environmental goals	4	5	1	6	1	3.4
energy resilience for critical electrical loads	6	6	6	3	2	4.6
"green" visibility	5	3	5	5	6	4.8

Table 4. Madison College's solar roadmap team rankings of motivations for solar energy.

Like many educational institutions, Madison College has separate budgets for capital and operating expenses. In any given year, the college may find itself faced with an annual deficit in the operating budget due to unforeseen expenses such as emergency repairs to facilities, or in recent years due to health care expenses that escalated at rates much higher than expected. For this reason, investment in a solar PV system can be very attractive because it allows a school to spend money from its long term capital budget to address and control future operational expenses. Many of the other schools that have toured the Madison College facility find themselves in the same situation. This type of budgeting and cost hedging strategy makes solar development a very attractive option for many educational institutions.

3. Identify Stakeholders: Determine who will be impacted by the solar plan (students, faculty, staff, different offices from the institution, utilities, community, etc.). This list will help guide the process, identifying who to work with and when their input will be needed. The stakeholder list will also facilitate communications when executing the plan to make sure that everyone is kept informed (See Table 5).

	START <--------------------------- Phases of Development ------------------------------> FINISH							
	Development of Solar Roadmap	**Prioritization of Solar Sites**	**Exploration of Funding Vehicles**	**Proposal and Approval of Projects**	**Legal/ Contractual**	**Project Design**	**Project Execution**	**Operations and Maintenance**
Internal Stakeholders	PV Roadmap team	PV RoadMap Team	PV RoadMap Team	PV RoadMap Team	Facilities Team	Facilities Team	Facilities Team	Facilities Team
		Campus Managers	Finanical Team	Presidents Office	Legal Office	Program Faculty	Faculty?	Faculty?
		PV Students?	College Foundation	College Board	Procurement Office	Students?	Students?	Students?
			Grants Office		Grants Office			
External Stakeholders	MREA	PV Contractors?	Electric Providers	WTCS	PV Developers	RE Industry Adv Board	PV Contrractors	PV Contrractors
	NREL	MREA	NSF, DOE, etc.	Electric Providers		Electric Providers	Electric Providers	
			PV Developers			Permitting Bodies		

Table 5. Stakeholder Chart for Madison College's Solar Roadmap. The chart identifies both internal and external stakeholders and indicates the phases of development during which they must be engaged in a solar project.

4. Quantify Energy Usage and Costs: At this stage, the team begins to gather information on the school's energy consumption and the associated costs. If the institution has multiple campuses and buildings, the data collection and analysis will be more complex. Some organizations may also wish to consider external costs (e.g. costs to the community's health due to power plant emissions), although these are much harder to quantify.

5. Document Energy Management Practices and Pursue Energy Efficiency: Quantifying the potential to reduce energy use is an important part of a sound Solar Roadmap. It is usually most cost effective to first make a strong commitment to energy efficiency and energy management before implementing solar projects. If the total amount of energy required by a facility is reduced, then a solar PV system of a given size can offset a larger portion of the building's energy needs (See Figure 15).

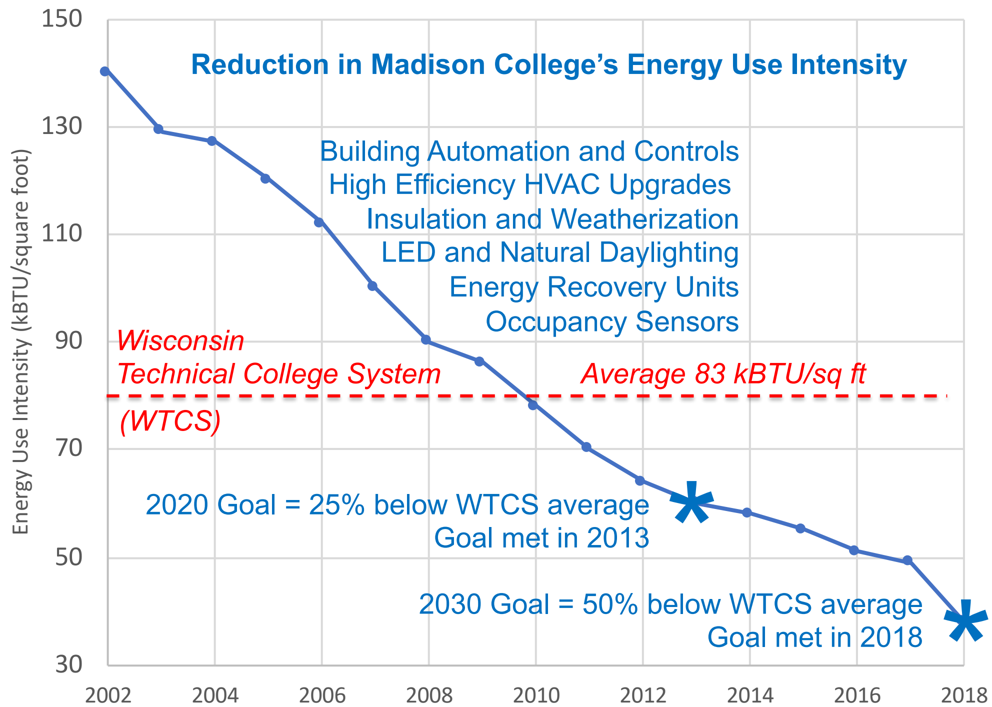


Figure 15. Prior to installing the Truax solar PV system, Madison College reduced its energy use intensity by more than 60% through multiple energy efficiency actions.

6. Assess Sites for Solar: The team must identify possible locations and structures where solar can be installed. It is necessary to explore the available solar resource, to identify landscape features such as trees that might cause shading, and to research building factors such as orientation and the age and structure of the roof (see Figure 16) . Local permitting and regulations may also be considered (e.g. interconnection rules, zoning restrictions, airport restrictions, etc). If the institution has more than one electrical meter, it will be desirable to compare electrical loads and electrical rate structures for each potential solar location.

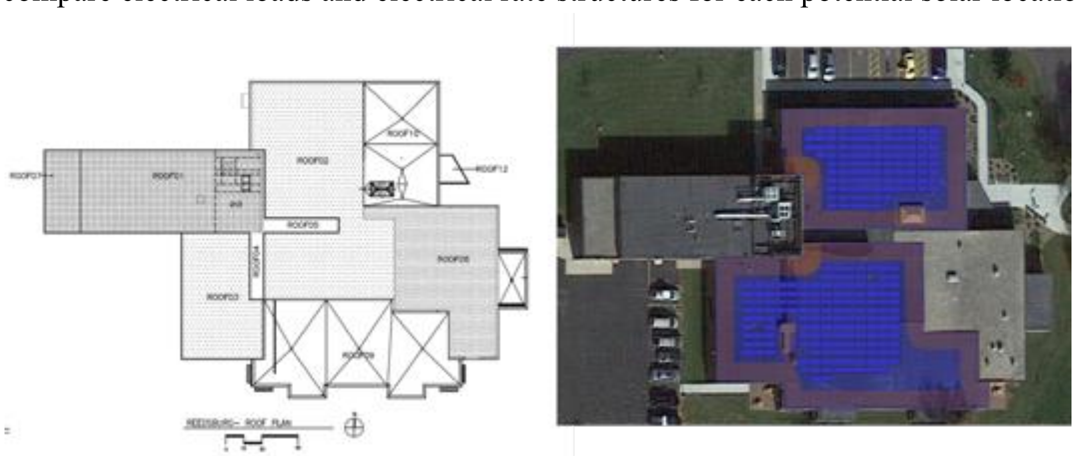
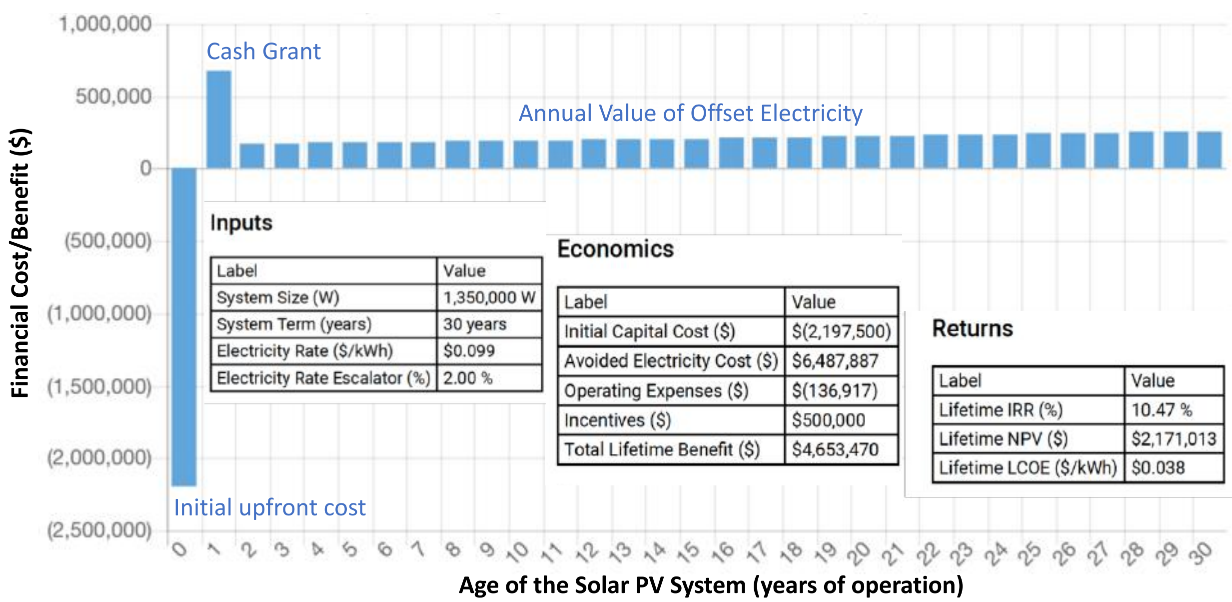


Figure 16. Solar site assessment for Madison College's Reedsburg Campus, one of the future installations considered in the college's solar roadmap. The age, area, and condition of various roof sections were evaluated, and the layout of solar modules was modeled using photovoltaic development software.

7. Funding: Identifying sources of funding is another important part of the Solar Roadmap process. Internal sources might include capital or operational dollars, and in some cases could include money from an endowment fund or charitable education foundation. The team may explore financing options such as bonding and tax equity financing. Pursuit of grants and other incentives can also help to improve project economic benefits. Project value can be assessed using a number of metrics such as the simple payback period, the internal rate of return, the net present value, or the levelized cost of electricity which can be compared to the current retail rate paid to the utility. (see Figure 17)



Inputs

Label	Value
System Size (W)	1,350,000 W
System Term (years)	30 years
Electricity Rate ($/kWh)	$0.099
Electricity Rate Escalator (%)	2.00 %

Economics

Label	Value
Initial Capital Cost ($)	$(2,197,500)
Avoided Electricity Cost ($)	$6,487,887
Operating Expenses ($)	$(136,917)
Incentives ($)	$500,000
Total Lifetime Benefit ($)	$4,653,470

Returns

Label	Value
Lifetime IRR (%)	10.47 %
Lifetime NPV ($)	$2,171,013
Lifetime LCOE ($/kWh)	$0.038

Figure 17. Annual cashflow and lifetime economic benefit of the Madison College solar PV system. Note that the levelized cost of electricity is less than half of what the college currently pays the electric utility for on-peak electrical energy during the day.

8. Model and Prioritize Projects: The team will want to use tools such as NREL's PV Watts, System Advisor Model, and/or ReOpt to model the energy and economic performance of potential projects. The energy generation potential for each of the candidate solar sites should be modeled, and economic parameters estimated. After these steps have been completed, the team formulates a priority list for the Solar Roadmap. Projects should be ranked based on the motivating objectives that were established in Step 2 of the Solar Roadmap process.

9. Disseminate the Plan: Once the roadmap is finalized, team members work to disseminate the plan, sharing it with the various stakeholders identified in step 3. The roadmap provides a guide for college leadership, and it will likely influence the institution's Facilities Plan, Academic Plan and Sustainability Plan. It also serves as a document for communicating the institution's goals and objectives to potential partners and community supporters who might be able to assist with future solar projects.

10. Implement Projects: The prioritized projects are then executed by the various stakeholders that were identified by the Roadmap. The projects will probably not happen all at once, but instead can be implemented over time as resources allow. When executing projects, the team will want to plan for future operations and maintenance. Solar panels are typically warrantied for 20-30 years, but there will be O&M costs that occur during that timeframe. Ideally, the roadmap can be published as a "living document" so that it can be updated as projects are completed, and priorities can be adjusted as situations change (for example if a roof is replaced on a building, that might bump it up in the rankings).

Conclusion – The Future of Schools is Solar Power

There are numerous factors that motivate schools to invest in solar PV systems. With funding from the US Department of Energy, the Midwest Renewable Energy Association has supported several college and university teams creating roadmaps for large (>1 MW) solar investments, including the Madison College case study described in this report. Since the conclusion of these projects, the authors have been contacted by numerous schools seeking to implement solar projects of their own. Based on these activities it was observed that institutions that successfully implemented large scale solar PV investments shared the following characteristics:

- The school has a Sustainability Director or similar staff person with support from and access to key decision-makers.
- The school has a sustainability plan that includes goals related to energy consumption and carbon footprint.
- The school has academic programs with educational objectives related to sustainability and/or renewable energy.
- The school has an electric service provider that supports school based solar investments.
- The school has made previous small-scale investments in solar PV on their campus.
- The school has relationships with peer institutions that have made large-scale solar PV investments and have shared their results and recommendations for future projects.

Today's education leaders are presented with a once in a generation opportunity to transform the way schools operate their buildings. Some states, counties, municipalities, and school districts are now adopting resolutions that all new construction must incorporate solar power. This trend is very likely to grow in the years ahead. There is a strong incentive for school leaders and renewable energy advocates to become familiar with the principles of solar design and engineering so that they can formulate plans for their facilities and make informed decisions about how solar is deployed on their campuses. Individuals that champion solar projects for their schools can be confident that their efforts will provide enormous benefit for education and the environment, while also delivering great economic value to the schools and communities that they serve.

Acknowledgements

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