Facility-Scale Solar Photovoltaic Guidebook

Bureau of Reclamation

Kosol Kiatreungwattana, Otto VanGeet, and Blaise Stoltenberg
National Renewable Energy Laboratory

Produced under direction of the Bureau of Reclamation by the National Renewable Energy Laboratory (NREL) under IAG-14-1950 and Task No WFGX.1021.

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Office of Energy Efficiency & Renewable Energy
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Strategic Partnership Project Report
NREL/TP-7A40-67122
September 2016

Contract No. DE-AC36-08GO28308

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List of Abbreviations and Acronyms

AC	alternating current
ACHP	Advisory Council on Historic Preservation
a-Si	amorphous silicon
BIPV	building integrated photovoltaics
BOS	balance-of-system
CdTe	cadmium telluride
CEQ	Council on Environmental Quality
CIGS	copper indium gallium selenide
CR	cultural resources
DC	direct current
DHI	diffuse horizontal irradiance
DNI	direct normal irradiance
DOI	U.S. Department of Interior
EA	environmental assessment
ECMs	energy conservation measures
EE	energy efficiency
EIS	environmental impact statement
EISA	Energy Independence and Security Act
E.O.	Executive Order
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act
ESCO	energy services company
ESPC	energy savings performance contract
FEMP	Federal Energy Management Program
FIT	feed-in-tariff
GHG	greenhouse gas
GHI	global horizontal insolation
IRR	internal rate of return
kW	kilowatt
kW/m^2	kilowatt per square meter
kWh	kilowatt-hour
kWh/m^2	kilowatt-hour per square meter
LCC	life cycle cost
LCCA	life cycle cost analysis
LCD	liquid-crystal display
LEED	Leadership in Energy and Environmental Design
MIRR	modified internal rate of return
mph	miles per hour
MW	megawatt

NEC	National Electrical Code
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NPV	net present value
N-HRE	non-hydro renewable energy
NREL	National Renewable Energy Laboratory
OMB	Office of Management and Budget
O&M	operation and maintenance
PPA	power purchase agreement
PV	photovoltaic
REC	renewable energy credit
RFP	request for proposal
SAM	System Advisor Model
SIR	savings-to-investment ratio
TOU	time of use
UESC	utility energy services contract
W	watt

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1 Introduction

The National Renewable Energy Laboratory (NREL) has an interagency agreement with the U.S. Bureau of Reclamation (Reclamation) to explore the use of non-hydro renewable energy (N-HRE) resources to meet the U.S. Department of Interior's objectives and Reclamation's mission. Under that agreement, NREL was contracted to develop a facility-scale solar photovoltaic (PV) guidebook for Reclamation. This guidebook presents readers with the processes and steps needed to assess and successfully implement facility-scale solar projects. Each part has several substeps and considerations.

1.1 Making the Case for Reclamation Facility Solar Energy Projects

Reclamation is the largest wholesale water supplier and the second largest producer of hydroelectric power in the United States, with operations and facilities in the 17 western states. Reclamation has a long and successful history providing renewable, clean, reliable, and affordable hydropower to its customers. As technology and demands for power and water use evolved over the last 100-plus years, Reclamation adapted to take advantage of new ways to help meet the nation's water and energy needs. As the agency moves well into its second century, Reclamation plays an important role in developing and supporting renewable energy production and the development, conservation, and integration of emerging renewable energy technologies into the nation's power grid.

Reclamation continues to improve and enhance our renewable hydropower capabilities, but will also support the development of other N-HRE, such as wind, solar, and geothermal, where it supports the agencies mission and goals. Figure 1 presents states where Reclamation's operations and facilities are located. The majority of these states have excellent solar resources.

Figure 1. States with Reclamation's operations and facilities

Reclamation's facilities such as office buildings, small pumping plants, and water treatment facilities could potentially use solar energy to meet all or a portion of the facility load. Solar energy is practical for meeting facility-scale needs and can be placed at different locations at a facility such as a roof or parking lot.

Facility-scale solar is most feasible where:

- Energy prices are high: >$0.09-$0.10 per kilowatt-hour (kWh)
- Incentives are available to subsidize the cost of PV installation, such as tax credits, local utility incentives, and renewable energy portfolio usage targets found in California, Arizona, Colorado, and New Mexico
- Sufficient space is available on rooftops, parking lots, or adjacent open land to site a solar installation capable of meeting a significant fraction of facility demand.

A combination of these factors makes the economics most attractive for investment in a facility-scale installation.

1.2 Legal and Regulatory Framework

As the nation's largest energy consumer, the federal government presents a tremendous opportunity for jump-starting a significant increase in domestic solar production. However, the solar installations must be implemented with appropriate consideration for other legal requirements (see section 4.4.1). The following subsections summarize some of the current laws and regulations defining federal renewable energy requirements and other laws that must be considered when planning and installing renewable energy systems.

1.2.1 Federal Renewable Energy Requirements

Executive Order (E.O.) 13693, *Planning for Federal Sustainability in the Next Decade*, signed on March 25, 2015, sets sustainability goals for federal government facilities that increase and improve their environmental performance, protect the planet for future generations, reduce spending, and increase efficiency and resilience. They key unifying goal within E.O. 13693 is to reduce agency greenhouse gas (GHG) emissions, with a stretch target of at least 40% by 2025.

E.O. 13693 requires that each agency propose to the Chair of the Council on Environmental Quality (CEQ) and the Director of the Office of Management and Budget (OMB) percentage reduction targets for agency-wide reductions of GHG emissions in absolute terms by the end of fiscal year 2025 relative to a fiscal year 2008 baseline. The Department of the Interior proposed, and CEQ accepted, a 36% reduction in Scope 1 and 2 emissions (which includes electricity consumption) and a 23% reduction in Scope 3 emissions (e.g., fugitive emissions, commuting and business travel).

The primary strategies to reduce Federal government GHG emissions is to reduce or eliminate the consumption of fossil fuels by reducing demand, improving facility efficiencies, and using alternative sources of energy. As such, E.O. 13693 establishes aggressive facility energy reduction and sustainability goals for federal agencies to:

1. Reduce energy intensity (BTU per gross square feet) by 2.5% per year for a total of 25% by 2025, compared to a 2015 baseline.
2. Design buildings, starting in 2020, to achieve net zero-energy by 2030.
3. Ensure that 15% of buildings meet *Guiding Principles for Sustainable Federal Buildings* by 2025.

It also directs agencies to meet the following goals specific to renewable energy:

1. Ensure that at a minimum a percentage of building electric energy and thermal energy shall be clean energy[1] as follows:

    - Not less than 10% in fiscal years 2016 and 2017
    - Not less than 13% in fiscal years 2018 and 2019
    - Not less than 16% in fiscal years 2020 and 2021
    - Not less than 20% in fiscal years 2022 and 2023
    - Not less than 25% by fiscal year 2025 and each year thereafter.

2. Ensure that a percentage of the total amount of building electric energy consumed by the agency is renewable electric energy as follows:

    - Not less than 10% in fiscal years 2016 and 2017
    - Not less than 15% in fiscal years 2018 and 2019
    - Not less than 20% in fiscal years 2020 and 2021
    - Not less than 25% in fiscal years 2022 and 2023
    - Not less than 27.5% in fiscal year 2024
    - Not less than 30% in fiscal year 2025 and each year thereafter.

3. As part of the renewable electric energy portion of the clean energy target, include:
    - Agency-funded onsite renewable energy projects where renewable energy credits (RECs) are retained
    - Contracted onsite or off-site renewable energy projects where RECs are retained or obtaining equal value replacement RECs
    - Purchasing electricity and corresponding RECs
    - Purchasing RECs.

4. Include in the alternative energy portion of the clean energy target:
    - Onsite thermal energy where RECs are retained or obtaining equal value replacement RECs
    - Combined heat and power processes at federal facilities
    - Fuel cell energy systems at federal facilities
    - Energy from new small nuclear reactor technologies.
    - Energy from new projects that actively capture and store carbon emissions associated with energy generation
    - Other alternative energy sources.

[1] Clean energy comprises renewable electric energy as well as *alternative energy* such as renewable heat sources (including biomass, solar thermal, geothermal, waste heat, and renewable combined heat and power [CHP]), non-renewable CHP, small modular nuclear reactors (SMR), fuel cell energy systems, energy generation with active capture and storage of carbon dioxide emissions (otherwise known as carbon capture and storage, or CCS), and other alternative energy approaches that advance the policy set forth in section 1 and achieve the goals of section 2 of E.O. 13693

Implementation and consumption of renewable energy is a key strategy in achieving the overarching federal energy and GHG emissions reduction goals. However, it must be implemented hand-in-hand with other energy reduction strategies in order to be most effective. Figure 2 depicts a common energy reduction hierarchy. Notice that renewable energy is not the first step to reducing energy use and costs, but an important step *after* reducing loads (through operational changes and improved facility management) and increasing energy efficiency (through installation of more efficient building systems). A PV system installed on an inefficient building is expensive and may pose a number of substantial risks. The PV system will need to be larger to cover the wasted and inefficient use, which will significantly increase the size and cost or the system, lengthen the payback period, and could potentially prevent the system from being profitable. However, when PV solar systems are installed after a thorough energy analysis and implementation of energy use reduction strategies,[2] the system can be sized accordingly to meet renewable energy and other goals at the least cost.

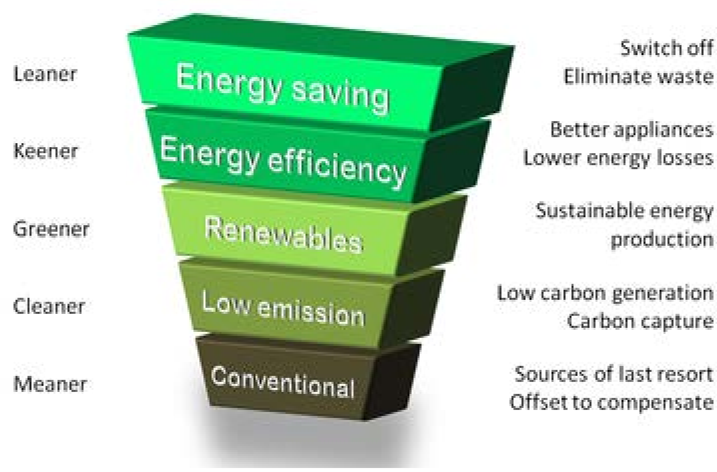

Figure 2. A common energy reduction hierarchy

1.2.2 Other Renewable Energy Requirements

In June 2013, President Obama released *The President's Climate Action Plan*.[3] The plan consists of a number of executive actions based on three main pillars: 1) cut carbon pollution in America, 2) prepare the United States for the impacts of climate change, and 3) lead international efforts to combat global climate change and prepare for its impacts. Under the Obama Administration, federal agencies have reduced GHG emissions by more than 15%—the equivalent of taking 1.5 million cars permanently off of the road. To build on this record, the Obama Administration is establishing a new renewable energy goal for the federal government: to consume 20% of its electricity from renewable sources by 2020. This more than doubles the current goal of 7.5%.

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[2] Reclamation has conducted numerous sustainable building assessments and energy (EISA) evaluations that analyze energy use and recommend energy conservation measures for improved facility performance. These reports can be referenced at https://dosp/policyandadmin/SustainableBldgs/Pages/Main.aspx (sustainable buildings) and https://teamsdrosp3.bor.doi.net/sustain/energy/eisa/Working%20Documents/Forms/AllItems.aspx (EISA evaluations).

[3] http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf, accessed May 05, 2015.

On June 02, 2014, the Environmental Protection Agency proposed new restrictions on carbon pollution generated by coal-fired power plants in the United States in an effort to take real action toward climate change. The final plan, entitled the *Clean Power Plan*, was unveiled by President Obama on August 3, 2015, requires states to cut back on the carbon emissions from their power plants by utilizing any of a number of different options, such as installing systems that operate on renewable energy sources like wind and solar.

Federal agencies are required to achieve *Guiding Principles for Sustainable Federal Buildings* at new construction, modernizations, and existing buildings greater than 5,000 gross square feet. A key metric of the Guiding Principles is to implement lifecycle cost-effective renewable electric energy and thermal energy projects onsite. As such, incorporation of renewable energy systems, like facility-level solar PV discussed this Guidebook, makes progress towards compliance with the Guiding Principles. Additionally, including a solar project in any design or retrofit helps earn credits toward certification with third-party sustainable building rating systems, such as Leadership in Energy and Environmental Design (LEED)[4] or Green Globes.[5] Typically, the number of credits a facility can earn toward a rating is based on the percentage of building energy cost that is offset by the system.

Other legal and regulatory requirements include utility requirements and historic building considerations among others. These topics are covered in the section discussing specific site analysis.

2 Solar Resource

Solar resource or the power of the sun striking the earth has been measured and mapped for the surface earth with varying degrees of resolution and accuracy. These measurements are the basis of estimating the energy production of a solar system and determining areas where high rates of solar energy production can be achieved. Solar resource measurements are broken down and reported in several different components since these different components can affect the energy production of different types of solar energy systems in different ways. Below is a discussion of solar resource components and other background material. Later in this guidebook these concepts will be used to explain how they affect energy production of different types of solar systems.

There are two basic components that are measured with respect to solar irradiance (power of the sun: kW/m^2) or insolation (energy over time: kWh/m^2): direct normal irradiance (DNI) and diffuse horizontal irradiance (DHI). DNI is the direct beam sun energy that comes directly from the solar disc and is measured as kW/m^2 on a plane that is always normal to the sun's beam as it traverses the sky during the day. DHI is the scattered irradiance of the sun which comes from all directions equally and is measured as kW/m^2 on a horizontal surface. One useful way to think about this is if you are out on a very clear day and your shadow is sharply defined then most of the sun's irradiance is direct (DHI) or if you are out on a cloudy day and you cast no definable shadow then the sun's irradiance is primarily diffused (DNI).

[4] http://www.usgbc.org/node/2612988?return=/credits, accessed September 01, 2016.
[5] https://www.thegbi.org/green-globes-certification/how-to-certify/, accessed September 01, 2016.

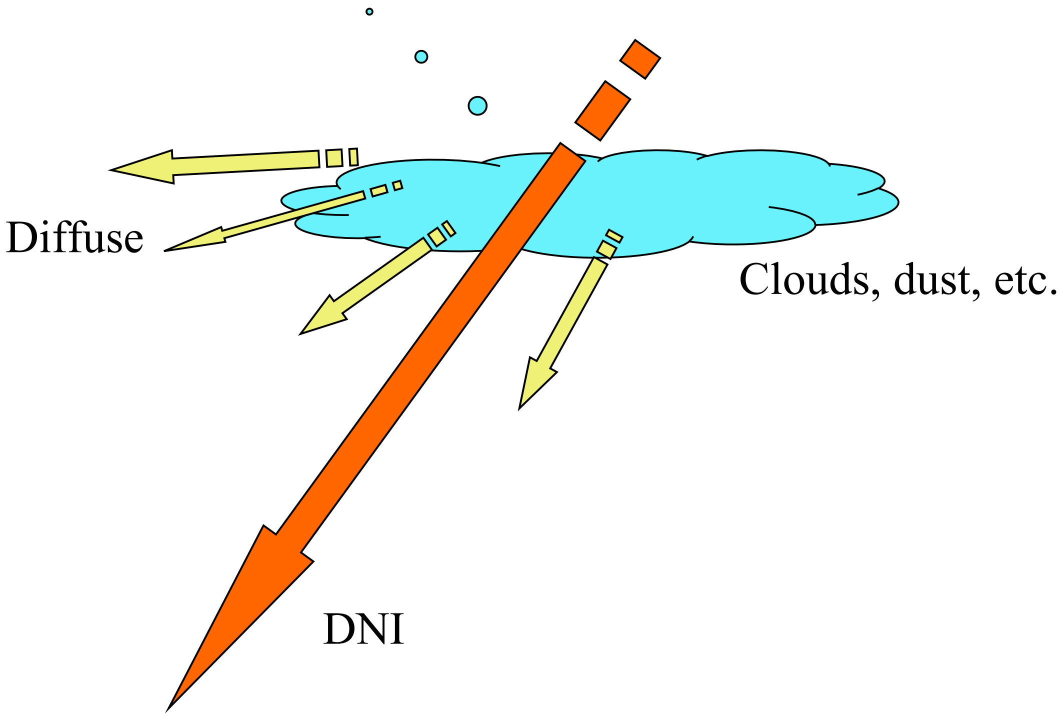


Figure 3. Solar irradiance

Source: NREL

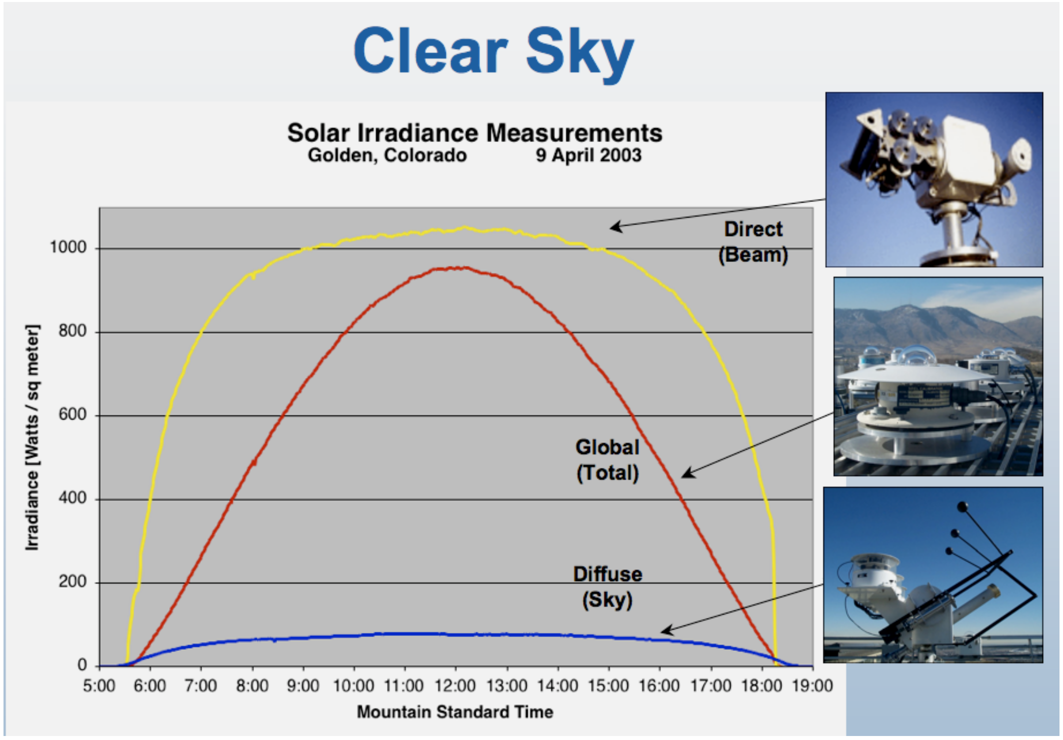


Figure 4. Hourly clear sky solar irradiance, Golden, Colorado

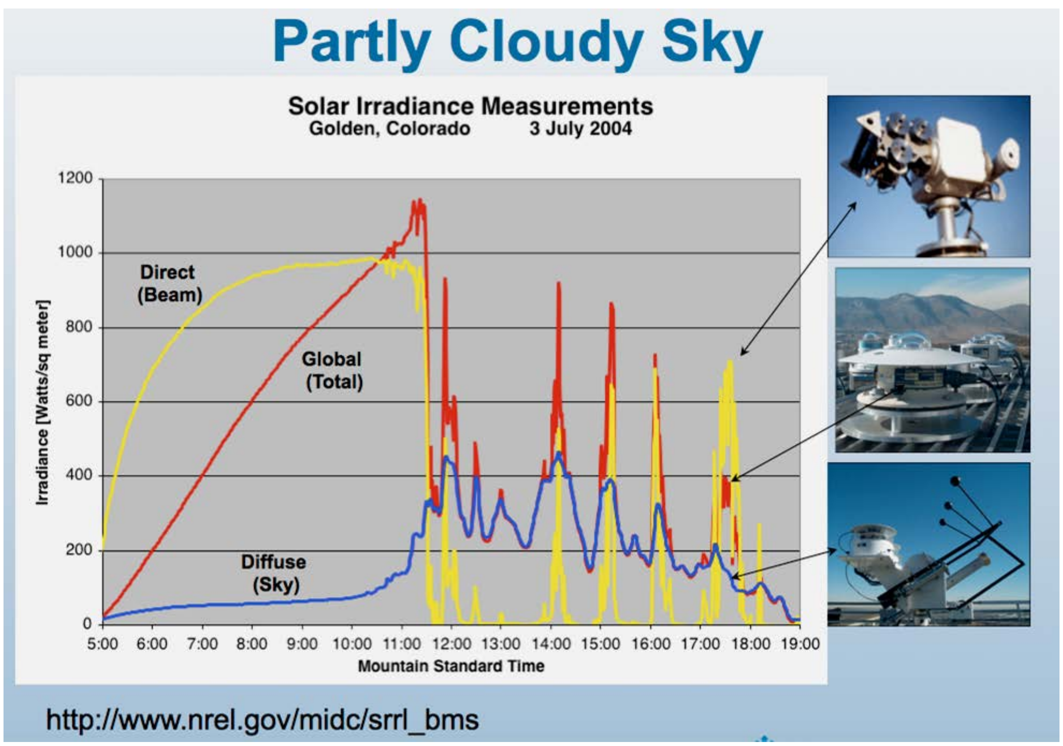


Figure 5. Hourly partly cloudy sky solar irradiance, Golden, Colorado

Combined DNI and DHI are the total sun's energy. They are used for high level estimates of solar energy for a site or are incorporated into weather files used with analysis programs for estimates of energy production for specified solar energy systems. Solar resource maps and mapping tools will usually include global horizontal insolation (GHI) and insolation on a collector with a tilt at latitude. GHI is the total of the sun's energy on a horizontal surface and is usually reported as the average annual kWh/m^2/day on that surface. GHI gives a good indication of the overall solar resource at a location. Since solar collectors are typically tilted up from the ground (i.e. not mounted horizontally) the metric tilt at latitude is often used to get a better idea of the solar energy striking an actual collector. The tilt at latitude is usually reported as the average annual kWh/m^2/day of solar energy striking a collector that is tilted up toward the equator at an angle that is equal to the latitude of the location. Tilt at latitude is used since this collector orientation is usually close to producing the maximum annual energy from a system. NREL's Solar Prospector[6] is an interactive web map tool that shows these metrics and can give a high level understanding to the solar potential of different locations quickly.

3 PV System Components

3.1 How PV Works

Solar PV technology converts energy from solar radiation directly into electricity. Solar PV cells are the electricity-generating component of a solar energy system. When sunlight (photons) strikes a PV cell, an electric current is produced by stimulating electrons (negative charges) in a layer in the cell designed to give up electrons easily. The existing electric field in the solar cell pulls these electrons to another layer. By connecting the cell to an external load, this current (movement of charges) can then be used to power the load, e.g. light bulb.

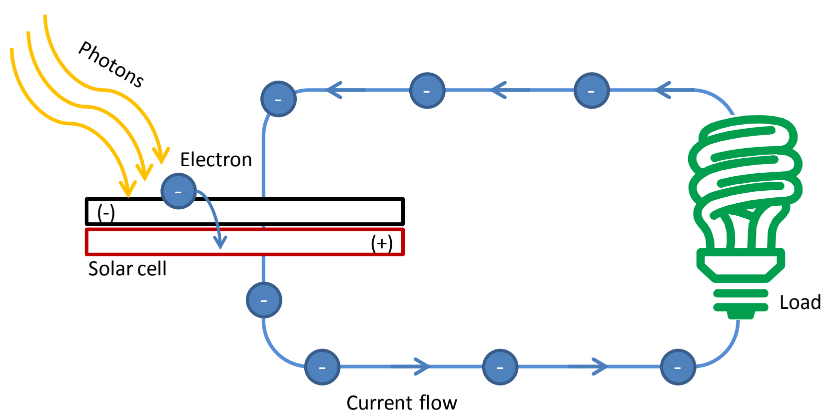


Figure 6. Generation of electricity from a PV cell

Source: NREL

PV cells are assembled into a PV panel or module. PV modules are then connected to create an array. The modules are connected in series and then in parallel as needed to reach the specific voltage and current requirements for the array. The direct current (DC) electricity generated by

[6] http://maps.nrel.gov/prospector.

the array is then converted by an inverter to alternating current (AC) that can be consumed by adjoining buildings and facilities or exported to the electricity grid. PV system size varies from small residential (2 kilowatts (kW)-10 kW), commercial (100 kW-500 kW), to large utility scale (10+ megawatts (MW)).

3.2 Major System Components

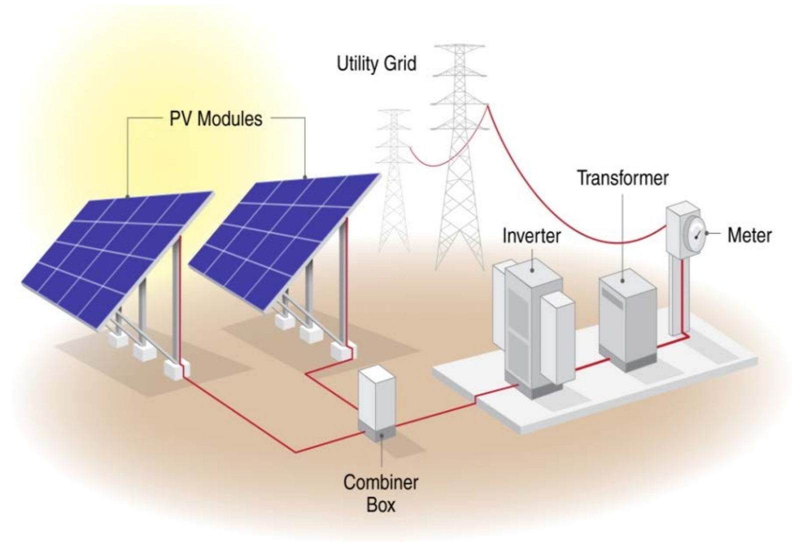


Figure 7. Ground mount array diagram

Source: NREL

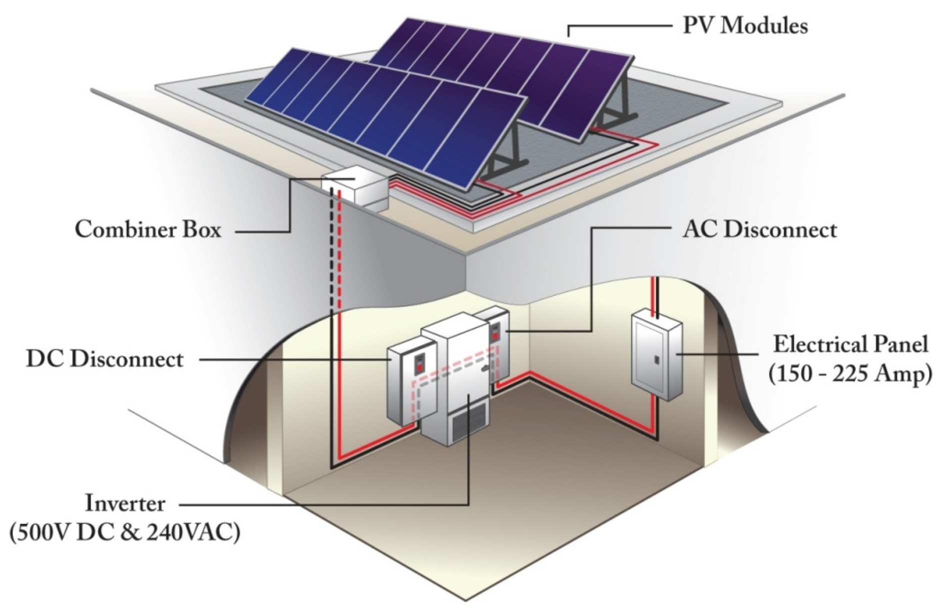


Figure 8. Roof mount array diagram

Source: NREL

A typical PV system is made up of several key components:

- PV modules
- Inverter
- Balance-of-system (BOS) components
- Battery (optional and off grid system).

These, along with other PV system components, are discussed next.

3.2.1 PV Module

Module technologies are differentiated by the type of PV material used, resulting in a range of conversion efficiencies from light energy to electrical energy. The module efficiency is a measure of the percentage of solar energy converted into electricity.

A typical PV module is UL listed and tested to withstand certain wind, snow, and hail loads. PV modules are rated in terms of maximum allowable pressure on the module surface. For example, Figure 9 is an example of a PV panel rating for wind, snow, and hail loads that shows the maximum pressure for snow load and wind load at 5,400 and 2,400 Pascal (Pa), respectively. PV modules are not rated to specific wind speeds (mph) or snow loads (psf) because the racking system might have a feature to adjust the tilt angle of the array, which would need to be taken into account when calculating the maximum pressure on the modules.

Figure 9. PV panel rating for wind, snow, and hail loads

Two common PV technologies that have been widely used for facility- and utility-scale projects are crystalline silicon and thin film. Other PV technologies use a variety of new materials besides silicon, including solar inks using conventional printing press technologies, solar dyes, and conductive plastics. The PV materials are less expensive than the silicon, but have lower efficiency.

3.2.1.1 Crystalline Silicon

Traditional solar cells are made from silicon. Silicon is quite abundant and nontoxic. It builds on a strong industry from both the supply (silicon industry) and product side. This technology has been demonstrated as a consistent and high efficiency technology over 30 years in the field. The performance degradation, a reduction in power generation due to long-term exposure, is under 1% per year. Silicon modules have typical power production warranties in the 25 to 30 year range but can continue producing energy beyond this timeframe.

Typical overall efficiency of silicon solar modules is between 12% and 18%. However, some manufacturers of mono-crystalline modules have demonstrated an overall efficiency over 21%. This range of efficiencies represents significant variation among the crystalline silicon technologies available. The technology is generally divided into mono- and multi-crystalline technologies, which indicates the presence of grain-boundaries (i.e., multiple crystals) in the cell materials and is controlled by raw material selection and manufacturing technique. Crystalline silicon modules are widely used based on deployments worldwide and commonly used for the facility-scale application. Figure 10 shows an example of crystalline solar modules

Figure 10. Crystalline solar modules

Source: NREL PIX 13823

3.2.1.2 Thin Film

Thin-film PV cells are made from amorphous silicon (a-Si) or non-silicon materials such as cadmium telluride (CdTe) or copper indium gallium (di) selenide (CIGS). These cells use layers of semiconductor materials only a few micrometers thick. Due to the unique nature of thin films, some thin-film cells are constructed into flexible modules or building integrated modules such as building integrated photovoltaic (BIPV). Other thin film modules are assembled into rigid constructions that can be used in fixed tilt or, in some cases, tracking system configurations. Due to the lower efficiency, thin film modules require more space than crystalline silicon modules at the same capacity. Thin film modules are frequently used in large scale or utility scale projects where space is not critically limited.

The efficiency of thin-film solar cells is generally lower than for crystalline cells. Current overall efficiency of a thin-film module is between 6% to 8% for a-Si, 11% to 14% for CIGS, and 11% to 14% for CdTe. Figure 11 shows thin-film solar modules.

Source: NREL PIX 14726 Source: NREL PIX 15160

Figure 11. Thin-film solar modules (left) and building integrated photovoltaics (right)

The cost of rigid thin-film solar modules is typically cheaper than crystalline modules. However, the popularity of crystalline modules worldwide makes the cost gap between the technologies smaller. Other thin-film application such as BIPV modules are used to replace conventional building materials in parts of the building envelope. They are incorporated into a new construction or a major renovation. It is important to note that BIPV prices are variable by market and by application so pricing is something of a moving target. The BIPV modules typically have a higher cost premium compared to the standard flat modules.

Industry standard warranties of both crystalline and thin-film PV modules typically guarantee system performance of 80% of the rated power output for 25 years. After 25 years, they will continue producing electricity at a lower performance level.

3.2.2 Inverter

Inverters convert DC electricity from the PV array into AC and can connect seamlessly to the electricity grid. Inverter efficiencies can be as high as 98.5%.

Inverters also sense the utility power frequency and synchronize the PV-produced power to that frequency. When utility power is not present, the inverter will stop producing AC power into the grid that can be dangerous to utility workers that are trying to fix what they assume is a de-energized distribution system. This safety feature is built into all grid-connected inverters in the market. Electricity produced from the PV system may be fed to a step-up transformer to increase the voltage to match the grid.

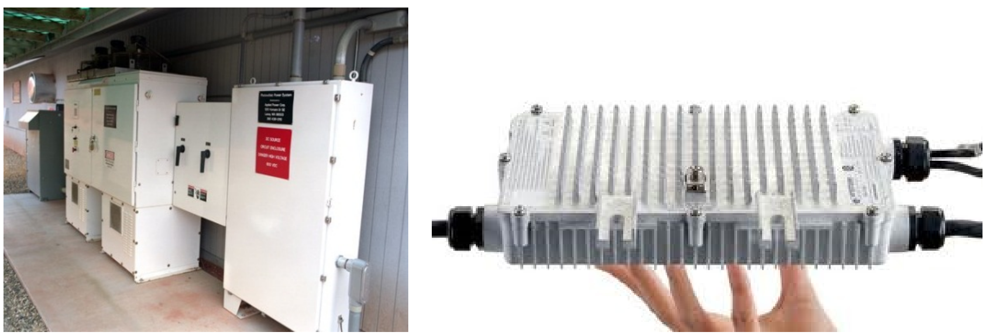
There are two primary types of inverters for grid-connected systems: string and microinverters. Each type has strengths and weakness and may be recommended for different types of installations.

String inverters are most common and typically range in size from 1.5 kW to 1,000 kW. These inverters tend to be less expensive on a capacity basis, and typically have high efficiency and lower operations and maintenance (O&M) costs. String inverters offer various sizes and capacities to handle a large range of voltage output. For larger systems, string inverters are combined in parallel to produce a single point of interconnection with the grid. Warranties typically run between 5 and 10 years, with 10 years being the current industry standard. On larger units, extended warranties up to 20 years are possible. Given that the expected life of the

PV modules is 25 to 30 years, an operator can expect to replace a string inverter at least one time during the life of the PV system.

Microinverters are dedicated to the conversion of a single PV module's power output. The AC output from each module is connected in parallel to create the array. This technology is relatively new to the market and in limited use in larger systems due to potential increase in O&M associated with significantly increasing the number of inverters in a given array. Current microinverters range in size between 175 W and 380 W. These inverters can be the most expensive option per watt of capacity. Warranties range from 10 to 20 years. Small projects with irregular modules and shading issues typically benefit from microinverters.

With string inverters, small amounts of shading on a solar module will significantly affect the entire array production. If microinverters are used shading impacts only the shaded module. Figure 12 shows a string and microinverter inverter.



Source: NREL PIX 07985 Source: Enphase

Figure 12. String inverter (left) and microinverter (right)

3.2.3 Balance-of-System Components

In addition to the solar modules and inverter, a solar PV system consists of other parts called BOS components, which include:

- Mounting racks and hardware for the modules
- Wiring for electrical connections.

3.2.3.1 Mounting Systems

The structure holding the PV modules is referred to as the mounting system. There are two primary applications of PV mounting systems: roof-mounted and ground-mounted systems. The mounting system can be either directly anchored into the roof or ground or ballasted on the surface without roof or ground penetration. For buildings, PV panels are mounted to the roof pitch. For flat roofs, though the ideal tilt is equal to latitude, the panels are typically mounted at 10° to 15° tilt. Higher tilt may result in higher wind loads and self-shading. Mounting systems should be selected and designed to withstand local wind loads, which range from 90 mph to 120 mph range for most areas or 130 mph or more for areas with hurricane potential. Depending on the region, snow and ice loads should also be design considerations for the mounting system.

Source: NREL PIX 21403

Source: NREL PIX 04478

Figure 13. Anchored and ballasted PV mounting systems

Typical ground-mounted systems can also be categorized as fixed tilt or tracking. Fixed-tilt mounting systems are characterized by modules installed at a set angle, typically based on site latitude and wind conditions, to increase exposure to solar radiation throughout the year. Fixed-tilt systems are the most common type. Fixed-tilt systems may have lower maintenance costs but generate less energy (kWh) per unit power (kW) of capacity than tracking systems (Figure 15).

Tracking systems rotate the PV modules so they are following the sun as it moves across the sky. The tracking systems increases energy output for roughly the same amount of space required for the fixed tilt system. This could be a very good justification for going with a tracking system if the project has some space restrictions. However, they also may increase maintenance and equipment costs slightly. Single-axis tracking, in which PV is rotated on a single axis, can increase energy output up to 25% or more. With dual-axis tracking, PV is able to directly face the sun all day, potentially increasing output up to 35% or more.

The selection of mounting type is dependent on many factors including installation size, electricity rates, government incentives, land constraints, latitude, and local weather.

Figure 14. PV system with fixed tilt

Source: NREL PIX 17394

Figure 15. PV system with single-axis trackers

Source: NREL PIX 00007

Figure 16. PV system with dual-axis trackers

Source: NREL PIX 04827

3.2.3.2 Wiring for Electrical Connections

Electrical connections, including wiring, disconnect switches, fuses, and breakers are required to meet electrical code (e.g., NEC Article 690) for both safety and equipment protection. In most traditional applications, wiring from (i) the arrays to inverters and (ii) inverters to point of interconnection is generally run inside electrical conduits.

3.2.4 Battery

A fundamental characteristic of a PV system is that power is produced only while sunlight is available. Batteries accumulate energy created by PV system and store it to be used at night or when there is no other energy input. For a grid-tied system, where batteries are not inherently required, they may be beneficially included for load matching or power conditioning. Unless batteries are required, they should be avoided because they have high first cost and O&M cost. If batteries are used they should designed to minimize life cycle cost (LCC) using a tool such as HOMER. A vast majority of PV systems are connected to deep cycle lead-acid batteries.

Figure 17. PV system with battery pack

Source: Kosol Kiatreungwattana, NREL

3.2.5 PV System Monitoring

Monitoring PV systems can be essential for reliable functioning and maximum yield of a system. It can be as simple as reading values such as produced AC power, daily kilowatt-hours, and cumulative kilowatt-hours locally on an LCD display on the inverter. For more sophisticated monitoring and control purposes, environmental data such as module temperature, ambient temperature, solar radiation, and wind speed can be collected. Remote control and monitoring can be performed by various remote connections and are often web based. Systems can send alerts and status messages to the control center or user. Data can be stored in the inverter's memory or in external data loggers for further system analysis.

Weather stations are typically installed at large scale systems. Weather data such as solar radiation and temperature can be used to predict energy production, enabling comparison of the target and actual system output and performance and identification of under-performing arrays. Operators may also use this data to identify required maintenance, shade on modules, accumulated soiling on modules, etc. Monitoring system data can also be used for outreach and education. This can be achieved with publicly available, online displays; wall-mounted systems; or even smart phone applications.

4 Solar Energy System Siting: General Technical and Site Specific Considerations

Siting and design of a solar energy system can quickly become a complex interplay of both technical and economic variables, and actions required to comply with other federal law. In this section the discussion will be limited to technical variables and specific site considerations. Economic considerations and environmental and historic preservation requirements will be discussed in a later section.

There are three basic types of siting or locations for facility-scale solar systems: 1) rooftop, 2) ground mount, and 3) carports. There are many different variations and technologies for implementation in these locations which is covered in the technology section.

There are many siting considerations when a specific site is being evaluated for a solar energy system:

- Solar collector access to the sun (i.e. collector orientation and shading analysis)
- Available areas to locate a solar system at a specific site or facility (e.g. rooftop, ground mount, and building integrated)
- Possible structural issues
- Compliance with National Environmental Policy Act (NEPA)
- Utility requirements
- Electrical interconnection
- Site master plan
- Compliance with the National Historic Preservation Act
- Computer network connectivity authority
- Climate considerations
- Vegetation considerations
- Auxiliary benefits.

4.1 Solar Collector Access to the Sun and Calculation of Available Area

Solar energy at specific locations is highly variable and is affected by site locations (latitude), hour of the day, day of the year, weather, elevation (i.e. thickness of the atmosphere), and the orientation of the solar collector. As the sun traverses the sky each day and from season to season, it is angled in relation to the solar collector changes and this incidence angle is a large determinate in how much of the sun's energy can be collected. If the sun's beam is perpendicular to a solar collector surface then the maximum solar energy can be collected but if the sun's beam is parallel to the collector surface then the collector cannot collect any of the beam energy. Note: the diffuse component of solar energy comes from all directions equally (e.g. cloudy days) therefore, sun angle does not affect the amount of diffuse energy that the collector collects. Figure 18 illustrates the sun path.

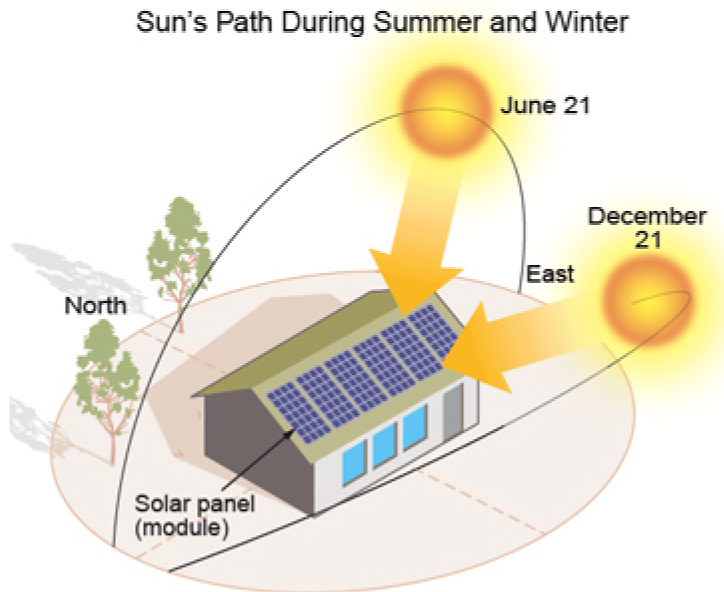


Figure 18. Sun path

There are a number of complex equations that enable exact calculation of solar incident angles for a specific latitude that enable the calculation of solar energy on different solar collector orientations throughout a year but conveniently there are easy-to-use tools that will calculate this and other factors to estimate energy production . These tools will be discussed in a later section.

For specific sites, shading analysis is key to determining collector access to the sun's energy. It is important to perform a shading analysis to determine if any obstacles exist around a specific site that might block the sun from striking a collector. These obstacles can include buildings (existing and planned), topography (e.g. mountains), vegetation (in its present or future state), power lines, and moveable assets (e.g. trucks, storage, or other temporary objects that may be placed in front of a collector).

A quick analysis of objects that might shade a site can be done without any specialized tool by following the process outlined in the solar screening checklist in Appendix A. There are also several tools on the market that make this shading analysis process very easy. As one example, Figure 19 shows a picture taken by a Solemetric SunEye that shows the sun path for the site latitude overlaid on the specific location and the objects that that would shade that site. It also calculates the percentage of annual solar access for the site for a specific collector orientation taking into account the objects that will shade the site. At the site below the site is shaded only in the early morning and late afternoon and has a calculated annual solar access of 96%.

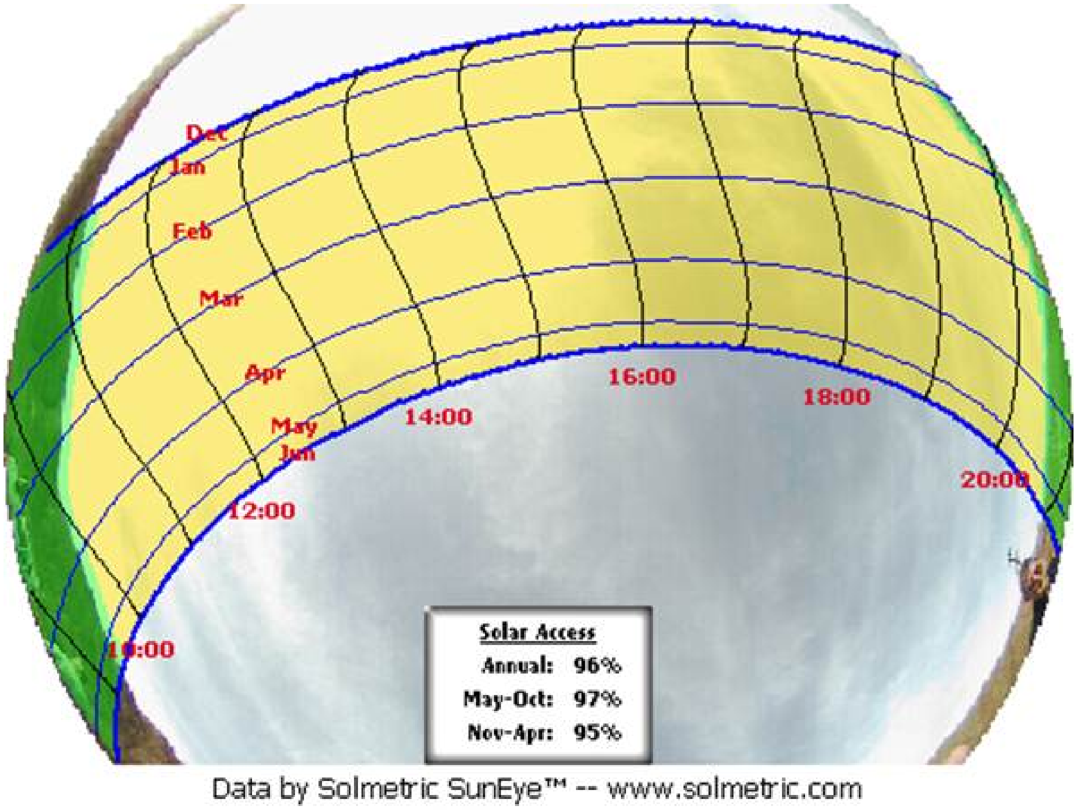


Figure 19. SunEye shade analysis

The goal of the shading analysis is to define the available useable areas for a solar energy system. Ideally, a site should have 100% annual solar access but this is not always the case so it is recommended that a site has a minimum of 90% to 95% annual solar access. There are always exceptions to this rule that depend on site goals and requirements, but in these circumstances extra care needs to be taken in the system design and wiring to help ensure maximum energy production.

Google Maps and Earth are useful tools in measuring and determining the areas of a site. There are also a number of remote shading analysis tools such as Solar Census. Two primary areas that can be used to locate a solar energy system are roof top and ground mount. If there is a building at the site, the system may be located on the rooftop or possible integrated into the building itself. If there is no building onsite or land area around the building, there are a number of ground-mounted systems options. The solar system technologies section describes the different technologies and mounting options that are available for these different locations.

4.2 Rooftop Solar Considerations

Rooftop systems need to take into account several different factors including:

- Roof age and condition
- Roof warranty
- Structural loading
- Fire safety guidelines
- Historic preservation.

The age and condition of the roofing material are two issues of concern when assessing conditions for a rooftop system. Solar systems typically have a life of 25 to 30 years. If the roof needs replaced during this time the system will most likely need to be removed and reinstalled. This could add significantly to the LCC of the system and possibly make it uneconomical.

Roof warranty can also be an issue as there can be disputes on who is responsible for fixing future roof problems, the solar system installer or roofing installer. It is recommended to contact the company responsible for the roof warranty and discuss what is needed to keep the warranty intact. If it is a new building, or if a new roof will be installed in conjunction with the solar system, a good option may be that one company is responsible for both the solar system and roof installation.

The structural loading of the roof is another key consideration. An assessment of the additional structural load the roof can carry should be performed. The most common PV installation method for flat roofs is a ballasted racking system. The typical weight of a ballasted PV system is about 4 pounds per square foot but varies based on design wind speed, collector tilt, and system design. If very little or no extra load can be placed on the existing roof structure (check technology section for estimated weights of rooftop solar systems), then an estimation of what is needed to increase the structural strength should be made. If roof structure enhancements are needed, they can be completed separately or included in the scope of the solar system installation. Structural enhancements can be expensive and may make solar uneconomical.

Rooftop systems may also need to comply with fire safety guidelines. Local fire authorities should be contacted to determine requirements and confirm that none of the requirements would make a system unfeasible. General Services Administration has a general purpose PV fire safety guideline.[7]

4.3 Ground Mount Solar Considerations

Ground-mounted systems offer a variety of mounting options, including fixed, parking shade structures, and 1-axis or 2-axis tracking. Each option has its advantages and disadvantages. Unless there is a specific mounting option that is required at the site, it is recommended that solar installers be given the option of proposing solutions that best meet the stated needs of the facility.

4.4 General Site Considerations

Site considerations for both roof- and ground-mounted systems include:

- Compliance with the National Environmental Policy Act (NEPA), National Historic Preservation Act (NHPA), Endangered Species Act (ESA), and other environmental laws
- Utility requirements
- BOS placement
- Site master plan

[7] www.google.com/url?url=http://fpemag.com/_pdf/Fire_Safety_Guideline-PV_System_Installations.pdf&rct=j&frm=1&q=&esrc=s&sa=U&ei=BZSgU66GJoK3yATSv4DICw&ved=0CBQQFjAA&usg=AFQjCNHEcw-h9vMtJF31NoHPaveuMYENGw

- Computer network connectivity authority
- Climate considerations
- Vegetation considerations.

4.4.1 Historic Preservation and Environmental Laws - General Considerations

Any type of system located on federal land or property, or one using federal funding or requiring federal approval, may trigger environmental or historic preservation consideration and mitigation under NEPA, NHPA, ESA, and other environmental laws. These laws should be addressed early in the planning and design process to minimize the potential for redesign, scheduling delays, or increased cost. The effort involved to comply with NEPA, NHPA, ESA and other environmental laws greatly depends on where the project location and also on the project's scale.

There are typically agency contacts that are responsible for compliance with each of these laws for specific administrative or geographic areas or facilities. Consulting with these experts early and often will ensure that they can provide timely input to help shape the decisions and the directions regarding the site selection for the project and design criteria. This (and possibly other information) will help avoid conflicts that could delay or even halt a project, and help define information that will eventually go into the request for proposal (RFP) and ensure that the project stays on track.

4.4.1.1 The NEPA process

The NEPA process begins with the agency environmental expert assessing the proposed system, and the assessment produces one of the following three results:

1. **Categorical exclusion (CE)**: A category of actions which do not individually or cumulatively have a significant effect on the human environment. Solar projects meeting the agency or bureau's definition provided in its CE and whose impacts would not result in significant impacts as described in Extraordinary Circumstances (43 CFR 46.215), are excluded from further analysis under NEPA. A Reclamation CE, (516 Departmental Manual 14.5) is appropriate to use for facility-scale solar projects, as long as the scope of the project is consistent with the definition and terms of the CE and there are no extraordinary circumstances (43 CFR 46.215).
2. **Environmental assessment (EA)**: An EA involves a higher level of analysis and documentation than a CE. It is used to identify the issues and the environmental effects of a proposed action. An EA has two possible outcomes:
    - Finding of no significant impact (FONSI): If an EA is required, the best outcome is receipt of a FONSI. This process usually costs less than $500,000 and takes 6 months to 1.5 years.
    - If the EA finds that environmental consequences could be significant, an environmental impact statement (EIS) must be completed.
3. **EIS**: If the environmental expert finds that the project could have a significant environmental impact from the beginning, an EIS is completed without completing an EA first. This process can cost $1 to $5 million and take from 18 months to 5 years. If successful, a record of decision is received and the project may proceed.

EAs and EISs have more details and usually apply to large scale and/or utility scale projects. All levels may results in environmental commitments that need to be included in agreement or contract documents and implemented during project construction and operation.

4.4.1.2 Endangered Species Act

The Endangered Species Act (ESA)[8] provides a program for the conservation of threatened and endangered plants and animals and the habitats in which they are found. The lead federal agencies for implementing ESA are the U.S. Fish and Wildlife Service (FWS) and the U.S. National Oceanic and Atmospheric Administration (NOAA) Fisheries Service. The FWS maintains a worldwide list of endangered species. Species include birds, insects, fish, reptiles, mammals, crustaceans, flowers, grasses, and trees. The law requires federal agencies, in consultation with FWS and/or the NOAA Fisheries Service, to ensure that actions they authorize, fund, or carry out are not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of designated critical habitat of such species. The law also prohibits any action that causes a "taking" of any listed species of endangered fish or wildlife. Likewise, import, export, interstate, and foreign commerce of listed species are all generally prohibited.

4.4.1.3 National Historic Preservation Act Compliance

Installation of a solar PV system may have an adverse impact on historic properties. Many Reclamation buildings and structures are historically significant. Section 106 of NHPA requires federal agencies to consider the effects of a project on historic properties. Historic properties are historically or culturally important resources that are listed on the National Register of Historic Places, and may include:

- Prehistoric or historic period archeological sites or districts
- Historically significant buildings and structures or historic districts
- Historically significant landscapes
- Sites or locations that are of religious or cultural importance to Indian tribes.

Good planning integrates NHPA compliance into project design, as minimizing any impacts typically involve site selection and design considerations. Adequate time and funding to comply with NHPA are to be built into the project schedule and budget requests. The cultural resources (CR) professional assigned to the office undertaking the project will have the lead on NHPA compliance.

When beginning a solar PV project, the CR lead will assess if historic properties might be affected by the proposed action, and then work with the solar team to seek ways to avoid or to minimize adverse effects. The CR lead will also define and implement compliance actions, in consultation with the solar team.

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8 www.nmfs.noaa.gov/pr/laws/esa/

When installing a solar PV system, actions to minimize impacts often include:

- Placing solar PV panels on a roof face that is less visible to public view or on later additions to historic buildings, or in an inconspicuous location on the property
- Minimizing removal or modification of original building materials or landscaping
- Selecting new materials that are compatible with a building or landscape's historic character and design
- Screening using plants or materials appropriate to the historic landscape.

If there are "adverse effects", mitigation may consist of documentation of the property prior to alteration, and/or presentation of site interpretive materials to the public. See Appendix J for further general guidance.

4.4.1.4 ESA Considerations

Section 7 of the ESA requires federal agencies to consult with the FWS and/or National Marine Fisheries Service (NMFS) for any action that "may affect" a federally listed endangered or threatened species or its designated critical habitat. If it is determined a proposed federal action will have "no affect" to a federally listed species or critical habitat, that determination is documented in the administrative record for the project and no further ESA compliance is necessary. If it is unknown or clearly a "may affect" situation, the consultation process can range from an informal consultation where a federal agency is requesting FWS or NMFS concurrence that its action "is not likely to adversely affect" a federally listed species (average 30 day response time) to a formal consultation where the federal agency determines a proposed action "may affect" a federally listed species and prepares a biological assessment and the FWS or NMFS issues a biological opinion on whether the proposed action would jeopardized the continued existence of a federally listed species or adversely modify critical habitat. This formal consultation process can take months or longer to complete. It is important that environmental compliance staff are engaged in the determination of affect to federally listed endangered and threatened species as early in the planning process as possible to allow for compliance time-frames as appropriate.

4.4.1.5 Other Environmental Laws

Compliance with other environmental laws, such as Migratory Bird Treaty Act and Clean Water Act may be required, based on location, size, scope and disturbance resulting from the action. As with all environmental considerations, consult with agency experts early in the process.

4.4.2 Utility Requirements

If a project includes PV, it also includes an electrical interconnection with the utility. The interconnection agreement is made between the organization and the utility regardless of the solar project developer's role. It is important to communicate with the utility about the proposed project early in the process. This ensures that all interconnection issues are taken into account early on, and helps avoid unpleasant surprises after significant effort has been expended. Depending on the utility and the local distribution system design, the project can be adversely affected by expensive interconnection hardware and requirements. Some requirements can be addressed during the design stage through equipment specifications, which incurs only a nominal extra cost as compared to purchasing additional equipment.

Changes in the electricity tariff rate structure should also be explored and discussed with the utility. Based on the system's projected hourly and seasonal performance, a more optimal tariff could be available that could potentially offset both energy charges and demand charges. Although utilities are important partners in the process, they might not be enthusiastic about reduced electrical consumption. Thousands of utilities operate in the United States with unique rate structures and policies, so it is important for those planning a renewable energy project to understand their rights as consumers and know what impact the solar system will have on future utility billings. For example, a utility could impose a standby charge to cover the cost of maintaining generation resources that are used when the solar energy system is not generating. An agency should also determine whether it can sign a utility interconnection agreement that has indemnification clauses.

The system owner and utility will develop an interconnection agreement that defines all the specific requirements and terms of the interconnection. Information on interconnection standards can be found at www.dsireusa.org/ (accessed September 01, 2016).

4.4.3 Balance-of-System Placement

The solar collectors are only part of the energy system and the equipment that connects the collectors to the load or grid needs to be placed. If the system will be mounted on a building, is there room for the inverters, electrical panels and other equipment in the existing mechanical room or is there another location where they can be placed? If it will be a ground mount system, are there any requirements on the BOS component placement? If there is more than one option, then it is probably best to state this in the RFP and let the solar installer propose their best option.

4.4.4 Site Master Plan

If there is a master plan for the site, it should be reviewed at this stage. A solar energy project is a long-term commitment, typically in place for 25 years or longer. When reviewing a master plan from a 25-year perspective, things to consider include plans for undeveloped land that might be a site for ground-mounted collectors or, in the case of rooftop arrays, determining if and when a building is scheduled for retirement. Also important is whether any architectural plans include aesthetic features that could preclude the installation of solar energy equipment. In such cases, site managers have found that their project site options can be significantly limited.

4.4.5 Computer Network Connectivity Authority

Many renewable energy systems require automated monitoring and control. This is usually accomplished by connecting the renewable energy system to a facility's existing building-monitoring system through a computer network connection. Some computer networks are operated under contracts that have very specific requirements. These contracts can be restrictive, allowing only network connection of specific devices, and sometimes even permitting only a limited set of preapproved software and hardware. It is crucial that the parties controlling the computer network be involved early in the process, because it is difficult and time-consuming to acquire the authority to operate a system connected to the network. An example is the United States Navy's computer networks, which are operated by a contractor under the Navy/Marine Corps Intranet contract. A renewable energy system that required a network connection was installed, but because of the contract it could not be operated until required permissions were obtained which was a long and difficult process. Another option to control the system is through a cell phone based monitoring system that would bypass the hardwired network.

4.4.6 Climate Considerations

The meteorological conditions (e.g. rainfall, solar radiation, wind speed and direction, temperature, and possibly corrosion such as salt mist) affect the PV system and system performance and design, both individually and in combination. It is important to understand the relevant meteorological conditions and their likely effects on the PV system performance.

4.4.6.1 Solar Resource Availability

Among the factors that are most important in evaluating whether a particular site is a good candidate for a PV system is whether the site receives abundant sun most of the day. Federal, state, or utility incentives may sufficiently improve the economics to enable PV systems in lower resource locations.

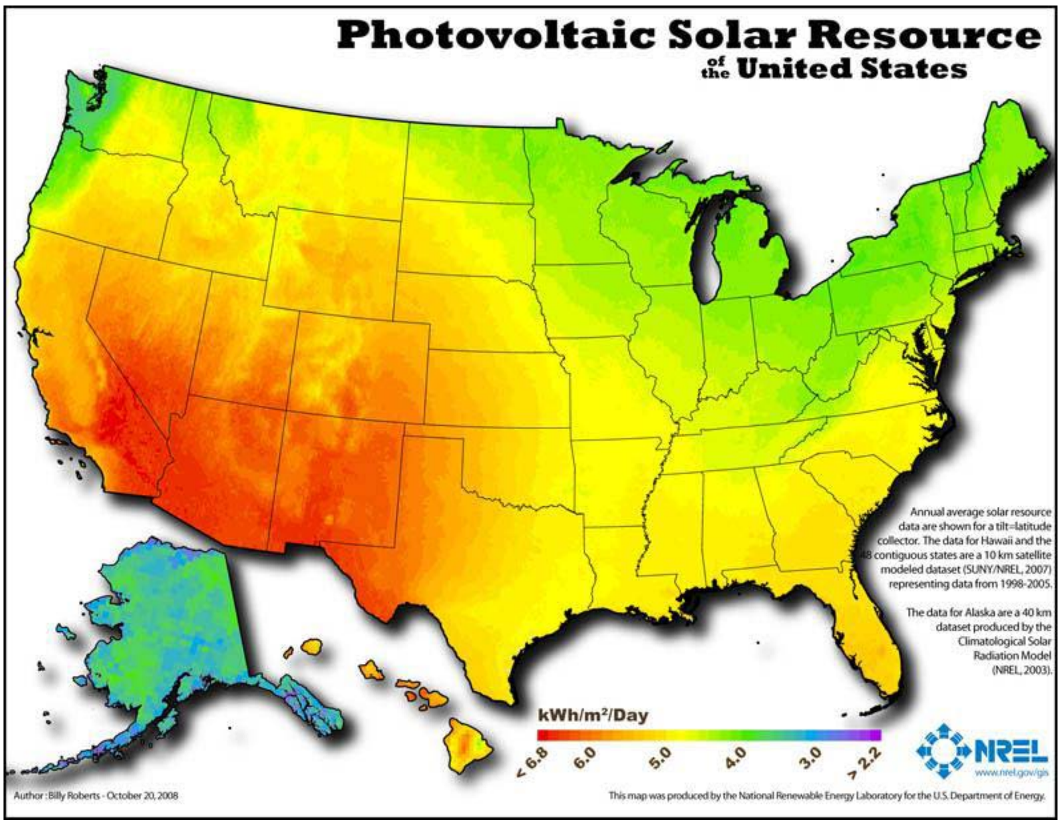

Figure 20. Photovoltaic solar resource

Figure 20 shows the national solar PV resource potential for the United States. This map is intended only to provide general guidance on available solar resource, and site-specific conditions may vary. For this reason, developers typically conduct an individual site assessment for purposes of evaluating and siting a solar system.

Site evaluations typically seek to identify portions of a given site that will receive sufficient sunlight throughout the year. This onsite assessment is generally carried out using industry tools, e.g. Sun Eye or Solar Pathfinder. See Section 4.1 for more details.

4.4.7 Vegetation Considerations

As mentioned in the shading analysis discussion, vegetation control and mitigation should be taken into account when specifying a system. This includes grasses, bushes, trees and other vegetation that may exist or grow in the future close to the site and shade the solar collectors. Mitigation of this shading possibility may be part of the operation and maintenance of the system (i.e. trimming and mowing) or specification of a ground mount system being a minimum height above the ground that is above the height of local vegetation growth or specification of ground treatment to eliminate vegetation around the system.

5 System Sizing and Energy Production Estimation

5.1 System Sizing

Sizing a solar energy system for a specific site includes many considerations to ensure a successful system installation:

- Project goals
- Site load
- Energy storage(if need backup power or off-grid system)
- Utility requirements, incentives, and rate structures (if grid connected)
- Available area.

5.1.1 Project goals

Project goals will determine what the motivating factors are for the solar system installation and this will drive the system size specification. Goals that might be considered include:

- Reducing fossil fuel consumption as much as possible
- Striving for a zero energy[9] facility
- maximizing production in the available space
- Buying the largest system possible with appropriated money
- Ensuring backup energy for critical facility functions,
- Off-grid operation for specific applications.

5.1.2 Site Load

Estimating or determining the site or application load is required for any project as this will be the basis for determining system size or limitations on system size.

If the load is a grid connected facility, the site load should be easily determined from the energy bill(s) for the facility. One year of bills would be the minimum required, but 3 to 5 years of bills

[9] A zero energy building is "an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the onsite renewable exported energy."

would be best in order to check for possible anomalies in power usage and/or trends in energy use over time. Anomalies can include construction projects, mechanical failures, and special events among other events. Increasing energy use can be due to more utilization of the facility, increasing facility size, increasing equipment energy requirements, etc. When determining the site load for design purposes these anomalies and energy use trends should be taken into account. Also energy efficiency measures are typically cheaper per kWh saved than what it would cost to produce the same kWh through PV. Therefore, it is recommended to consider and implement energy efficiency measures first and reduce site load projections accordingly.

New facilities will typically include energy use estimates in the design documents and these can be used to estimate site load.

Systems that will be designed to power a specific application (e.g. gate operation) may require measurement/metering of the load over time or extrapolation of short term measurements to load would be over time. If it will be an off-grid application, peak power consumption will need to be determined in addition to energy use and specified period of autonomy (i.e. the period when the solar cannot charge or add energy to the energy storage system).

5.1.2.1 Example calculations

Specific operation for off-grid:

> Max energy (kWh) * # operations per day (#/day) * # days (days) / DC-AC conversion efficiency (%) = Required energy storage capacity (kWh)

Where:

- Max energy for each operation (kWh), best if measured
- # days (days): number of day the system needs to operate without energy input to batteries (typically 3 days but can be adjusted for climate)
- DC-AC conversion efficiency (%), converter efficiency to convert DC to AC power.

Backup power:

> Load per day (kWh/day) * # days autonomy (days) / DC-AC conversion efficiency (%) = Required energy storage capacity (kWh)

Where:

- Load per day (kWh/day): the load can be the whole facility or just critical loads that can be powered separately by the system.
- # days autonomy (days): number of day the system needs to operate without energy input to batteries (typically 3 days but can be adjusted for climate)
- DC-AC conversion efficiency (%): converter efficiency to convert DC power to AC power need to run equipment.

For any energy storage systems the equations above are for useable capacity of the energy storage system selected. The useable capacity of an energy storage system will depend on the technology selected as some storage technologies will be damaged if they are completely discharged. This means that the nameplate capacity may be larger than the calculated required capacity.

5.1.3 Utility Requirements and Rate Structures

Utility interaction in the early stages of the project can be critical. Key issues are interconnection requirements and limitations, net metering rules, any site specific issues, and rate structures. Interconnection requirements can include any specialized equipment the utility might require and any limitations on the size of the system the utility will allow to be connected to the grid. It is important to note that there have been several instances where systems have been installed that are larger than what the utility will interconnect leaving some of the installed system idle and non-productive. Therefore, it is recommended to call the utility engineering department at the beginning of the project to confirm there are no specific technical site limitations. Rate structures will affect the business case and life cycle cost analysis (LCCA) calculation but can also affect the sizing of the system (e.g. if there is net-metering, the system should probably not produce more than the site energy use).

5.1.4 Available Area

Sizing of rooftop installations can be roughly estimated at about 100W/m^2 of available area. But it depends on the solar collector technology selected and the type of roof that will be utilized.

For example: For a roof with a reasonable tilt and azimuth, then the maximum array size would be about 10 W per m^2 per 1% efficiency of the module selected (e.g. the maximum system size in 100 m^2 with 15% efficiency modules would be 15 kW). PVWatts allows a user to draw the available area of your system on the facility's roof with various module efficiencies to calculate what the maximum size could be. PVWatts is an online tool that aids in the design and evaluation of solar PV systems. A flat roof needs spacing between rows of solar collectors, which depends on the tilt and width of the collectors. If roof space is shaded or space is limited, high efficiency panels are recommended. With the same capacity, high efficiency panels use less space on the roof than the lower efficiency panels. In this case a 100 W/m^2 is a reasonable number for 12% efficient module but can increase with higher efficiency modules (e.g. the National Park Service at Alcatraz Island could only use one building rooftop and to get the required size system they needed to specify high efficiency module).

Ground mount systems typically require more area per kW installed than rooftop due to access and boundary issues, and racking type. Table 1 gives estimates of the area needed per W of capacity depending on technology or racking type. The given areas include the outer boundary of the array (i.e. includes all area inside security fencing). Table 1 presents energy density by PV panel technology and mounting type.

Table 1. Energy density by panel and system for ground-mounted PV

Module Type	System Type	
	Fixed-tilt	Single-axis Tracking
Crystalline Silicon	2.9 – 5.5 DC-Watts/ft^2 (31.2 – 59.2 DC Watts/m^2)	2.4 – 4.5 DC-Watts/ft^2 (25.8 – 48.4 DC Watts/m^2)
Thin Film	1.7 – 2.9 DC-Watts/ft^2 (18.3 – 31.2 DC Watts/m^2)	1.4 – 2.4 DC-Watts/ft^2 (15.1 – 25.8 DC Watts/m^2)

Source: "Best Practices for Siting Solar Photovoltaics on Municipal Solid Waste Landfills", NREL report # TP-7A30-52615, February 2013.

5.2 Energy Production Estimation

Energy production estimates for a PV system can be accomplished through several different methods including simplified hand calculations to a number of software tools. Simplified calculations and a couple free software tools will be covered below.

5.2.1 Software Tools for Estimating Energy Production

There are many software tools that will estimate energy production from a solar energy system but two freeware tools are worthy of mention: PVWatts and System Advisor Model (SAM). PVWatts is a web-based tool that requires only a few inputs. SAM is a downloadable freeware that can perform a more detailed production and financial analysis of a system, if you have specific system specifications.

5.2.1.1 PVWatts

PVWatts[10] is an online tool developed by NREL that aids in the design and evaluation of solar PV systems. It starts with identifying the system location so it can retrieve solar resource data. It will accept an address, zip code, or latitude-longitude coordinates. Once solar resource data has been confirmed, basic system info is input. Figure 21 is a screenshot of PVWatts.

[10] http://pvwatts.nrel.gov/.

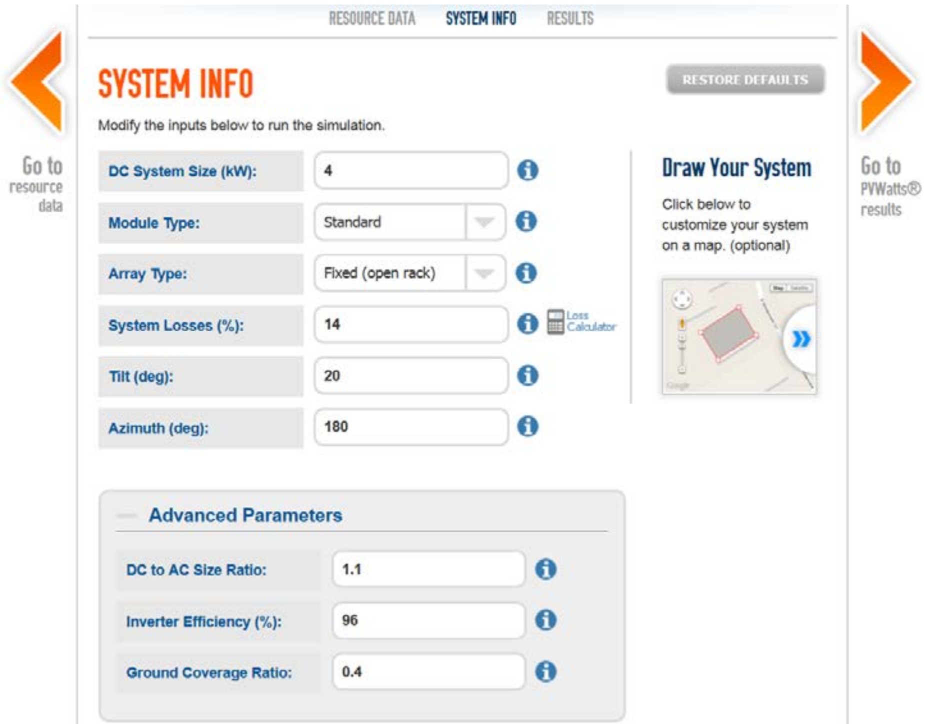

Figure 21. PVWatts

DC System Size (kW): Unless the system size is fixed, recommend 1 kW as input and scale annual energy production.

Array Type: Options are fixed (open rack), which is typically ground mounted; fixed (roof mount); 1-axis tracking and 2-axis tracking, typically ground mounted.

Azimuth: This is the orientation of the array (i.e. the direction it is facing). North=0, East=90, South=180 and West-270.

System Losses: This is a factor that derates system production for a number of known and possible system losses. The 14% losses default value should normally be used. Next to this input is a button that opens a calculator that will allow recalculation of default setting for specific systems. Tilt (deg) is the angle between the horizontal and the collector. The PVWatts default is latitude of the location entered. Most systems will have a tilt between 10° and 25° unless it is a tracking system. For 1-axis tacking, it is the tilt of the tracker axis from the horizontal (typically 0) and for 2-axis tracking this parameter is ignored. Figure 22 shows the system losses factor in PVWatts.

These are all the inputs needed for a PVWatts energy production calculation. PVWatts will calculate monthly and annual AC Energy production (kWh). Figure 22 shows the results for a 1 kW system as an example.

RESOURCE DATA SYSTEM INFO RESULTS

Go to system info

RESULTS

Print Results

1,529 kWh per Year *

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Energy Value ($)
January	3.57	93	9
February	4.21	98	9
March	5.61	142	13
April	6.15	147	13
May	6.46	156	14
June	6.74	154	14
July	6.60	152	14
August	6.44	148	14
September	5.99	136	12
October	4.99	121	11
November	3.80	94	9
December	3.38	89	8
Annual	5.33	1,530	$ 140

Figure 22. PVWatts results for a 1 kW system

5.2.1.2 System Advisor Model

SAM uses either the PVWatts calculator or has a component-specific option to calculate system energy production. If the specifics of the system are known or comparison of different components is desired, SAM contains a library of system components and their characteristics as well as detailed system inputs that can provide a more accurate estimate of energy production for a specific system. The SAM website includes links to resources for learning the software. Detailed information on SAM, video tutorials, and links to downloading the software are located at https://sam.nrel.gov/ (accessed May 05, 2015). Figure 23 shows a summary of SAM outputs.

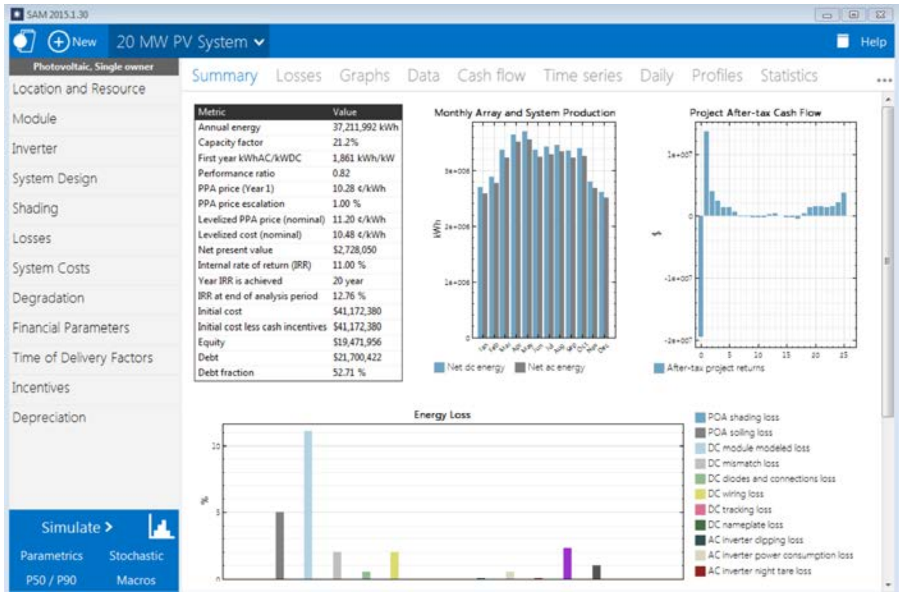

Figure 23. Screen shot of the System Advisor Model outputs

5.2.2 Energy Production Estimation and Collector Orientation

Understanding the effect and importance of solar collector orientation on energy production can be difficult to grasp. An optimum is to orient the collectors to get the maximum energy production. Figure 24 shows the effect of collector orientation for Boulder, Colorado. On average, the maximum energy production orientation is about 37° tilt and an azimuth of about 9° east of south. The findings show that energy production does not degrade quickly as the orientation is changed from the optimum. For this reason, other factors such as mounting structure for wind loading, collector spacing, wiring, and other requirement that affect the economics and technical requirements can become more important than optimal orientation.

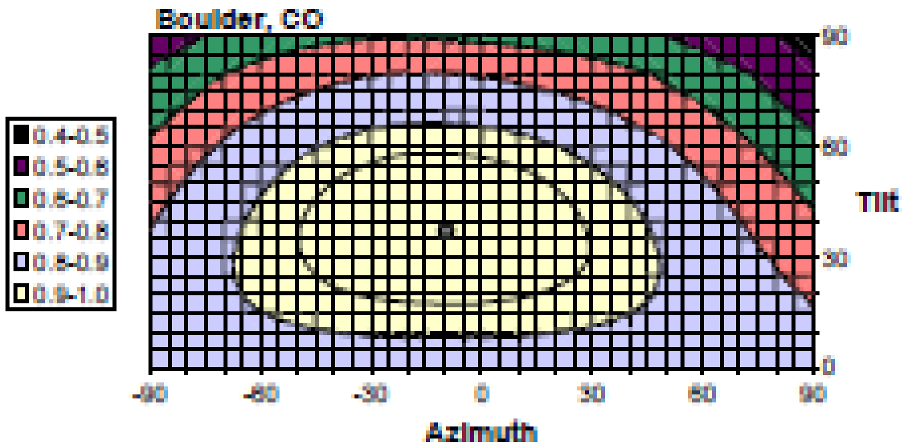

Figure 24. Effect of collector orientation

Source: Proceedings of Solar Forum 2001: Solar Energy: The Power to Choose April 21-25, 2001, Washington, DC, *Effects of Tilt and Azimuth on Annual Incident Solar Radiation for United States Locations*, Craig B. Christensen, Greg M. Barker.

6 Cost Overview

6.1 Cost Trends and General Rule of Thumb for PV Costing

The cost of a PV system depends on the system size and other factors such as geographic location, mounting system, and type of PV module, among others. Based on significant cost reductions seen in 2015, the average cost for non-residential, grid-tied systems have declined from $3.95 per watt in Q1 2013 to $2.92 per watt in Q4 2015. With a growing market and an increasing supply, further cost reduction is expected as market conditions evolve. Figure 25 shows the cost per watt of PV system from 2013 to 2015 for non-residential and utility scale projects.

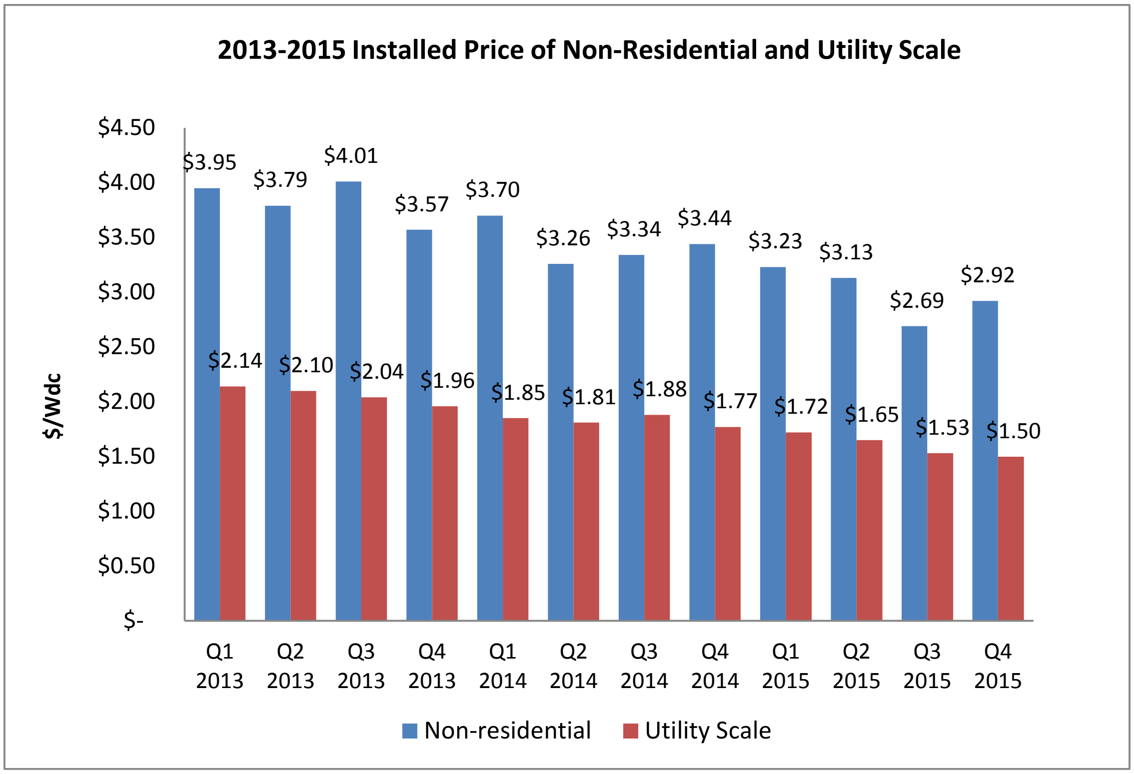

Figure 25. Average PV system cost from Q1 2013 to Q2 2015[11]

Source: U.S. Solar Market Insight2015, Solar Energy Industries Association

6.2 Cost per Watt Breakdown

Historically, PV modules have represented approximately half of the system cost. Based on significant price reductions due to a variety of market forces, the module cost represented about 30% of overall system costs as of a 2015 assessment. Costs for each component category as a proportion of overall system cost are shown in Figure 26.

[11] U.S. Solar Market Insight 2015 Year-end Review, Solar Energy Industries Association.

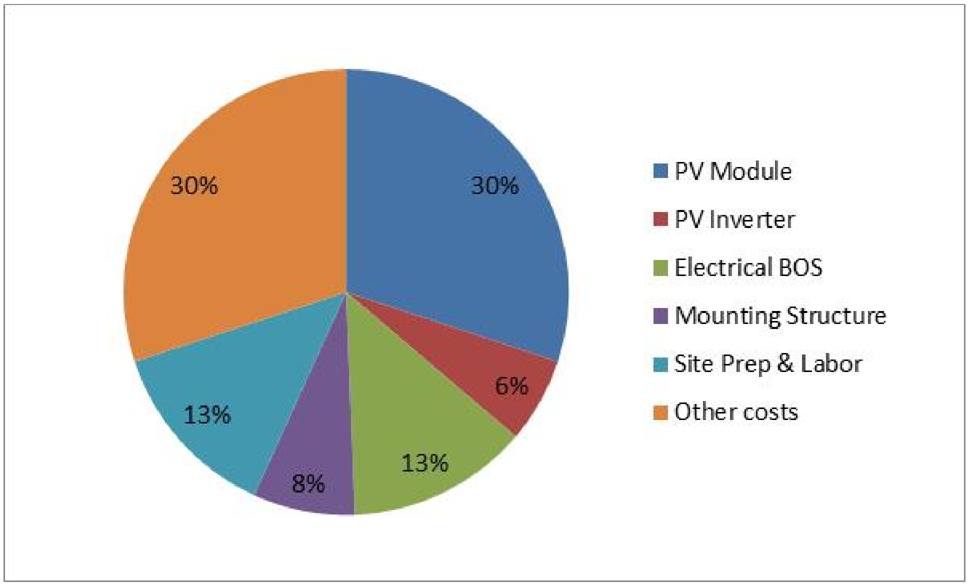

Figure 26. Cost contributions of PV system components

Source: U.S. Solar Energy Market Insight Report 2015, Solar Energy Industries Association

6.3 Operation and Maintenance

The Federal Energy Management Program (FEMP) has tabulated O&M costs for grid-tied distributed generation scale systems varying from $21 +/- $20 /kW/year for systems < 10kW to $19 +/-$10 /kW/year for large systems >1 MW.[12]

PV operation and maintenance includes the following areas:

- Monitoring: Monitor system and analyze data to remain informed on system status and performance. Includes comparing results of system monitoring to benchmark expectation.
- Administration of Operations: Ensure effective implementation and control of O&M activities including archival of as-built drawings, equipment inventories, owners and operating manuals, and warranties. Also keep records of performance and O&M measures,
- Directions for the Performance of Work: Specify the rules and provisions to ensure that maintenance is performed safely and efficiently
- Operator Knowledge, Protocols, and Documentation: Ensure that operator knowledge, training, and performance will support safe and reliable system operation.

[12] www.nrel.gov/docs/fy15osti/63235.pdf.

- Preventative Maintenance: Schedule preventive maintenance to conform to the manufacturer recommendations as required by the equipment warranties.

- Corrective Maintenance: Repair damage or replace failed components. Less urgent corrective maintenance tasks can be combined with scheduled, preventative maintenance tasks.

Maintenance on PV systems is typically low relative to other forms of energy generation. Solar PV systems to maintain include the solar panels, mounting systems, inverter, and wiring and connections. This assumes a system without batteries. The following activities should be performed on a routine basis and approximate timeframes are provided. The environment, location, and system design are other considerations when determining how often to perform routine maintenance. Always refer to any operating manuals received after installation for manufacturer's recommendations.

Solar Panels:

- Perform a visual inspection for chips, cracks, delamination, and water leaks approximately every six months.

- Remove dirt and dust with water and/or a sponge depending on the amount of fouling. Do not use brushes, any types of solvents, abrasives, or harsh detergents.

Mounting System:

- Perform a visual inspection for rusted bolts or connections annually.

- Ensure frame and modules are secure annually.

Inverter:

- Clean (vacuum) dirt and dust from heat rejection fins annually.

Wiring and connections:

- Perform a visual inspection for cracks, corrosion, and deterioration in wiring insulation and conduit annually.

Service descriptions for preventative maintenance and corrective maintenance can be found in Appendix G and H.

7 Economic Analysis and Business Structures

7.1 Economic Analysis

The intent of Reclamation's economics technical memorandum No. EC-2013-02, *The Basics of Lifecycle Cost Analyses Supporting Reclamation's Sustainable Energy Goals*, is to develop the economic analysis for a solar energy system. Calculation of LCCA, savings-to-investment ratio (SIR) and modified internal rate of return (MIRR) are all mandated by 10 CFR 436A for analysis of energy projects. Reclamation's guide[13] provides step-by-step instructions on how to perform the necessary calculations and gives sources for finding and developing the required input data. The discussion below is a summary that will support and assist with the development of these analyses as defined by the Reclamation's guide.

7.1.1 Life Cycle Cost Analysis

An LCCA is the primary tool mandated by legislation and executive orders for economic analysis of federal investments in energy and water conservation and renewable energy in federal buildings. An understanding of LCCA will assist Reclamation staff in achieving the goals for non-hydroelectric renewable energy at Reclamation facilities. For more information, see Appendix I: *The Basics of Lifecycle Cost Analyses Supporting Reclamation's Sustainable Energy Goals*. Another source of general cost data is The Open PV Project[14] which can be searched by state, type of system, and size of system. The U.S. Department of Energy also has a website to help with energy analysis with links to reports and tools on solar cost information that can be found at: www1.eere.energy.gov/analysis/ (accessed September 01, 2016).

Generally, the cost for a solar energy system at a federal facility may be more than the cost of a commercial system due to Federal Acquisition Regulation (FAR) and wage requirements. Rule-of-thumb installed cost, operation and maintenance cost can also be found at www.nrel.gov/analysis/tech_lcoe_re_cost_est.html (accessed September 01, 2016). Capital replacement costs for a PV system can be assumed to be an inverter replacement in year 15 at a cost of around $0.15/W.

7.1.2 Savings-to-Investment Ratio

SIR is a ratio of the present value of net savings to the present value of net cost the solar energy system. The net savings includes energy cost savings and any O&M cost savings the system will produce. The net cost includes the initial investment and replacement cost less salvage value.

7.1.3 Modified Internal Rate of Return

MIRR is a modification of the internal rate of return (IRR). The IRR is the discount rate that would make the net present value (NPV) of a project equal to zero but assumes that positive cash flows from the project can be reinvested at the same rate as the IRR. MIRR is different from IRR in that the reinvestment rate is set equal to the cost of capital or financing rate (i.e. not the calculated IRR).

[13] https://www.usbr.gov/power/Reclamation%20Sustainable%20Energy%20Strategy%20.pdf.
[14] https://openpv.nrel.gov/.

7.2 Factors Affecting Economic Analysis Inputs

- Utility tariff structure
- Available incentives
- Ownership model.

7.2.1 *Utility Tariff Structures*

Understanding the utility tariff structures is required to be able to calculate actual possible energy cost savings. Some utilities may require the facility to change to a different rate structure if it installs a solar energy system that may or may not be beneficial economically. It is important to know what rate structures would be available to the facility if it a solar energy system is installed, so a correct economic analysis can be made.

Three typical rate structures are flat-rate, time of use (TOU) and block rates. Flat rate is where each kWh is the same price no matter how many kWh are consumed. TOU rates are where the cost of each kWh depends on the time of day and day of the week when the kWh is consumed. Block rates have a different cost per kWh depending on how many kWh are consumed in that period (e.g. the first 500 kWh consumed during the billing period would be one price and the next 1,000 kWh would be another price, and so on).

The utility may also pay a different price for kWh fed back into the grid than for kWh consumed from the grid. In addition to energy charges the tariff structure may include demand charges. Demand charges are based on the peak power needed by the facility during a specified amount of time and are billed in $/kW. Solar energy systems typically provide minimal demand savings due to clouds but may help reduce demand charges since solar produces energy at the same time as typical peak power consumption. SAM software has the capability to analyzing complex rate structures that depend on the time of day the solar energy is producing energy (e.g. TOU) and demand charges.

Net metering policy should be fully understood. Net metering means that excess kWh produced by a solar energy system and put into the grid will be used to offset energy consumed by the facility from the grid at a later time (i.e. the grid is used as a battery for the solar energy system). There are several key criteria that can vary including system capacity limits, eligible customer and system types, how any excess generation is treated at the end of a billing period, and who owns the RECs. Information on net metering policy can be found at: http://www.dsireusa.org/ (accessed September 01, 2016).

A feed-in-tariff (FIT) could be another option for selling and valuing the energy production from a solar energy system. FITs in general are long-term contracts (10 to 20 years) with the utility to sell the energy produced by the solar energy system. Policy and rules can vary widely where FITs are available. The DSIRE website has first level information on FITs by state but the serving utility would be able to confirm availability and terms.

7.2.2 *Available Incentives*

Incentives can reduce the cost of solar energy systems. The DSIRE website has first level information on solar incentives but the availability and terms would need to be confirmed by the entity offering the incentive (e.g. state, local government, utility, or other).

7.2.3 Ownership Models

There are two basic ownership models available for a Reclamation facility solar energy system: 1) federal funded and owned or 2) owned by a third-party. If the business case for the solar system meets agency criteria and funds are available to purchase the system, then a federal owned system is an option. If federal funds are not available for the solar energy system, there are several contracting options to that may be used.

The primary issue with procuring a solar energy without agency funding is a need for long-term contracts to make the project economically viable. Solar energy system cost is primarily initial installation cost with low operating cost (e.g. no fuel cost) and the system produces energy for 20 years or more. Therefore, contracts with the third-party owner of the system need to be long-term (15 to 20 years) to make the annual or kWh cost of energy from the system competitive with alternatives. Due to restrictions on contract lengths that federal agencies can enter into (10 years), there are only a few contracting authorities that allow contract of the needed length. FEMP supports federal agencies identify, obtain, and implement project funding for energy projects and information on this assistance can be found at http://energy.gov/eere/femp/project-funding (accessed September 01, 2016). Also, detailed descriptions and step-by-step guidance for these contracting options are given in *Procuring Solar Energy: A Guide for Federal Facility Decision Makers*.[15]

Below is a brief description of each option with some updates. Available options include:

- Power purchase agreement
- Energy savings performance contract
- Utility energy services contract.

7.2.3.1 Power Purchase Agreements

Power purchase agreements (PPA) have been used to finance solar projects since 2003 and are now driving most commercial solar installations. Under a PPA, a private entity (typically a group consisting of developers, construction companies, and finance companies) installs, owns, operates, and maintains customer-sited (behind the meter) solar energy generation equipment. The site purchases electricity through a long-term contract with specified energy prices. Payment is based on actual energy (kilowatt-hours or therms) generated from the solar equipment and consumed by the site. PPAs typically require long-term contracts to make the offered price of energy competitive. To address the contract length limitation, federal agencies are exploring methods that are available under existing federal laws and regulations, and also are making other contractual issue improvements. One option is if the facility is in the Western Area Power Administration's (Western) territory, Western can use its long-term contracting authority to purchase renewable energy from a renewable energy system on a federal site on an agency's behalf.

7.2.3.2 Energy Savings Performance Contracts

Energy savings performance contracts (ESPC) have a long history of use in the federal sector and have primarily been used for energy efficiency projects. They are increasingly being seen,

[15] www1.eere.energy.gov/solar/pdfs/47854.pdf, accessed September 01, 2016.

however, as a long-term financing method for solar projects. An ESPC is a guaranteed savings contracting mechanism that requires no up-front cost. An energy services company (ESCO) incurs the cost of implementing a range of energy conservation measures (ECM) which can include solar and is paid from the energy, water, and operations savings resulting from these ECMs. The ESCO and the agency negotiate to decide who maintains the ECMs. Payments to the contractor cannot exceed savings in any one year.

There are a number of ways a solar project can be implemented under the ESPC contracting authority. Most ESPC solar projects to date have been done in combination with energy efficiency measures where the complete project bundle (i.e. solar and energy efficiency) meets the criteria for an ESPC (i.e. annual payments to the contractor cannot exceed savings). For smaller ESPC projects FEMP has implemented ESPC ENABLE that provides a streamlined process to implement specific ECMs in six months or less. The allowed ECMs include solar PV. The ENABLE[16] program utilizes the General Services Administration schedule with pre-approved vendors and pre-negotiated pricing. Another option that is being considered is to allow a PPA to be an ECM under an ESPC contract (i.e. a PPA using the long-term contract authority of an ESPC). This option is known as an ESPC RECM.

7.2.3.3 Utility Energy Services Contract

Utility energy services contracts (UESC), like ESPCs, have a history of use in the federal sector primarily for energy efficiency projects. These contracts are also being seen as a method of long-term financing, with the added benefit of usually being a sole source contract. A UESC is an agreement that allows a serving utility to provide an agency with comprehensive energy- and water-efficiency improvements and demand-reduction services. The utility could partner with an ESCO to provide the installation, but the contract is between the federal agency and the utility. This contracting mechanism primarily is for bundled energy-efficiency and renewable energy projects, and typically is not used for standalone renewable energy projects. The steps in the UESC process are well defined, but different utilities might describe them differently.

8 Project Execution

This section summarizes the steps needed to execute a specific site solar procurement. More detailed information on these steps is located in *Procuring Solar Energy: A Guide for Federal Facility Decision Makers*.[17] Though this section largely considers single site installations, agencies should look for innovative ways to aggregate procurements as much as possible to benefit from economies of scale and to reduce transaction costs.

Project Steps:

Step 1. Identify needs and goals

Step 2. Assemble an onsite team

Step 3. Evaluate candidate solar energy sites

[16] http://energy.gov/eere/femp/espc-enable, accessed September 01, 2016.
[17] https://www1.eere.energy.gov/solar/pdfs/47854.pdf, accessed May 05, 2015.

Step 4. Consider project requirements and recommendations

Step 5. Make a financing and contracting decision

Step 6. Follow the process for the financing and contracting method selected.

8.1 Identify needs and goals

Several common reasons for considering a solar project include:

- Agency must meet renewable energy targets
- Appropriations are available for improving a facility
- Project is a good way to meet a site's needs—depending on site conditions, there can be many smart reasons to implement a solar project including off-grid or backup power for remote locations
- Project can provide energy cost savings
- Project can reduce future energy cost volatility and uncertainty
- Project will earn credits toward LEED certification.

The reasons for considering a solar project help to define the needs and goals that the project will address. Needs and goals comprise the vision, the touchstone, and the principles that guide the process of setting priorities, creating decision criteria, and making decisions. Solar should be part of a broader vision of whole systems design for buildings and sites. Potential goals or criteria include the following:

- Maximize onsite solar energy production (particularly within a restricted budget)
- Maximize the return on investment
- Meet a minimum annual solar energy production target
- Maximize GHG reductions.

Goals could adjust or change as the project develops, but they always should be at the forefront during the decision-making process.

8.2 Assemble an onsite team

At this point, a solar project team should be identified. The team is important not only for getting the work done, but also for making sure that all issues are considered. Even small oversights can be costly in terms of dollars and time, and can even result in a failure to accomplish project goals.

One of the most important features of the team should be its alignment with the project's goals. Another important feature of the team is to ensure it includes or involves persons who can address other legal requirements, such as NEPA, NHPA, and ESA. The project goals can adjust with team input and healthy debate on project questions. Step 4 - Consider project requirements and recommendations can help when considering the makeup of the team. It outlines the diverse considerations that feed into successful project completion. It is important to recognize that it takes a diverse group of people with a wide range of skills to bring a project to fruition.

8.3 Evaluate candidate solar energy sites

Detailed information is needed to evaluate specific sites for solar energy installations. These findings may be available from an agency-wide solar screening if your agency has one, or they may need to be compiled by the solar project team.

There are two recommended levels of solar site evaluation:

1. A project solar screening, which is a high-level, preliminary analysis used to determine a site's likely viability.
2. A project solar feasibility study, which is a more rigorous engineering and economic analysis to define specific system design considerations for use in requests for proposals and/or scope of work development. This would also include collecting data to determine NHPA and ESA compliance requirements.

For projects that propose to use alternative financing, a project solar screening is sufficient to proceed. For agency funded projects, a solar feasibility study is recommended.

8.4 Consider project requirements and recommendations

If, at this point, the solar screening demonstrated that the project is viable, the following should be considered:

- Utility interaction
- NEPA, NHPA, ESA and other environmental compliance
- Site master plan review
- E.O. 13693 and other renewable energy goal requirements
- Project incentives
- Historic building issues
- Computer network connectivity authority.

8.5 Make a financing and contracting decision

Unless funding is designated for the project (i.e., the agency will fund the project), this can be a complex decision. If no direct funding is available, financing options must be considered. Before choosing an available financing option, review the options. FEMP maintains a website and offers webinars and workshops to educate participants on the different financing options available. The FEMP financing information can be found at http://energy.gov/eere/femp/project-funding (accessed September 01, 2016). The FEMP training information is available at http://energy.gov/eere/femp/training (accessed September 01, 2016).

8.6 Follow the process for the financing and contracting method selected

The solar project shall consult on a process for financing and contracting with the Acquisition and Assistance Management Division that has overall responsibility for Reclamation's acquisition and financial assistance policy, acquisition and financial assistance operations, and property programs.

Appendix A. Self-Guided Solar Screening

A preliminary solar energy site screening provides a rough estimate of the solar resource, energy production, and cost of a PV system. It also provides information for a go- or no-go decision to proceed further in the procurement process. A more thorough solar energy site screening may be needed later to better quantify the energy production and costs before proceeding further.

A summary sheet is included at the end of this section to record the data and observations. The summary sheet, along with any drawings or photographs, is needed for the next steps in procuring a PV system. Shooting photographs of the site and equipment is critical, as they allow others to confirm the preliminary estimate or make recommendations without visiting the site.

Solar Site Screening

Prior to a Site Visit

Preview the site using PVWatts (http://pvwatts.nrel.gov/) or Google Earth (http://earth.google.com) to identify possible land or roof areas for a PV system.

- Identify roof areas with flat or equator-facing surfaces (e.g., south in the northern hemisphere) with little or no equipment on the roof
- Identify large, open land areas
- Print an overhead map of the site and mark these potential land and roof areas on the map for ease of location during site visit.

Use PVWATTS (http://pvwatts.nrel.gov/). Calculate, and print out, the energy production for a 1 kW PV system tilted at 10 degrees, and use the defaults for all other inputs. The monthly and yearly energy outputs for a 1 kW system are useful numbers for scaling to larger systems. For example, a 55 kW PV system produces 55 times the energy of a 1 kW PV system.

When on Site

Access the roof or land area being considered for PV systems. Note the tilt angle and orientation of the equator-facing or flat roof area. Also note the type, condition, and age of the roof. For land area note the approximate grade and orientation of the land area. Take photographs.

The objective now is to determine the area of the site for a potential solar system as this will allow an estimation of the potential system size. The site needs to be very clear of objects that could cast shadows on the proposed site. While standing on the proposed site, use your thumb and fist to estimate the angle of the object from the horizon to the top of the object. A sideways thumb held at arm's length is about 2 degrees from the bottom to the top of the thumb. A fist held in front of your body is about 10 degrees from the bottom (little finger) to the top (pointer finger) of the fist (see www.vendian.org/mncharity/dir3/bodyruler_angle/). Objects that are less than 20 degrees in height above the site, that are skinny (e.g., power poles), or that can be removed should be ignored for this preliminary estimate. For objects that are on the site, make height-angle measurements close to the roof or ground where the collectors will be placed.

Determine the square footage of the site that is not shaded by objects, as determined above. For a preliminary estimate, the distances could be paced off. If available, use a measuring device such as a range finder or a rolling wheel tape measure. Take several photographs that could be used to make a panoramic photograph.

If a roof area is being considered, ask the people on site if the roof leaks, when it was last replaced or repaired, or if they have any concerns about it. Note their answers. Take photographs of the roof and the underside from inside the building if possible. Ask about the roof age and construction and whether any drawings are available. Make a copy or take a photo of any drawings.

Photovoltaic Specific Assessment

Identify the nearest location for housing the inverters. It is best if this location is shaded or enclosed. Small inverters (6 kW or less) can hang on a wall. Larger inverters (greater than 6 kW) are placed on the ground or floor. Note the distance from the proposed PV system location to the inverter bank. Take photographs.

Identify the nearest electrical panel and record the location and distance from the inverter bank to the electrical panel, voltage at the electric panel (V), the number of phases (1 or 3), capacity of the main breaker (amps), and the capacity of the panel (amps). Take photographs of the equipment, including the circuit breakers.

Energy Production Estimate

Estimate the size of the PV system by multiplying the proposed site area (ft^2) times 9.3 W/ft^2. This corresponds to a fairly typical 14% efficient crystalline PV module. This preliminary solar energy site assessment is for no, or relatively few, solar obstructions. If the solar obstructions become numerous or complicated, then a more detailed solar energy site assessment should be made.

PVWatts can also be used for estimating PV capacity and electricity production of a proposed site area. A user can use the map tool to roughly approximate the size based on the roof or ground area available for the array at the system location. The map tool calculates a value for the DC nameplate size and populates the System Size input with the value.

Site Energy Requirements

Prior to a site visit, or while on site, determine the annual energy usage from the utility bills. Ask the site personnel if any energy efficiency changes will be made or if electrical load increases are anticipated.

Determine the annual electrical energy consumption for the building or site. Compare this number to the estimated energy production from a PV system. In most locations there is little economic sense to produce more energy than is consumed. If needed, reduce the PV system size to just meet the annual electrical energy usage.

Divide the estimated PV system production by the annual electrical energy usage. This is the percentage of annual energy supplied by the PV system.

Cost Estimate

A conservative price estimate for a fully installed PV system is $3,500 to $4,500 per kW of PV. Large PV systems (greater than 100 kW) or PV systems on sites with uncomplicated site access or conditions have been installed for less money. This price range is for a simple grid connected PV system without batteries. Systems with batteries can easily double the installed price.

Incentives

Available incentives for solar projects can be critical to the economic feasibility of a prospective project. Look up and list incentives that apply to the project. The DSIRE Web site lists most incentives available for solar projects from federal, state, local, and utility sources (www.dsireusa.org, accessed September 01, 2016).

Go- or No-go Decision

The information compiled here will form the basis of the economics that will be used for a decision to explore the feasibility of the project further.

Appendix B. Summary of Preliminary Solar Energy Site Screening for Photovoltaics

Name of Location: ____

Latitude and longitude, or ZIP code: ____________________________________

Assessment performed by: (include contact information)_________________________

____

Date of Assessment: ____

Area (ft^2)	
Maximum PV system size (kW)	
Estimated annual PV system energy production (kWh/yr)(from PV WATTS)	
Building or site annual energy consumption (kWh/yr)	
Percent solar contribution(production divided by consumption [%])	
Distance from PV system to inverter (ft^2)	
Electrical service (voltage and # of phases)	
Total installed price estimate ($)	
Present price of energy ($/kWh)	
Estimated annual energy savings ($/yr) (estimated annual energy production multiplied by present price of energy)	

Possible Site Issues

Historic building issues? ____

Structural issues (if rooftop)? ______________________________________

Roof age and condition? ____

Planned replacement?____

List available incentives for solar projects on the site:_______________________________

____

Comments (use another page if necessary):____________________________________

____

Attach drawings, photographs and printouts.

Appendix C. Solar Screening Evaluation Checklist

This is a checklist to review the adequacy and quality of a given solar screening and to determine if a more detailed screening needs to be done. If an applicable element is missing from the screening, it is recommended a more detailed solar screening for the site be obtained.

The checklist is in two parts. The first part is for solar screenings and pertains to financing mechanisms other than agency funded. The second part is for solar feasibility studies and includes recommended information in addition to the solar screening.

Solar Screening minimum recommended information (items 1 – 5)

1. Confirm shading analysis, available square footage and preliminary size estimate:

☐ Satellite map view or use of an accurate aerial tool to analyze the potential shading impacts of neighboring buildings, rooftop protrusions, parapets, or vegetation that could block sunlight from a potential solar array and relate these impacts to the available roof or ground area.

☐ Satellite or accurate aerial tool measurement of the available square footage or acres

☐ Preliminary estimate of the system size

2. Confirm annual energy production per unit of capacity:

☐ Electricity production estimates

__________ (kWh/yr/kW installed)

(available online tools: PVWATTS).

Inputs for this level of analysis are as follows (unless site conditions preclude, i.e., a steep pitch roof that does not face the equator):

☐ 1 kW system size

☐ 10 degrees from horizontal-tilt (if you have a pitched roof, enter actual pitch)

☐ Local location or nearest location option with similar sun exposure

☐ 14% system losses

☐ Azimuth (compass orientation—select 180 degrees or 0 degrees so array faces equator or, for a pitched roof, enter the direction that the roof faces)

☐ Solar thermal (available online tool: RetScreen www.retscreen.net/ang/home.php)

☐ Solar ventilation preheat (available online tool: RetScreen)

☐ Solar pool heating (available online tool: RetScreen)

3. Confirm economic analysis:

☐ Confirm local energy rates

___________ ($/kWh or $/therm)

☐ Annual savings

___________ ($/yr/ kW installed)

☐ Any available incentives?

___________ ($/W or $/yr/W)

(i.e. rebates, local Renewable Energy Credits market, other).

Check DSIRE: www.dsireusa.org

☐ Any extraordinary project specific costs?

___________ ($/W)

Confirm that structural, electrical inter-connection, and equipment location issues have been investigated and any additional costs related to these have been estimated.

☐ Estimated System cost

___________ ($/W)

☐ Appropriate economic metric for your decision-making process.

___________ (SIR, NPV, LCC, other)

(Solar Advisor Model is available online and does some financial analysis.)

NOTE: In general, the estimated cost should not exceed $4 per watt except in special circumstances.

4. If proposed system is rooftop:

☐ Age of roof

___________ (yrs)

☐ Condition of roof

___________ (yrs of expected remaining life)

☐ Roof warranty

___________ (yrs remaining)

☐ Estimated structural capacity available for solar system

___________ (lbs/ft^2)

☐ Estimated maximum weight of solar system

__________ (lbs/ft^2)

5. Confirm other considerations have been addressed:

☐ Historic building issues (is the proposed system on a historic building or in a historic district?)

☐ National Environmental Policy Act (NEPA) issues.

Solar feasibility study minimum recommended information in addition to the Solar Screening information (items 1-9)

6. Confirm recommended size

☐ Is the recommended size in assessment reasonable and is there opportunity for a larger system?

__________ (kW or area of collectors)

In PVWatts is a Web tool that uses aerial maps and a draw feature to estimate PV system size on a site. See http://pvwatts.nrel.gov/.

7. Confirm shading analysis (recommendations for report)

☐ Detailed shading analysis with solar collector exclusion areas marked on the plan view of the site adjacent shading obstructions. Exclusion areas should be indicated to the east, west, and toward the equator (if in the northern hemisphere- to the south) of any shading obstruction.

☐ Unless the array is installed with zero degrees tilt (horizontal), need to see some space between rows in the array layout to prevent rows of PV shading each other.

8. Confirm investigation into interconnection issues:

☐ Requirements to get utility approval for interconnection (estimated costs if special equipment is required)

☐ Recommended interconnection point

☐ Confirmation of space for system electrical equipment

9. Confirm annual energy production for site-specific recommended system

☐ Electricity production estimates

__________ (kWh/yr)

(available online tools: PVWatts).

Inputs are:

☐ __________ (kW) system size

☐ __________ (degrees from horizontal) tilt

- ☐ __________ Location
- ☐ __________ Derating factor (default is 0.77)
- ☐ __________ (degrees-compass orientation) Azimuth
- ☐ Solar thermal (available online tool: RetScreen)
- ☐ Solar ventilation preheat (available online tool: RetScreen)

Appendix D. PV Project Design Evaluation Checklist

This checklist has been created to assist you in the design phase of the system during the 25%, 50%, and final review stages.

Site Layout

☐ __________ (degrees) tilt

☐ __________ (degree) azimuth

☐ __________ (kW or MW) system size

☐ Engineer's stamp on PV array mounting design for wind loading

☐ Confirm shading analysis has been done and site layout conforms to it.

Rooftop system:

☐ Engineer's stamp on roof structural weight carrying capacity for solar system

☐ Confirm weight of system is within carrying capacity of roof (lbs/sq ft)

☐ What type of roof penetrations, if any, and confirm construction detail to weatherproof penetrations

☐ Check PV layout compliance with fire specifications. (Fire Safety Guideline for Photovoltaic System Installations: www.fpemag.com/_pdf/Fire_Safety_Guideline-PV_System_Installations.pdf)

Ground-mount system:

☐ __________ (ft) Height of lower edge of collector to ground. Usually like to see a minimum of 2 feet between the lower edge of the PV modules and the ground. This can be location specific (examples):

i. In desert areas where vegetation does not grow tall and could possibly shade the array, the array could be closer to the ground.

ii. In areas of high snow fall the array should be higher from the ground to prevent snow building up at the lower edge of the array as it slides off, thus causing the array to be shaded.

iii. Some key things to consider regarding location are vegetation, snow, material that may drift around the array, future development, and other possibilities for future shading problems.

iv. Decisions around this issue can be a balance between location conditions, O&M costs for periodic removal of shading problems, and specifications for the ground under the array (e.g., weed barriers and gravel).

☐ Perimeter fence:

i. Confirm the fence doesn't shade the array.

ii. It is a good idea to restrict access and keep out tumbleweeds and animals that may damage the system.

Electrical Design:

Based on one-line or three-line diagram:

☐ Final electrical design has engineer's stamp

☐ __________ (volts) Check PV string maximum/minimum voltages (extreme weather) and confirm within inverter specifications (most inverters have a "string calculator" on their site, for example:www.aesolaron.com/SolarStringCalc.aspx)

☐ __________ (kW) Check PV array maximum DC power to each inverter (extreme weather-cold and clear) to confirm it is within inverter specifications.

☐ PV-each string protected (fuse or breaker)

☐ __________ (% efficiency, configuration & capacity) Transformer specification (recommended minimum efficiency of 97%)

☐ Module grounding: confirm there is a specific grounding wire or the rack/module system is Underwriters Laboratories rated for grounding

☐ AC disconnects specified and location easily accessible

☐ DC disconnects specified and location easily accessible.

Interconnection: Inside building must meet NEC 690:

Sum of PV breaker and panel main breaker less than or equal to 120% of panel rating

☐ __________ (amps) Panel rating

☐ __________ (amps) Panel main breaker rating

☐ __________ (amps) PV Breaker

Interconnection: Direct tie:

☐ Is there an acceptable plan?

System Components Specifications:

☐ System components meet "Buy American" criteria?

☐ PV CEC approved?

- ☐ Inverter(s) CEC approved?
- ☐ __________ % Inverter efficiency
- ☐ __________ (years) Inverter warranty (recommended 10 year minimum)
- ☐ __________ PV module warranty (recommended 10 year 90%, 20 year 80% minimum)

Appendix E. PV Commissioning Checklist

(See IEC 62446 for more details)

Before Commissioning

The items below should be completed before commissioning or available at the site.

- ☐ All permits have been signed off
- ☐ Utility has given permission to operate system
- ☐ One or three line drawing of system
- ☐ System layout drawing (shows module layout, location of BOS components, disconnects, and wiring and conduit specifications)
- ☐ PV module specifications
- ☐ Inverter specifications
- ☐ Combiner box specifications
- ☐ Feasibility Study Review (if available)

Visual Inspection

Verify the installation is complete to the design drawing.

- ☐ All PV modules are permanently installed (confirm modules are in good condition)
- ☐ All inverters permanently installed
- ☐ All combiner boxes permanently installed
  - ☐ All disconnects and switchgear permanently installed
- ☐ Wiring is completed (no loose connections or damaged wires)
- ☐ No potential for wire damage (e.g., deburred metal and proper sheathing to protect wires)
- ☐ Utility power connected
- ☐ Internet connection operational (if applicable)
- ☐ Physical installation is per design drawing and manufacturer's specification, and it meets visual requirements
- ☐ System is compliant with applicable building and electrical codes
- ☐ Protective fencing and enclosures are installed

☐ Verify outdoor equipment is of proper material for location (e.g., UV-rated wire, stainless steel, hot dipped galvanized, other as specified)

☐ Dissimilar metal should be electrically isolated to avoid galvanic corrosion

☐ Verify grounding of metallic surfaces that might become energized

☐ Wire and conduit sizes installed per plan

☐ Fuses and breakers are sized and installed properly

☐ Document as-built conditions

☐ All equipment is labeled as required.

Performance Testing

Verify the system is performing within acceptable limits.

☐ Conductor insulation test using a megohm meter on all homerun wiring to ensure no leakage currents to earth (Pos-to-GND and Neg-to-Gnd resistance > 2 megaohms). This may need to be done during construction while conductors are accessible.

☐ Grounding resistance is < 5 Ohms

☐ Measure and record open-circuit voltage (Voc) and polarity of each string. (Verifies all strings have the same number of modules.)

☐ Measure and record short-circuit current (Isc) of each string.

☐ Inverter startup sequence – follow manufacturer's instructions for initial startup.

☐ Measure and record maximum power point current (Imp) for each string. (Current measurements for each string should be within a 0.1A range of each other, assuming consistent weather conditions and all string having same tilt and azimuth angle. If a string is outside the range, check for shading or a ground fault.)

☐ Confirm inverter's internal power meter and display using independent meters. (Once this is done, inverter-displayed power readings can be used for subsequent reporting.)

☐ Confirm the system output under actual conditions meet minimum expected output. Actual performance should be within about 5% of expected, calculated performance. This procedure includes system nameplate rating (kW), solar irradiance measurement (W/m^2) and module cell temperature (C). Procedure is best conducted during consistent weather conditions, where no array shading is present, and solar irradiance is not less than 400 W/m^2.

Appendix F. Example of Requirements for a PV System

TABLE OF CONTENTS

SECTION 26 31 10
PHOTOVOLTAIC SYSTEM

PART 1 GENERAL

1.01 BACKGROUND

A. Reclamation FACILITY issuing a “Request for Proposal: for designing, furnishing, installation, and/or delivery of the following photovoltaic systems:

1. First photovoltaic system shall be a (ground mount, roof mount) sized at xx kW_{AC} (approximate xx kW_{DC}) grid-tied for main facility usage.

1.02 DESCRIPTION

A. Contractor’s proposal shall be for a firm-fixed price contract to design-build, install, and/or deliver the following photovoltaic systems:

1. One ground mount grid-tied photovoltaic system providing approximate xx kW_{AC} (approximate xx kWh/year for an average year using typical weather data.

B. Contractor shall provide all labor, equipment, transportation, material, supplies, permits, and certifications to design, furnish, install, test, deliver, and commission all four photovoltaic systems.

1. The xx kW_{AC} grid-tie system includes trenching, backfilling, compaction, underground conduits, cabling, access boxes, labor, equipment, inverters, panels, etc. to connect photovoltaic system to BOR FACILITY existing main electrical service 208/480 V switchgear located approximately xx linear feet from photovoltaic panel installation site.

1.03 MEASUREMENT AND PAYMENT

A. Offeror’s proposal shall provide payment schedule and recommended contract line items.

1.04 REFERENCE STANDARDS

A. International Code Council (ICC)

1.	IBC-latest	International Building Code

B. International Electrotechnical Commission (IEC)

1.	IEC 61215:latest	Crystalline Silicon Terrestrial Photovoltaic (PV) Modules - Design Qualification and Type Approval
2.	IEC 61853-1:latest	Photovoltaic (PV) Module Performance Testing and Energy Rating

3. IEC 62446:latest — Grid Connected Photovoltaic Systems - Minimum Requirements for System Documentation, Commissioning Tests and Inspection

4. IEC 62759-1:latest — Photovoltaic (PV) Modules - Transportation Testing - Part 1: Transportation and Shipping of Module Package Units

C. National Fire Protection Association (NFPA)

1. NFPA 70-latest — National Electric Code

D. Underwriters Laboratories (UL)

1. UL 1703-02 — Flat-Plate Photovoltaic Modules and Panels

2. UL 2703 — Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for use with Flat-Plate Photovoltaic Modules and Panels

1.05 SUBMITTALS

A. Submit the following in accordance with Section 01 33 00 - Submittals.

B. RSN 26 31 10-1, Manufacturer’s Product Data:

1. Approval data for each PV system component includes modules, inverters, panels, mounts, etc.

C. RSN 26 31 10-3, PV Performance Report (PVPR):

1. Contractor shall prepare a written report of inspections and tests perform during installation of PV modules and array systems. The report shall include the following data and information:

   a. Comparison of manufacturer’s data to field observations and tests.

   b. Report includes array location, date of tests, list of tests being performed, name of personnel performing tests or recording information, and list of equipment.

      1) If required, name of personnel performing peer review/quality control or witnesses to tests.

      2) Equipment list includes manufacturer’s data sheet, purpose of equipment, methods and techniques use with equipment during measurements, and last date equipment was calibrated.

D. RSN 26 31 10-4, xx kW_{AC} Single Line Diagram:

1. Furnish a printed and electronic (Adobe “pdf” or AutoCAD “dwg” file formats) single line diagram of xx kWAC Grid-Tie ground based photovoltaic system.

E. RSN 26 31 10-6, Interruption of Service Request:

1. List utility and location where interruption will occur.

2. Outline procedures for accomplishing work including specific safety precautions to be taken, methods for Tag-Out & Lock-Out, usage of barricades and warning signage, etc.

3. Commencement and duration of work.

4. Indicate that required materials are on site and ready for installation.

F. RSN 26 31 10-7, Operation Manual(s):

1. Submit for each system component following detailed instructions:

   a. Detail step by step procedures for Startup, Normal Operations, and Shut Down.

   b. Detail step by step procedures for Emergency Operations include Shut Down.

   c. Detail step by step procedures for programming components which includes a list of default program values, variables, set points, wiring diagrams, and key instructions.

   d. Detail step by step procedures for PV System maintenance activities.

      1) Maintenance activity list shall include recommended interval period(s) including a description of activity for PV System components requiring maintenance.

         a) Pertinent information shall include preventative maintenance intervals and replacement list of components.

         b) Provide recommended manufacturer products for such items as cleaning agents, fuses. etc.

         c) Revise operation's manuals due to field adjustment or correction during installation.

   e. Detail step by step procedures for PV System components which require removal and installation as part of maintenance or replacement due to failure.

   f. Submit according to "Section 01 78 30 – Project Record Documents" an Equipment and Warranty List.

2. Submit information in electronic format such as Adobe "pdf", Microsoft Word "doc", or AutoCAD "dwg" file formats.

G. RSN 26 31 10-8, As-Built drawings:

1. Provide "As-Built" drawings xx kW_{AC} grid-tie ground mount PV system include foundations, supports, brackets, trenching, electrical wiring diagrams, field adjustments, etc.

2. Submit "As-Built" drawings in electronic format such as Adobe "pdf" or AutoCAD "dwg" file formats.

1.06 OFFEROR'S PROPOSAL

A. Offeror shall estimate performance of the PV modules energy delivery and the complete PV system. The power ratings are for Standard Test Conditions (STC) of 1000 W/m2 solar irradiance at 25ºC PV module temperature.

The STC power value, inverters, and system losses will be entered into a System Advisor Model (SAM) or similar program to determine estimated energy delivery in kWh. The estimated energy delivery shall be based on average weather for LOCATION for the following PV systems:

1. AC energy delivery:

    a. xx kW_{AC} PV grid-tie ground mount PV system.

2. The Government's preferred model is from NREL, other similar models will be acceptable to the Government.

    a. The STC power values, inverters, switches, and associate losses will be entered into SAM to determine average estimated energy delivery in kWh per month and year. Offeror shall document equipment and material performance factors including design assumptions used in the SAM.

B. Offeror shall provide a One-Line diagram showing all major components such as PV panels and array orientation, disconnects, inverters, transformers, utility lines, meters, etc. for each of the propose PV systems.

C. Offeror shall provide sufficient details on foundation and mounting systems for the xx kW_{AC} grid-tie PV system.

1. Manufacture model data and shop drawings.

2. Tracking is not allowed for this project.

D. Offeror shall provide construction schedule starting from time of contract award to completion of PV systems and commissioning, in calendar days. The following are potential key elements for consideration in construction schedule:

1. At 90% complete design of the PV systems include a 14-day Government review and comment period.

2. Lead time for permits, materials, deliveries, key coordination meetings, and working with utilities for commissioning of PV system.

3. Mobilization and preparations of project site(s).

4. Begin and finish dates for construction of foundations, supports, and bollards for each of the four PV systems.

5. Begin and finish dates for installation of panels and electrical systems.

6. Testing and commissioning of all four PV systems.

7. Demobilization from project site.

8. Please note any additional key milestones.

E. Offeror should describe method of controlling vegetation growth under panel arrays.

F. Offeror should describe method of constructing bollards and installation process.

G. Price Proposal:

1. Offeror's shall break down price proposal per each of the four PV systems and list all major cost components such as materials, equipment, and labor.

2. Offeror's price proposal shall be valid for 90 days, from Government's receipt.

H. Evaluation Criteria:

1. Offeror's proposal will be evaluated on best value to the Government and the following criteria:

a. Government considers Tier 1 PV modules have higher overall value in each PV systems.

b. Offeror's ability to demonstrate ability to provide warranty coverage and technical support of PV systems supplied under this RFQ.

c. Offeror's past performance.

d. PV Systems components, approach, and mythology will be evaluated during the selection process, but the focus will be placed on the AC energy delivery and cost in \$/kWh.

PART 2 PRODUCTS

2.01 PHOTOVOLTAIC SYSTEMS

A. PV systems shall be fully operational and allow automatic operation without operator intervention. Each PV system shall have the following key elements:

1. Each PV system shall minimize maintenance requirements.

2. Offeror shall provide onsite and remote access to PV power production data. Manufacturer or vendor shall provide web-based remote access to PV system real-time system performance data. System performance data shall include at a minimum solar irradiance, ambient air temperature, AC real time power production, and ability to see hourly outputs and recall hourly, daily, monthly, and yearly production data.

2.02 COMPONENTS

A. Photovoltaic Modules (Solar Electric):

1. Tier 1 PV Modules shall meet or exceed the following standards:

   a. UL - Standard 1703 Standard for Safety for Flat-Plate Photovoltaic Modules.

   b. IEC 61215 Crystalline Silicon Terrestrial Photovoltaic (PV) Modules-Design Qualification and Type Approval.

   c. PV modules shall be provided with a nameplate with key electrical design information such as rated power, short circuit current, open circuit voltage, and datasheet including details such as coefficients relating how these parameters change with temperature.

   d. Offeror shall furnish and supply to Reclamation spare (replacement) PV modules totaling 1% plus one module based on total number of installed modules, if different panels are used for grid-tie and off-grid PV systems supply spare PV modules of each type.

   e. Foundation supports, and mounting hardware shall be corrosion resistant.

   f. PV arrays shall be a minimum of 12 inches above the ground surface.

2. PV modules and components shall be rated and warranted to withstand and operate under temperature extremes and humidity conditions found at BOR FACILITY.

B. Inverters, disconnects, boxes, enclosures, panel boards, etc.:

1. Key components such as disconnects, inverters, and panel boards shall be located in accessible area, weather-protected, and secure.
2. Electrical metal components shall be bonded to the ground conductors.

3. Inverters shall be UL 1741 approved, located away from direct sunlight, and have a minimum 10-year warranty.

   a. Approved list of inverters can be found at the following website: http://www.gosolarcalifornia.ca.gov/equipment/inverters.php.

C. Transformers:

1. If required, NEMA Premium.

2.03 ELECTRICAL EQUIPMENT

A. Furnish all cables, conduits, terminations, and accessories required for interconnecting the equipment included in this Section.

B. Power and control cables: Designed for outdoor use, with a water, oil, and ultraviolet-light resistant cable jacket.

2.04 PROTECTIVE COATINGS

A. Epoxy, powder coats, acrylic, and anti-reflection coatings are lead and chromate free.

B. Manufacturer or suppliers when available use green alternates as described at US. EPA Comprehensive Procurement Guidelines available online at http://www.epa.gov/epawaste/conserve/tools/cpg/index.htm.

C. Volatile Organic Compounds (VOC):

1. Do not exceed maximum permitted by federal, state, and local air pollution control regulations. Do not exceed maximum content as supplied in container or by addition of thinner material.

2. Use thinners recommended by manufacturer for each coating material.

D. Color or Tint: Supply according to Government approved submittal. If damage requires repairing at project site do not color or tint at jobsite.

1. Color and gloss to meet one or more of following:

   a. Munsell Book of Color.

   b. Fed Std 595B.

   c. Manufacturer's standard color.

2. Gloss abbreviations:

   a. FG: Full Gloss.

   b. SG: Semigloss.

   c. F: Flat.

3. Color, tint, and gloss of final coats to be approved by the Government prior to application.

PART 3 EXECUTION

3.01 PROTECTIVE COATINGS

A. Delivery, Storage, and Handling of Coating Materials or Products:

1. Deliver materials, products, or supplies to jobsite in original, undamaged, unopened packaging or crates. Include any special instructions for unloading or repair of damage coatings.

2. Comply with manufacturer's storage instructions.

B. Damage to coating systems shall be repaired according to manufacturer, supplier, or coating applicator recommendations.

1. Protect items or surfaces not to be coated when repairing damaged coatings.

2. Protect from abrasive blast particles and airborne coating particles.

3. Repair within minimum and maximum recoat window time in accordance with coating manufacturer's recommendations.

a. Repair pinholes, holidays, laps, voids, and other defects.

b. Inspect repaired areas for compliance with specifications.

C. Items to be coated:

1. Frame and support assemblies.

2. Brackets.

3. Electrical panels and components.

3.02 INSTALLATION

A. Install PV Systems (arrays) according to required kW output at locations shown in Sketch "A" entitled "Site Plan."

B. Install PV System (arrays) components and accessories according to Offeror's design criteria per each array.

C. Verify existing underground utilities and infrastructure prior to trenching for connection between 120 kW array and electrical service MS-1 (switchgear) as required by Offeror's design criteria.

3.03 INTERRUPTION OF SERVICE

A. Coordinate interruption of service with COR.

1. When Contractor's work cannot be performed during approved IOS schedule, notify COR that IOS is not required.

2. Modify IOS schedule and receive written (email is acceptable) Government approval.

B. No specific interruption of service will be considered unless:

1. COR has reasonable assurance that materials and equipment are onsite for performance of work.

a. Submittal have been reviewed or approved by Government.

b. Contractor will be prepared to perform work on date and during period of time requested for specific interruption of service.

2. Interruption of service schedules will depend upon Government's power demand requirements and related operating conditions. Government reserves right to re-schedule interruption of services for any period during 24-hour day, any day of week.

3. Contractor shall inform the COR verbal within 2 hours prior to interruption of service.

C. Interruption of services may be scheduled during off-peak periods, nights, or weekends.

D. Review submittals for accuracy and provide corrections if process or time schedule has changed from time of submittal.

3.04 CONTRACTOR'S TESTING

A. Contractor shall perform inspections and tests according to IEC 62446 Grid connected photovoltaic systems - Minimum requirements for system documentation, commissioning tests and inspection" throughout the construction and commissioning processes.

B. Periodic "Quality" inspections shall be conducted to support progress payments as identified in the contractor's quality control plan.

1. Perform testing in presence of the Government representative.

2. Notify the COR a minimum of 5 days in advance of tests being performed.

C. Inspections and tests shall verify contract assumptions through documentation and observations by Contractor's Quality Control Personnel and certify work accomplishments and attainment performance of PV systems.

1. Unless otherwise identified, manufacturer recommendations shall be followed during all inspections and test procedures.

2. Commissioning Array Tests shall include the following:

a. Measure and record individual string voltages, current, and solar irradiance as measured in the plane of the PV array.

b. Conduct and record IV curve trace of each strings compared to panel manufacture data. This data shall be used to confirm proper performance of the PV system.

c. After completion of inspections and tests the Offeror shall provide a written report of comparisons and data observations. Provide electrical copy of the PV Array Performance Report (PVPR) to the COR. The PVPR shall include the following information for each PV module and array systems:

1) Location of testing, date of tests, list of tests performed, and name of personnel performing tests, recording data, and if required name of peer review or witnesses to testing activities.

2) The PVPR shall include the following information such as date of equipment calibration, describe equipment and purpose, and methods/techniques used during measurements.

3) At time of tests record present state of PV array construction and operating phase of PV array.

d. In addition, the PVPR shall include system performance (model based) estimates compared to actual field installed performance. Include at a minimum solar irradiance, DC and AC energy outputs, ambient air temperature, and PV cell temperatures. PV System performance shall be measured and reported for a performance period of 72 hours.

1) During performance monitoring of the installed PV System arrays indicate that kW productions are lower than expected, the Contractor shall investigate and repair to meeting required kW production outputs at the Contractor’s expense.

2) After adjustments or repairs Contractor shall perform performance monitoring until PV System arrays meets required kW output.

3) Measurements made under actual installation and temperature will be normalized to STC.

3.05 ACCEPTANCE

A. Upon completion of each PV array and after commissioning array tests, the Offeror shall demonstrate the performance of the system to the Government.

1. Acceptance shall be after one week of performance measurement at a cell temperature corrected Performance Ratio (PR) of 90% or greater with 100% system availability.

2. Document all performance measurements.

3.06 TRAINING

A. Provide 8-hour onsite training covering the following:

1. Instruct the Government in operation and maintenance of each PV array system and components. Including written instructions and procedures for all key components of each PV array. Key elements include:

    a. Inverters, disconnects, panels, and other prudent equipment.

    b. Supply manufacturer's specified equipment required to perform maintenance or repairs of PV systems.

    c. Review with the Government Contractor's recommended spare parts or component lists. List shall be sufficient to allow for Government procurement.

    d. Government reserves the right to video tape training session for official use only.

B. Contractor (Offeror) shall provide technical support for a two year period after Government has made final payment.

3.07 WARRANTIES

A. Provide warranties in accordance with the clause at FAR 52.246-21 "Warranty of Construction," the specifications, and this section.

B. Warranty of Construction

1. Submit data concerning warranty of construction, required by the clause at FAR 52.246-21 "Warranty of Construction" including the warranty period (dates), and warranty contacts with names, addresses, and telephone numbers.

    a. Government requires the construction warranty for a period of five (5) years from date of substantial completion. This warranty requires four additional years of warranty over the base one year provided in clause FAR 52.246-21 "Warranty of Construction" for all equipment, materials, supplies, etc. to the installation of the PV systems.

C. Warranties for PV System Components

1. For PV component warranties, including those warranties for equipment supplied under this RFQ include manufacturer or brand name and model.

2. Warranty List:

    a. Provide electronic document containing a complete list of all warranted equipment, products, materials, processes, and other warranted items furnished under this contract. Fully execute and deliver this “Warranty and Equipment List” to the Government within 14 days after receiving written notice of substantial completion. One approved format for the “Warranty and Equipment List is as follows:

WARRANTY AND EQUIPMENT LIST

Contract No.:____________________ Title:______________________________________

Contractor’s Information (include name, addresses, phone number, and contact person):

Business Name:____

Point of Contact:____

Address:____

Phone No.:____

Email:____

Warranty Item(s)	Manufacturer’s Information	Model and Serial Number(s)	Warranty Period and Dates	Location of Component
PV Modules (Installed)				
PV Modules (Spares)				
PV Modules (Replacement)				
Inverters				
Disconnects and Panels				
Meters				
Solar Array Mounting Racks				
Software				
Other PV Components				

D. Mobile PV generator shall have a minimum warranties:
1. PV modules (panels): 25 years, minimum.
2. PV components: 5 years, minimum.
3. PV battery packs: 7 years, minimum.

END OF SECTION

Appendix G. Service Descriptions for Preventive Maintenance

ACTIVITY AREA	COMPONENT	DESCRIPTION	INTERVAL	SERVICE PROVIDER
Cleaning	PV Module General	Clean PV modules with plain water or mild dishwashing detergent. Do not use brushes, any types of solvents, abrasives, or harsh detergents.	Condition or study dependent	Module Cleaning
Cleaning	PV Module	Snow Removal	Condition or study dependent	Module Cleaning
Cleaning	PV Module	Dust: Agricultural /Industrial/Pollen Cleaning	Condition or study dependent	Module Cleaning
Emergency Response	System	Contractor available by email and phone 24x7x365	Ongoing	Journeyman Electrician
Inspection	AC Wiring	Inspect electrical boxes for corrosion or intrusion of water or insects. Seal boxes if required.	Annual	Electrician
Inspection	AC Wiring	Check position of disconnect switches and breakers.	Annual	Electrician
Inspection	AC Wiring	Exercise operation of all protection devices.	Annual	Electrician
Inspection	AC Wiring	AC disconnect box inspection	Annual	Electrician
Inspection	DC Wiring	Test system grounding with “megger”	Annual	Electrician
Inspection	DC Wiring	Scan combiner boxes with Infrared camera to identify loose or broken connections	Annual	
Inspection	DC Wiring	Inspect cabling for signs of cracks, defects, pulling out of connections; overheating, arcing, short or open circuits, and ground faults.	Annual	Electrician
Inspection	DC Wiring	Check proper position of DC disconnect switches.	Annual	Electrician
Inspection	Combiner and Junction Boxes, DC Wiring	Open each combiner box and check that no fuses have blown and that all electrical connections are tight. Check for water incursion and corrosion damage. Use an infrared camera for identifying loose connections because they are warmer than good connections when passing current.	Annual	Electrician
Inspection	DC Wiring	Look for any signs of intrusion by pests such as insects and rodents. Remove any nests from electrical boxes (junction boxes, pull boxes, combiner boxes) or around the array. Use safe sanitation	Annual	Vermin Removal

ACTIVITY AREA	COMPONENT	DESCRIPTION	INTERVAL	SERVICE PROVIDER
		practices because pests may carry disease.		
Inspection	Inverter	Observe instantaneous operational indicators on the faceplate of the inverter to ensure that the amount of power being generated is typical of the conditions. Compare current readings with diagnostic benchmark. Inspect Inverter housing or shelter for physical maintenance required if present.	Monthly	Inspection
Inspection	Monitoring	Spot-check monitoring instruments (pyranometer, etc.) with hand-held instruments to ensure that they are operational and within specifications.	Annual	PV Module/Array Specialist
Inspection	PV Array	Test open circuit voltage of series strings of modules.	Annual	Journeyman Electrician
Inspection	PV Array	Check all hardware for signs of corrosion, and remove rust and re-paint if necessary.	Annual	Mechanical Technician
Inspection	PV Array	Walk through each row of the PV array and check the PV modules for any damage. Report any damage to rack and damaged modules for warranty replacement. Note location and serial number of questionable modules.	Annual	PV Module/Array Specialist
Inspection	PV Array	Inspect ballasted, non-penetrating mounting system for abnormal movement.	Annual	Mechanic
Inspection	PV Array	Determine if any new objects, such as vegetation growth, are causing shading of the array and move them if possible. Remove any debris from behind collectors and from gutters.	Annual	Tree Trimming
Inspection	PV Module	Use infrared camera to inspect for hot spots; bypass diode failure.	Annual	PV Module/Array Specialist
Inspection	Transformer	Inspect transformer meter, oil and temperature gauges, include housing container, or concrete housing if presentment.	Annual	Journeyman Electrician
Inspection	Controller	Check electrical connection and enclosure for tracking motor/controller.	Annual	Electrician
Inspection	Motor	Check electrical connections.	Annual	Electrician
Inspection	DC Wiring	Check grounding braids for wear.	Annual	Electrician
Inspection	Transformer	Transformer/switchgear inspection.	Annual	Electrician
Inspection	Tracker	Anenometer Inspection.	Annual	Inspector
Inspection	Tracker	Driveshaft torque check & visual inspection.	Annual	Mechanical Technician
Inspection	Tracker	Inclinometer inspection	Annual	Mechanical Technician

ACTIVITY AREA	COMPONENT	DESCRIPTION	INTERVAL	SERVICE PROVIDER
Inspection	Tracker	Limit switch inspection	Annual	Mechanical Technician
Inspection	Tracker	Module table inspection	Annual	Mechanical Technician
Inspection	Tracker	Screw jack inspection	Bi-annual	Mechanical Technician
Inspection	Tracker	Slew gear torque check & wear inspection.	Bi-annual	Mechanical Technician
Inspection	Tracker	Torque inspection	Annual	Mechanical Technician
Inspection	Tracker	Tracking controller inspection	Annual	Mechanical Technician
Inspection	Tracker	Universal joint inspection, gears, gear boxes, bearings as required or documented by manufacturer.	Annual	Mechanical Technician
Inspection	PV module	PV module torque check & visual inspection.	5 years	PV Module/Array specialist
Inspection	PV module	Racking torque check and inspection	5 years	PV Module/Array specialist
Inspection	PV module	Inspection: corrosion and encapsulate yellowing	Annual	PV Module/Array specialist
Inspection	PV Module	Galvanization inspection	Annual	PV Module/Array Specialist
Management	Asset Management	Daily Operations and Performance Monitoring	Ongoing	Admin Asst.
Management	Asset Management	Monitor alarms and site-specific alert parameters.	As needed	Journeyman Electrician
Management	Asset Management	Manage inventory of spare parts	As needed	Journeyman Electrician
Management	Asset Management	Monitoring annual service package	Ongoing	Admin Asst.
Management	Documents	Document all O&M activities in a workbook available to all service personnel.	Ongoing	Admin Asst.
Management	Documents	Confirm availability and take any measures to secure operating instructions, warranties and performance guarantees, and other project documentation.	Monthly	Admin Asst.
Management	Documents	Review O&M agreements and ensure that services are actually provided.	As needed	Admin Asst.
Management	Documents	Update record with preventative maintenance activities and track any problems or warranty issues and secure the record onsite.	Ongoing	Admin Asst.
Management	Documents	Meet with key site staff to continue awareness, question any issues, and report on findings.	Annual	Inspection

ACTIVITY AREA	COMPONENT	DESCRIPTION	INTERVAL	SERVICE PROVIDER
Management	Meter	Maintain a log of cumulative power delivery (kWh to date) and chart this value against date. Chart the value even for uneven or infrequent intervals. Explain variation by season or weather.	Monthly	Admin Asst.
Management	Electrical	Electrical labor mobilization	Annual	Master Electrician
Management	Mechanical	Mechanical labor mobilization	Annual	Admin Asst.
Management	IT	Check central SCADA/network manager, include software IT and IT hardware updates as required.	Annual	IT Specialist
Service	AC Wiring	Re-torque all electrical connections on AC side of system.	Annual	Electrician
Service	DC Wiring	Re-torque all electrical connections in combiner box.	Annual	Journeyman Electrician
Service	Instruments	Exchange or re-calibrate instruments	As per manuf.	Journeyman Electrician
Service	Inverter	Replace transient voltage surge suppression devices	As per manuf.	Inverter Specialist
Service	Inverter	Install any recent software upgrades to inverter programming or data acquisition and monitoring systems.	5 years	Inverter Specialist
Service	Inverter	Clean (vacuum) dust from heat rejection fins.	Annual	Inverter Specialist
Service	Inverter	Replace any air filters on air-cooled equipment such as inverter.	As needed	Inverter Specialist
Service	PV Array	Remove bird nests from array and rack area.	Annual	Vermin Removal
Service	PV Array	Nesting vermin removal, nesting vermin prevention.	Annual	Vermin Removal
Service	Tracker	Lubricate tracker mounting bearings/gimbals as required by manufacturer.	Annual	Mechanical Technician
Service	Tracker	Lubricate gearbox as required by manufacturer.	Bi-annual	Mechanical Technician
Service	Tracker	Screw jack greasing as required by manufacturer.	Bi-annual	Mechanical Technician
Service	Tracker	Slew gear lubrication as required by manufacturer.	3 years	Mechanical Technician
Service	Tracker	Universal joint greasing (zerk fitting) as required by manufacturer.	Bi-annual	Mechanical Technician
Testing	Documents	Perform performance test: measure incident sunlight and simultaneously observe temperature and energy output. Calculate PV module efficiency as a function of temperature and calculate the balance-of-system efficiency. Compare readings with diagnostic benchmark (original efficiency of system).	Annual	PV Module/Array Specialist

ACTIVITY AREA	COMPONENT	DESCRIPTION	INTERVAL	SERVICE PROVIDER
Testing	Inverter	Test overvoltage surge suppressors in inverter.	5 years	Inverter Specialist
Testing	PV Module	Test output of modules that exhibit cracked glass, bubble formation oxidation of busbars, discoloration of busbars, or PV module hot spots (bypass diode failure).	Annual	PV Module/Array Specialist
Testing	PV Module	Test modules showing corrosion of ribbons to junction box	Annual	PV Module/Array Specialist

Appendix H. Service Descriptions for Corrective Maintenance

The following is a list of corrective/reactive maintenance measures that would be performed to fix problems encountered in operation of a PV system over time.

ACTIVITY AREA	COMPONENT	SERVICE DESCRIPTION	FREQUENCY/RESPONSE TIME	SERVICE PROVIDER
Emergency Response	System	Dispatch contractor in response to alarms, alerts, or contact by others.	As needed	Journeyman Electrician
Repair	AC Wiring	Replace inverter AC fuse(s)	As needed	Electrician
Repair	AC Wiring	Replace protective devices (breakers) in building panel	As needed	Electrician
Repair	AC Wiring	Replace broken/crushed AC wiring conduit and fittings	As needed	Electrician
Repair	AC Wiring	Repair line-to-line fault	As needed	Electrician
Repair	AC Wiring	Locate line-to-line fault	As needed	Inspection
Repair	DC Wiring	Replace failed fuses in combiner box	As needed	Electrician
Repair	DC Wiring	Replace MC Connectors between modules.	As needed	Electrician
Repair	DC Wiring	Replace MC connector lead to combiner box.	As needed	Electrician
Repair	DC Wiring	Re-route conduit	As needed	Electrician
Repair	DC Wiring	Replace broken/crushed Dc wiring conduit and fittings.	As needed	Electrician
Repair	DC Wiring	Repair ground fault	As needed	Electrician
Repair	DC Wiring	Locate ground fault	As needed	Electrician
Repair	DC Wiring	Locate underground DC wiring as part of repairs to faults.	As needed	Specialist
Repair	DC Wiring	Replace fuse(s) on DC source circuits to inverter.	As needed	Master electrician
Repair	DC Wiring	Seal leaking junction box	As needed	Journeyman Electrician
Repair	Inverter	Replace fuse	As needed	Journeyman Electrician
Repair	Inverter	Start/stop inverter (reboot to clear unknown error).	As needed	Journeyman Electrician
Repair	Inverter	Replace inverter fan motor	As needed	Inverter Specialist
Repair	Inverter	Replace inverter data acquisition card/board; diagnose with fault code	As needed	Inverter Specialist
Repair	Inverter	Replace inverter control card (PWM signal, voltage, phase, frequency, shut-down); diagnose with fault code	As needed	Inverter Specialist
Repair	Inverter	Replace IGBT driver card/board; diagnose with fault code	As needed	Inverter Specialist

ACTIVITY AREA	COMPONENT	SERVICE DESCRIPTION	FREQUENCY/RESPONSE TIME	SERVICE PROVIDER
Repair	Inverter	Replace maximum power point tracker card/board; diagnose with fault code	As needed	Inverter Specialist
Repair	Inverter	Replace AC contactor in inverter	As needed	Inverter Specialist
Repair	Inverter	Replace IGBT matrix in inverter	As needed	Inverter Specialist
Repair	Inverter	Replace 24VDC power supply for inverter controls	As needed	Inverter Specialist
Repair	Inverter	Replace DC contactor in inverter	As needed	Inverter Specialist
Repair	Inverter	Replace surge protection in inverter	As needed	Inverter Specialist
Repair	Inverter	Replace GFI components in inverter	As needed	Inverter Specialist
Repair	Inverter	Replace capacitors in inverter	As needed	Inverter Specialist
Repair	Inverter	Replace inductors (coils) in inverter	As needed	Inverter Specialist
Repair	Inverter	Replace fuses internal to inverter	As needed	Inverter Specialist
Repair	Inverter	Replace inverter relay/switch	As needed	Inverter Specialist
Repair	Inverter	Replace overvoltage surge suppressors for inverter	As needed	Inverter Specialist
Repair	Inverter	RE-install inverter control software	As needed	Inverter Specialist
Repair	Inverter	Manual reset of arc-fault trip (NEC 690.11)	As needed	Inverter Specialist
Repair	Monitoring	Restore lost internet connection	As needed	Network/IT
Repair	PV Array	Excavate and replace failed foundation element.	As needed	Structural Engineer
Repair	PV Array	Repair or replace rack parts damaged by corrosion or physical damage.	As needed	PV Module/Array Specialist
Repair	PV module	Replace modules failing performance test after showing cracks in glazing, discoloration of metallic contacts, delamination or signs of water in.	As needed	Electrician
Repair	PV module	Repair cracking of PV module back sheet.	As needed	PV Module/Array Specialist
Repair	PV module	Repair or replace damage to module frame.	As needed	Specialist
Repair	Roof	Repair roof leaks as related to PV structure penetrations problems.	As needed	Roofer

ACTIVITY AREA	COMPONENT	SERVICE DESCRIPTION	FREQUENCY/RESPONSE TIME	SERVICE PROVIDER
Repair	Roof	Re-roof (new roof) as related to PV structure penetrations problems.	As needed	Roofer
Repair	Roof	Roof tile repair leaks as related to PV structure penetrations problems.	As needed	Roofer
Repair	Tracker	Repair/replace tracker drive shaft	As needed	Mechanical Technician
Repair	Tracker	Replace tracker drive bearing	As needed	Mechanical Technician
Repair	Tracker	Replace tracker mount bearing	As needed	Mechanical Technician
Repair	Tracker	Replace tracker motor controller	As needed	PV Module/Array Specialist
Repair	Tracker	Replace/upgrade tracker control software	As needed	PV Module/Array Specialist
Repair	Tracker	Replace tracking controller power supply fan filter	As needed	Mechanical Technician
Repair	Tracker	Replace hydraulic cylinder	As needed	Mechanical Technician
Repair	Transformer	Replace transformer	As needed	Electrician
Repair	Transformer	Re-tap transformer	As needed	Electrician
Repair	Inverter	Replace terminal block	As needed	Journeyman Electrician
Repair	IT, internet connections	Repair/Replace repair onsite IT, internet connections	As needed	IT
Repair	Monitoring Devices	Replace monitoring components at combiner boxes	As needed	Journeyman Electrician
Repair	Environmental Sensors	Repair/replacing environmental sensors	As needed	Journeyman Electrician
Repair	Combiner Boxes	Repairing/replacing combiner boxes (DC, AC side)	As needed	Journeyman Electrician
Repair	Inverter	Replace inverter	As needed	Journeyman Electrician
Repair	AC Wiring	Locate underground AC wiring	As needed	Utilities Locator

Appendix I. The Basics of Lifecycle Cost Analyses Supporting Reclamation's Sustainable Energy Goals

RECLAMATION
Managing Water in the West

Economics Technical Memorandum No. EC-2013-02

The Basics of Lifecycle Cost Analyses Supporting Reclamation's Sustainable Energy Goals

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

August 2013

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Economics Technical Memorandum No. EC-2013-02

The Basics of Lifecycle Cost Analyses Supporting Reclamation's Sustainable Energy Goals

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BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Economics, Planning, and Technical Communications Group, 86-68270

Economics Technical Memorandum No. EC-2013-02

The Basics of Lifecycle Cost Analyses Supporting Reclamation's Sustainable Energy Goals

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ACRONYMS AND ABBREVIATIONS

BLCC5	Building Lifecycle Cost Program
DOE	Department of Energy
FEMP	Federal Energy Management Program
Guiding Principles	*Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings*
kg	kilograms
LCA	life cycle cost analysis
MOU	*Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding*
NECPA	National Energy Conservation Policy Act
NIST	National Institute of Standards Technology
NREL	National Renewable Energy Lab
OMB	Office of Management and Budget
P&Gs	*Economics and Environmental Principles and Guidelines for Water and Related Land Resources Implementations Studies*
PG&E	Pacific Gas and Electric Company
PV	present value
Reclamation	Bureau of Reclamation
SAM	System Advisor Model

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Appendices

1.0 INTRODUCTION

The Bureau of Reclamation's (Reclamation) Research and Development Office partnered with the National Renewable Energy Laboratory (NREL) in 2010 to provide Geographic information System (GIS) screening and case studies analysis for non-hydroelectric renewable energy at Reclamation facilities. This research effort provided detailed examples of assessments for wind and solar renewable energy generation installations at Reclamation land and facilities in order to inform Reclamation policies and practices regarding developing non-hydroelectric renewable energy (N-HRE). The details of these analyses can be found in Hasse et al, 2013.

The purpose of this report is to provide further details related to the economic analysis conducted by NREL. Further research identified legislation and executive orders related to economic assessments of federal investments associated with energy and water conservation and renewable energy in federal buildings. A life cycle cost analysis (LCA) is the primary tool mandated by legislation and executive orders for economic analysis of federal investments in energy and water conservation and renewable energy in federal buildings. An understanding of life cycle cost analyses will assist Reclamation staff in achieving the goals for non-hydroelectric renewable energy at Reclamation facilities.

The specific goals of this effort are listed below.

1. Introduce basic economic concepts including time value of money, compounding, discounting, and discount rates
2. Introduce analytical measures for project evaluation
3. Introduce the Federal requirements related to economic analyses
4. Outline the steps necessary for conducting an LCA
5. Discuss available tools for conducting an LCA
6. Discuss other non-economic decision making considerations
7. Provide general recommendations regarding LCA
8. Review of the National Renewable Energy Lab analysis (Haase et al. 2013) on Lake Berryessa and Willows solar projects. This economic evaluation was conducted for the Bureau of Reclamation (found in Appendix A)

9. Provide an example of an LCA (found in Appendix B).

2.0 BASIC ECONOMIC CONCEPTS

The purpose of this section is to provide the reader an understanding of several basic economic concepts and techniques, including time value of money, compounding, discounting, and discount rates.

2.1 Time Value of Money

The timing of benefits and costs are central to economic analyses of investment related decisions. In all but the most unusual circumstances, a dollar received today is worth more than a dollar received in the future. This concept, referred to as the time value of money, is an important consideration when evaluating investment decisions. For example investors will prefer receiving project benefits as soon as possible and would rather pay project costs at a future date. There are two techniques used in economic analyses to adjust for time value of money: compounding and discounting.

2.2 Compounding

Compounding is the technique used to estimate the future value of money invested or loaned today. For example, if $100 is invested today into a savings account earning 5 percent interest during the year, it would be worth $105 at the end of this year. This growth is called compounding. The higher the interest rate the faster the investment compounds which increases the return on investment.

The compound amount or future value is calculated using equation (1).

(1)

$$FV = PV * (1 + i)^T$$

Where:

FV = Future value
PV = Present value or the amount invest in the present time
i = The annual interest rate or rate of return
T = The total number of years the investment is allowed to compound

2.3 Discounting

Discounting is the opposite of compounding. Discounting is the technique for estimating the present value, or today's value, of a benefit or cost to be received or paid at later dates. For example if an individual is offered a single payment of $500 in two years, assuming a discount rate of 5 percent, the present value can be estimated using equation (2). Equation (2) is derived algebraically by solving for Present Value in equation (1). Using equation 2, substituting $500 for the future value (FV), 2 for (T), and 0.05 for (d) the present value (PV) is estimated as $453.51.

(2)

$$PV = \frac{FV}{(1+d)^T}$$

The more general form of equation (2) which accounts for both costs (C) and benefits (B) over some period of time is shown in equation (3). This formula is known as the Net Present Value (NPV) formula, the discounting formula, and/or the future value formula. In equation (3), $\sum$ is the mathematical summation operator, B_t is the benefit occurring at time (t), C_t is the cost occurring in time (t), and (d) is the discount rate. In mathematical notation, time subscript (t) runs from t=0, the time of the initial investment, to the final or terminal period, t=T.

(3)

$$NPV = \sum_{t=0}^{T} \frac{(B_t - C_t)}{(1+d)^t}$$

Equation (3) is used in economics, engineering, and finance to compare the NPV of investments made today which have costs and benefits in the future. An example of this is shown in table 1. In this table the net benefits ($B_t - C_t$) for two investment alternatives (Investment A and Investment B) are shown.

Table 1.—Net benefits ($B_t - C_t$) for Investment A and Investment B

Time	0	1	2	3	4	5
Investment A	$-2,000	$0	$0	$0	$1,000	$3,000
Investment B	$-2,000	$1,000	$500	$1,000	$500	$1,000

As shown in table 1, each investment has the same initial investment cost of ($2,000). If one were to add up the net benefits of each investment option, each would pay out $2,000. However this does not correctly account for the timing of the costs and benefits and would result in the wrong investment decision.

To correctly evaluate Investments A and B, one must account for the timing of the costs and benefits. This requires calculating the NPV for each investment using Equation (3). The NPV for Investment B, equals $1,464.61, using equation (3) at a 5 percent discount rate. The details of this calculation are shown in equation (4).

(4)

$$NPV_B = \frac{-2{,}000}{(1+.05)^0} + \frac{1{,}000}{(1+.05)^1} + \frac{500}{(1+.05)^2} + \frac{1{,}000}{(1+.05)^3} + \frac{500}{(1+.05)^4} + \frac{1{,}000}{(1+.05)^5}$$

Using equation (3) the NPV for Investment A equals $1,173.28. In this example Investment B, results in a higher NPV. Therefore after properly accounting for the timing of the costs and benefits, Investment B is a wiser investment compared to Investment A. This example clearly shows how the timing of the net benefits influences investment decisions.

2.4 Discount Rates

Discounting, as described above, is the method for converting costs and benefits that occur at different points in time to a present value. The rate at which future costs and benefits are discounted is called the discount rate[1] (parameter d in Equations 3). The purpose of this section is to 1) demonstrate how discount rates influence investment decisions, 2) describe the types of discount rates and 3) provide general guidance on selecting the proper rate.

Economic analyses are very sensitive to discount rates. For example, using equation (2), one can calculate the NPV using varying discount rates and years in the future for a future one-time payment ($500 in this example). Table 2 illustrates that a higher discount rate reduces the present value of future benefits and costs relative to a lower discount rate.

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[1] It should be pointed out that it is common to use the word "interest rate" however economists typically use the term "discount rate".

Table 2.—Net present value estimates for a future one-time payment of $500 using varying discount rates and years

Discount rate	Years in the future (T)		
	10	**50**	**100**
1.00%	$452.64	$304.02	$184.86
3.00%	$372.05	$114.05	$26.02
8.00%	$231.60	$10.66	$0.23
10.00%	$192.77	$4.26	$0.04

Discount rates are generally categorized as nominal or real discount rates. The relationship between the nominal rate and the real rate is shown in Equation (5).

(5)

$$d = (1 + r) * (1 + i) - 1$$

Where:

d = Nominal discount rate
r = Real discount rate
I = Inflation rate

The real rate (parameter r) is the money paid for the use of capital, expressed as a percentage per period that does not include a market adjustment for the economy's anticipated general price inflation rate. The inflation rate (parameter i) is the percentage rate of change of the aggregate price level from one period to another.

When using nominal discount rates in present value calculations benefits and costs should be expressed in current dollars. Current dollars are dollars of non-uniform purchasing power, including general price inflation or deflation, in which actual prices are stated. Whereas when real discount rates are used in present value calculations benefits and costs should be expressed in constant dollars. Constant dollars are uniform purchasing power tied to a reference year (typically the base year of the study) and are exclusive of general price inflation or deflation. For analysis of federal investments the discount rate is often prescribed in the federal requirements pertaining to the analysis. Many of these federal requirements are discussed in Section 3.0 of this paper.

3.0 FEDERAL REQUIREMENTS FOR ECONOMIC ANALYSES

Office of Management and Budget (OMB) Circular A-94 provides general guidance for analyses of federal investments. However, water resource projects and Federal energy management programs are exempted from OMB A-94 (OMB Circular A-94, 4.b.1 and 4.b.3). The majority of Reclamation's economic analyses are subject to the Economics and Environmental Principles and Guidelines for Water and Related Land Resources Implementations Studies (P&Gs[2]) (U.S. WRC, 1983).

Economic analyses for energy conservation and renewable energy investment in new or existing federal owned or leased property must be performed in accordance with *Code of Federal Regulations, Title 10, Part 436, Subpart A, Federal Energy Management and Planning Programs: Life Cycle Cost Methodology and Procedures (*10 CFR 436A). This CFR can be found on the US Government Printing Web site at: http://www.ecfr.gov.

OMB Circular A-94 provides guidance on both economic benefit cost analyses and economic cost effectiveness analyses. The P&Gs provide guidance for performing economic cost benefit analyses.

3.1 Guidelines for LCAs Related to Energy and Water Conservation and Renewable Energy

The National Energy Conservation Policy Act (NECPA) was signed into law in 1978. The NECPA serves as the underlying authority for federal energy management goals and requirements. NECPA tasked the Department of Commerce, National Institute of Standards Technology (NIST) with providing technical assistance to the Department of Energy (DOE) and the Federal Energy Management Program (FEMP) in developing and implementing lifecycle cost methods related to energy and water conservation and renewable energy investments. NIST provides guidance on the LCA method through several publications which are discussed below.

[2] The Water and Resource Development Act of 2007 instructed the Secretary of the Army to develop updated P&Gs. In 2009 the Obama administration began the process of updating the P&Gs and included Federal agencies engaged in water resource planning. In March 2013, the administration released updated P&Gs called the Principles and Requirements. The administration released the final set of Principles and Requirements that lay out broad principles to guide water investments, and also released draft Interagency Guidelines for implementing the Principles and Requirements. Once the draft Interagency Guidelines are finalized, each agency will update its procedures that are necessary for their specific agency mission. The Principles and Requirements take effect 180 days after the publication of the final Interagency Guidelines.

The *National Institute of Standards Technology (NIST) Handbook 135 – Life-cycle Costing Manual for Federal Energy Management Program (FEMP)* (Fuller and Peterson, 1995) expands on the 10 CFR 436 methods and criteria. Handbook 135 provides an in depth tutorial on the LCA method. The Handbook describes the LCA methods and assumptions and also provides several examples. Handbook 135 can be found on NIST, Building and Fire Laboratory's Web site at: http://www.fire.nist.gov/bfrlpubs/build96/art121.html

A supplement to Handbook 135 is published annually (Rushing et al., 2012). The supplement is entitled *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis, Annual Supplement to NIST Handbook 135 and NBS Special Publication 709.* The supplement provides the latest price indices and discount rates for performing LCAs for Federal energy and water conservation and renewable energy investments. The supplement can be found on the following Web site: http://www1.eere.energy.gov/femp/information/download_blcc.html#handbook

In 2012 Reclamation published "*Interpretation of the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings – Existing Buildings*." This publication provides guidance and Reclamation's interpretation of the *Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings* (Guiding Principles). The Guiding Principles are defined as a set of sustainable building requirements. This document also describes Reclamation's specific sustainable building requirements.

4.0 ANALYTICAL METHODS FOR PROJECT EVALUATION

This section provides brief descriptions of the analytical methods that are commonly used to evaluate the economic or financial viability of a project that is under consideration. The analytical methods discussed include benefit cost analysis (BCA), lifecycle cost analysis (LCA), cost effectiveness, savings to investment ratio, the internal rate of return (IRR), the modified internal rate of return (MIRR)[3] and the payback period.

4.1 Benefit Cost Analysis

The purpose of the BCA is to measure and compare the present value of the benefits and the present value of the costs over a designated period of analysis for

[3] Modified Internal Rate of Return is also known as Adjusted Internal Rate of Return (AIRR) (Fisher et al).

the proposed project. The results of the BCA are expressed as the NPV of the proposed project as shown in equation (3). If the NPV is positive, implying that present value of the benefits exceeds present value of the costs, the project could be considered economically justified. In studies where multiple mutually exclusive alternatives are being considered, the alternative with the greatest positive NPV would be preferred from a strictly economic perspective.

The BCA results are sometimes presented in terms of a benefit-cost ratio (BCR). A BCR is estimated by dividing the present value of the total benefits by the present value of the total costs. If the BCR is >1 the project is considered economically justified.

The BCR is sensitive to the definition of benefits and costs. It's recognized that a positive benefit can also be defined as a negative cost. This distinction makes a difference in the calculation of the BCR in terms whether the positive benefit is added to the numerator, or the negative cost is subtracted from the denominator. For this reason the BCR is not the preferred method for presenting BCA results.

In theory BCA takes into account all monetary and non-monetary costs and benefits that accrue to society. However in practice it is rarely possible to quantify all of the costs and benefits. In some cases it may not be possible to quantify all of the significant physical impacts of a proposed project or alternative. For example it may not be possible to measure all the physical ecosystem changes resulting from a proposed plan. In another example it is not possible to estimate the spiritual value of resources. In these cases, the analyst could provide a qualitative discussion of the potentially important impacts that cannot be monetized and included in the BCA.

4.1.1 Lifecycle Cost Analysis

A LCA is a type of BCA that assesses the total cost of facility ownership. The LCA[4] accounts for all the costs of ownership including construction, operation, maintenance, and salvage value of a building or building system. A LCA adjusts all costs to reflect the time value of money. When a LCA is applied to energy conservation and renewable energy investments, the benefits to society are the cost savings resulting from reduced energy usage and carbon emissions. The equation used in a LCA for energy or water conservation measures as presented in Handbook 135 is shown below.

[4] Note a Life Cycle Evaluation or Analysis while a similar term is not considered a lifecycle cost analysis. A Life Cycle Evaluation or Analysis evaluates the environmental consequences of an activity or good from extraction to disposal and includes inventory, impact assessment, and improvement analysis. A Life Cycle Evaluation or Analysis includes economic and social components in addition to physical quantities.

(6)

$$LCC = I + Repl - (+)\ Sal + E\ (W) + OM\&R$$

Where:

LCC	=	Total life cycle cost in present value (PV) dollars
I	=	Present Value of Initial Cost of the energy conservation or renewable energy component prior to actual use (year 0)
Repl	=	Present Value of capital replacement costs
Sal	=	Present Value of residual or salvage value of the energy conservation measure at the end of the LCA period of analysis. This value can be positive or negative
E(W)	=	Present Value of total energy cost or the Present Value of total water costs
OM&R	=	Present Value of total operating, maintenance, and repair costs which are distinctly tied to the energy conservation or renewable energy component

The LCA can also be expressed in Net Savings (Equation 7). Net savings for a retrofit project is found by subtracting the lifecycle costs based on the proposed project from the life cycle costs generated in the absence of the proposed project or baseline conditions. A project would be considered justified if the net savings with respect to the base case is positive. When comparing multiple mutually exclusive alternatives the alternative with the greatest positive net savings would be preferred.

The formula for Net Savings is:

(7)

$$Net\ Savings = LCC_{base\ case} - LCC_{Alternative}$$

Where:

LCC = Lifecycle Costs

4.2 Cost Effectiveness

A cost effectiveness analysis is distinctly different from a BCA. The economics discipline has defined cost effectiveness as a method that seeks to identify the least-cost way to achieve a given objective, without considering whether there is any economic justification for achieving that objective. Cost of effectiveness is derived by dividing the total discounted costs by the physical output or service that is generated by the project over the period of analysis.

The formula for a Cost Effectiveness Ratio is:

(8)

$$Cost\ Effectiveness\ Ratio = \frac{\sum_{t=0}^{t=n} \frac{C_t}{(1+d)^{t}}}{Total\ Output\ or\ Services}$$

Where:

C_t = Cost in each year
t = Year of occurrence (where 0 is the base date)
n = Number of years
d = Discount rate

A cost effectiveness analysis can be employed when the project or alternative's benefits cannot be expressed in monetary terms and therefore cannot be included in a traditional BCA. In this case a cost effectiveness analysis provides a basis for comparing project alternatives. A cost effectiveness analysis is sometimes used when a level of service is mandated and thus the objective of the analysis is to determine which program or alternative under consideration achieves the mandated level at the lowest cost. When projects or alternatives are mandated it is assumed that the economic benefits outweigh the costs. The limitation of a cost effectiveness analysis is that the analysis does not provide the necessary information to determine if project or alternative is economically justified.

4.3 Savings to Investment Ratio

The SIR, as defined in 10 CFR 436.2, is the ratio of the present value of net savings to the present value of the net costs of an energy or water conservation measure. The numerator is the present value of the net saving in energy or water and no-fuel or non-water operations and maintenance cost attributable to the proposed conservation measure. The denominator is the present value of the net increase in investment and replacement costs less salvage value attributable to the proposed conservation measure. An investment is considered justified if the SIR is greater than zero, thus net savings are greater than zero.

The formula for SIR is:

(9)

$$SIR_{A:BC} = \frac{\sum_{t=0}^{N} \frac{S_t}{(1+d)^t}}{\sum_{t=0}^{N} \frac{\Delta I_t}{(1+d)^t}}$$

Where:

S_t = Savings in year t in operation costs attributable to the alternative
ΔI_t = Additional investment related costs attributable to the alternative
t = Year of occurrence (where 0 is the base date)
d = Discount rate
N = Length of the study period

4.4 Internal Rate of Return

The IRR method is another analytic measure used to evaluate investment alternatives. The IRR is the discount rate at which the NPV is equal to zero, as illustrated in Equation (10). The IRR is the maximum rate that a project can pay for the resources used for the project to recover its investment and operating costs and still break even (Gittinger, 1982). A project is considered justified if the IRR is greater than the discount rate established for the analysis.

(10)

$$NPV = \sum_{t=0}^{T} \frac{(B_t - C_t)}{(1+IRR)^t} = 0$$

The IRR method assumes that reinvested cash flows earn a rate or return exactly equal to IRR. If this is not the case, this method may lead to the wrong conclusions. The IRR method can also result in multiple results if the cash flows alternate from positive to negative.

4.5 Modified Internal Rate of Return

As the name implies the MIRR is a modification of IRR that assumes the reinvestment rate equals the cost of capital. The MIRR is the rate that equates the project's cost to the future value of all the net cash inflows (positive net cash flows) at the end of the project life. The MIRR is compared against the discount rate (the minimum acceptable rate of return) in the case of a federal investment for energy conservation (10 CFR 436). If the MIRR is greater than the discount rate the project is economically justified.

The formula for MIRR is:

(11)

$$MIRR = \sqrt[T]{\frac{-FV(pos\_cash\_flow, reinvestment\ rate)}{PV(neg\_cash\_flows, finance\ rate)}} - 1$$

Where:

T	=	The number of equal periods at the end of which the cash flows occur
pos_cash_flow	=	Positive net benefits of the project
neg_cash_flows	=	Negative net benefits of the project
reinvestment rate	=	Rate of return on reinvested profits
finance rate	=	Borrowing or loan rate

The MIRR formula requires a reinvestment rate and a finance rate. The reinvestment rate could be calculated based on historic rate or the rates of recently approved projects. The finance rate represents the cost of capital for the organization.

4.6 Payback Period

The payback period is the time it takes to recover the initial investment based on the earnings (savings) expected to result from the investment. The basic idea behind the use of the payback period method is that the faster the initial investment dollars are recouped the better the economics of the investment. An alternative with a lower payback period is considered the better investment using this method. The payback period can be calculated in two primary ways which are often referred to as the simple payback period and the discounted payback period.

The example below shows how a simple payback period is calculated for a stream of uneven benefits and costs.

Year	0	1	2	3	4	5	6	7
Benefits ($)	0	300	300	300	300	300	300	300
Costs ($)	800	500	250		50		100	
Net Benefits ($)	-800	-200	50	300	250	300	200	300
Cumulative Benefits ($)	-800	-1,000	-950	-650	-400	-100	100	400

(12)

$$\text{Payback Period} = Y + A/B$$

Where:

Y = The number years before the final payback year (5 years in the example above)
A = Total remaining to be paid back at the start of payback year ($100 in the example above)
B = Net Benefits in Payback Year ($200 in the example above).

The payback period in the example is 5.5 years.

The drawback of using the simple payback method is that it ignores the time value of money. The discounted payback period is the generally accepted and preferred method for calculating the payback period. The discounted payback period method requires that cash flows occurring each year be discounted to the present value, therefore accounting for the time value of money.

According to ASTM International (2013) (formerly known as American Society for Testing and Materials) the discounted payback method finds the length of time between the date of the initial project investment and the date when the present value of the cumulative future earnings or savings, net of the cumulative future costs, just equals the initial investment. The standard equation, accepted by ASTM International, for the discounted payback period is shown in Equation (13).

(13)

$$Discount\ Payback\ Period = \sum_{t=1}^{PB} \frac{(B_t - \tilde{C}_t)}{(1+d)^t} = C_0$$

Where:

B_t = Dollar value of benefits in period t for the building or system being evaluated less the benefits in period t for the mutually exclusive alternative against which it is being compared.
$\tilde{C}_t$ = Dollar value of costs in period t for the building or system being evaluated less the costs in period t for the mutually exclusive alternative against which it is being compared.
C_0 = Initial project investment cost as of the base time (year 0)
d = Discount rate
t = Time period t

Both the simple and discounted payback period methods have several shortcomings. The first shortcoming is that the payback method does not consider the entire life of the project and ignores the savings after the payback period. The following example demonstrates this point. Consider two investments with the same initial costs ($10,000) and annual savings ($2,000). The life of project A is 10 years, while the life of project B is 20 years. Both project A and B would have equal payback periods but project B is expected to provide earnings for an additional 10 years. Therefore project A is economically inferior to project B.

The payback method often involves setting a maximum acceptable payback period, which is usually subjective. For example suppose the maximum payback period is 5 years. If Alternative A has a payback of 4 years and Alternative B has a payback period of 20 years. Alternative A would be an acceptable investment.

5.0 Types of Capital Investment Decisions and Preferred Analysis Method

The LCA method along with the SIR and MIRR methods are mandated by 10 CFR 436A for analyses of energy conservation, water conservation, and renewable energy measures in Federal buildings. The 10 CFR 436 recommends that the payback period method be used as a rough screening tool to determine if a more rigorous LCA should be employed.

The LCA is particularly useful for analyzing mutually exclusive conservation investments that typically have higher initial costs but lower operating costs over time. As discussed in the NIST Handbook 135, the lifecycle cost methodology is well suited for a variety of decision types. These five general decision types are listed below.

1. Accept or reject a project. An example of this type of decision is the installation of storm windows or standard single pane windows.

2. Determine acceptable level of energy efficiency. A good example of this type of decision is determining the optimal thermal resistance (R value) of attic insulation.

3. Selecting between systems that provide the same level of service. Selecting between a geothermal heat pump and a standard gas furnace is an example of this type of decision.

4. Determining the combination of interdependent systems or components. This refers to selecting two or more building systems at the same time. For example, selecting the type of heating system and the insulation R values. For this type of decision, it's recognized that the implementation of one system will have effects on the energy savings of the other.

5. Prioritization of independent projects. For this type of decision 10 CFR 436 requires the use of the SIR or the MIRR (referred to as AIRR in 10 CFR 436). In this case projects are ranked by SIR or MIRR and funded in descending rank order.

6.0 LIFECYCLE ANALYSIS STEPS

This section describes the necessary steps for preforming a LCA. The steps are listed below followed by brief descriptions of each step.

1. Develop project description
2. Collect annual cost data for various categories for two or more alternatives
3. Obtain the appropriate discount rate
4. Determine period of analysis
5. Compute the present value of costs incurred over the period of analysis for each alternative
6. Sum present values of each alternative to find it's lifecycle cost
7. Compare lifecycle costs for each alternative
8. Document the analysis

6.1 Project Description

The project description should define the purpose of the study, summarize the alternatives, describe the services that will be provided by each alternative, and identify the type of decision that the analysis will support. This information may assist in determining the study's data needs.

6.2 Collect Lifecycle Cost Data

The estimated lifecycle costs are only as good as the data supporting them. Some projects may be at a screening or cursory level while others may be supported by detailed engineering designs and cost estimates. As designs and data are refined over time the lifecycle cost analysis should be updated to reflect improved estimates. Fortunately lifecycle costing software makes it simple to provide updated results as design and cost data evolve. The LCA has very little usefulness unless the lifecycle costs of the proposed alternatives are compared against the lifecycle costs of the base case. Therefore it's imperative that the analyst collect the data and prepare the lifecycle costs for the proposed alternatives and the base case.

Sunk costs related to investment and operations are also omitted. Sunk costs are not considered because they are unrecoverable and will not be affected by the decision to build or not build a project. Sunk costs as defined by 10 CFR 436 are costs incurred prior to the time at which the lifecycle analysis occurs.

It is also important for the analyst to understand what year the costs are estimated for and when they will occur in the study period timeframe. The cost or design engineers typically identify the year in which the costs are estimated for. The schedule of investment and operation costs can also be provided by the engineers. It's important to distinguish both single year costs and annually recurring costs.

6.2.1 Data Requirements

The specific data requirements for a Lifecycle Cost Analysis can be categorized into two general categories; 1) investment related and 2) operations related. Along with the costs, it's also important to determine the year in which these costs will occur. Table 3 summarizes these requirements. To provide a general understanding of the data requirements a brief description is provided below.

Investment related costs include costs associated with engineering design, purchase, and construction. Capital replacement and salvage value (resale or disposal) costs are also investment related costs which are often overlooked. Capital replacement costs depend on the system and estimated service life. Salvage Value (resale or disposal) is the remaining value of the system at the end of the study period. These are based on the resale value, scrap value, and any disposal costs.

Operation costs relate to the long run operation of a building or system and primarily include energy costs as well as maintenance and repair costs. Energy conservation, water conservation, and renewable energy projects reduce energy consumption and therefore long run costs for operation. Estimating energy and/or water costs requires energy and/or water consumption or savings estimates for

Table 3.—Summary of data requirements and potential sources

Data category	Data input	Source
Analysis	Discount rate	*Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis, Annual Supplement to NIST Handbook 135 and NBS Special Publication 709*
	Study period	10 CFR 436A, subsequently modified under the Energy Independence Security Act 2007
Investment	Engineering and design costs	Cost and design engineers often provide these estimates to the analyst. The Handbook 135 also suggests various cost estimating guides
	Construction costs	
	Capital replacement costs	
	Salvage value	
Operations	Quantity of energy used	Cost and design engineers often provide these estimates to the analyst. The estimates are made based on technical specifications and computer simulation
	Local energy prices	Local utilities
	Energy price escalation rates	*Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis, Annual Supplement to NIST Handbook 135 and NBS Special Publication 709*
	Operation and maintenance	Cost and design engineers often provide these estimates to the analyst. The estimates are made based on technical specifications and computer simulation
	Quantity of carbon generated	Computer simulation, for example Buildings Life Cycle Cost (BLCC) program
	Price of carbon	*Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis, Annual Supplement to NIST Handbook 135 and NBS Special Publication 709*
	Carbon price escalation rates	*Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis, Annual Supplement to NIST Handbook 135 and NBS Special Publication 709*
	Water usage	Cost and design engineers often provide these estimates to the analyst. The estimates are made based on technical specifications and computer simulation
	Water costs	Local utility

both with and without the implementation the conservation measure for each year in the study period. For example, what is the building's energy use with and without solar panels. This is primarily an engineering exercise based on technical specifications and energy efficiency factors. For some conservation measures, like solar panels, it's important to include degradation factor if the efficiency over the life the product is expected to decline. A variety of computer simulation models are available to compute energy savings with and without project alternatives.

Energy or water usage is monetized using local energy prices. FEMP requires the use of local energy or water prices in a LCA rather than regional or national average prices. FEMP also requires that energy price escalation rates be used in an LCA. As mentioned previously the energy price escalation rates are published in the Annual Supplement to Handbook 135. There are no DOE water price escalation rates.

Future carbon prices, considered an operational cost, should be considered in a LCA analysis. In 2010 a series of tables projecting potential future carbon prices and electricity related carbon emission rates under a range of carbon policy scenarios were included in the Annual Supplement to Handbook 135. The Annual Supplement of Handbook 135 relies on the EPA study entitled Supplemental EPA Analysis of the American Clean Energy and Security Act of 2009 to create these scenarios. Analysts would be wise to include a range of carbon policy scenarios in an LCA.

Federal agencies are eligible for some state and utility level incentives. These incentives are generally available as up-front incentives at the time of installation or as performance based incentives paid out as the system generates power (Cory et al. 2009). Incentives are generally not included in an economic analysis because they are considered a transfer payment. Transfer payments represent a shift of payments from one sector of society to another but do not change cost or benefits from a national perspective. However, incentives may be included in a financial analysis which is outside of the scope of this paper.

6.3 Determine Discount Rate and Study Period

Inputs related to analysis, also shown in table 3, primarily include discount rates and study period. The discount rates for federal energy and water conservation projects are determined annually by FEMP. These rates, as discussed previously in Section 3.1, are published annually in the publication entitled "Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis, Annual Supplement to NIST Handbook 135 and NBS Special Publication 709."

The current maximum study period for a LCA was revised in Section 441 EISA (2007) to 40 years. The study period, which is the length of time over which an investment is analyzed, must be equal for all alternatives, depending on the expected life of the project and/or the investor's time horizon but cannot exceed 40 years.

6.4 Preparing the Lifecycle Cost Comparison and Results

Recall the LCA measures the present value of the cost of owning, operating and maintaining over its useful life (including its fuel and water, energy, labor and replacement components), and disposing of the building system(s) over a given study period. Once the cost data is collected by year for each alternative and a discount rate and study period are determined the lifecycle costs can be calculated, using Equation (6). The alternative with the lowest lifecycle cost, greater than zero, is the preferred alternative. If the estimate lifecycle costs are negative the project or alternative is not considered justified.

Recall that the LCA can also be expressed in Net Savings (Equation 7). A project would be considered justified if the net savings with respect to the base case is positive. When comparing multiple mutually exclusive alternatives the alternative with the greatest positive net savings would be preferred.

6.5 Documenting the Analysis

Detailed documentation for a LCA should be an important requirement for all studies. Careful documentation is necessary for a decision record. Detailed documentation also allows for easy review of the inputs which is necessary for accuracy or future updates. Handbook 135 provides a list of suggested items to be documented in a LCA report, which is reproduced below in table 4.

7.0 TOOLS FOR CONDUCTING LCA

A LCA can be conducted using a variety of tools. Three possible tools are discussed below.

7.1 Spreadsheet

A simple spreadsheet can be developed by an analyst who is knowledgeable of the LCA methodology and the requirements set out in 10 CFR 436. Built into a spreadsheet, such as Microsoft Excel, are all the necessary functions/formulas to conduct a LCA and supplementary measures such as MIRR. A spreadsheet is powerful and readily available tool however the analyst must have the proper training and background in order to properly set up a spreadsheet application.

Table 4.—Recommended documentation items for a lifecycle cost analysis report

1. Project description	General information	5. Computations	Discounting
	Type of decision to be made		Computation of lifecycle costs
	Constraints		Computations of supplementary measures
2. Alternatives	Technical description	6. Interpretation	Results of LCC comparison
	Rationale for including them		Uncertainty assessment
	Non-monetary considerations		Results of sensitivity analysis
		7. Non-monetary savings/costs	Description of intangibles
3. Common parameters	Study period	8. Other considerations	Narrative
	Base date	9. Recommendations	
	Service date		
	Discount rate		
	Treatment of inflation		
	Operational assumptions		
	Energy and water price schedules		
4. Cost data and related factors	Investment related costs		
	Operating related costs		
	Energy usage amounts and type		
	Timing of costs		
	Cost data sources		
	Uncertainty assessment		

Source: NIST Handbook 135.

7.2 SAM

A better approach to conduct a LCA would be to use a tool specifically developed for analyzing energy and water conservation and renewable energy projects. The National Renewable Energy Lab has tool call System Advisor Model (SAM) available for LCA analyses. In addition to the LCA analysis SAM also includes a performance model which calculates an alternatives energy output on an hourly basis (sub-hourly simulations are available for some technologies). The drawback of this tool is that is not specifically built for federal analyses so it would require more knowledge of the federal requirements and methodology described in 10 CFR 436.

7.3 BLCC5

The tool that is recommended for a LCA related to federal energy and water conservation and renewable energy is called the Building Lifecycle Cost Program (BLCC5) (Peterson, 1995). NIST developed BLCC5 under the sponsorship of FEMP. The program has been in use since the 1970's to evaluate building related energy and water conservation projects and renewable energy projects according to 10 CFR 436. The program is updated annually to include the current discount rates and energy price indices found in the Annual Supplement to the NIST Handbook 135. The BLCC5 program calculates the lifecycle costs in terms of net savings, and calculates other measures such as SIR, MIRR, and the payback period.

BLCC5 also estimates emissions reductions (CO2, SO_2, and NO_x). Unfortunately the current version of BLCC5 does not monetize carbon savings for renewable energy alternatives. An analyst can easily monetize these values, for inclusion in the LCA outside the model using a spreadsheet application. Specifically the carbon savings can be monetized, in a spreadsheet, by combining the physical estimates (in kilograms) provided by BLCC5 and the Carbon prices and indices provided in the Annual Supplement to Handbook 135, Tables D-1 and D-2, respectively.

8.0 Other Non-Economic Decision Making Considerations

This paper focused on conducting the economic analysis of federal investments related energy and water conservation measures. However, there may be non-economic decision criteria that influence the decision to adopt energy and water conservation measures. It's also recognized that it may not be possible to quantify all the project benefits and costs. Handbook 135 suggests documenting any non-economic considerations in the LCA report.

The decision criteria must comply with the related statues, regulations, and executive orders as well the agency's policy and related directives and standards. Decisions regarding all federal investments must be integrated with the agency's mission and budgeting process.

Other non-economic decision making considerations that could influence the decision to adopt energy and water conservation measures include:

- Achieve agency goals and targets for greenhouse gas reduction and renewable energy
- Mitigate the agency's risk and vulnerabilities related to climate change
- Increase the use of renewable energy
- Hedge against future power price increases
- Improving or maintaining the agency's public perception
- Extending current energy and water supplies
- Altruism

9.0 RECOMMENDATIONS

A few recommendations for Reclamation staff responsible for conducting or overseeing economic analyses related to energy and water conservation and renewable investments in new and existing federally owned or leased buildings are highlighted below.

1. An understanding of the methodology for LCA as outlined in 10 CFR 436 is recommended before implementing LCA analyses.
2. Familiarity with legislation, rulemakings, and executive orders related to the use of LCA methodology, especially NIST Handbook 135 and the annual supplement to Handbook 135 will be useful.
3. Analysts should consider adopting the use of BLCC program for LCA of federal investments related to energy and water conservations measures.
4. A detailed documentation of inputs, including source information, and results as described in NIST Handbook 135 should be required.

GLOSSARY

Base Case: The building system against which an alternative building system is compared.

Base Year: Year 0 of the Study Period.

Constant Dollars: Dollars of uniform purchasing power tied to a reference year (usually the base year) and exclusive of general price of inflation or deflation.

Cost of Capital: The rate of return that capital could be expected to earn in an alternative investment of equivalent risk.

Current Dollars: Dollars of non-uniform purchasing power, including general price inflation or deflation, in which actual prices are stated.

Discount Rate: The rate at which future benefits and costs are discounted.

Nominal Discount Rate: The rate reflecting the time value of money stemming from both inflation and the real earning power of money over time.

Mutually Exclusive Projects: Projects where the acceptance of one precludes acceptance of the others.

Present Value: The time equivalent of past, present, or future Cash Flows as of the beginning of the Base Year.

Real Discount Rate: The rate of interest reflecting the portion of time value of money attributable to the real earning power of money over time and not to general price inflation.

Replacement Cost: Capital cost for replacing a system component during the Study Period.

Residual Value: The estimated value, net of any Disposal Costs, of any building or building system removed or replaced during the Study Period, or remaining at the end of the Study Period, or recovered through the resale or reuse at the end of the Study Period.

Study Period: The length of time period covered by the economic evaluation.

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APPENDIX A

NREL Report Review

The National Renewable Energy Lab (NREL conducted an assessment of Photovoltaic (PV) solar arrays for two Reclamation offices; Willows and Lake Berryessa for Reclamation's Research and Development office (Hasse et al, 2013). Reclamation's Economics, Planning, and Technical Communications Group, (86-68270) was asked by Reclamation's Research and Development office to review the economic evaluation and prepare comments. The purpose of the assessment is to provide an engineering and economic evaluation of these facility scale solar applications.

It should be noted that NREL's analysis was conducted to provide illustrative examples of how a N-HRE assessment is conducted and the potential that exists and demonstrate how incentives apply to the Federal government. The following comments are provided to emphasize the required detail necessary for future analyses.

NREL Report Analysis of Economic Evaluation

Overall the assessment emphasized the engineering aspects of the solar applications but the economic evaluation lacked detail and documentation. Therefore it was difficult to determine if the federal guidelines for analyzing the economic cost effectiveness were followed.

The NREL evaluation employed the payback method to evaluate the Willows and Lake Berryessa applications. In future analysis, the report should indicate whether a simple payback period or a discounted payback was used. Also, it is recommended that an LCCA be prepared rather than a payback analysis because payback method does not consider the entire life of the project and ignores the savings after the payback period. Also, the payback method often involves setting a maximum acceptable payback period, which is subjective. Finally, the payback method ignores the time value of money unless the discounted payback period method was employed.

A life cycle analysis does require a few more inputs but can used to quickly compare the solar applications to baseline or status quo alternatives and provides decision makers with a less subjective analysis.

Generally the input data employed in the NREL economic analysis was difficult to determine or evaluate. For example, the source of the price of electricity was not documented. It's also unclear if the price of electricity is for residential or commercial customers. Through discussions with NREL's staff many of the input questions (what was used and/or data source) were answered. However the analysis would benefit from a detailed careful documentation of the data assumptions including the data sources. It's recommended that future documentation follow the recommendations made in Handbook 135.

Also, the NREL evaluation would be more meaningful if several inputs were included in the analysis. First, NREL's analysis assumed static energy cost rather than using the escalation factors supplied in the Annual Supplement to Handbook 135. Second, the analysis assumed no replacements costs. And finally, future carbon price were not considered.

In summary, the recommendations to improve future economic analysis are listed below.

- Use a Lifecycle Cost analysis method
- Adopt the use of the BLCC tool
- Carefully document assumptions and data as described in Handbook 135
- Document each component of the installation costs
- Include replacements costs necessary for a PV system
- Include maintenance costs, if $0 document this assumption
- Include salvage values, if $0 document this assumption
- Include energy price escalation factors provided in the Annual Supplement to the Handbook 135
- Include future carbon prices and policy scenarios using the data provided by BLCC and the Annual Supplement to the Handbook 135
- Consider future panel efficiency by adopting a panel degradation factor

APPENDIX B

LCA Example Using Building Lifecycle Cost Software

This appendix presents an example of a lifecycle cost analysis, employing the BLCC5 software. A lifecycle cost analysis is an economic benefit cost analysis which determines if a proposed project is economically justified. An economic benefit cost analysis attempts to consider all project benefits and cost and determines if a project is justified from a national or societal perspective. It's appropriate for federal agencies to conduct an economic analysis versus a financial analysis because a federal agency must compare projects or alternatives from a broader national perspective. A financial analysis is narrowly focused on determining if the beneficiaries of the project be financially better compared to the project costs.

The example shows the suggested method for which a lifecycle cost analysis is documented and reported. Recognize that each analysis is unique and may require other reporting requirements and categories. It should be noted that some of the data inputs were assumed for the purpose of this example. Every attempt was made to use the assumptions from the NREL report (Hasse et al. 2013) related to the photovoltaic (PV) system application at Lake Berryessa. However some of the data necessary for an LCC analysis were not available in this report so assumptions were made without technical validation. Therefore the results are not to be used for decision making purposes.

BLCC EXAMPLE

The Bureau of Reclamation (Reclamation) Lake Berryessa Field Office is located in Napa, California. The Lake Berryessa field office is part of the Reclamation's Mid Pacific Region, Central California Area Office. The Lake Berryessa office is connected to the Pacific Gas and Electric Company (PG&E). The purpose of this study is to conduct a lifecycle cost analysis for the Lake Berryessa Office Area 1 (Hasse et al. 2013) PV system compared to the baseline conditions.

PROJECT DESCRIPTION

For the purpose of this analysis two alternatives were analyzed; Status Quo (Alternative 1) and a 2) PV system application (Alternative 2). Alternative 1 assumes that the Lake Berryessa office energy needs will be met by PG&E. Alternative 2 assumes that some of the Lake Berryessa Office's energy needs would be offset by a PV system, equal to the amount produced by the solar array (76,957 kWh annually). The engineering data and site analysis are explained in the NREL report (Hasse et al. 2013).

The purpose of this analysis is to compute the lifecycle costs for each alternative. In this example Alternative 1 serves as the baseline against which Alternative 2 will be compared. The type of decision this research will support is determining the cost effectiveness, using a lifecycle analysis, and therefore whether Alternative 2 should be accepted as compared to Alternative 1, status quo operations.

It should be noted that the data used in this analysis is on a cursory level, therefore the lifecycle cost results should only be used for screening purposes. As design and cost data evolve the lifecycle analysis should be updated using the more refined data.

The parameters and assumptions common to both Alternative 1 and Alternative 2 are shown in Table B-1 below.

Table B-1.—Common assumptions for alternatives

Assumption	Description	Source
Location	Lake Berryessa Field Office, Napa, California	NREL Report
Rationale for including the alternatives	The office is favorably located for PV systems since the highest rates are mid-day during the summer when PV output is maximum	NREL Report
Type of decision to be made	Determine the economic cost effectiveness using a lifecycle cost analysis of a grid connect solar application compared to baseline conditions	NREL Report
Technical description	The area office manager desires to analyze a PV solar array to offset office energy requirements.	NREL report
Constraints	Many data inputs were not researched or verified therefore these results are only for the purpose of providing an example of an lifecycle cost analysis using BLCC5	Assumed[1]
Computation method	Lifecycle cost analysis	NA
Computation of lifecycle costs	BLCC5 model	NA
Computations of supplementary measures	Net savings is also presented	NA
Non-monetary considerations	None	Assumed[1]
Useful life of systems	25 years	NREL Report
Energy price	$0.15 kWh	NREL Report
Study period	25 years	NREL Report

Table B-1.—Common assumptions for alternatives

Assumption	Description	Source
Treatment of inflation	Discounts rates are real exclusive of general inflation	Handbook 135 recommendation for federal appropriations
Operational assumptions	None	Assumed[1]
Discount Rate	3 percent	2012 Annual Supplement to Handbook 135
Energy escalation	Price escalation factors incorporated in BLCC5. Note that these are real rates exclusive of general inflation.	2012 Annual Supplement to Handbook 135, Tables Cb-1-5.

[1] Assumed indicates there was insufficient data in the NREL report to determine.

Alternative 1: Status Quo Data Assumptions

Alternative 1 assumes status quo operations of the Lake Berryessa office. The relevant data and the timing of the cost data for this alternative are shown in the table B-2 below.

Table B-2.—Alternative 1 data assumptions

Data category	Assumption	Timing of cost	Source
Baseline Alternative: Investment related costs	$0	NA	Assumed[1]
Baseline Alternative: Operational related Costs	$0	NA	Assumed[1]
Baseline Alternative: Replacement Costs	$0	NA	Assumed[1]
Baseline Alternative: Energy Usage	182,080 kWh	Annually	NREL report
Baseline Alternative: Energy Price	$0.17 kWh	NA	NREL report
Baseline Alternative: Solar Savings	0	NA	NREL report
Uncertainty Assessment	Data were assumed and was not technically verified for the purpose of this example. Decisions should not be based on these data	NA	Assumed[1]

[1] Assumed indicates there was insufficient data in the NREL report to determine.

Alternative 2: PV System Application Data Assumptions

Alternative 2 assumes that a PV system will be installed at the Lake Berryessa office. The PV system will offset 76,957 kWh of the building's annual energy usage (182,080 kWh). The relevant data assumptions for this alternative are shown in the table B-3 below.

Table B-3.—Alternative 2 data assumptions

Data category	Assumption	Timing of cost	Source
Solar alternative: operating related costs	$462	Annually	NREL report[1]
Solar alternative: energy usage amounts	182,080 kWh annually	Annually	NREL report
Solar alternative: energy price	$0.17 per kWh	NA	NREL report
Solar alternative: energy savings[2]	76,957 kWh	Annually	NREL report (as estimated by PV Watts)
Solar alternative: replacement costs	Inverters, at $5000	Every 15 years	Assumed[1]
Solar alternative: incentives/rebates[2]	$0	NA	Assumed[1]

[1] Assumed indicates there was insufficient data in the NREL report to determine.
[2] The NREL included some performance based incentives these were not included in the economic analysis because they are considered transfer payments.

It should be noted that the NREL report included some performance based incentives these were not included in this economic analysis. Incentives are generally not included in an economic analysis because they are considered a transfer payment. Transfer payments represent a shift of payments from one sector of society to another but do not change cost or benefits from a national perspective. However, incentives may be included in a financial analysis, which is outside of the scope of this paper.

Analysis Methods

The data assumptions presented in table B-3 were entered into BLCC5 to calculate the lifecycle costs of each alternative. Carbon effects were calculated outside of BLCC5 in a spreadsheet. BLCC5 estimates the quantity of emissions in kilograms as shown in table B-4. The information in table B-4 were combined with the Project Carbon Dioxide emissions prices and the projected carbon

Table B-4.—Emissions reduction summary

Energy type	Average base case (kg)	Annual alternative (kg)	Emissions reduction (kg)	Life-cycle reduction (kg)
Electricity				
CO_2	47,875	27,641	20,234	505,801
SO_2	11.8	6.81	4.99	124.67
NO_x	19.67	11.35	8.32	207.78

Source: BLCC5.

dioxide emissions rates of escalation found in the 2012 Annual Supplement of Handbook 135 Tables D-1 and D-2 respectively to estimate the annual benefit of carbon emissions for the solar alternative. The present value of this benefit was added to the present value of the lifecycle costs estimates from BLCC5 to estimate the Present Value Life-Cycle-Costs.

For the purpose of this analysis 3 carbon policy scenarios were chosen: (1) no policy, (2) low pricing, and (3) high pricing. These scenarios are consistent with the data present in 2012 Annual Supplement of Handbook 135. The Annual Supplement of Handbook 135 relies on the EPA study entitled Supplemental EPA Analysis of the American Clean Energy and Security Act of 2009 to create these scenarios. The Low Pricing scenario assumes that developing countries do not take any action over the next 40 years to restrict carbon emissions. The High Pricing scenario assumes that carbon offsets from other countries are not allowed and nuclear and biomass capacity construction is restricted.

ANALYSIS RESULTS

Based on this analysis the present value of the lifecycle costs for the solar alternative are greater than those of the baseline alternative. Therefore the solar alternative is not lifecycle cost effective. The Net Savings for Alternative 2 is negative also indicating the alternative is not cost effective. The recommendation to the decision maker based on these results would be to continue with the status quo alternative assuming that economics is the only consideration. The agency may consider other factors to move forward with this project such as:

- Achieve agency goals and targets for greenhouse gas reduction and renewable enrgy
- Mitigate the agency’s risk and vulnerabilities related to climate change
- Increase the use of renewable energy

- Hedge against future power price increases
- Improving or maintaining the agency's public perception
- Extending current energy and water supplies
- Altruism

Again, the purpose of showing these results is purely to show an example of a lifecycle cost analysis using BLCC5. These results are shown in table B-5.

Table B-5.—Comparison of present value life-cycle-costs

		Alternative			Net savings		
	Base case	Low emission policy	High emission policy	No emission policy	Low emission policy	High emission policy	No emission policy
Initial investment costs:							
Capital requirements as of base date	$0	$271,550	$271,550	$271,550	($271,550)	($271,550)	($271,550)
Future costs:							
Energy consumption costs	$471,713	$272,341	$272,341	$271,341	$199,372	$199,372	$199,372
Energy demand charges	$0	$0	$0	$0	$0	$0	$0
Energy utility rebates	$0	$0	$0	$0	$0	$0	$0
Water costs	$0	$0	$0	$0	$0	$0	$0
Recurring and non-recurring OM&R costs	$0	$8,046	$8,046	$8,046	($8,046)	($8,046)	($8,046)
Capital replacements	$0	$3,210	$3,210	$3,210	($3,210)	($3,210)	($3,210)
Residual value at end of study period	$0	$0	$0	$0	$0	$0	$0
Subtotal (for future cost items)	$471,713	$555,147	$555,147	$555,147	($83,434)	($83,434)	($83,434)
CO_2 emissions benefit	$0.00	$5,042.78	$22,734.38	$0	$5,042.78	$22,754.38	$0.00
Total PV life-cycle cost	**$471,713**	**$560,190**	**$577,901**	**$555,147**	**($78,391)**	**($60,680)**	**($83,434)**

Appendix J. National Alliance of Preservation Commissions – Sample Guidelines for Solar Systems in Historic Districts, National Park Service – Incorporating Solar Panels in Rehabilitation Project

National Alliance of Preservation Commissions

NAPC

Sample Guidelines for Solar Systems in Historic Districts

education + advocacy + training

The rapidly growing trend toward retrofitting homes to be more energy efficient has brought an increase in the number of applications for installing solar energy systems on buildings within locally designated historic districts. The increase in solar systems applications in recent years has prompted numerous local preservation commissions to hastily develop guidelines for them with varying degrees of success.

The following Sample Guidelines for Solar Systems for Locally Designated Historic Properties were developed in 2009 by Kimberly Kooles, NAPC support staff and revised by Caty Rushing in 2011. They are intended to serve as a starting point for local preservation commissions developing their own guidelines for solar systems.

Types of Systems:

- ## Photovoltaic

  A photovoltaic system (or PV system) is a system which uses one or more solar panels to convert sunlight into electricity. It consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output.

- ## Solar Shingles

  Solar shingles, also called photovoltaic shingles, are solar cells designed to look like conventional asphalt shingles. There are several varieties of solar shingles, including shingle-sized solid panels that take the place of a number of conventional shingles in a strip, semi-rigid designs containing several silicon solar cells that are sized more like conventional shingles, and newer systems using various thin film solar cell technologies that match conventional shingles both in size and flexibility

- ## Freestanding

  Freestanding PV panels or freestanding arrays allow the benefits of renewable solar power without disrupting the roofline or altering the house. They are placed away from the residence and connected through an undergroud wiring. When a roof may be blocked by trees or not recieving direct sunlight, the mobillity of a freestanding panel allows the ability to move into optimal sunlight areas that may change seasonally.

Sample Guidelines for Solar Systems for Locally Designated Historic Projects

When planning the installation of solar panels the overall objective is to preserve character-defining features and historic fabric while accommodating the need for solar access to the greatest extent possible. All solar panel installations must be considered on a case by case basis recognizing that the best option will depend on the characteristics of the property under consideration. Some guidelines apply to virtually all installation options and are repeated in each section.

All solar panel installations should conform to the Secretary of the Interior's Standards for Rehabilitation.
Applicable Standards are:

Standard Two: The historic character of a property shall be retained and preserved. The removal of historic materials or alteration of features and spaces that characterize a property shall be avoided.

Standard Nine: New additions, exterior alterations, or related new construction shall not destroy historic materials that characterize the property. The new work shall be differentiated from the old and shall be compatible with the massing, size, scale, and architectural features to protect the historic integrity of the property and its environment.

1 Primary Elevations

For most properties, locating solar panels on the primary facade is the least desirable option because it will have the greatest adverse effect on the property's character defining features. All other options should be thoroughly explored.

- Utilization of low-profile solar panels is recommended. Solar shingles laminates, glazing, or similar materials should not replace original or historic materials. Use of solar systems in windows or on walls, siding, and shutters should be avoided.

- Panels should be installed flat and not alter the slope of the roof. Installation of panels must be reversible and not damage to the historic integrity of the resource and district.

These solar panels low profile and location make them unobtrusive even though they are visible from the public right of way. Photo by Paul Trudeau

- Solar panels should be positioned behind existing architectural features such as parapets, dormers, and chimneys to limit their visibility.

- Use solar panels and mounting systems that are compatible in color to established roof materials. Mechanical equipment associated with the photovoltaic system should be treated to be as unobtrusive as possible.

2 Secondary Elevations

- Solar panels should be installed on rear slopes or other locations not easily visible from the public right-of-way. Panels should be installed flat and not alter the slope of the roof. Installation of panels must be reversible and not damage the historic integrity of the resource and district.

- Flat roof structures should have solar panels set back from the roof edge to minimize visibility. Pitch and elevation should be adjusted to reduce visibility from public right-of-way.

- Solar panels should be positioned behind existing architectural features such as parapets, dormers, and chimneys to limit their visibility.

2 Secondary Elevations (Continued)

- Use solar panels and mounting systems that are compatible in color to established roof materials. Mechanical equipment associated with the solar panel system should be painted or treated to be as unobtrusive as possible

- Use of solar systems in non-historic windows or on walls, siding, or shutters should be installed as to limit visibility from the public right of way.

3 Historic Accessory Structures

Solar panels placed on an accessory structure not visible from the public right of way should still follow the slope of the roof and have a low profile. Photo courtesy of Dan Corson

- Solar panels should be installed on rear slopes or other locations not highly visible from the public right-of-way. Panels should be installed flat and not alter the slope of the roof. Installation of panels must be reversible and not damage the historic integrity of the resource and district.

- Flat roof structures should have solar panel installations set back from the roof edge to minimize visibility. Pitch and elevation should be adjusted to reduce visibility from public right-of-way.

- Solar panel installations should be positioned behind existing architectural features such as parapets, dormers, and chimneys to limit their visibility.

- Use solar panels and mounting systems that are compatible in color to the property's roof materials. Mechanical equipment associated with the photovoltaic system should be as unobtrusive as possible.

- Use of solar systems in non-historic windows or on walls, siding and shutters should be installed as to limit visibility from the public right of way.

4 Freestanding or Detached

- Freestanding or detached on-site solar panels should be installed in locations that minimize visibility from the public right of way. These systems should be screened from the public right of way with materials elsewhere in the district such as fencing or vegetation of suitable scale for the district and setting.

- Placement and design should not detract from the historic character of the site or destroy historic landscape materials.

Freestanding solar panels should be installed in locations that minimize visibility from the public right of way.

Consideration to the visibility of solar panels from neighboring properties should be taken, without infringing upon the required solar access.

5 New Construction On-Site

- Solar panels should be integrated into the initial design of new construction or infill projects, when possible, to assure cohesion of design within a historic context.

- Solar panels should be installed on rear slopes or other locations not highly visible from the public right of way whenever possible. Panels should be installed flat and not alter the slope of the roof.

- Flat roof structures should have solar panels set back from the roof edge to minimize visibility. Pitch and elevation should be adjusted to reduce visibility from the public right-of-way.

- Use solar panels and mounting systems that are compatible in color to established roof materials. Mechanical equipment associated with the solar panel system should be treated to be as unobtrusive as possible.

- Use of solar systems in windows or on walls, siding, or shutters should be installed with limited visibility from the public right-of-way.

Not Recommended for Any Reason

- Removal of historic roofing materials during the installation of solar systems.
- Removing or otherwise altering historic roof configuration – dormers, chimneys, or other features – to add solar systems.
- Any other installation procedure that will cause irreversible changes to historic features or materials.

When considering retrofitting measures, historic building owners should keep in mind that there are no permanent solutions. One can only meet the standards being applied today with today's materials and techniques. In the future, it is likely that the standards and the technologies will change and a whole new retrofitting plan may be necessary. Thus, owners of historic buildings should limit retrofitting measures to those that achieve reasonable energy savings, at reasonable costs, with the least intrusion or impact on the character of the building.

(National Park Service. Preservation Brief 3: Conserving Energy in Historic Buildings. Available from http://www.nps.gov/history/hps/TPS/briefs/brief03.htm#Preservation%20Retrofitting. Accessed on August 10, 2009.)

National Park Service
U.S. Department of the Interior
Technical Preservation Services

ITS
NUMBER 52

Interpreting
The Secretary of the Interior's Standards for Rehabilitation

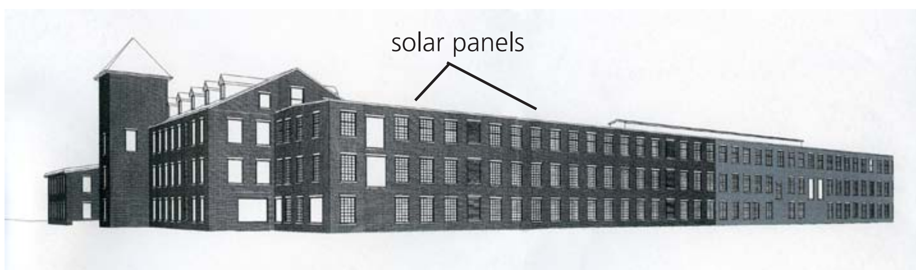
Subject: Incorporating Solar Panels in a Rehabilitation Project

Applicable Standards:
2. Retention of Historic Character
9. Compatible Additions/Exterior Alterations

Issue: Enhancing the energy efficiency of a historic building is important. To that end, it is often possible to install features such as solar panels and photovoltaic cells provided they are installed in a sensitive manner. Because these elements must be positioned to take advantage of unobstructed sunlight, the roof of a historic structure is an obvious location. The roofline of a historic building is often a distinctive feature. Therefore, the installation of solar panels should conform to guidance regarding rooftop additions, i.e. that they be minimally visible, to avoid altering the historic character of the building. Historic buildings with a flat roof or parapet can usually accommodate solar panels because the panels will be hidden, while properties with a hipped or gabled roof are generally not good candidates for a rooftop solar installation. Solar panels on historic buildings should not be visible from the public right of way such as nearby streets, sidewalks or other public spaces.

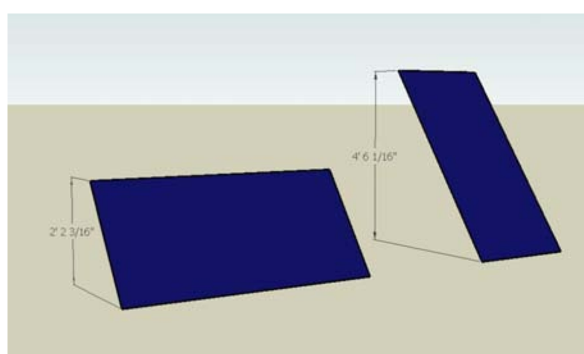
In circumstances where solar collectors are not placed on rooftops, they should only be positioned in limited or no-visibility locations in secondary areas of the property. Vegetation or a compatible screen may also be an option to further reduce the impact of these features on a historic property. For some historic buildings, it may not be possible to incorporate solar panels and meet the Secretary of the Interior's Standards for Rehabilitation.

Application 1 (*Compatible treatment*): The rehabilitation of this mid-nineteenth century mill incorporated a large, roof-mounted photovoltaic installation. Although the historic building does not have a parapet wall at the roofline, the height of the building and the arrangement of the panels render the entire installation invisible from the ground. It is important to note that the panels are placed horizontally. Had the panels been installed with a vertical tilt, the angle required to maximize efficiency would have caused the panels to extend significantly higher above the roof. Simply changing the direction in which the panels are tilted can affect their visibility and reduce their impact on the character of the historic property.



Because of the size of this historic mill, a large array of solar panels could be installed on the flat roof without being seen from the ground.

Solar panels installed on the flat roof.



By placing the panels horizontally, the overall height of the installation and its visibility is reduced.

Application 2 (*Incompatible treatment*): During the rehabilitation of this late-nineteenth century commercial building, a conspicuous rooftop monitor with prominent solar panels and skylights was constructed on the one-story structure. The size and finish of this rooftop addition are incompatible with the historic character of the building. However, the building could have accommodated both skylights and solar panels if they had been installed differently. An alternative design that could have met the Standards would have included low-profile skylights and solar panels concealed behind the parapet wall.

The addition of a large rooftop monitor featuring skylights on the front slope and solar panels on the rear slope is not compatible with the historic character of this small, one-story commercial building.

Application 3 (*Compatible treatment*): The rehabilitation of this historic post office incorporated solar panels as dual-function features: generation of electricity and shading for south-facing windows. In this instance, the southern elevation of the building is also a secondary elevation with limited visibility from the public right of way. Additionally, because this area of the building is immediately next to the post office's loading dock, it has a more utilitarian character than the primary facades and, therefore, can better accommodate solar panels. Because the panels are in a suitable location at the rear of the property and are appropriately sized to serve as awnings, they do not affect the overall historic character of the property. Additionally, a screen of tall plantings shields the solar panels from view from the front of the building, further limiting their visibility.

Above: *Shown from the rear of the property, these solar panels serve a secondary function as awnings to shade south-facing windows. Because of their location at the back of the building immediately adjacent to a loading dock, the installation of these panels does not affect the historic character of the property.*

Left: *The solar panels are not visible from the front of the building. Additionally, even if the vegetation were removed, the installation would only be minimally visible along an alley at the rear of a secondary side elevation.*

Jenny Parker, Technical Preservation Services, National Park Service