Better Buildings®
U.S. DEPARTMENT OF ENERGY

On-Site Commercial Solar PV Decision Guide

25 SEPTEMBER 2014

Acknowledgments

This report was prepared by Navigant Consulting, Inc. under the guidance of Amy Jiron and Kristen Taddonio of the U.S. Department of Energy's Better Buildings Alliance program in collaboration with Olayinka Kolawole of the U.S. Department of Energy's SunShot program. The paper was reviewed by Sarah Truitt and Jason Coughlin of the National Renewable Energy Laboratory. We would also like to thank Dan Ciarcia of the Green Parking Council for his review.

Disclaimer

Executive Summary

Following through on the interest expressed by Better Buildings Alliance (BBA) members in recent discussions at the 2013 Efficiency Forum, and general member interest, the U.S. Department of Energy (DOE) established a pilot project team focused on integration of renewable energy technologies in buildings. Strategic use of renewables can help businesses to reduce building energy costs and environmental footprint. The Renewables Integration Project Team provides limited unbiased technical assistance and a venue for sharing (best practices, lessons learned, application experiences) to help Better Buildings Alliance members navigate complex regulations, business models, and utility policies. Individual members often do not have the resources or expertise to address these very specialized issues, and vendors selling renewables projects have a vested interest in promoting these solutions.

Better Buildings Alliance members' highest priority for the Team was to help commercial building and owners navigate the decisions regarding installing solar photovoltaics (PV) on commercial buildings. This guide serves that purpose and is intended for anyone investigating the addition of PV to a single or multiple commercial buildings. Interested parties could include building energy managers, facility managers, and property managers in a variety of sectors, including retail, food service, healthcare, higher education and the public sector.

This guide covers each major step in procuring PV:

- Conducting technical and financial studies
- Financing a PV system
- Procurement
- Project execution
- Operations and maintenance
- Assessing benefits

The guide provides information on the basic steps, key considerations, and where to go for more information. It is intended to provide an overview and some level of detail, with pointers to highly detailed information and resources.

Nomenclature

AC	Alternating current
AHJ	Authority having jurisdiction
ASCE	American Society of Civil Engineers
BBA	Better Buildings Alliance
BIPV	Building-integrated photovoltaic
BOS	Balance-of-system
CO_2	Carbon dioxide
CREST	Cost of Renewable Energy Spreadsheet Tool
DC	Direct current
DOE	U.S. Department of Energy
DSIRE	Database of State Incentives for Renewables and Efficiency
eGRID	Emissions & Generation Resource Integrated Database
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
EUL	Enhanced Use Lease
IEEE	Institute of Electrical and Electronics Engineers
IREC	Interstate Renewable Energy Council
ITC	Investment Tax Credit
kW	Kilowatt
kWh	Kilowatt-hours
LBNL	Lawrence Berkeley National Laboratory
LCOE	Levelized cost of electricity
LEED	Leadership in Energy and Environmental Design
MW	Megawatt
MWh	Megawatt-hour
NABCEP	North American Board of Certified Energy Practitioners
NEC	National Electrical Code
NFPA	National Fire Protection Association
NO_X	Nitrous oxide
NRCA	National Roofing Contractors Association
NREL	National Renewable Energy Laboratory
NSRDB	National Solar Radiation Data Base
O&M	Operations and maintenance
OpenEI	Open Energy Information
PM	Particulate matter
PPA	Power purchase agreement
PV	Photovoltaic
REC	Renewable Energy Credit
RFP	Request for proposal

ROI	Return on investment
RPS	Renewable Portfolio Standards
SAM	Systems Advisor Model
SEIA	Solar Energy Industries Associations
SO_X	Sulfur oxide
SREC	Solar Renewable Energy Credit
TMY	Typical meteorological year
UL	Underwriters Laboratory
UPS	Uninterruptible Power Supply

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Introduction

The DOE Better Buildings Alliance Program

The Better Buildings Alliance (BBA) is a U.S. Department of Energy (DOE) effort to promote energy efficiency in U.S. commercial buildings through collaboration with building owners, operators, and managers. Members of the Better Buildings Alliance commit to addressing energy efficiency needs in their buildings by setting energy savings goals, developing innovative energy efficiency resources, and adopting advanced cost-effective technologies and market practices.

As of 2014, Better Buildings Alliance members represent more than 9 billion square feet of commercial building space, approximately 20% of the total U.S. floor space in their representative sectors. The Better Buildings Alliance is composed of subgroups focusing on the following areas:

- Retail – Retailers, supermarkets, and restaurants
- Commercial Real Estate – Commercial real estate and hospitality
- Healthcare – Hospitals and healthcare organizations
- Higher Education – Colleges, universities, and other postsecondary institutions
- Public Sector – state, municipal, and K-12 buildings.

All Better Buildings Alliance efficiency initiatives are driven by targeted Project Teams composed of Better Buildings Alliance members and Building Technologies Office technical experts across all relevant commercial sectors:

- Lighting and Electrical
- Space Conditioning
- Renewable Energy Integration
- Plug and Process Loads
- Refrigeration and Food Service
- Market Transformation
- Energy Management Information Systems
- Laboratories

When to Use This Guide

This guide is intended for anyone investigating the addition of PV to a single or multiple commercial buildings. This could include building energy managers, facility managers, and property managers in a variety of sectors, including retail, food service, healthcare, higher education, and the public sector.

Not every building and region is suitable for onsite PV. Some buildings may have the wrong orientation, too much shading, or not enough space to accommodate the system(s). Parts of the country may have the wrong combination of solar insolation (sunlight) and electric rates to make PV financially feasible. In addition, a variety of incentives, metering capabilities, and financing options exist for installing PV at your facility, all of which can influence the financial feasibility of a PV project.

This document’s intent is to guide the reader through the steps of evaluation of the feasibility and benefits of PV, procurement, installation, and operation. It provides information, templates, and references to other documents to facilitate these steps, but you may need additional help from professional engineers, accountants, and/or subject matter experts to facilitate your decision making.

Efficiency First

A solar PV system should be considered only after the host building has reduced its overall load as much as possible. This should be done through other energy efficiency measures so that the maximum potential of the solar PV system can be realized and unnecessary losses can be avoided. By reducing the demand of the building first with least-cost measures, the size and cost of the solar PV system can be reduced.

Purchasing Renewable Energy Certificates (RECs)

If installing PV at your facility is not possible, you can:

- Purchase Renewable Energy Credits (RECs)(the positive environmental attributes of PV)
- Participate in your local utility's green purchasing program
- Participate in a community solar program; or
- Participate in a virtual net metering program.

Details on these types of programs are outside the scope of the document, but more information can be found via the DOE's Green Power Network at http://apps3.eere.energy.gov/greenpower/ and the U.S. Environmental Protection Agency's (EPA's) Green Power Partnership at http://www.epa.gov/greenpower/index.htm.

PV and New Construction

The guide is aimed at building owners considering adding PV to an existing building. However, new commercial buildings can be designed to accommodate PV. This can be done in two ways:

- Adding PV to the building design: This can be done by working with your design team to include PV. In addition, if you are targeting energy certification (such as EnergyStar qualification or Leadership in Energy and Environmental Design [LEED] certification), adding PV can help the building meet its energy goals.
- Designing the building to easily accommodate PV in the future: This can improve the economics of the future installation and potentially allow you to install more solar. For more information on how to accomplish this, refer to the National Renewable Energy Laboratory's (NREL's) Solar Ready Buildings Planning Guide[1]. This guide provides checklists and details on steps to take during design that will minimize solar installation costs and maximize solar production potential in the future.

Options If You Do Not Own Your Building

If you rent space in a building, you have three options for procuring PV:

- Refer to Section 0 and purchase RECs to offset your electrical usage.
- Work with the building owner to install PV. You would have to negotiate terms with the building owner to install PV that works for the owner.

[1] Available at http://www.nrel.gov/docs/fy10osti/46078.pdf

- Some states and jurisdictions allow for “community shared” solar installations. Community shared solar systems are solar-electric systems that provides power and/or financial benefit to multiple community members. These systems need not be located onsite. For more information, refer to National Renewable Energy Laboratory’s (NREL’s) A Guide to Community Shared Solar: Utility, Private, and Nonprofit Project Development[2].

How PV Works

PV systems produce energy by converting photons into direct current (DC) electricity. The amount of current produced depends on the amount of light hitting the semiconductor material from which PV modules are fabricated, and the efficiency of the system. DC equipment can use that DC electricity with no conditioning or minimal conditioning. Alternatively, the DC current can be converted into alternating current (AC) electricity and used by AC equipment. In most commercial building applications, the output of the PV system is converted to AC electricity and consumed by the loads associated with the building or facility. When a facility’s electricity needs are lower than the PV system’s output, the excess AC electricity is typically sold back into the electric grid.

PV systems are composed of several major components. (Source: Navigant)

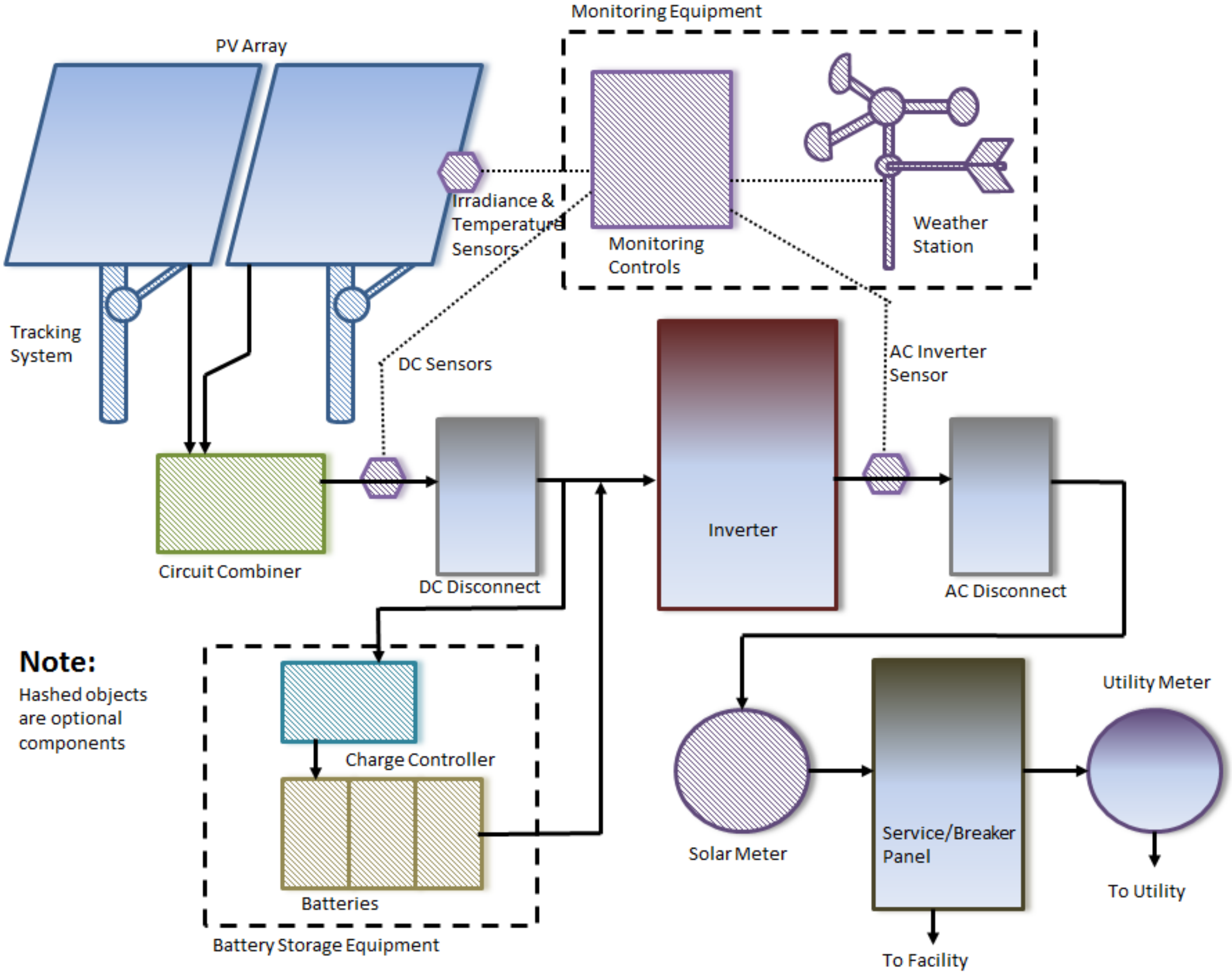
Table 1 lists the core components most commonly found in commercial building applications and several optional components. Figure 1 shows a schematic of typical system components.

Core Components	Optional Components
▶ Racking/Mounting System	▶ Monitoring System
▶ PV Array	▶ Tracking System
▶ Inverters	▶ Battery Storage System
▶ Disconnect Switches	
▶ AC Circuit Breaker	
▶ Meters	

(Source: Navigant)

[2] Available at http://www.nrel.gov/docs/fy12osti/54570.pdf

Table 1. Major Components of a PV System



(Source: Navigant)

Figure 1. Summary of Major PV System Components

Racking Systems

Racking systems are used to attach the PV modules to the roof of a building or to a ground-mounted structure. It is imperative that the racking system securely supports the PV array and its attached components under worst-case loading conditions. Wind loading and snow loading are common sources of stress on the racking system. Numerous product offerings are available that enable custom racking solutions for most roof types and ground-mounted structures.

Tracking Systems

Tracking systems can be employed to improve the annual production from a PV array. Tracking systems rotate the PV modules to follow the sun throughout the day and year. For some systems, single-axis tracking can improve system output by 24%, and double-axis tracking can improve system output by 38%

relative to a fixed-tilt system[3]. Higher power output in the mornings and evenings is an added benefit of tracking systems. Tracking is most often used on ground-mounted projects, where the costs of the tracking systems can be reduced through economies of scale. However, some tracking products may become available for rooftops in the future. Arrays equipped with tracking require more space in order to prevent self-shading. Tracking systems include moving parts that will require operations and maintenance (O&M) planning and budgeting.

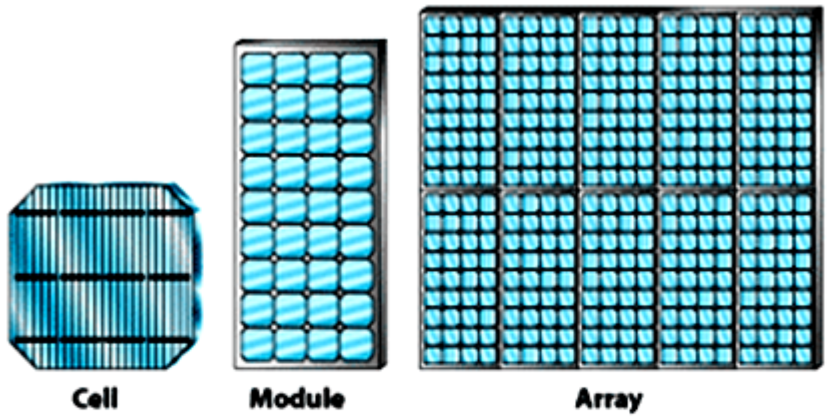
Battery Storage Systems

Battery storage systems are employed in off-grid facilities, in facilities wanting emergency backup power for critical loads, and in facilities actively managing their loads seen by the utility. There are DC-coupled and AC-coupled battery systems, where the former is the most prevalent. DC-coupled systems rely upon a DC battery charge controller and a battery-based inverter. AC-coupled systems use a grid-direct inverter and a battery-based inverter/charger. Both systems utilize a battery bank operating at a moderate nominal DC voltage. Storage systems may also rely on diversion loads, where excess PV energy can be dissipated to prevent overcharging the batteries when the grid is not available[4].

PV Arrays

PV arrays are typically composed of many PV modules (see Figure 2). Modules come in many shapes and sizes, and they have widely differing operating characteristics. For more information on different technologies, refer to technology summaries available from the DOE's SunShot program[5]. Within each of the module types, the module efficiency—in terms of electrical output per square foot under standard testing conditions—varies greatly among manufacturers and products. Higher efficiency modules often garner higher prices. Building-integrated PV (BIPV) is another option. BIPV typically uses a less common type of PV material, which can be integrated directly into the envelope of a building structure in the form of roof shingles, skylights, windows, or facades.

[3] Stephen Smith. "PV Trackers." *SolarPro*, p. 28. Jun/Jul 2011.
[4] Joe Schwartz. "AC Coupling in Utility-Interactive and Stand-Alone Applications." *SolarPro*, p. 74. Aug/Sep 2012.
[5] The DOE's SunShot program provides technology summaries at http://energy.gov/eere/sunshot/photovoltaics-research-and-development



(Source: DOE)

Figure 2. PV Arrays Are Composed of Modules that Are Composed of Cells[6]

Inverters

A PV system that ties into the electric grid or an AC network uses an inverter to condition the electricity from the array before it is connected to the AC system. The inverter converts the DC electricity from the PV array into AC electricity and ensures that the quality of the AC electricity meets all required standards; all grid-interactive inverters in the United States must meet the Underwriters Laboratory (UL) 1741 and Institute of Electrical and Electronics Engineers (IEEE) 1547 standards requiring that inverters cease the export of power in the event that grid power is de-energized. This is a safety mechanism that protects line technicians working on the grid. String inverters allow the combined DC output from many modules to be converted into AC power from a single inverter. Systems using microinverters connect each module, or sometimes pairs of modules, to a microinverter, and the AC output from those microinverters is then combined. The advantages and disadvantages of string inverters versus microinverters highly depend on the system.

Disconnect Switches

The National Electrical Code (NEC) requires that disconnect switches be installed on a grid-connected PV system. One disconnect switch is located on the DC side of the inverter (often it is integrated into the inverter), and the other is located on the AC side of the inverter. Systems that use microinverters do not require a DC disconnect switch. The disconnect switches allow conductors and equipment to be de-energized, which allows workers and fire safety personnel to safely work with and around the equipment. According to the NEC, switches must be manually operable without exposing the operator to contact with live parts and must be readily accessible. Utilities may have more restrictive requirements for AC disconnects. For example, the utility may require that the AC disconnect be located near the utility meter and be accessible on a 24-hour basis. Many states and utilities are removing the requirement for small PV

[6] Source: Office of Energy Efficiency & Renewable Energy. http://www.energy.gov/eere/energybasics/articles/photovoltaic-system-basics

systems, particularly those smaller than 10 kilowatts (kW), to include a utility external disconnect switch that exceeds the requirements that the NEC describes[7,8]. The NEC may require additional fuses or switches, depending on the system design.

AC Circuit Breakers

Back-fed circuit breakers are installed in a facility's primary electric panel or sub-panels in order to connect the AC output from the inverters to a facility's electrical system. Adding a back-fed circuit breaker for the PV system can be straightforward, depending on the rating of the existing panel and the availability of space within that panel. If the existing panel's ratings will not permit the additional electricity from the PV array, the existing panel may have to be replaced or significantly modified.

Meters

PV systems can require different metering strategies. The simplest form of metering is to use a standard uni-directional utility meter. A uni-directional utility meter should only be used if the output from a PV system will never exceed a building's electricity consumption at any moment in time. When the output of the system has the potential to exceed consumption, a bi-directional utility meter should be used. Bi-directional meters allow the meter to "spin backward" when there is excess PV electricity. In both cases, the utility meter reports the net consumption of the facility after PV output has been subtracted. Some utilities may require that a bi-directional meter be installed on all facilities with a grid-connected PV system, despite the possibility for excess PV electricity. In many situations, an additional solar meter will be used to record only the output from the PV system. Although the accuracy of solar meters varies, numerous models are revenue-grade with accuracies of +/- 0.2%[9]. Many solar meters offer functionality such as cellular- or internet-based tracking of system output. This allows the system owners, lessees, installers, operators, or financiers to monitor the production with greater time resolution. Accurate, high-resolution information about system performance permits better discovery of system issues and better valuation of electricity output.

Monitoring Systems

As an upgrade from smart solar meters, monitoring systems are becoming more prevalent as the costs of these systems decline and the need for accurate and comprehensive data about system performance increases. Monitoring systems can be used as a marketing or educational tool, as a maintenance detection system, or as a means to verify that production and revenue contracts are being met. Information about the system can be collected at the inverter, the subarray, the string, or even the module level. Some systems

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[7] Michael T. Sheehan. "Utility External Disconnect Switch: Practical, Legal, and Technical Reasons to Eliminate the Requirement". Interstate Renewable Energy Council. Sep 2008. http://www.solarabcs.org/about/publications/reports/ued/pdfs/ABCS-05_studyreport.pdf

[8] M.H. Coddington, R.M Margolis, J. Aabakken. "Utility-Interconnected Photovoltaic Systems: Evaluating the Rationale for the Utility-Accessible External Disconnect Switch". NREL Technical Report . TP-581-42675. Jan 2008. http://www.nrel.gov/docs/fy08osti/42675.pdf

[9] Go Solar California has compiled a list of solar meter models, and the list indicates whether meters pass the California Energy Commission's definition of revenue-grade. That list can be accessed at http://www.gosolarcalifornia.ca.gov/equipment/system_perf.php.

may also monitor the weather, the solar irradiance, and the building load. Most monitoring systems require an internet or a cellular connection to collect the data. Graphical user interfaces for the monitoring systems will range from simplistic to highly detailed and customizable. Some may include automatic alerts, error diagnosis, work order initiation, performance ratios, detailed reports at different time resolutions, or the ability to compare multiple sites. When determining the granularity and sophistication of a monitoring system, the revenue loss implications of a poorly performing system should be considered[10,11].

Value Chain

As shown in (Source: Navigant)

Table 2, the realization of a PV system involves many companies and roles. When the scope and complexity of a project are significant, project developers can be contracted to take a comprehensive approach to all components of the development process. In this case, the project developers will serve as a central planning agent and liaison to numerous entities involved in the process. While it may be possible to interact directly with the equipment manufacturers, often a potential project interacts with manufacturers' certified distributors. It is especially important to learn the reputation of each manufacturer, to understand the terms of its product warranties, and to consider the likelihood that the manufacturer will stay in business long enough to uphold its warranties. In many cases, equipment manufacturers are becoming vertically integrated and can offer products, planning and design services, financing, and installation. Design firms evaluate the site and the needs of the end-user and they use advanced software packages to engineer/design the system. With a system design in hand, the installation contractor will construct the array, connect it to the facility's electrical system, and perform commissioning services. Once the array is operational, an O&M service provider can perform routine inspections, cleaning, and maintenance. When the useful life of the equipment has ended, recycling contractors may be able to salvage the recyclable material from the modules and other system components. Financing firms and financing mechanisms specifically focus on the execution of PV development projects.

[10] Kyra Moore, Rebekah Hren. "Commercial PV System Data Monitoring." *SolarPro*, p. 86. Dec/Jan 2012.
[11] Casey Miller, Todd Miklos. "Determining Optimal PV System Monitoring Granularity." *SolarPro*, p. 86. Aug/Sep 2013.

Entity	Role
Project developer or manager	Coordinates all aspects of the PV installation from start to finish and puts systems in place to ensure PV performance, longevity, and financial feasibility
Equipment manufacturer	Supplies equipment, gives technical advice on best applications for equipment, and warrantees the equipment
Design firm	Evaluates the site, determines optimal system configuration based on cost and performance, selects the appropriate equipment, and provides detailed electrical and mechanical drawings
Construction contractor	Procures equipment and materials, applies for appropriate permits, constructs the PV system, makes final electrical connections or tie-ins, commissions the system to verify proper performance (can be performed by independent third party), and warrantees craftsmanship
O&M contractor	Provides ongoing monitoring, inspection, and maintenance services and guarantees a defined level of performance
Financier	Formulates financing mechanisms, provides capital, may require a performance guarantee
Salvage contractor	Salvages recyclable material at the end of the system's useful life

(Source: Navigant)

Table 2. Roles in the PV Value Chain

How Solar PV Can Benefit Your Facility

Financial Benefits

Solar PV can offset your grid purchases of electricity and can reduce your monthly electric bill costs through reduced energy and demand charges. In addition, a variety of federal, state, and local incentive programs can reduce the initial cost. Finally, many third-party ownership models have been developed that increase the financial attractiveness of solar PV. All of these items are discussed in detail in the following sections.

Environmental Benefits

Installing solar PV directly offsets purchases of grid-supplied electricity. The emissions offsets of doing so will vary depending on your location, but it will generally result in reduced carbon dioxide (CO_2), nitrous oxide (NO_X), sulfur oxide (SO_X), and particulate matter (PM) emissions from the combustion of fossil fuels in natural gas- and/or coal-fired power plants. For detailed information on local emissions profiles, refer to the EPA's Emissions & Generation Resource Integrated Database (eGRID), a comprehensive source of data on the environmental characteristics of almost all electric power generated in the United States[12].

Marketing Benefits

Solar PV is a highly visible asset that has several marketing benefits:

- If you have corporate or organizational sustainability goals, solar PV will help you meet your targets
- For federal, state, and local buildings, you may have clean energy or sustainability targets that solar PV will help you to achieve
- For commercial buildings that lease floor space, your tenants may value the presence of solar PV, and you may be able to pass this value on through the lease price
- If you have a commercial building and your target market values sustainability and environmental issues, solar PV can be included in your advertising efforts
- For schools and other educational buildings, solar PV can be used as an educational tool to teach students about solar energy and sustainability

Other Benefits

Solar PV has other benefits beyond those stated above, which may not be applicable to every building:

- Reliability – If solar PV is part of a microgrid that you are installing at your facility, it can help power your building during an outage or when disconnected from the grid. Alternatively, if you do not have a microgrid system but would like your PV to be available during an outage, you can work with your designer/installer to assess the feasibility and costs of this.
- Cooling Load Reduction – Adding solar PV to a roof will reduce your buildings cooling load. If solar PV is installed as a canopy, it will provide shading. Both of these configurations reduce the urban heat island effect.
- LEED Credentials – If you are seeking to obtain LEED certification from the U.S. Green Building Council[13], solar PV counts toward several of the credit categories.

[12] The eGRID database and more information is available at http://www.epa.gov/cleanenergy/energy-resources/egrid/
[13] See www.usgbc.org for more information

Screening for Solar PV at a Facility

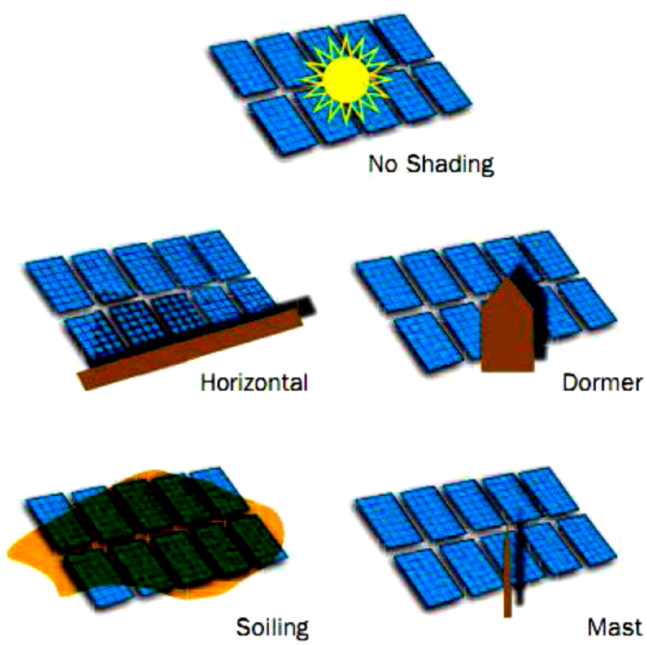
Technical Feasibility

Considerations

The first step in screening for solar PV at your facility is to assess the technical suitability of your building for PV. Several key considerations are shading, roof orientation, structural requirements, space requirements, utility interconnections, load/power factors, and carports. These elements are discussed in the following sub-sections.

Shading

Shading can have a disproportionately large impact on the output of an array. In string configurations, the worst-performing module will drag down the performance of the entire string. If just one module in a string is heavily shaded, it can significantly reduce the power produced by the entire string. The same is true for cells within a single module. Figure 3 shows some of the common types of shading. Note that an obstruction as small as a mast can hinder the performance of a system based on its configuration. For this reason, it is important to perform a thorough shading analysis of the candidate site.



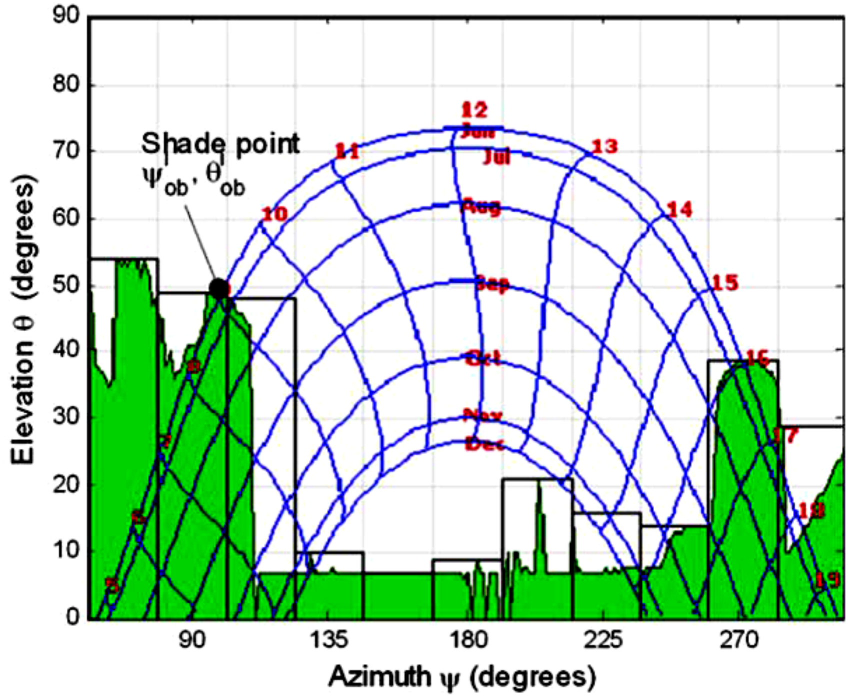
(Source: NREL)

Figure 3. Common Types of Shading[14]

Tools such as Solmetric's SunEye, Wiley's Solar ASSET, or the Solar Pathfinder are available to identify where shading will come from at different times of day and year. These tools can be integrated with other

[14] Source: Chris Deline, Jenya Meydbray, Matt Donovan, Jason Forrest. Photovoltaic Shading Testbed for Module-Level Power Electronics. NREL Technical Report TP-5200-54876. May 2012.

software to determine how that shade might impact the array's performance. A typical shading analysis, shown in Figure 4, allows a system designer to determine the hours of the day in each month when objects will cast shadows on an array.

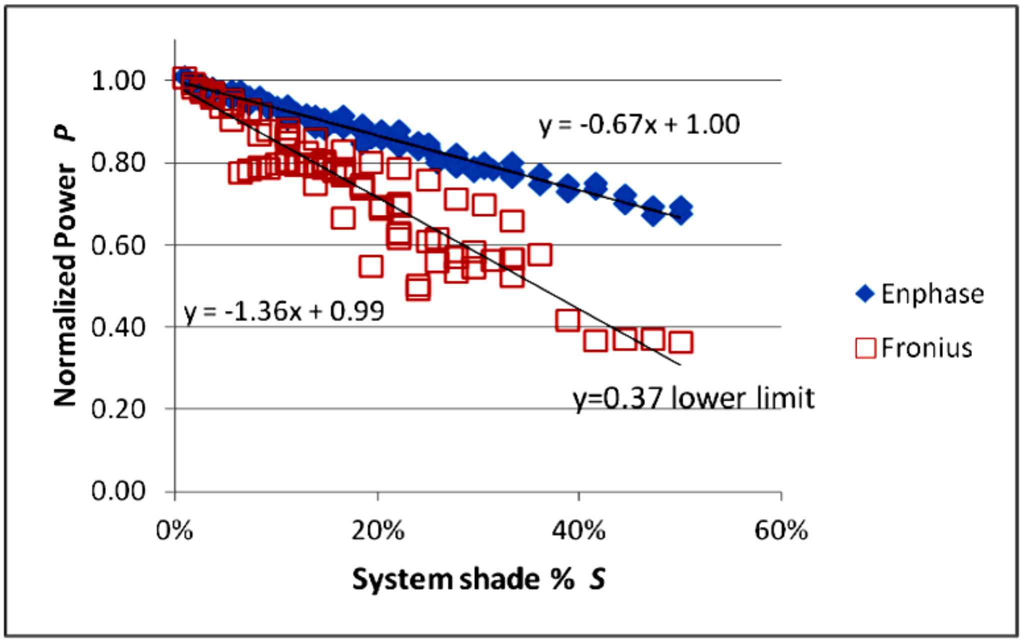


(Source: NREL)

Figure 4. Evaluation of Shading by Month and Time of Day[15]

If shading cannot be avoided, various system design strategies can be implemented to mitigate the impact from shading. One option is to avoid including modules with dissimilar shading profiles in the same string. Another option is to use microinverters, which enable each module to operate independently of one another. Analysis from NREL indicates that microinverter-based arrays may be able to produce significantly more electricity than string-inverter-based arrays when shading is appreciable[16]. For a string-inverter and a microinverter system, Figure 5 illustrates how array power output decreases as the percentage of the array that is shaded increases.

[15] Chris Deline. "Partially Shaded Operation of Grid-Tied PV System." NREL Conference Paper CP-520-46001, p. 4. June 2009.
[16] Chris Deline, Jenya Meydbray, Matt Donovan, Jason Forrest. "Photovoltaic Shading Testbed for Module-Level Power Electronics." NREL Technical Report TP-5200-54876. May 2012.



(Source: NREL)

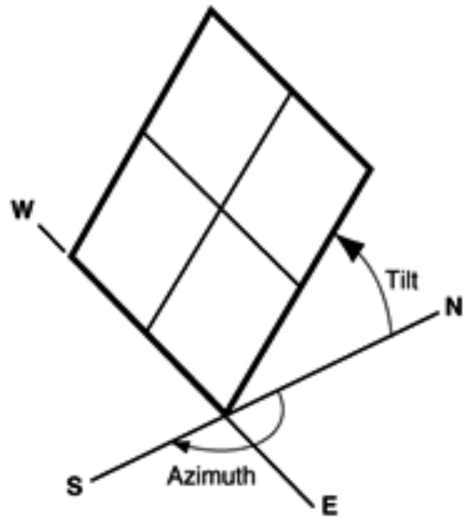
Figure 5. Comparison of the Normalized Power Output from an Enphase Microinverter System and a Fronius String-Inverter System as a Function of System Shading

In addition, system designers must plan for self-shading of arrays with multiple tilted rows of modules. NREL recommends that arrays with multiple tilted rows be spaced such that each row can receive full sun by 10 o'clock a.m. on the winter solstice[17].

Roof Orientation

Two important concepts in PV system design are the azimuth and tilt angle of the array (see Figure 6). The azimuth refers to the direction that the modules face, such as true south or 15 degrees east of south. The tilt refers to the angle or slope of the modules, such as 34 degrees, relative to a horizontal plane. Assuming cloudless skies year-round, annual output from a PV array in North America is typically maximized when the array is facing true south and has a tilt angle equal to the latitude at that location. In practice, system designers have much flexibility in their selection of azimuths and tilt angles, and they may choose to sacrifice some annual production to achieve other goals. Annual production from PV systems is generally more sensitive to the angle of tilt than it is to the azimuth.

[17] L. Lisell, T. Tetreault, A. Watson. "Solar Ready Buildings Planning Guide." NREL Technical Report TP-7A2-46078. Dec 2009.



(Source: NREL)

Figure 6. A PV Array Facing South at a Tilt[18]

Roofs are often categorized as low-slope or sloped, where low-slope roofs range from flat to 3:12 pitch (24 degrees). Sloped and low-slope roofs each have advantages and disadvantages. It is often easier for technicians to perform work on a low-slope roof, partly because fall protection is easier to achieve on low-slope roofs. In addition, system designers might have more freedom in the azimuth and the tilt of the array when working on a low-slope roof. The disadvantages of low-slope roofs are that the racking system for a tilted array is more costly and laborious, and the tilted arrays must be constructed to withstand significant wind loading. Systems installed on flat roofs may use a tilt angle less than the optimal angle for the given latitude. This sacrifice in annual production is made in order to reduce the spacing requirements caused by self-shading, and it decreases the potential wind loads that could be experienced by the array structure. Flat or zero-tilt arrays are sometimes used on low-slope roofs because they have high annual output per square foot of roof space and because they minimize wind loading. These flat configurations are susceptible to higher levels of snow loading and soiling.

A real advantage can exist when an array can be attached parallel to a sloped roof with a minimal gap of separation. Parallel mounting can significantly reduce racking material costs and labor, and it reduces the wind loading pressures that the array will experience. Unfortunately, the sloped roof may not be at the ideal angle for the PV system, and a tilted racking system might still be required. Sloped roofs also benefit from lower risk of water pooling. Some disadvantages of sloped roofs are the increased need for fall protection and the burden of having to work on a steep surface. It may be more difficult to orient modules toward a southern azimuth on sloped roofs, which can decrease the production from the array. When a sloped roof has different sections with multiple orientations and string inverters are employed, care must be taken to ensure that modules within strings share similar irradiance profiles throughout the day.

[18] NREL. http://rredc.nrel.gov/solar/calculators/pvwatts/system.html

Structural

If a roof will need to be replaced within the economic lifetime of a PV system, it is usually best to replace the roof at the time of the solar installation. If a roof requires routine maintenance, special consideration should be given to installing a PV system that will not hinder maintenance. Before installing PV on a roof, ensure that the methods used will not invalidate any warranties from the roof manufacturer or installer. On low-slope roofs (flat to 3:12 pitch), care should be taken to allow proper drainage of water and to prevent puddle formation. Roofs are made of many different material types, each requiring unique methods of ensuring weatherproof installation for PV systems. For example, asphalt roofs must be flashed with asphalt-based flashing membranes, single-ply PVC membrane roofs must be flashed with PVC-based membranes, metal roofs must be flashed with custom metal flashings, etc. It is advisable to consult a roofing professional to assess the roof substrate and to give guidance about the most appropriate PV racking and attachment approaches. The National Roofing Contractors Association (NRCA) has developed a guide for roof-mounted PV systems[19] that covers these topics in greater detail.

All roof-mounted systems need to account for the pressures applied to the racking system and roof from static and dynamic loads. The roof must be able to support the weight of the PV system plus the weight of snow, slow-running water, or a technician, plus any downward pressure that wind exerts on the system. The maximum weight that most roofs can support is 5 to 10 pounds per square foot (lbs/sq ft)[20]. NREL estimates that typical PV and racking systems weigh about 3 lbs/sq ft, and ballasted PV systems can weigh between 4 and 6 lbs/sq ft[21]. Moreover, the roof and system attachment points must be able to withstand any upward lift caused by wind. Systems that are mounted parallel to the roof and that do not have a gap larger than six inches above the roof will experience wind loads similar to the building cladding. Under these circumstances, the guidance on wind loading from the American Society of Civil Engineers (ASCE) international building code's Chapter 7 might be applicable. For systems that do not fall under this category, such as self-ballasted systems and tilted systems on low-slope roofs, an engineering analysis should be performed using the actual system topology, the building dimensions, and local wind data[22].

Ballasted vs. Attached Roof-Mounted Systems

Mounting configuration is an important factor for commercial buildings.

Ballasted systems have the advantage that they can be easier to install, and they require no penetrations into the roof. The disadvantage is that some roofs cannot handle the weight, more advanced wind-loading evaluations must be performed, proper roof drainage can be disrupted, and some jurisdictions will not allow these systems.

Attached systems have the advantage that they can be used on more roof types and in more jurisdictions. The disadvantage is that they can be more difficult to install, and they can reduce the weather seal that the roofing membrane provides.

Space Requirements

Planning ahead for the space required by a PV array and its balance-of-system (BOS) components, such as combiner boxes, disconnects, inverters, and AC distribution panels, will greatly facilitate the installation

[19] "Guidelines for Roof-Mounted Photovoltaic System Installations." NRCA. www.nrca.net
[20] Colleen O'Brien, David Banks. "Wind Load Analysis for Commercial Roof-Mounted Arrays." *SolarPro*. Jun/Jul 2012.
[21] L. Lisell, T. Tetreault, A. Watson. "Solar Ready Buildings Planning Guide." NREL Technical Report TP-7A2-46078, p. 14. Dec 2009.
[22] Stephen Barkaszi, Colleen O'Brien. "Wind Load Calculations for PV Arrays." Solar American Board for Codes and Standards. June 2010.

process. The NEC establishes clearance requirements for inverter and electric panel components. Suitable clearances must be maintained above, around, and in front of these components.

The footprint that the array requires will vary greatly, depending on the type of PV module used and the design of the system. More efficient modules can produce more power in a smaller footprint. For roof-mounted systems, the following power densities can be used to estimate the required roof area: crystalline modules produce 8-11 watts per square foot (W/sq ft), high-efficiency crystalline modules produce 17-18 W/sq ft, and thin film modules produce about 5 W/sq ft[23]. For ground-mounted arrays larger than 1 megawatt (MW), the array may require 4.5-7.5 acres per MW[24]. Publicly available models, such as NREL's System Advisor Model or PVWatts, can help you make detailed estimates[25]. Remember to consider the location and size of existing rooftop equipment when estimating available roof area for PV.

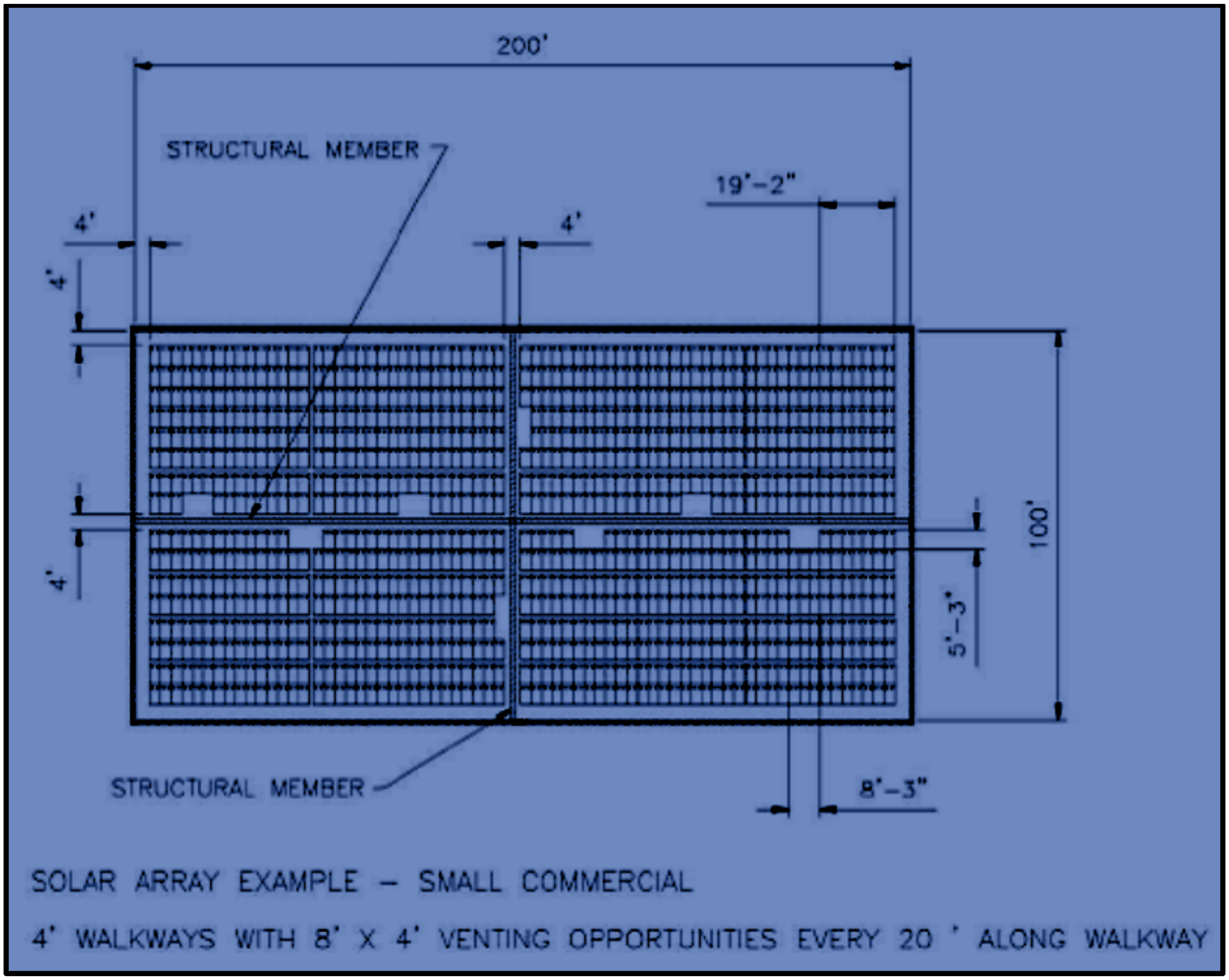
When designing a rooftop system, it is imperative to account for access pathways and egress routes required by building codes and fire service professionals. As an example, commercial buildings typically require a clear pathway around the perimeter of a roof and along the centerlines of both axes of the roof. All skylights, roof access hatches, and other ventilation locations on the roof must be accessible from the perimeter by means of a clear pathway. Figure 7 depicts the pathways and ventilation locations for an illustrative small commercial building. These pathways should be located along structural members, and racking structures and electrical conduits must not create a trip hazard along these cleared pathways. In addition, there may be restrictions on the distance of an array along either axis. The perimeter and interior of ground-mounted systems must be cleared of brush. Although each local authority having jurisdiction (AHJ) may have different requirements, the California Department of Forestry and Fire Protection has a widely emulated guide on PV installation[26].

[23] L. Lisell, T. Tetreault, A. Watson. "Solar Ready Buildings Planning Guide." NREL Technical Report TP-7A2-46078, p. 26. Dec 2009.

[24] Sean Ong, Clinton Campbell, Paul Denholm, Robert Margolis, and Garvin Heath. "Land-Use Requirements for Solar Power Plants in the United States." NREL Technical Report TP-6A20-56290. June 2013.

[25] Models available at http://pvwatts.nrel.gov/ and https://sam.nrel.gov/

[26] "Solar Photovoltaic Installation Guide." California Department of Forestry and Fire Protection. Apr 2008. http://osfm.fire.ca.gov/pdf/reports/solarphotovoltaicguideline.pdf



(Source: California Department of Forestry and Fire Protection)

Figure 7. Example of a Small Commercial Rooftop Layout with Walkways and Venting Opportunities

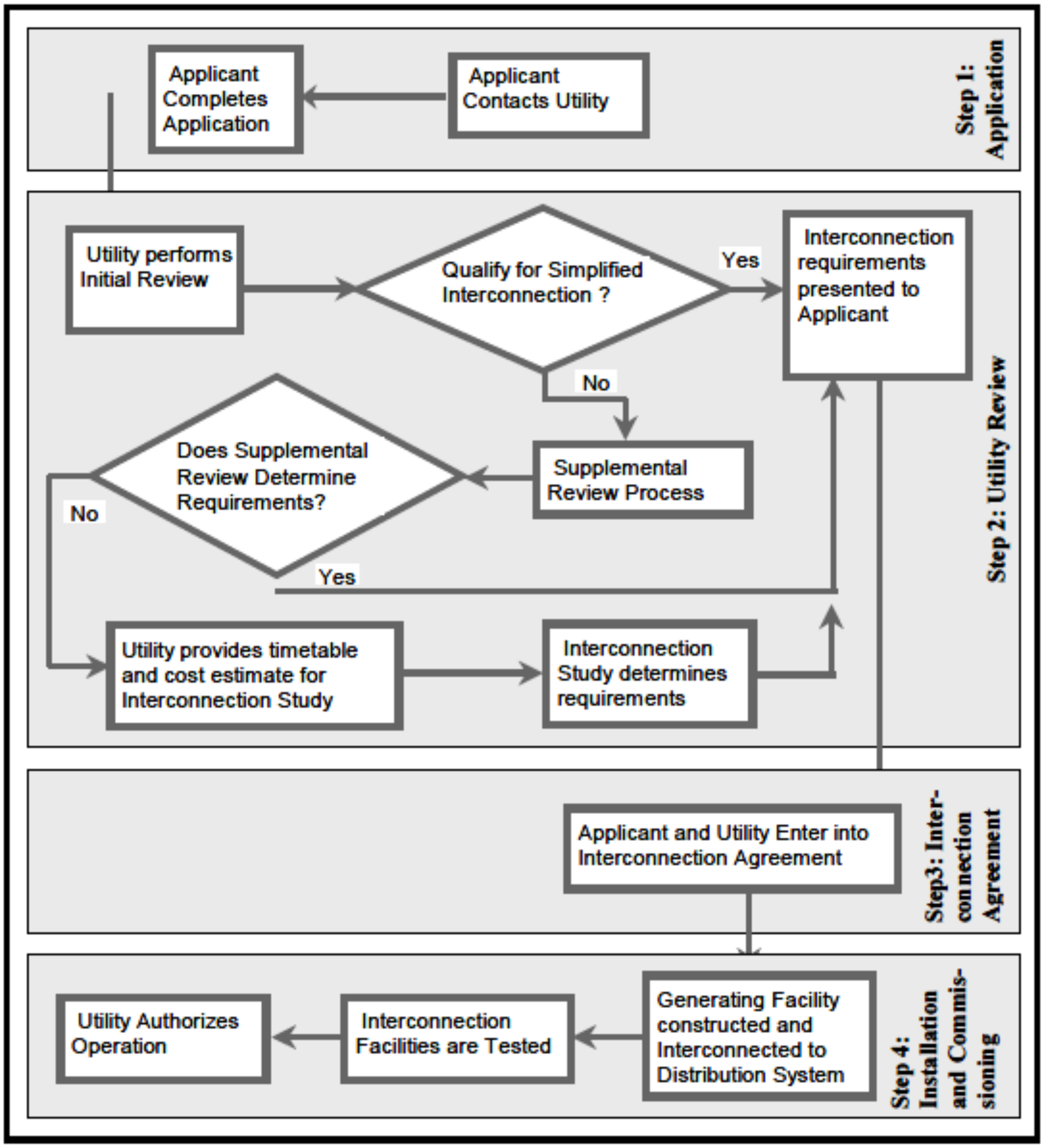
Utility Interconnection

In a grid-tied system, you must apply for a utility interconnection. The application should be submitted early in the project development phase to ensure that the system is approved and to prevent the system from sitting idle while waiting for approval. Interconnection rules vary significantly by state, locality, and utility. Contacting the local utility is the best means of gathering information about the interconnection procedures and requirements. Another good reference for interconnection standards is the Database of State Incentives for Renewables & Efficiency (DSIRE)[27].

Some interconnection standards have a fast-track process for systems that meet certain requirements. If possible, designing a PV system to meet the fast-track requirements can reduce the time, effort, and costs devoted to the interconnection process. Some elements that may impact the complexity of the interconnection application process are the size of the system, the equipment listings and certifications, the presence of a utility external disconnect switch, coverage under general liability insurance(typically

[27] The Database of State Incentives for Renewables & Efficiency can be accessed at http://www.dsireusa.org/

required for most interconnection applications), whether power will be exported, whether the system will be connected to a distribution or transmission network, whether electricity will be sold into wholesale markets, and whether the facility is on a spot or area network. Figure 8 presents an illustrative utility interconnection process, which is based on the California Public Utilities Commission's current Rule 21.



(Source: California Energy Commission)

Figure 8. Flow Diagram for California's Utility Interconnection Process[28]

[28] "California Interconnection Guidebook: A guide to Interconnecting Customer-owned Electric Generation Equipment to the Electric Utility Distribution System Using California's Electric Rule 21." Prepared for California Energy Commission by Overdomain, LLC, Endecon Engineering, and Reflective Energies. Sep 2003, p. 19. http://www.energy.ca.gov/reports/2003-11-13_500-03-083F.PDF

PV owners can expect to pay an interconnection application processing fee and possibly other fees, the cost of which will likely range from a few hundred dollars to a few thousand dollars[29]. If the project does not meet the simplified screening process and requires supplemental review, the applicant might be required to pay for the actual cost of that review or a fixed fee. PV projects that require an engineering review to ensure that the grid is not adversely impacted by the proposed system will face additional fees or charges. This is typically required if you are installing solar PV on a distribution line that already has significant solar PV capacity installed. If an engineering review determines that distribution system upgrades or additional interconnection facilities are needed to support the proposed system, those costs may be passed onto the PV owner[30].

Load/Power Factor

Depending on the percentage of a facility's electric load that a PV system will meet and the types of loads present at the facility, an evaluation of the impact of the PV system on the facility's power factor should be considered. Under certain circumstances, a PV system can reduce a facility's power factor as measured by the utility. Utilities often require large commercial and industrial customers to maintain a power factor above a certain threshold, and violation of the threshold can lead to additional charges or different rate schedules[31].

If an evaluation suggests that a PV system may negatively impact a facility's power factor (see box), inverter manufacturers can offer guidance on how to minimize the impact. Most inverters can provide and absorb reactive power, but these capabilities are typically disabled as a default setting. Another option is to add power-factor-correcting capacitors to the facility.

Power Factor

The power factor is found by dividing real power (often in kW) by apparent power (often in kVA), where apparent power is the vector sum of real power and reactive power (often in kVAR). Most inverters produce power at a unity power factor, meaning that all of the power produced is real. If a facility's real power demand is reduced due to the PV system and the facility's reactive power demand stays the same, then the power factor of the facility will decrease. Note that the power factor of the loads within the facility does not change, but the power factor that is seen by the utility may decrease. This is only likely to occur if a substantial percentage of a facility's load is met by a PV system and the facility has an appreciable amount of reactive load.

Special Considerations for Carports and Parking Lots

Carports and other shade-providing structures can make excellent platforms for PV arrays. They offer the dual benefit of being able to provide shade or protection from the elements, as well as solar electricity. Solar carports are a great way to showcase a facility's investment in sustainability. In many instances, a facility may not have a rooftop that can support a PV system, or the facility may not have enough unused area for a ground-mounted system. Note that, while the footprint is generally smaller for carport systems, you may lose some parking space due to the footers required.

Additional advantages of a carport installation include:

- The system provides shelter and shading for the cars that park underneath (those parking spots become highly desirable spots)

[29] IREC "Freeing the Grid 2013, Best Practices in State Net Metering Policies and Interconnection Procedures" November, 2013 available at http://freeingthegrid.org/wp-content/uploads/2013/11/FTG_2013.pdf
[30] Jason B. Keyes, Kevin T. Fox. "Comparison of the Four Leading Small Generation Interconnection Procedures." Prepared for the Solar America Board for Codes and Standards by the Interstate Renewable Energy Council. Oct 2008.
[31] Dave Click, Bob Reedy. "PV Generation and Its Effect on Utilities: Perspectives from the Other Side of the Meter." *SolarPro*, Jun/Jul 2013.

- As compared to installing solar PV in an open field, pavement is easier and more reliable to install PV on a hard flat surface
- You do not need to worry interfering with the roof of the building, structural loading issues
- You typically have reduced liability from a roof installation as the solar PV is no longer part of the building

Building a solar carport includes some considerations that are not typically encountered with rooftop and ground-mounted systems. Due to the large size of the structure and the need for stable supporting members, geotechnical evaluations are often necessary during the design phase. A common challenge that arises during construction is navigating through all of the underground utilities and other surprises. PV implementers rarely have the expertise to build such structures, so much of the concrete and steel work will be completed by other contractors, adding complexity to the project. A surveyor, geotechnical engineer, structural engineer, drilling excavator, concrete supplier, and steel erector are professionals that will be active in the carport project. Finding a carport implementer that has experience with the local permitting process will greatly facilitate the successful completion of the project. A code-compliant design often includes considerations for rights-of-way, offsets, and accessibility for the disabled and for fire service vehicles.

The highly visible nature of a carport structure requires that craftsmanship be aesthetically pleasing. Managing wiring and electrical conduit should be a priority. When selecting the materials used to construct the structure, recognize that a painted structure will require recurring maintenance costs. All system components should be installed in a manner and location that will minimize potential vandalism, theft, or accidental damage[32].

In addition, the schedule and impact on your parking lot users should be factored in. You may need to provide alternate parking options during construction.

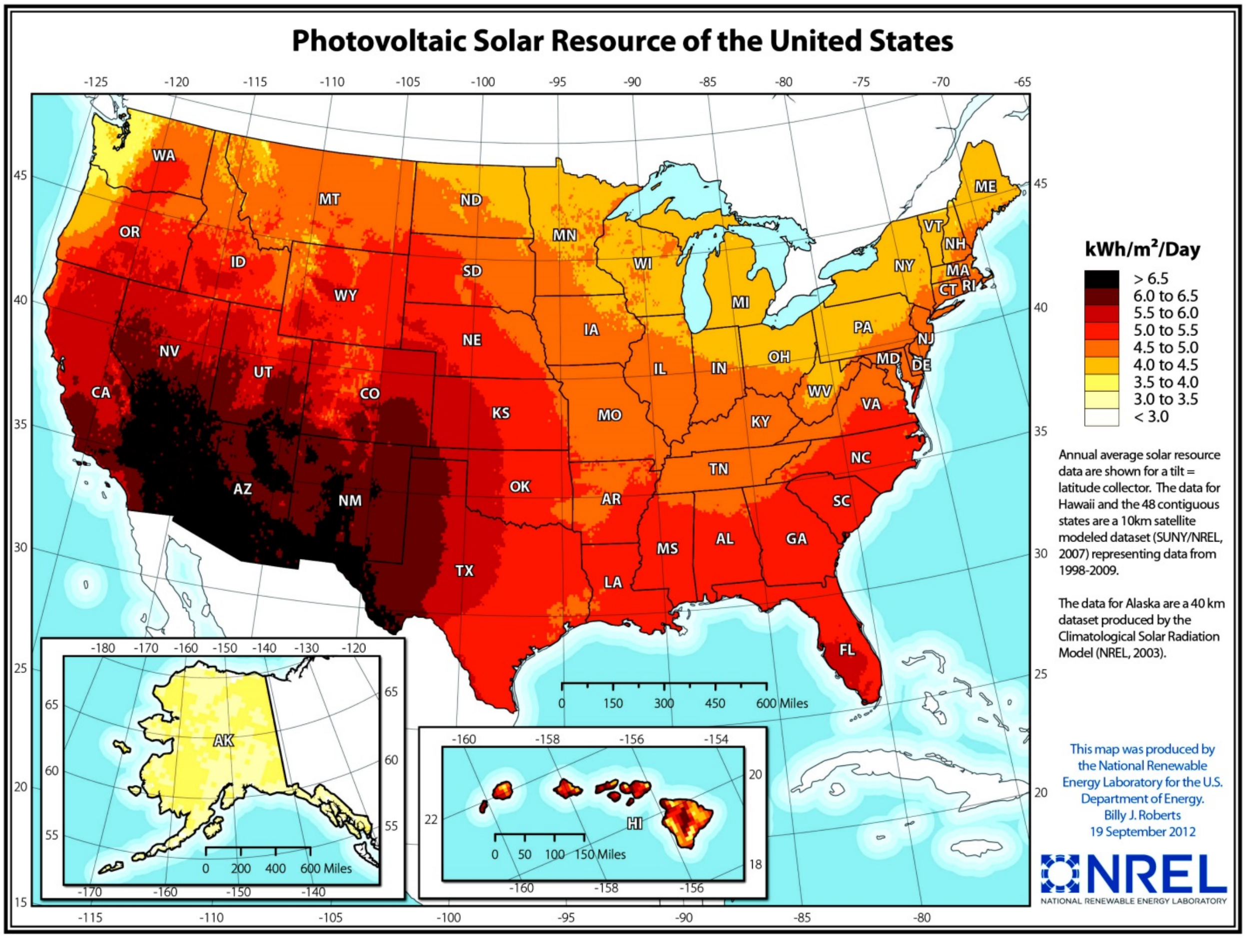
Solar Insolation

Solar insolation is the amount of solar energy that falls on a given area over some period of time. Insolation is often given in terms of kilowatt-hours (kWh) of energy per square meter per day. A similar concept is solar irradiance, which is the instantaneous power that falls on a given area at a single instance in time (often measured in watts per square meter). Solar insolation is simply the solar irradiance levels multiplied by the amount of time those levels are observed.

The output from a PV array is directly related to the amount of insolation that falls on the array. This is because current from a PV module increases as the irradiance striking the module increases. The EPA recommends that candidate PV sites have insolation levels higher than 3.5 kWh per square meter per day. As is depicted in Figure 9, most of the continental United States and Hawaii have annual average insolation levels greater than 3.5 kWh per square meter per day.

Tracking systems follow the sun as it moves through the sky, thereby increasing the amount of irradiance that strikes the array during the course of a day. The additional insolation landing on some single-axis tracking systems can increase output by 24% relative to a fixed-tilt array, while some dual-axis tracking systems can experience 38% more output.

[32] David Brearley. “Designing and Deploying Carport-Mounted PV Systems.” *SolarPro*. Issue 7.1, Dec-Jan 2014.



(Source: NREL)

Figure 9. Average Daily Solar Insolation in the United States[33]

To determine the insolation at a given location, many resources are available. The PVWatts calculator is a simple tool that allows a user to select a general location and view the typical solar insolation throughout the year[34]. The detailed data that underlies the PVWatts tool is typical meteorological year (TMY) weather data, which can be downloaded from the National Solar Radiation Data Base (NSRDB)[35]. TMY data is meant to represent a typical year, and it may not include extreme or unusual weather events. For this reason, TMY data can under- or over- estimate insolation by 10% on a yearly basis and by 30% on a monthly basis[36]. To better understand the best- and worst-case scenarios for solar insolation, many years of historical weather data should be analyzed. The NRSDB also provides historic weather data. Commercial vendors are another option for acquiring very detailed and location-specific insolation data.

More sophisticated tools, such as the System Advisor Model (SAM), PVSyst, PV-DesignPro, and PV*SOL, allow users to evaluate how solar insolation and shading might impact the production from a customized PV system. These tools provide flexible means of inputting weather and insolation data.

[33] NREL. http://www.nrel.gov/gis/images/eere_pv/national_photovoltaic_2012-01.jpg
[34] PVWatts can be accessed at http://pvwatts.nrel.gov/
[35] The National Solar Radiation Database can be accessed at http://rredc.nrel.gov/solar/old_data/nsrdb/
[36] "PVWatts: Cautions for Interpreting the Results." NREL. http://rredc.nrel.gov/solar/calculators/pvwatts/interp.html

Energy Storage

As part of your technical assessment, you may want to consider the addition of energy storage to your building. Energy storage can perform the following applications:

- Backup Power: Chances are that, if your building has critical loads that require backup power, you already have it installed. If not, you may consider complimenting your PV system with energy storage to provide backup power. Energy storage for backup power has been deployed for many decades and is a well-understood, low-risk solution. You will need to work with your PV system designer to identify critical facility loads, and they can help you size a system.
- Power Quality Management: If your building has strict power quality requirements, energy storage can serve as an Uninterruptible Power Supply (UPS) or to help manage power quality. This application is well understood, and your system designer can help you assemble a system.
- Energy Cost Management: The two applications above have been available for many years and are well understood. A relatively new application is using energy storage to manage energy costs. Some companies (both solar developers and energy storage companies) offer products for this application. Energy cost management can be achieved by (1) discharging the energy storage during periods of high demand to reduce your demand charges or (2) charging the energy storage during periods of low energy price and discharging during peak pricing periods. This application could save on energy costs but is a function of the difference between on-peak and off-peak energy prices, how many months peak prices are in effect, how big demand charges are, and how many months high demand charges are applicable. Since this is a new application and involves new hardware and software, consider the following before selecting a demand-control hardware or software provider: how long the vendor has been in business, how current systems are performing, what validation they have done, efficiency of system, how controls work, and what the expected operations and maintenance costs are.

At this time, only a few utilities offer incentives for energy storage, but this may change as the energy storage industry grows and the need for distributed generation expands for power assurance. Visit http://www.energystorageexchange.org/policies to monitor the availability of incentives. For more information on energy storage technologies, case studies and applications, visit http://energystorage.org/energy-storage or http://www.sandia.gov/ess/tech_batteries.html.

Resources

Many great tools and informational resources are available for free to help support your technical feasibility assessment. Some of them are referenced above; the full list includes the resources listed in (Source: Navigant)

Table 3.

Resource	Description	Link
Solar Power Prospector	Provides maps of solar resources across the U.S.	http://maps.nrel.gov/node/10
National Solar Radiation Data Base	Includes historic weather and typical meteorological year data for multiple locations	http://rredc.nrel.gov/solar/old_data/nsrdb/
PVWatts	Simple calculator that determines the expected electricity production from an array	http://pvwatts.nrel.gov/

Resource	Description	Link
System Advisor Model (SAM)	Sophisticated calculator that determines expected performance and financial indicators of PV systems	https://sam.nrel.gov/
U. of Oregon sun path charting software	Creates sun path charts in Cartesian coordinates for different times of day and month	http://solardat.uoregon.edu/SunChartProgram.php
DNV wind load calculator	Estimates wind loads applied to sloped modules on flat roofs	http://www.dnvusa.com/industry/energy/segments/solar_energy/index.asp
Freeing The Grid Report	Provides information on state and local interconnection rules	http://freeingthegrid.org/
National Solar Permitting Database	Details the PV permitting requirements across the U.S.	http://solarpermit.org/
Solar Ready Buildings checklist	Checklist that can be used when building plans are being developed	http://www.nrel.gov/docs/fy10osti/46078.pdf
Open Energy Information (OpenEI)	Includes links to many useful PV-related websites	http://en.openei.org/wiki/Gateway:Solar
Solar Census Software	Online rooftop shade analysis tool	http://www.solarcensus.com/
Open PV Project	A comprehensive database of PV installations in the U.S.	https://openpv.nrel.gov/
Technology Performance Exchange	View product and performance data for various PV modules	https://performance.nrel.gov/
GoSolarCalifornia	Database of PV equipment that is eligible for incentives in CA	http://www.gosolarcalifornia.ca.gov/equipment/

(Source: Navigant)

Table 3. Useful Resource Related to Technical Feasibility Assessment

Detailed Technical Potential Studies: Some parts of the country have conducted building-level technical potential studies with the assistance of third parties. These studies include the following, among others:

- Building-level technical potential information at many locations across the United States is available from www.sunnumber.com, and www.geostellar.com.
- The county of Los Angeles shows the results of a detailed study at http://solarmap.lacounty.gov/
- New York City has made a solar map available at http://www.nycsolarmap.com/
- The city of San Francisco conducted a detailed study, which can be found at http://sfenergymap.org/

This is just a sampling of studies. You should check whether a study has been done in your area, as it can be a valuable resource for your feasibility assessment.

Financial Feasibility

Assessing Financial Impacts

Once you have taken advantage of all available load reduction opportunities, the value of a solar PV system is derived from the ability to either offset energy and demand charges or secure stable electricity pricing. In many cases, solar potential energy correlates with peak demand, where electricity prices are at their highest. Estimating the impacts from avoided energy charges is a straightforward calculation if you have information on past energy bills, utility rate structure, and potential solar output. However, estimating demand charge savings is more complicated. Given that PV is a variable resource and your building's peak load could be variable, it is difficult to know if and how much PV will offset your peak demand charges. A rough estimate can be arrived at if you have hourly load data and access to hourly PV simulation tools (see Section 0 for a listing), you could run simulations to estimate savings, realizing that the actual savings may be zero in a given month or year.

Depending on how your firm makes decisions, you should measure solar PV against different metrics:

- Payback Period: Payback from a directly owned system should be done by considering reduction in utility bills, tax credits and other incentives, while third-party-owned system paybacks should be considered by comparing difference in the cost of your negotiated price (including any escalator) versus what you would have paid to your utility. Therefore, historical and current electricity pricing should be reviewed when calculating the potential benefits of a solar PV installation.
- Levelized Cost of Electricity (LCOE): LCOE captures the life cycle costs and lifetime energy production. The EPA has recently released a LCOE[37] calculator, which can be used to more closely evaluate the financials and potential payback of a solar investment or third party owned solar PV system. LCOE is also calculated in the SAM model discussed in Section 0 and as shown in the following equation:

$$LCOE\ (\frac{\$}{kWh}) = \frac{\text{Total Life Cycle Cost}}{\text{Total Lifetime Energy Production}}$$

- Return on investment (ROI): If you use ROI, a cash flow model may help you make decisions. You can create one on your own or leverage existing ones, such as the Cost of Renewable Energy Spreadsheet Tool (CREST) model available from NREL and described below in Section 0.

Some building owners may be aware of net metering in residential solar PV systems. This typically does not impact commercial systems because they are not sized such that power is exported back to the grid (i.e. the PV system output is less than the building's baseload). However, if rate structures are changed as a result of net metering reforms, the economics of a solar PV system may be impacted. Several states and utilities are considering changes to their net metering programs. We recommend checking on local proceedings in your state.

Cost Data

An important input to your financial feasibility assessment is the cost of solar PV and associated operations and maintenance costs. The costs of solar PV have been declining over time and vary by system size, state, and technology type. Rather than report current cost data here, we recommend that you collect up to date information when you conduct your assessment. Sources of cost information include the following:

- **Annual Tracking the Sun Report:** The Lawrence Berkeley National Laboratory (LBNL) publishes an annual study that reports cost data by system size and location. The 2013 report is available at http://emp.lbl.gov/sites/all/files/lbnl-6350e.pdf.
- **CSI database:** The California Solar Initiative reports system costs for projects that apply for rebates. Data is available at http://www.californiasolarstatistics.ca.gov/.
- **SEIA reports:** The Solar Energy Industries Association puts out regular installation and cost information and

[37] LCOE Calculator: http://www.epa.gov/greenpower/documents/events/webinar_20140416_calculator.xlsx

the most recent report is available at http://www.seia.org/research-resources/solar-market-insight-report-2013-year-review

- **NREL manufacturing cost team:** NREL has a manufacturing cost team that periodically looks at solar costs. Their most recent report is available at http://www.nrel.gov/docs/fy12osti/53347.PDF.

Resources

Many great tools and informational resources are available for free to help support your financial feasibility assessment. Some of them are referenced above; the full list includes the item below. In addition, the SAM model discussed in Section 0 can be used for financial analysis.

CREST: NREL developed CREST, which is an economic cash flow model, to allow policymakers, regulators, and the renewable energy community to assess project economics, design cost-based incentives (e.g., feed-in tariffs), and evaluate the impact of various state and federal support structures. It is available at https://financere.nrel.gov/finance/content/crest-cost-energy-models.

PV Value: Sandia National Laboratory developed PV Value, which is intended to help determine the value of a new or existing PV system. It is designed to be used by many different parties. A PV system is valued using an income capitalization approach, which considers the present value of projected future energy production along with estimated operating and maintenance costs that are anticipated to occur during the PV module power production warranty timeframe. PV Value is available at http://energy.sandia.gov/?page_id=8047.

Template Contracts: NREL and DOE have been organizing an initiative to develop standardized contracts for the solar industry. They have produced a standardized contract for commercial power purchase agreements (PPAs), which is available at https://financere.nrel.gov/finance/solar_securitization_public_capital_finance.

Utility Rate Data: If you do not have immediate access to your electric utility rates, the Open Energy Information (OpenEI) database maintained by NREL tracks utility rates around the country. It is available at www.openei.org.

How to Procure Solar PV

Ownership Options

Once you have decided to move forward with a solar project at your facility, or facilities, you should determine which ownership option is best for you and your organization. Currently, there are two widely used ownership models. Each has its own advantages and challenges and is determined by individual preference and overall project goals. Below we list several types of ownership models available to building owners looking to install solar PV.

Direct Ownership

Directly owned systems accounted for 49% of the commercial markets in 2009 and increased to 58% in 2011[38]. This is due to a combination of a recovery in the lending markets, improvement in property values, and additional options available in the market, such as property assessed clean energy financing (PACE) in CA. Additional benefits, which have driven growth, include a 30% federal Investment Tax Credit (ITC) applied to the cost of the installation and direct cash incentives offered by some states and utilities, including rebates or performance payments. [39]

While direct ownership has some key benefits, mainly that the owner captures 100% of the electricity produced by the system and thus, maximizes the utility bill savings , it does come at the cost of assuming all of the financial and operational risks over the life of the system. However, if you are willing to assume these risks, direct ownership will also provide direct benefits, such as tax credits, depreciation benefits, rebates, and, depending on the state, RECs. It is important that you evaluate your tax burden when evaluating direct ownership so that you can monetize the tax credits effectively. Benefits such as tax credits, rebates, and even realizing the value of RECs can vary, and in most cases the owner will need to fully finance the project up front and wait several months to capitalize these benefits. Aside from uncertainties surrounding the financial benefits, self-ownership also comes with performance risks, although this may be mitigated by negotiating a production guarantee from the vendor. Fully understanding the maintenance and monitoring systems will be key in mitigating these risks and developing a successful and sustainable solar project.

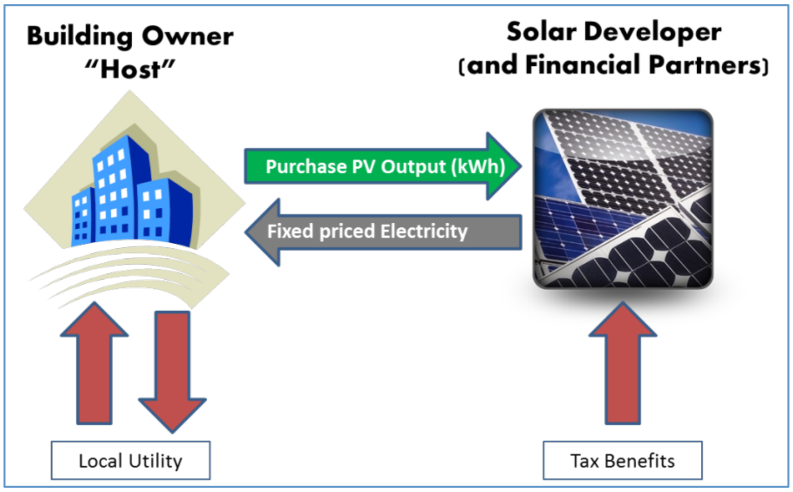
Third-Party Ownership

Third-party-owned systems accounted for 42% of all commercial solar installations in 2011 and are attractive because they have no or low upfront costs[40]. Additionally, these systems have benefits beyond reducing the building owner's upfront capital outlay. Third-party-owned PV systems are beginning to increase in popularity in the commercial sector; for example in California, they have grown to represent 26% of all commercial systems in 2012[41]. This growth is due to growing maturity of financing mechanisms available and developing incentives.

[38] P.10 http://www.alta-energy.com/reports/SEPA%200612%20Paper%20-%20PV%20Ownership%20Report.pdf
[39] http://www.seia.org/policy/finance-tax/solar-investment-tax-credit
[40] P.15 http://www.alta-energy.com/reports/SEPA%200612%20Paper%20-%20PV%20Ownership%20Report.pdf
[41] http://votesolar.org/wp-content/uploads/2012/08/Commercial-Scale-Solar-Financing-Report-07-30-12.pdf

Power Purchase Agreement Project

A PPA is a legal contract between an electricity generator (provider) and a power purchaser (buyer). Typical contract terms last 15 to 25 years. During this time, the power purchaser buys energy (and possibly other services) from the electricity generator. PPAs play an important role in financing independently owned (i.e., not owned by a utility) electricity-generating assets[42]. Figure 10 illustrates how a PPA works.



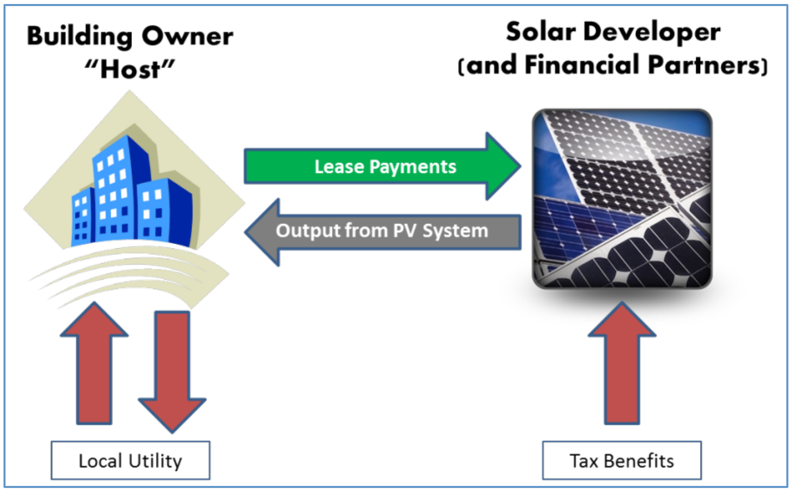
(Source: NREL)

Figure 10. Third-Party Power Purchase Agreement

Lease/Pre-Paid Lease Project

In a solar lease (or pre-paid lease) project, the customer does not purchase power from a third party but simply leases the equipment and receives the power generated by that equipment[43]. The PPA diagram above has been slightly modified in Figure 11 below to represent the relationship between involved parties in a solar lease project. Under this agreement, the solar developer typically guarantees a level of availability or system production level that is a function of solar insolation. This is typically called the performance ratio, which is the ratio of the electricity generated to the electricity that would have been generated if the plant converted sunlight at the level expected from the nameplate rating or advertised rating. Performance ratios for new systems typically range from 0.6 to 0.9[44].

[42] http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/fed_facility_guide_fc_chp.pdf
[43] http://www.nrel.gov/docs/fy10osti/46723.pdf
[44] http://www.nrel.gov/docs/fy13osti/57991.pdf



(Source: NREL)

Figure 11. Third-Party Lease

(Source: Navigant)

Table 4 below presents a summary of the advantages and challenges of each of the types of ownership models discussed above.

	Direct Ownership	Third-Party PPA	Third Party Lease
Advantages	▶ Full control over a project: design, operations, and risks ▶ Ability to choose what to do with renewable energy attributes generated by the project (retain or monetize) ▶ Renewable energy tax incentives (federal and state)	▶ No/low upfront outlay of capital and potentially savings passed on from federal tax incentives ▶ Predetermined electricity price for 15–25 years ▶ No operating and maintenance responsibilities ▶ Path to ownership (if included as an option in PPA agreement) ▶ Opportunity to wrap into larger performance contract (including load reduction/energy efficiency improvements)	▶ No/low upfront outlay of capital and potentially savings passed on from federal tax incentives ▶ Process similar to other conventional leases for automobiles, etc. ▶ Possible option in states that do not allow PPAs ▶ Fixed lease payments ▶ No O&M for solar lease (not available for net leases)
Challenges	▶ Have to finance or pay for it ▶ Must monitor the system performance	▶ The process of negotiating a PPA can be lengthy and costly	▶ May be less expensive to self-finance ▶ Incentives accrue to lessor

(Source: Navigant)

Table 4. Advantages and Challenges of Direct-Ownership, Third-Party PPAs, and Third-Party Leases for Building Owners45

[45] Source: Cory et al. 2008, Pearlman 2011a. (adapted from http://www.nrel.gov/docs/fy12osti/53622.pdf)

Building Owner Roof Lease to Solar Developer

Building owners that lease their spaces to tenants may find that there are other pathways to solar than through direct-ownership or third-party ownership. Recently, building owners have been working with and seeking out solar developers to lease out roof space to site solar arrays. In many ways, this method is similar to an Enhanced Use Lease (EUL). The agreement is not an energy contract but rather a real estate agreement that focuses on unused roof space. In this scenario, the owner is neither obligated to use the solar electricity produced nor can they benefit from any incentives typically available to solar project owners or developers. In many cases, developers offer the power produced by the system to the building owner, who in turn can pass that savings on to their tenants. Considerations for both parties include access for maintenance, tax and depreciation issues, liability for damage, and responsibility for utility interconnection.

24 Applegate Drive, Robbinsville, NJ

Prudential Real Estate Investors (PREI) is hosting an installation of solar panels owned and operated by SunRay Power in a roof lease agreement. The site consists of 1 Million square feet of warehouse/industrial property built in 2001. The system will generate a total of 6.8MW when completed. Phase 1 consisted of 12,000 panels generating an estimated 3.4MW of power.

Photo courtesy of Prudential

Procurement Strategies

As solar PV has grown in popularity, many solar developers and vendors have entered the marketplace to take advantage of the growth. This rapid growth has given consumers many options; however, it has also resulted in non-standardized practices and procedures. To prepare yourself for maintaining best practices during your solar procurement, there are several steps you should take before contacting potential vendors or developing a request for proposal (RFP). First, you should collect all relevant facility and utility information and pre-screen the site to enable vendors to more accurately estimate the costs and design the system to the best possible standards[46]. Once relevant data is collected, you can then create the RFP package for consideration by potential vendors. If you are considering different financing models, it is always best to request both proposals from the vendor at the same time so that they can be compared side by side during the initial stages of the planning process. The EPA has recently released a set of tools and templates for higher education that can be adapted for use in the private sector.[47] These should be considered as a baseline guide as you navigate the procurement process.

[46] Source EPA. http://www.epa.gov/greenpower/documents/events/webinar_20140416_guide.pdf
[47] Source EPA: http://www.epa.gov/greenpower/events/16apr14_webinar.htm

U.S. DEPARTMENT OF ENERGY

Financing a Solar PV System

Key Questions[48] to Consider

Several key considerations related to financing must be weighed before considering how you will finance a solar installation at your property. These are tied to the ownership options discussed above in Section 0.

In order to answer many of these questions, you must first understand which incentives and other options are available for your specific project. Incentives from federal, state, and local governments, as well as utilities, are available to those who choose to finance a system themselves. These incentives are outlined below. Additional considerations are outlined for third-party-owned and financed systems.

Key Considerations

- Do you have access to financing or have cash on hand?
- Can you take advantage of the tax credits?
- Are you located in a state that allows third-party ownership?
- Are local rebates and incentives available where you are located?
- Do you have other investment opportunities or needs?

Direct Ownership

The cost of owning and self-financing a solar PV system has continued to decline in the past several years. Not only has the price per kW decreased over the past several years, but real costs are dramatically less when considering a wide range of financial incentives that are offered to businesses that choose to finance solar on their own. These incentives are offered at the federal, state and local government level, and in many cases can be combined with additional incentives offered by your utility. For a comprehensive listing of all incentives that may apply to your project, visit the DSIRE database at http://www.dsireusa.org/. Be aware when searching the database that not all incentives apply to commercial systems; however, many do. Applicable types of federal, state, local, and utility incentives are outlined below.

Federal Incentives

The U.S. federal government has supported energy investments for many years under various forms of U.S. tax code favorable to solar investments. These include two distinct programs aimed specifically at commercial building owners and developers - the ITC and Depreciation of Solar Energy Property. A summary of each is below and detailed information of each of these programs can be found on the DSIRE website.

Federal Incentives Impact Model-300kW Commercial System:

- $1,071,000 (at $3.57/W)
- 30% ITC = $321,300
- NPV of MACRS Depreciation Benefit = $246,544
- 53% of Initial Capital Costs Covered by Federal Incentives

ITC: The ITC is a corporate tax credit of 30% of the system cost for commercial solar systems. This credit has been extended through the end of 2016.

Depreciation of Solar Assets: A variety of solar-electric technologies are eligible under the federal Modified Accelerated Cost-Recovery System (MACRS). This

[48] Source: Commercial Solar Financing Overview, April 8, 2014, Jason Coughlin

incentive allows businesses to recover investments in solar property through depreciation deductions. Five year MACRS schedule, allowing for accelerated depreciation-related deductions, can help to recover up to 26% of system costs on a present value basis[49]

State, Local, and Utility Incentives

Many states, local governments, and utilities offer solar PV incentives that should be considered when financing a solar installation. These include such incentives as upfront cash incentives, performance based incentives (including feed-in tariffs), and many property and sales tax incentives. These incentives vary by state and location and some incentives are limited by certain funding levels or volume of participants. Again, the DSIRE website is the best source when searching for what incentives apply to your project or projects.

Direct Cash Incentives: These incentives are offered in a variety of ways and include upfront rebates, and grants. Typically, these types of incentives help to reduce upfront costs. Alternatively, performance based incentives provide a secure income stream that is attractive when pursuing traditional financing. More than 20 states and 200 utilities offer these types of incentives and they can cover as much as 30% of projects costs[50].

Property Tax Incentives: These tax incentives offer exemptions, abatements, credits, or special assessment that mitigate or eliminate the increase in assessed taxable value of a property. More than 30 states offer various forms of property tax incentives for solar installations[51].

Sales Tax Incentives: This type of tax incentive allows for exemptions (or refunds) of sales tax for the purchase and installation of a solar PV system. Currently, 20 states offer some form of sales tax incentives for solar installations[52].

Tax Credits: Similar to the federal ITC, some states have their own investment tax credits. These credits operate in the same way as the federal credit and provide a direct reduction in a tax payer's tax liability for a portion of the costs associated with a solar installation. However, state tax credits are often spread out over multiple years rather than applicable in a single year like the federal ITC. Today, approximately 20 states offer corporate investment tax credits to help offset the cost of purchasing and installing solar[53].

Loan Programs: State and local governments offer a variety of loans that can be applied to non-residential projects. These typically have maximum loan amounts of around $1 million[54].

Permitting Incentives: Permitting incentives reduce or take away local building permit fees, plan check fees, design review fees, and/or other charges that businesses will incur when installing a solar energy system. The incentives are typically provided at the local level and vary widely by location[55] .

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[49] http://emp.lbl.gov/sites/all/files/REPORT%20lbnl-1410e.pdf
[50] http://www.dsireusa.org/solar/solarpolicyguide/?id=10
[51] http://www.dsireusa.org/solar/solarpolicyguide/?id=11
[52] http://www.dsireusa.org/solar/solarpolicyguide/?id=12
[53] http://www.dsireusa.org/solar/solarpolicyguide/?id=13
[54] http://www.dsireusa.org/solar/solarpolicyguide/?id=15
[55] http://www.dsireusa.org/solar/solarpolicyguide/?id=16

Additional Considerations

Along with incentives there are several other factors that could impact the lifetime cost of a Solar PV system. These include Solar Renewable Energy Credits (SRECs)typically offered by utilities, property assessed clean energy (PACE) financing and the overall impact on your utility bill in the form of reduced load. These factors should be considered once upfront costs are determined and should be incorporated into financial models when calculating payback periods and ROI.

SRECs: SRECs represent the environmental attributes of solar energy systems and can be traded separately from the actual electricity produced by a system. One SREC is generated for every megawatt-hour (MWh) of electricity generated from the system. For example, a typical 100 kW system could generate 120 SRECs annually. This could amount to over $20,000/year in New Jersey where the weighted average price in April 2014 was $174.15 per credit.[56] SRECs are a form of RECs that were created to aid utilities in meeting Renewable Portfolio Standards (RPS) implemented by states to meet certain energy goals. SREC markets currently exist in New Jersey, Massachusetts, Pennsylvania, Maryland, Ohio, Delaware, North Carolina, and the District of Columbia[57]. Other states are considering implementing similar laws to allow for SREC markets to exist in their states; however, it is not clear if, when or where new markets will develop. System owners could sell these directly to purchasers or sell them to an aggregator providing an extra revenue stream.

PACE Financing: State and local governments offer these incentives, which allow property owners to borrow money to pay for energy improvements which is then repaid via property taxes. Typically, these programs are an alternative to a loan and have a special assessment on the property for a number of years that passes with the property from owner to owner. These programs are available in a limited amount of locations; however, their numbers are growing as they gain greater acceptance across the United States.

PBIs: These incentives are production-based cash payments offered by utilities for the number of kWh generated by the solar PV system. These incentives are based on a system's actual performance and are unlike other incentives that may be based on a system's rated capacity.

Utility Bill Considerations: Utility bill impacts should also be considered when looking at the overall financing of a solar PV system. Solar PV systems provide power to their host building during

Staples Headquarters, Framingham, MA

Staples worked with Sun Edison through a PPA to install their Solaire solar parking structure 684 kW system that will generate an estimated 700,000 kWh/year at their headquarters in Massachusetts. This system is designed to withstand 55 pounds per square foot of snow loads and 100 mph wind loads, and consists of more than 2,440 solar modules or panels. The solar power will offset more than 12,000 tons of CO_2 over the next 20 years.

Photo courtesy of Solaire Generation

[56] https://gats.pjm-eis.com/gats2/PublicReports/SolarWeightedAveragePrice
[57] http://www.srectrade.com/srec_markets/introduction

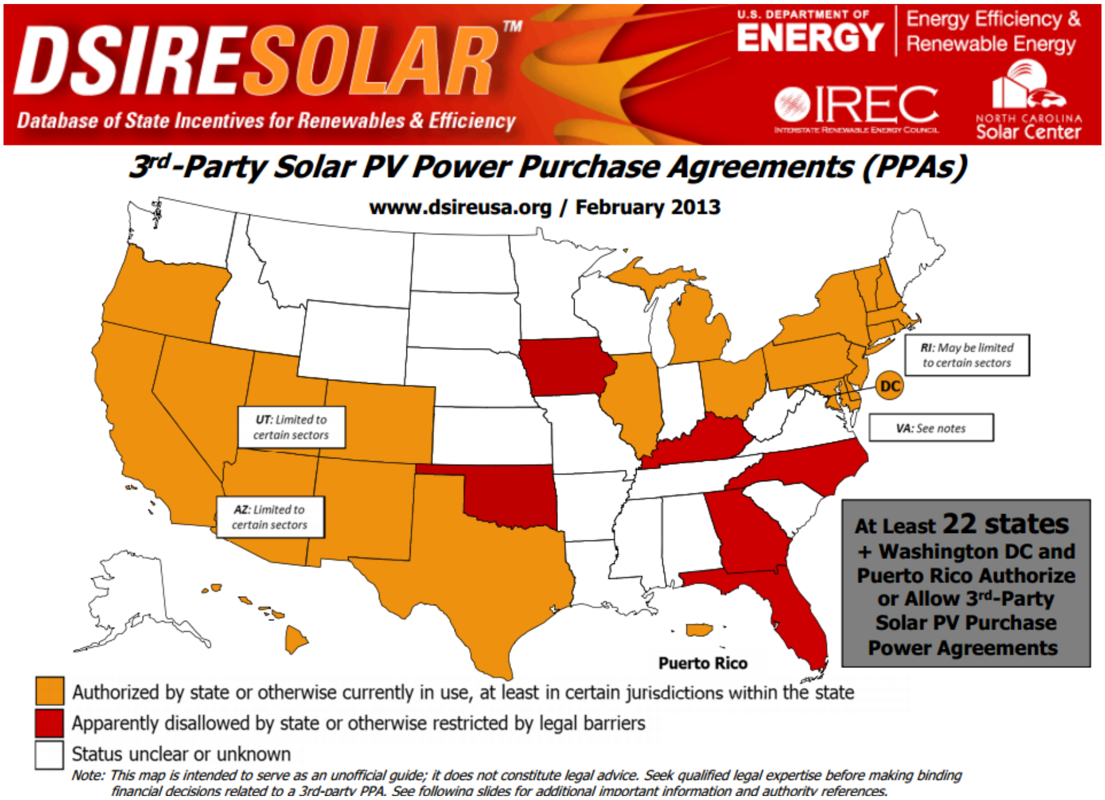
peak hours. During these hours, depending on your electricity rate structure, the typical cost of electricity may be much higher than during off-peak hours. A solar PV system can dramatically impact the load during peak hours. This savings should be built in to the overall project cost.

Residual Value: Typically, solar PV panels have a performance warranty of 25 years but may have a useful life much longer than that. As a result, a project that is financed for a 10- to 15-year term can be significantly impacted by residual value (RV) or salvage value. In the LCOE model, the RV should be incorporated into the total cost of operation, as shown in the equation found in section 0.

Third-Party Ownership

Third-party ownership is an alternative to direct ownership if self-financing or incentives are not available or do not provide favorable financial results. As mentioned above, the two models currently widely available across the United States are the PPA and the third-party lease model. While these are available in many states, there are a number of states where this type of financing is not yet allowed. Figure 12 below is an illustration from DSIRE showing where third-party PPAs are allowed by state and where it is unclear how these agreements should be treated and protected. If PPAs are allowed in your state, you may still find that contract terms vary among vendors. NREL, along with a consortium of solar energy developers, law firms, financiers, and analysts, through the Solar Access to Public Capital (SAPC) working group, has released a standard commercial PPA contract[58]. In addition to this standard contract, the SAPC is working on other contract forms, such as commercial leases, as well as datasets on system and credit performance. The site will also soon include best practices for installation and O&M. The SAPC aims to provide investors due diligence tools to get more comfortable with this asset class and build and maintain solar facilities with high levels of quality assurance.

[58] Commercial PPA Contract: https://financere.nrel.gov/finance/content/terms-service-commercial



(Source: DSIRE)

Figure 12. Information from DSIRE on the Availability of Solar Power Purchase Agreements

Execution of a Solar PV Project

Assembling a Team

At the outset of a project, it is advisable to assemble a team of individuals who will contribute to the successful completion of the project. Good communication and collaboration between the team members will ensure that a proactive rather than reactive approach is taken to addressing challenges that arise. (Source: Navigant)

Table 5 gives some examples of members who might form such a team.

Team Member	Role
Facility representative	Makes final decisions related to the implementation alternatives available
Owner's engineer	Contracted by the facility owner to perform all project engineering or simply to act as an overseer of engineering design
Attorney or general counsel	Protects the legal interests of the facility owner
Construction manager	Oversees permitting, procurement, safety processes, construction, and commissioning
Utility representative	Ensures that utility interconnection requirements are met and any rebates are obtained
Financial representative	Coordinates the solicitation process, monitors budget constraints, and ensures that project meets financing requirements; can be in-house or hired consultant
Facility engineer/manager	Works with contractors to grant access to mechanical and electrical areas, and to coordinate equipment placement and connection points

(Source: Navigant)

Table 5. Project Team Members and Their Roles

Soliciting Bids and Selecting a Winner

Selecting an experienced and highly capable contractor to install the PV system is crucial to the success of the project. Installers certified by the North American Board of Certified Energy Practitioners (NABCEP) have at least one year of experience and have completed training courses and rigorous exams. Although the NABCEP PV installer certification is nationally recognized, it is a voluntary program and is rarely required to install PV systems. Some incentive programs in various states require that the system be installed by NABCEP-certified workers. On the other hand, each state requires contractor licensure. Another option is to work with the local chapter of the National Electrical Contractors Association, which has members across the country that are apprenticed and qualified to install solar PV.[59] Most states allow those having a general electrical license to build PV systems, but several states require a more specialized

[59] National Electrical Contractors Association provides a database of contractors qualified to install solar: http://apps.necanet.org/PortalTools/DirConnection/Index.cfm

license focused on solar installations[60]. The NABCEP[61] and SEIA[62] websites are good places to find certified and licensed vendors, while the Interstate Renewable Energy Council (IREC)[63] and DSIRE[64] websites are useful for finding information about licensing and certification requirements in various states.

Obtaining at least three PV contractor quotes will allow you to uncover the best value and competitive advantage. Another option is to release an RFP. The DOE has a document that lists the steps involved in issuing an RFP[65]. In addition, that document recommends that the RFP include the following details:

- Clarification of party responsible for obtaining permits
- Commissioning plan
- Definition of infrastructure requirements
- Requirements for historic buildings
- Due diligence related to unexpected changes in scope and nature of work
- Limits on proposed project timeline
- Requirements for extended warranties or maintenance agreements
- Restrictions on parties allowed to submit proposals
- Statement of work
- Specification of post-commissioning performance
- Criteria and process used to evaluate proposals
- Explanation of how proposal process will be administered
- Timelines for proposal process

Once the RFP is complete, there are multiple websites where you can post the RFP to be viewed by solar contractors. The DOE has a useful webpage that lists some of these sites[66].

A multi-site RFP can be more efficient. Dealing with a single contracting entity might be more desirable than dealing with multiple contractors. Another advantage to a multi-site RFP is the possibility of reducing project costs through economies of scale. Conversely, it may be more desirable to award contracts to multiple firms in order to mitigate the contractor risk. The timeline of each site is worth considering before pursuing a multi-site contract. With a multi-site RFP, construction cannot begin on one site until all sites have undergone a walk-through and have been evaluated by potential bidders.

The facility walk-through is a way for potential bidders to evaluate the site and sharpen their cost and time estimates. During this process, the potential bidders will assess any obstacles and challenges that may arise during the project. They will be interested in visiting the rooftop or space where the array will be constructed, and they will want to know where the points of interconnection to the facility will be. This is the standard process for public sector procurements, but it is not always done for private sector procurements.

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60 "Contractor Licensing and Certification." Database of State Incentives for Renewable Energy. http://www.dsireusa.org/solar/solarpolicyguide/?id=23
61 NABCEP provides a Certified Locator at: http://www.nabcep.org/installer-locator
62 The SEIA membership directory can be accessed at: http://www.seia.org/directory
63 The IREC Solar Licensing Database can be accessed at: http://www.irecusa.org/workforce-education/solar-licensing-database/
64 DSIRE includes contractor licensing requirements at: http://www.dsireusa.org/incentives/index.cfm?SearchType=License&&EE=0&RE=1
65 Blaise Stoltenberg, Eric Partyka. "Procuring Solar Energy: A Guide for Federal Facility Decision Makers." U.S. Department of Energy. Sep 2010. www.solar.energy.gov/federal_guide/
66 The DOE webpage that provides links to locations where RFPs can be posted is accessible at: http://apps3.eere.energy.gov/greenpower/financial/

When selecting a winning bid, it is useful to define a list of criteria and a meaningful scoring method. Tally the scores from each bid and use those scores to identify the top several bids. Once the top bids are identified, discuss the difficult-to-quantify pros and cons that may not have been captured in the scoring system. Closely scrutinize low-cost bids to ensure that they aren't the result of poor judgment on the part of the contractor, and ensure that each bid appropriately accounts for risk. Even if a preferred bid is identified, awarding the contract can depend on further discussions and negotiations with the contractor.

Ensuring Successful Construction

A one-line or three-line diagram, along with a site diagram, should be available at the site. These diagrams can help a facility owner or project manager ensure that construction is aligned with the diagrams. Any changes to the layout or configuration of the system should be recorded on the diagrams, along with an explanation of why the plans were adjusted.

Many of the items described in Section 0 related to inspecting a PV system are performed during the construction process to ensure a quality installation. Similarly, IREC has a useful field inspection guide that covers elements such as inspecting the array and ground mount systems, ensuring that appropriate signage is in place, and verifying that equipment ratings are consistent with the application and signs[67].

Commissioning

Once the PV system is constructed, interconnected, and operational, a commissioning process should take place. Most faulty equipment will fail soon after being put into service. The commissioning process is intended to identify these failures and align the system with expected performance. Commissioning also serves as a quality and safety control process. This is the time when the contractor's workmanship and adherence to safety requirements, manufacturer's specifications, and engineering designs should be closely scrutinized. Due to conflicts of interest, it is often prudent to hire a third-party expert to commission the system. The expectations of what will be investigated during the commissioning process and the requirements that must be met should be clearly defined during early discussions and negotiations with candidate contractors.

The commissioning process includes many of the same inspection and maintenance activities that are discussed in detail in Sections 0 and Appendix A. Along with IREC's field inspection guide referenced in Section 0, the DOE's guide for federal decision makers includes an informative checklist for commissioning[68]. In order for commissioning to begin, all permits should be signed off, and internet and permanent power should be available. Commissioning should take place in good weather conditions having irradiance levels of at least 400 W/m^2. Anytime that major system repairs are made, the system should be re-commissioned.

When the system passes a commissioning process, the facility owner can have a reasonable assurance that the system is complete, performs to expectations, is safe, and has been documented well enough that

[67] "Field Inspection Guidelines for PV Systems." Prepared by Brooks Engineering for Interstate Renewable Energy Council. Jun 2010.

[68] See Appendix B of: Blaise Stoltenberg, Eric Partyka. "Procuring Solar Energy: A Guide for Federal Facility Decision Makers." U.S. Department of Energy. Sep 2010. www.solar.energy.gov/federal_guide/

future O&M activities can be performed safely and efficiently.

How to Operate and Maintain a Solar PV System

Direct Ownership

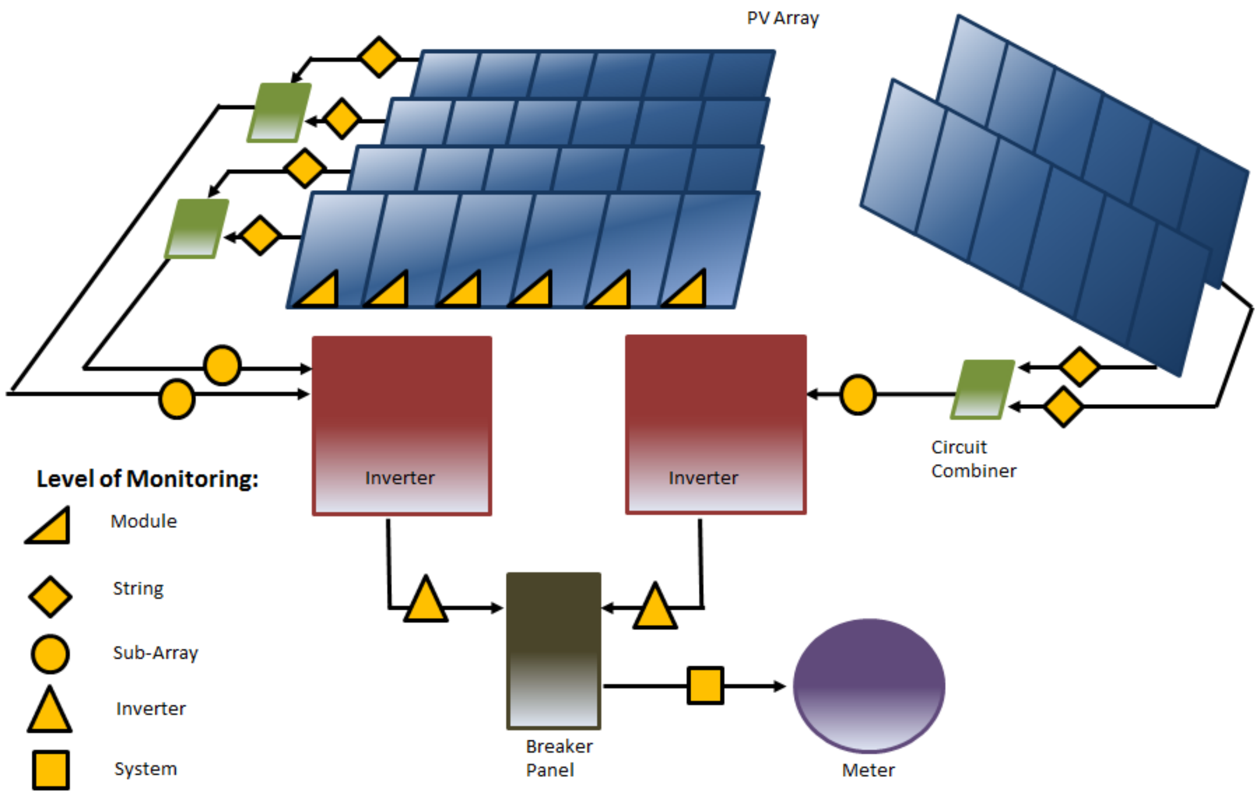
If you have decided to own and maintain your solar PV project, operation and maintenance encompasses many areas: monitoring, safety, cleaning, inspection, and annual maintenance. The following sections discuss each of these items in detail.

Monitoring

A monitoring system is a beneficial tool in identifying performance issues with a PV system and diagnosing possible causes for performance reductions. Monitoring systems may measure and display module temperature, irradiance, wind speed, ambient air temperature, and precipitation. Web portals can enable individuals to view and analyze monitored and trended data[69].

The granularity of a monitoring system is a system design option that can have significant economic impacts. The decision to employ array, subarray, inverter, string, or module-level monitoring should weigh the benefits to the costs. Because the majority of commercial PV systems use central inverters, commercial systems are rarely monitored with granularity greater than the string level. Additional granularity requires additional current transformers, data communication devices, and power supply and communication cabling and conduit. The collection of more granular data requires more sophisticated data management systems to store, analyze, and report system performance. The benefit of highly granular monitoring is that degradation in production can be more quickly discovered, and the location and cause of the issue can be narrowed to fewer possibilities. Figure 13 shows possible monitoring locations.

[69] Kyra Moore, Rebekah Hren. “Commercial PV System Data Monitoring (Part 1).” *SolarPro*, Oct/Nov 2011.



(Source: Navigant)

Figure 13. Possible Monitoring Locations

Consider a 100 kW_{AC} system that is expected to generate on average 131,400 kWh per year. The irradiance on this system is measured with a sensor having +/- 5% accuracy. If array-level monitoring is employed and a maximum of 5% inaccuracy is assumed, then the monitoring system will have a blind spot of roughly 5 kW_{AC} or 6,750 kWh/year. This means that a technician monitoring the system cannot have confidence that the system is underperforming until more than 5 kW_{AC} of power output is lost. Compare that situation to a system with string-level monitoring, where each string accounts for about 3.33 kW_{AC} of power. With 5% maximum inaccuracy in string monitoring, the blind spot is reduced to 0.17 kW_{AC} or 219 kWh/year[70]. With string monitoring, much less energy is lost before a technician can identify the issue and pinpoint the location of the poorly performing string. The system designer must weigh the cost of increased monitoring to the value of increased production and reduced man-hours spent searching for the location of the problem.

The value of the energy at risk will determine the frequency at which the system's performance should be evaluated. On a small system, it may only be necessary to compare performance to an expected or predicted value every quarter. On large systems, where the loss of an inverter might have significant economic implications, it might make sense to benchmark performance on a daily basis. Many monitoring

[70] For an informative case study on the economics of monitoring granularity, see: Casey Miller, Todd Miklos. "Determining Optimal PV System Monitoring Granularity." *SolarPro*, Aug/Sep 2013.

systems come with software that will aid in the benchmarking process. Some monitoring systems can be configured to automatically detect underperformance or inverter failures and send an alert to the appropriate personnel.

Safety

Safety is paramount when installing and maintaining a PV system, but a comprehensive discussion is outside the scope of this document. All regulations issued by the federal Occupational Safety and Health Administration (OSHA) and any regulatory add-ons at the state level must be adhered to. In addition, electrical safety requirements mandated by the NEC and the National Fire Protection Agency (NFPA) must be followed. Refer to those documents and other local, state, and federal codes.

Cleaning

Cleaning the solar panels is an O&M activity that may or may not be required. Dust, dirt, sand, tree sap, leaves, and bird droppings are common sources of PV module soiling. Module soiling can significantly reduce performance. One study in California and the desert Southwest found soiling rates to be 0.1% to 0.3% per day. At such rates, 10 days of cumulative soiling could lead to a 1% to 3% reduction in system performance[71]. Many studies have shown that rainfall and snowfall can successfully eliminate soiling and its impacts on system production. As little as 0.2 inches of rainfall can be nearly as effective as manually washing the modules and can return a system to 95% of its soil-free performance[72]. Flat arrays will not benefit from rain and snow to the degree that tilted arrays will benefit.

In regions where there are long periods without rainfall or snowfall, the degradation in system performance from soiling can become very large. An economic evaluation should be performed to determine if the cost of washing the modules will not exceed the value of the expected increase in production. Soiling is usually worst during summer months, when the value of electricity is the highest. Lost production during those times can be detrimental to the project's economic feasibility. The cost of washing a small system is often much larger than the value of the increased production, but there may be better economic justification for cleaning large systems. Another issue related to cleaning modules is the inability to predict the next rainfall or snowfall and the uncertainty of whether money spent on cleaning will be squandered if there is a rain or snow event immediately after washing the system. Despite the costs and uncertainty, many facilities have found it economically beneficial to pay for manual cleaning of the modules and to go as far as installing automated sprinkler and cleaning systems on their arrays.

If a facility chooses to use its own personnel to clean the PV system rather than to hire professional contractors, the module manufacturers can offer advice on appropriate cleaning methods and materials. It is important that staff members are trained to protect themselves against fall hazards and electric shock. Likewise, if personnel must stand on the array to clean it, they need to be aware of the areas that can support the weight of an individual in order to prevent damage to the modules. A final consideration is that

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[71] A. Kimber, L. Mitchel, S. Nogradi, H. Wenger. "The Effect of Soiling on Large Grid-Connected Photovoltaic Systems in California and the Southwest Region of the United States." PowerLight Corporation.

[72] Hammond, R.; Srinivasan, D.; Harris, A.; Whitfield, K., et al. "The Effects of Soiling on PV Module and Radiometer Performance." Arizona State University. Photovoltaic Specialists Conference, 1997. Conference Record of the Twenty-Sixth IEEE. Oct 1997.

modules should not be subjected to large temperature differentials between the module itself and the cleaning solution, or thermal stress, cracking, or breaking may occur.

Inspection

A PV system should be inspected consistently throughout its operating life. The level of rigor will depend on the various stages of the PV system's life. For example, a detailed inspection should occur as part of the commissioning process. After the commissioning process, frequent but low-rigor inspections will help reduce maintenance costs and increase system availability. If system performance declines significantly after the commissioning process, another rigorous inspection may be required to identify opportunities to improve performance. Inspections can be performed by minimally trained staff and should occur at least twice per year. Appendix A.1 includes a list of activities that can be performed as part of a routine inspection.

Annual Maintenance

PV systems are generally reliable, low-maintenance power sources, but they do require annual maintenance to ensure good performance and high availability. Although there are endless opportunities to analyze an existing system and improve performance, maintenance activities should focus on critical system components and cost-effective improvements. Maintenance activities can fall into three categories: preventative, corrective or reactive, or condition-based. Preventative maintenance includes many of the inspection activities listed in Appendix A.1 and is intended to prevent system failures before they occur. Corrective or reactive maintenance is premised on waiting until a component fails or system production declines significantly before any action is taken. Finally, condition-based maintenance uses up-to-date data on system components and performance—and possibly weather—to schedule targeted maintenance activities[73].

The report cited above from the Electric Power Research Institute (EPRI) suggests that O&M costs range from $6/kW to $27/kW for systems under 1 MW in size. EPRI found that those O&M costs represented between 5 percent and less than 1 percent of "all-in" costs.

In order to achieve high system availability, many PV integrators have found it necessary to buy spare parts, components, and modules at the time the system is built and to keep those parts onsite. With the rapid obsolescence of PV system components, this helps ensure that compatible replacement parts are available. It also reduces the possibility of system downtime that might occur if there is a large lag time in acquiring replacement components.

Special attention should be paid to components that tend to have the greatest impact on system performance and availability. Inverters and AC subsystem components, such as AC fuses, disconnects, and wiring, rank among the top causes of system downtime. The next most common maintenance issues stem from site-related issues, data acquisition systems, and tracking systems. With a well-designed maintenance program in place, many of the typical failure points can be addressed, which ensures the

[73] "Addressing Solar Photovoltaic Operations and Maintenance Challenges: A Survey of Current Knowledge and Practices." Electric Power Research Institute (EPRI). July 2010

longevity and economic feasibility of the PV system. Appendix A.2 provides a detailed list of maintenance activities that should be performed at least once per year.

Staffing In-House vs. Outsourcing

As was described in the sections above, specific training and knowledge is required to operate and maintain a PV system. If a facility already has highly qualified staff onsite, performing all O&M activities in-house might make sense. However, if qualified staff is not available or enrolling staff in training courses is not feasible, it might be more appropriate to outsource the O&M activities to a qualified contractor. A third option is to hire an O&M company to simultaneously manage the O&M operations and train in-house staff. As in-house staff members become competent and qualified to maintain the system on their own, the services that the contractor offers will taper off, and the O&M responsibilities will fall on the system owner.

In-house management of O&M activities offers an opportunity to reduce the cost of maintaining a PV system. It also allows the system owner to only perform activities deemed to be necessary and cost-effective. The cost savings and flexibility are contingent on the availability of highly qualified staff. On the other hand, hiring an O&M contractor removes the need for staff with expertise in high-voltage PV systems. In difficult fiscal times, it is often much easier to end services provided by a contractor. Outsourcing can also shift some of the risk related to system performance to a third party. A downside is that costs for O&M services may be higher, and there is always a possibility that the work will be subcontracted to unqualified technicians. O&M service providers can be located through directories compiled by industry organizations like the SEIA and the NABCEP.

Third-Party Ownership

One of the attractive elements of third-party ownership is that the third party operates and maintains the PV system. Under such arrangements, the facility owner and the PV owner must agree upon the framework for validating system production and the types of services that the third party will provide.

It is common for the third-party owner to provide a performance guarantee to the facility owner. The performance guarantee defines a level of system output that must be met. A well-constructed performance guarantee will often use a detailed model of the PV system to generate expected performance values for varying irradiance and temperature conditions. This model is then used to validate actual performance. The contract between the facility owner and the third party should clearly define the actions and damages that will occur when the actual performance deviates by varying degrees from the expected performance.

In order to compare actual performance to expected performance, detailed monitoring will be required. Very few third-party owners will offer a guarantee that does not adjust expected production based on weather because weather is a risk that they cannot control. The result is that most contracts will specify that module temperature and plane-of-array irradiance will be measured and used in the predictive model. In addition, the system's AC production will be measured so that it can be compared to the model. The contract should clearly define the metrics that will be measured, the types and accuracies of the hardware used to measure and to collect the data, the software used to report the data, the methods used to predict the production, and the frequency at which expected and actual performance will be compared and reported (as well as how performance is documented). Because damages are often assessed based on the deviations between expected and actual performance, it is important that some redundancy be designed into the measurement system to account for component failure. Moreover, the contract should specify the frequency and standard at which sensors will be recalibrated. The frequency and level of detail of performance reports should not exceed the value of the damages that could be incurred from underperformance.

The performance contract should clearly define actions that can be taken to improve system performance rather than rely solely on damage claims. The ultimate goal of the contract is to ensure that the system is functioning properly. Facility owners should be aware that third-party PV system owners will constantly compare the cost of system maintenance to assessed damages. If the assessed damages are less than the cost of maintenance, it is unlikely that the third party will respond to system underperformance. Clearly outlined responsibilities within the contract can help prevent inaction from the third-party owner. Even a well-constructed contract is of little value if the third party runs into issues with solvency. For this reason, facility owners should consider the size of a third party's balance sheet before partnering with that entity[74].

[74] Mat Taylor and David Williams wrote two informative articles in *SolarPro* magazine related to performance guarantees. The first article appears in the June/July 2011 issue and is titled "PV Performance Guarantees (Part 1): Managing Risks and Expectations." The second article appears in the August/September 2011 issue and is titled "PV Performance Guarantees (Part 2): Proof of Performance & Guarantee Structures."

Assessing Benefits

After your system is installed and operating as planned, you will likely want to assess its benefits. Several data metrics can help you assess the benefits:

- Electricity Costs – Comparing monthly electricity costs before and after installing PV can provide you with information about the financial impacts of your system. To account for monthly variations in solar insolation, compare the current month's bill to the same month from the year before you installed PV. Assuming that building activity (e.g., number of occupants or occupied square footage) is the same, your utility payments should have decreased. If your system is third-party owned, your utility payments plus your third-party payments should be less than your utility payments before you installed PV.
- Annual Production – Tracking annual electricity production from your PV system can give you a proxy for the environmental benefits. While actual emissions vary for a utility depending on the time of day and time of year, the EPA has regional data on annual average emissions of several pollutants, including CO_2, methane and NO_X. The EPA provides this information through its eGRID program, and data can be found at http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html. You can multiply your annual production (in MWh) by your regional emissions factors (typically in lb/MWh) to estimate your emissions offsets.
- Peak Demand – Your peak electric demand (in kW or MW) can be used as a proxy for how much strain your building places on the local electric grid. If your rate structure includes a demand-based component, you can compare your monthly demand before and after installing PV to see if PV impacts your demand.
- Customer and Employee Feedback – If one of your drivers was the marketing benefits of solar PV, asking your customers or employees their opinion of the system and its benefits can help you assess its marketing impact.

After collecting data, you should be able to answer some questions in order to assess if you should pursue PV at your other facilities:

- Am I meeting my financial expectations and goals?
- Am I saving enough energy or reducing my emissions as much as expected?
- Have I seen any marketing benefits from this project?
- Will my other locations have similar solar insolation levels, rebates, electric rates, and space available for PV?

If the answer is yes to all of these questions, you should consider PV at other facilities. If some of the answers to these questions are no, then you should investigate possible obstacles before considering PV further.

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Appendix A Inspection and Maintenance

Appendix A provides a detailed list of activities that can be performed as part of a routine inspection and maintenance program. The inspection activities can be performed by minimally trained staff and should be completed at least twice per year. The maintenance activities must be performed by highly qualified[75] staff at a frequency of once per year.

A.1 Inspection

This section will focus on inspection activities that can be performed by minimally trained staff, that are relatively low cost, and that should be completed several times per year. Activities that require highly qualified staff and that tend to be more costly and laborious are discussed in Section A.2.

Personnel performing system inspections must follow all Occupational Safety and Health Administration (OSHA) requirements regarding safety. Although none of the activities described in this section requires the individual to access or work with electrical conductors or equipment, staff should be trained to work near high-voltage electrical systems.

The following activities should be performed as part of a low-rigor inspection program at a frequency of at least twice per year.

- Investigate the data that the monitoring system or production meter generates to confirm that performance aligns with expectations and that no data is missing or erroneous
- Remove any vegetation or debris that may be shading the modules and ensure that no new objects like satellite dishes are shading the array
- Observe whether excessive soiling may require cleaning to be scheduled
- Look for signs of animal infestation, such as nests, excessive bird droppings, or wires that have been chewed on
- Take note of any wire connectors emanating from the modules that do not appear to be well connected
- Record the location of any wires that are poorly fastened to the racking structure, that are rubbing against an abrasive surface, that are showing breakdown from ultraviolet exposure, or that are bent in such a way that might damage the integrity of the conductor
- Inspect the modules for discoloration, signs of breakage, delamination, vandalism, or theft
- Ensure that roof drainage is not blocked and that there are no signs of pooled water near the array or conduit
- Verify that conduit is well supported and firmly intact
- Ensure roof penetrations are water tight and that no damage is apparent on the rooftop
- Confirm that the racking system is structurally secure and shows no signs of corrosion
- For tracking systems, check alignment, look for signs of excessive wear or rubbing of parts, verify that the system stows properly, and lubricate appropriate equipment
- Visually inspect the exterior of all electrical cabinets, such as combiner boxes, junction boxes, disconnects, and inverters for corrosion, discoloration, debris, and solid attachment to a stable structure
- Check that all inverters are operational, and record the inverter error logs
- Lastly, thermal imaging using infrared equipment can be used to record the location of excessive heat

[75] According to Article 100 of the National Electrical Code, qualified personnel can be described as “One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved.”

dissipation in module cells, wire connections, electrical cabinets (only the exterior of electrical cabinets should be imaged), and tracking motors

With system availability typically being the one of the largest drivers of economic feasibility, the activities listed above will greatly improve the chance of identifying issues before they cause system downtime. Furthermore, these activities are relatively low cost and can be performed by in-house personnel.

A.2 Maintenance

This section will focus on maintenance activities that should be performed by highly qualified individuals[76] and that should be completed once per year or as corrective maintenance. Activities that can be performed by less-qualified staff and that should be completed more regularly are discussed in Section A.1

Individuals performing maintenance on a PV system must follow all OSHA requirements regarding safety. Because many of these tasks involve working with high-voltage conductors and electrical equipment, the staff must meet the National Electrical Code's (NEC's) definition of "qualified personnel." Due to the high direct current (DC) voltages that can be present in PV systems, staff must be trained in arc flash protection and wear all appropriate arc flash protection equipment.

The following activities should be performed as part of a high-rigor maintenance program with a frequency of once per year or as issues arise.

- Ensure sensors related to the data monitoring systems are properly attached and orientated and clean irradiance sensors
- Compare readings from sensors to recently calibrated sensors to ensure sensor accuracy, and check the voltages of power supplies to the sensors and communication devices
- Measure the power at the production meter, and compare it to the meter's readings to ensure meter accuracy
- Clean modules if it is required and economically justified
- Eliminate opportunities for animal infestation
- Reconnect any loose wire connectors
- Fasten any hanging wires to a supportive structure, and repair or replace any damaged wires
- Replace broken, delaminated, malfunctioning, or stolen modules
- Correct any issues with water drainage or any issues that are degrading the integrity of the rooftop
- Repair conduit that is not intact or firmly supported
- Correct any issues with the structural integrity of the racking system, and replace any corroded components
- Correct any alignment issues with the tracking system, use a digital level to check the calibration and position of inclinometers, check voltages within the controller box, ensure there is no discoloration of the logic controller, and tighten wire terminals
- Verify the continuity of all equipment grounding of racking systems, junction boxes, combiner boxes, disconnects, and inverters
- Replace or repair any corroded electrical cabinets, and ensure that all electrical cabinets are weather tight
- Measure module string open-circuit voltage, maximum power current, and short-circuit current, and compare these measurements against expected values or perform I-V curve tests to identify malfunctioning modules

[76] According to Article 100 of the National Electrical Code, qualified personnel can be described as "One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved."

- Perform Megger resistance tests to verify that wire insulation is intact and suitable
- Test continuity of system grounds to all major components
- Test continuity of fuses in combiner boxes, disconnects, and inverters; tighten all wire terminals; and inspect components for discoloration or excessive heat dissipation
- Measure the DC input power and alternating current (AC) output power from the inverter and confirm that appropriate efficiencies are being realized and that inverter readings are accurate
- Clean or replace air filters on inverters
- Test fans on inverters for proper operation
- Use infrared thermal imaging to identify faulty wire connections and subcomponents within electrical cabinets