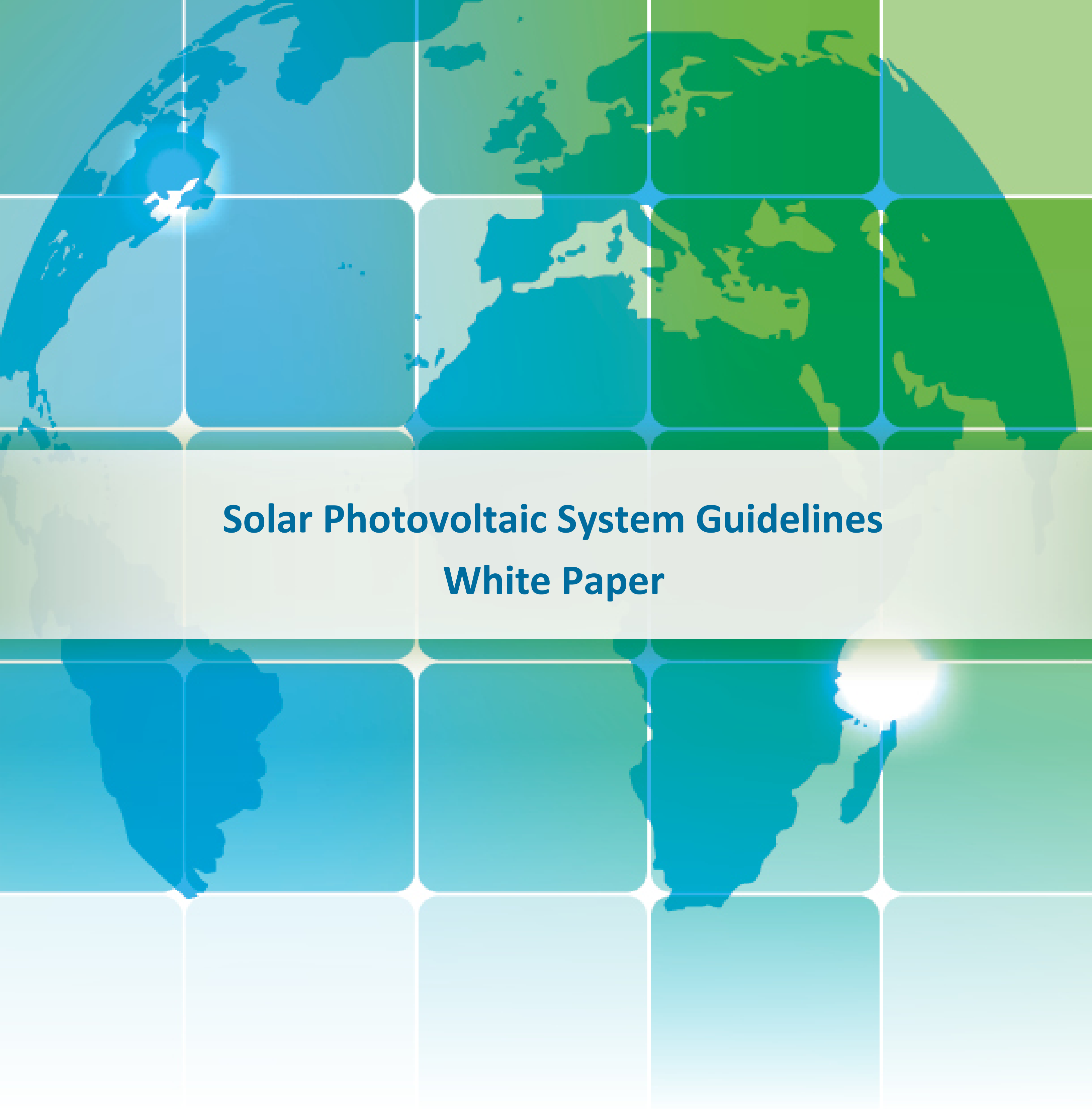

Solar Photovoltaic System Guidelines
White Paper

International Association for Cold Storage Construction

IARW International Association of Refrigerated Warehouses

By HD Boesch and Members of the Solar Energy Subcommittee

For the International Association for Cold Storage Construction and the International Association of Refrigerated Warehouses

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Background

At the 2012 Global Cold Chain Alliance Assembly of Committees, held in July 2012 in Washington, D.C. a subcommittee to the Construction/Codes Committee was organized to study solar system installation for temperature-controlled facilities. The Construction/Codes Committee is a joint committee of the International Association for Cold Storage Construction (IACSC) and the International Association of Refrigerated Warehouses (IARW).

The purpose of the subcommittee was to help the members to identify requirements and pros and cons of solar systems in general and of different types of solar technologies & mounting systems in specific.

To accomplish this mission, the Solar Subcommittee decided to create guidelines for members that would help identify the optimal solar system for their specific requirements as well as identifying potential challenges and problems before installation.

The white paper was reviewed by the members of the 2012-2013 IACSC-IARW Construction/Codes Committee and then presented at the 2013 IARW-WFLO Convention & Expo on May 6, 2013 as part of an educational session.

The white paper is available online at www.gcca.org under “Resources.”

Note: This white paper is not intended to be the “final word” on this subject. As processes and technologies change, IACSC and IARW intend to revise this white paper as the industry changes. Members are encouraged to submit comments for consideration on the white paper at any point. Comments may be sent email@iacsc.org.

Acknowledgements

IACSC and IARW would like to acknowledge and thank all the members of the 2012-2013 Construction/Codes Committee who participated in the review and development of this white paper.

The associations would like to particularly recognize the members of the Solar Subcommittee who authored the white paper.

- HD Boesch, CTO, Mangan Renewables
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- Thomas McClellan, CEO, Cool Lumens, Inc.
- Gerard N. von Dohlen, President, Port Newark Refrigerated Warehouse
- Mike Walters, Project Developer, HelioSage, LLC

Finally, the Solar Photovoltaic System Guidelines would not be possible without the dedicated leadership of HD Boesch, who served as the chairman of the subcommittee and is the primary author of the white paper.

1. Introduction

A Solar Photovoltaic System is an installed aggregate of solar arrays generating power for a given application. These systems have become a potential energy solution for temperature-controlled facilities.

This Solar Photovoltaic System Guideline is intended to give a general overview about solar technology, the components of a solar photovoltaic system and their performance. Moreover, this guideline will aid in selecting an optimal system for specific requirements by showing the pro's and con's of different solutions, and by identifying potential challenges and problems that can occur during and after installation.

The Solar Photovoltaic System Guideline is not intended to replace the discussions with solar experts; instead it is intended to enable productive discussions leading to the best possible solar photovoltaic system for a given set of specific requirements.

All numbers throughout the Solar Photovoltaic Guideline are valid for the U.S. only.

Figure 1: 576 kW AC in Baltimore, Maryland, USA. Courtesy of HelioSage

Figure 2: 3MW AC in Mira Loma, California, USA. Courtesy of Mangan Renewables

2. Photovoltaic Solar System – Overview

"Photovoltaic" means "light-electricity". It follows, then, that Solar Photovoltaic (PV) Systems generate electricity.

The main elements of each PV system are the **solar panels** (see paragraph 5.1.1) that convert light into electricity in an identical manner as the small photocells used on calculators and other equipment. As long as the sun shines the electricity generated is a constant electric current, called DC (Direct Current). The electricity used in the facilities is AC (Alternating Current). One or more **inverters** (see paragraph 5.1.2) convert DC to AC electricity, whereby the AC current is totally synchronized with the utility, same Volt and same frequency, so that the equipment in the facility receives identical electricity, independent of the source.

The inverter(s) are connected to the existing electric system of the facility thru the existing **switchgear**, which now has two sources of electricity, utility and PV system. It is physical law that electricity will take the path of the lowest resistance, thus, the PV generated electricity will be used first whenever electricity is used in the facility, and the utility electricity will be complementary. This ensures that there will be enough electricity at any given time, independent of the actual sunshine.

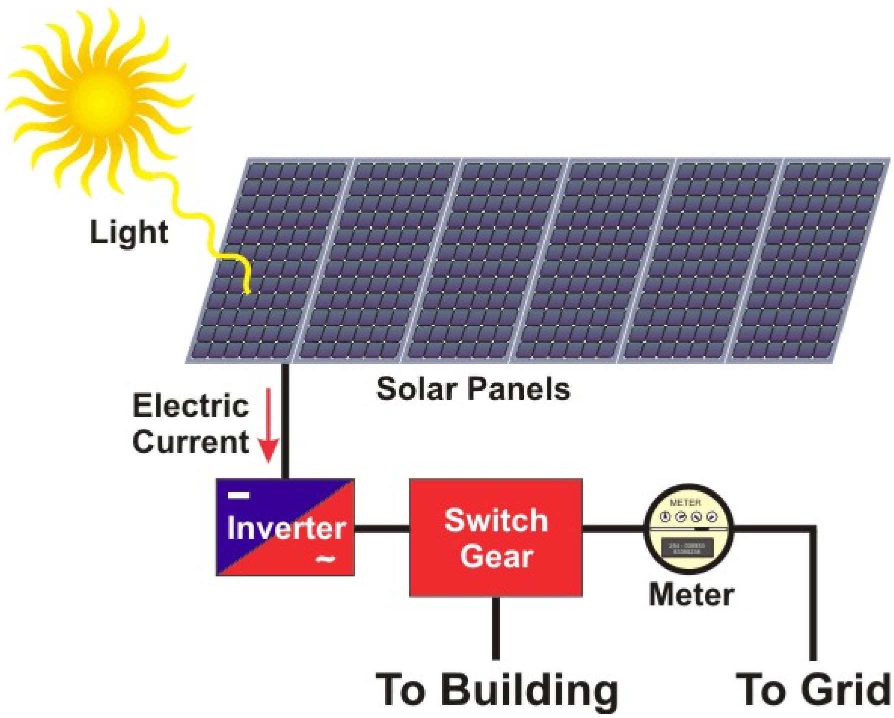


Figure 3

Additional elements of a typical commercial solar system are combiners and disconnects. Combiners allow the reduction of the number of wires from the solar array to the inverter. Disconnects are used for safety as well as for maintenance. For more details see paragraph 5.1.3 “Electrical Components”.

Wiring has a significant influence on the efficiency of the solar system. In commercial systems wiring typically is several hundred feet long; correct sizing has to ensure that the power loss thru the wires is below the percentage used in the generation prediction; typically 3% for AC and DC wiring combined.

Typically PV systems for warehouse owners offset a portion of the required electrical demand; the remaining electricity has to be purchased from the utility. The existing meter counts the electricity delivered by the utility.

In case the PV system generates more electricity than used, the access electricity typically will be fed into the grid. Many utilities credit the access electricity, measured by the meter that now runs in the opposite direction (“backwards”), at the amount specified by the respective tariff (see also paragraph 8.1). It is strongly recommended to know how the respective utility handles access electricity before discussing details about a PV system.

Some utilities also offer to buy the solar electricity. If the price is regulated, it is called a Feed-in Tariff (FiT).

3. Economics of Solar PV Systems

The price of solar PV systems is very comparable across the United States. Costs are mainly divided into two categories, (1) systems with union labor or prevailing wages and (2) systems with non-prevailing wages. However economics greatly depends on the cost of electricity at the specific location, the amount of sunshine, and the available incentives such as rebates, tax incentives, and sales of Renewable Energy Certificates (RECs).

In order to compare the economics of a solar system in different scenarios, it is generally assumed that the financial goal is a simple payback between 4 and 5 years. It is further assumed that the Federal Investment Tax Credit "ITC", in the amount of 30% of the purchase price, will be used, either by the facility owner or by the financing company.

Location is critical to assessing the economics. The Photovoltaic Solar Resource map (Figure 3.1) identifies the average energy from sunshine available per day across the United States. Tables 3.1 and 3.2 show guidelines how much rebate and state tax credit respectively, is needed for a simple payback up to 5 years dependent on the available sunshine and the local cost of electricity. Individual cases my significantly deviate from typical values.

Table 1

Necessary Rebate		Sunshine [kWh/m2/Day]		
for up to 5 years payback		>6.0	5.0 - 6.0	4.0 - 5.0
Electricity Cost	$0.07 - $0.09/kWh	$0.06/kWh	$0.08/kWh	$0.10/kWh
	$0.09 - $0.11/kWh	$0.04/kWh	$0.06/kWh	$0.08/kWh
	$0.11 - $0.13/kWh	$0.02/kWh	$0.04/kWh	$0.06/kWh
	$0.13 - $0.15/kWh	none	$0.02/kWh	$0.04/kWh
	$0.15 - $0.17/kWh	none	none	$0.02/kWh
	$0.17 - $0.19/kWh	none	none	none
	>$0.19/kWh	none	none	none

ASSUMPTION: Rebate paid over 5 years or longer

NOTE: In CA using "renewable tariffs" the necessary rebate typically is $0.02/kWh lower

Table 2

Necessary State Tax Credit for up to 5 years payback		Sunshine [kWh/m2/Day]		
		>6.0	5.0 - 6.0	4.0 - 5.0
Electricity Cost	\$0.07 - \$0.09/kWh	15%	20%	25%
	\$0.09 - \$0.11/kWh	10%	15%	20%
	\$0.11 - \$0.13/kWh	5%	10%	15%
	\$0.13 - \$0.15/kWh	none	5%	10%
	\$0.15 - \$0.17/kWh	none	none	5%
	\$0.17 - \$0.19/kWh	none	none	none
	>\$0.19/kWh	none	none	none

ASSUMPTION: State Tax Credit paid over 5 years

Example: If the solar radiation (sunshine) is 5 - 6 kWh/m^2/Day and electricity cost is \$0.11-\$0.13/kWh, a rough estimation is that either rebate of \$0.04/kWh or a state tax credit of 10% is needed to get the payback below 5 years.

In case the state or utility offers to buy the solar electricity, the above tables can be used, replacing the electricity cost with the purchase price for the electricity.

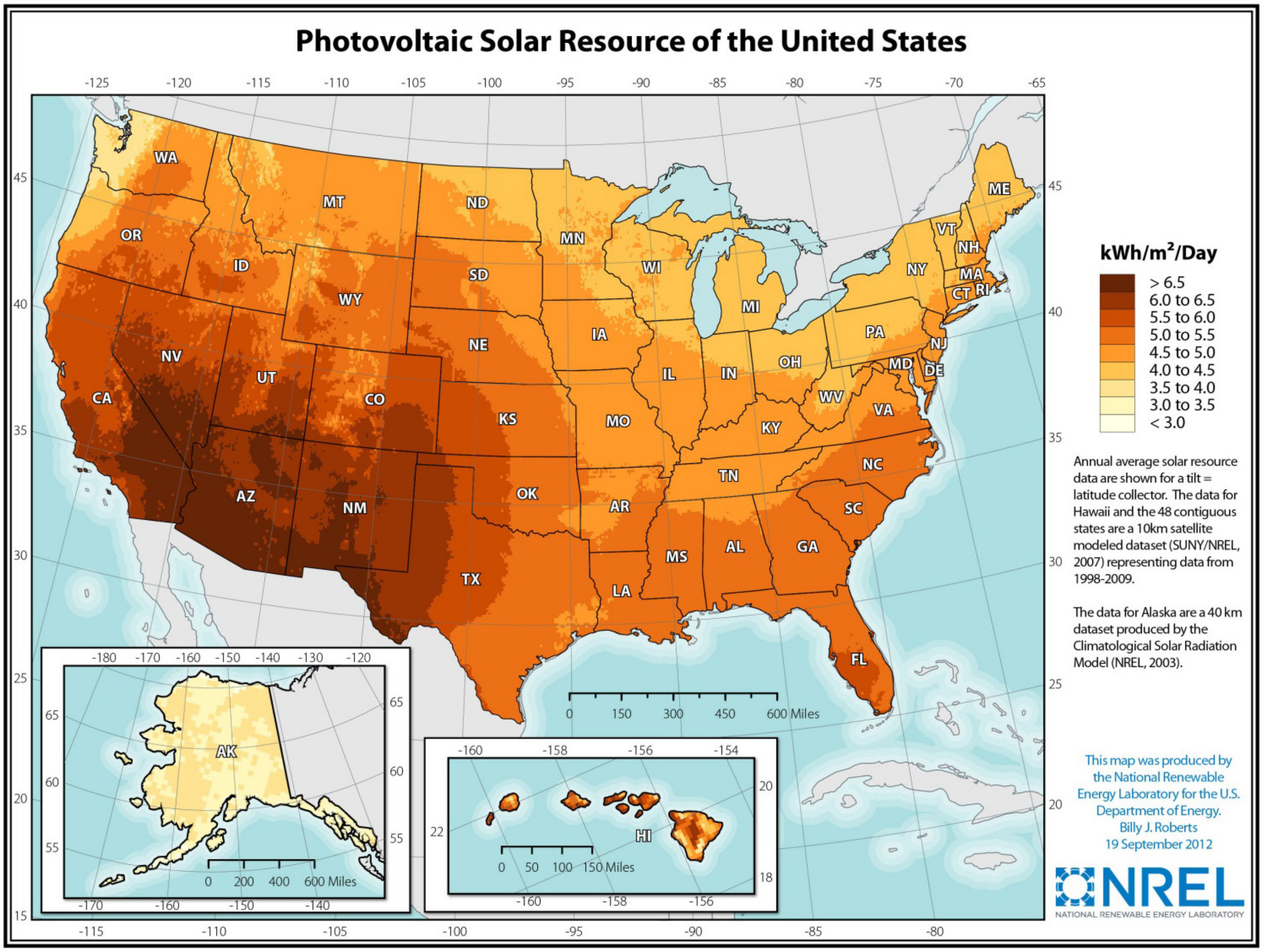


Figure 4

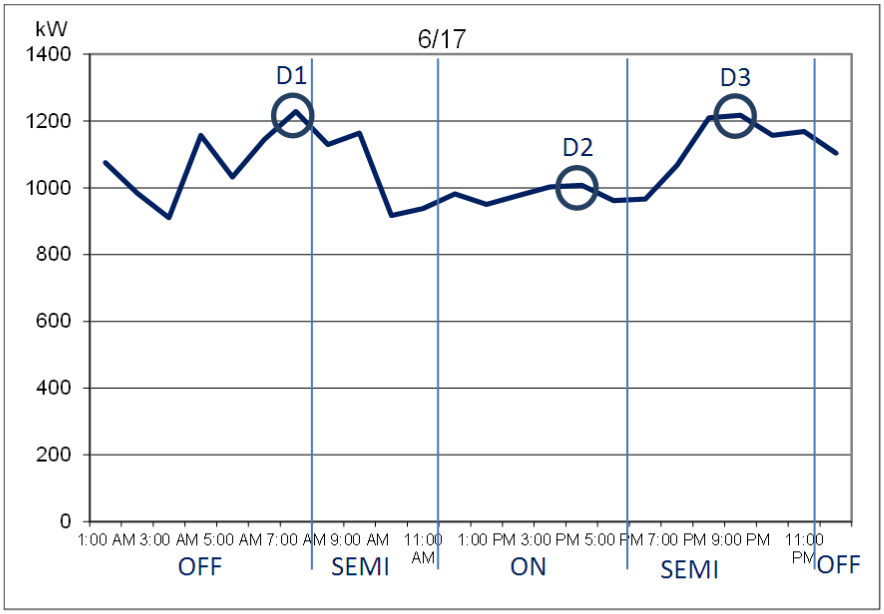
The following states offer solar incentives that are worthwhile to be considered: Arizona, California, Connecticut, Florida (Gainesville utility), Hawaii, Indiana (Indianapolis and NIPSCO territory), Massachusetts, New York (Long Island), North Carolina, Rhode Island, South Carolina (PEC territory), Utah, and Washington (OPALCO territory, max 200 kW per system). Please be aware that this is a snapshot as of January 2013. Incentives and programs change frequently.

The Database of State Incentives for Renewables & Efficiency (DSIRE) is a comprehensive and reliable source for information on federal, state and utility incentive programs. DSRIE is an ongoing project of the North Carolina Solar Center and the Interstate Renewables Energy Council, Inc., funded by the U.S. Department of Energy. Learn more at www.DSIREUSA.org.

Rebates and incentives typically include milestones with hard deadlines. If a deadline is missed, the rebates/incentive typically is dismissed automatically; see also chapter "Best Practice".

Solar Photovoltaic systems can be financed in different ways: loan and standard equipment lease, operating lease and Power Purchase Agreement (PPA). Operating lease and PPA have the specific feature that the lessor and the PPA supplier will use all tax incentives to lower the lease or PPA rate. In all forms of financing the facility owner owns the system except PPA. The PPA supplier owns and operates the system and sells the electricity to the facility owner. Typically all financing methods are compatible with local rebate and incentives; but there are exceptions in particular for PPAs. Confirmation about the compatibility should be one of the first steps in the evaluation process.

All above information is worthless if the savings are incorrectly estimated. If the utility tariff (also called “rate” or “schedule”) charges for energy only, that is cent per kWh purchased, the saving can be easily estimated by multiplying the generated kWh with the respective rate. If the tariff includes charges for kW demand, it gets complex; and if the tariff has Time-of-Use (TOU) components for energy charge and/or for demand charges, it gets really complex. Any simplifying approach using average rates per kWh are so incorrect, that they will almost certainly lead to false decision to purchase or not to purchase a solar system.



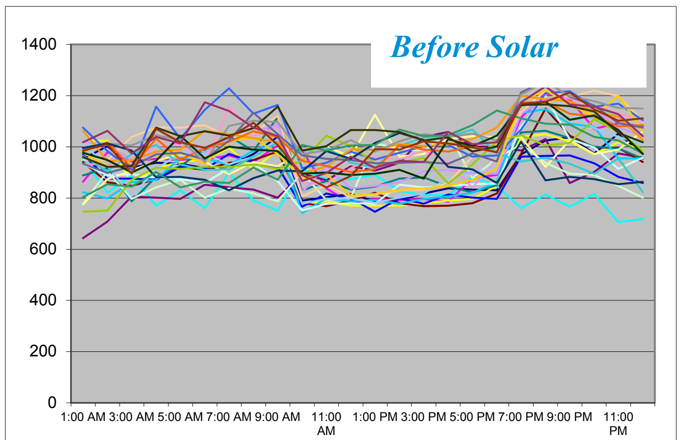
The graph above shows the usage of a cold storage facility on one day of the year, June 17. To explain how a demand charging TOU tariff works, we used Southern California Edison’s “TOU-8B” tariff.

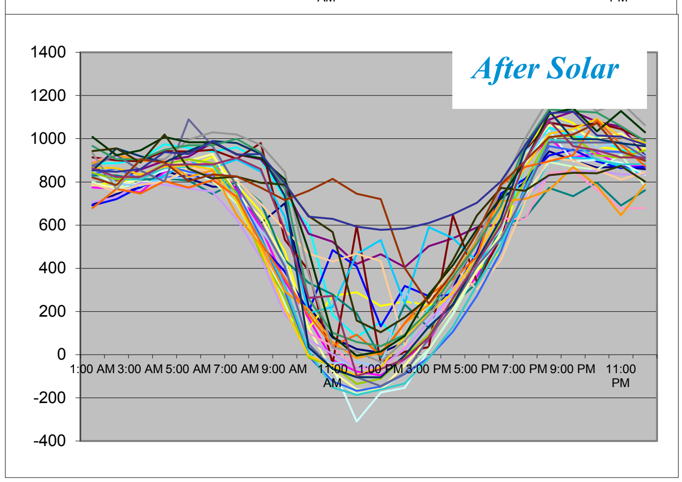
The day is divided into three phases: On-Peak “ON”, Semi-Peak “SEMI” and Off-Peak “OFF”. Each has a different rate for the kWh energy. Thus, in order to estimate the cost, the amount of kWhs per phase has to be known and then multiplied with the respective rate, for every day of the month.

Now let's introduce the demand charges. There is one generic demand charge for the highest demand peak of the month, also called facility demand charge or non-coincident demand charge, because it is not a coincident with any time. In our example it is "D1" 1,229 kW. But there are two more demand charges, the On-Peak demand charge; in our example "D2" 1,008 kW; and the Mid-Peak "D3" 1217 kW. To calculate the demand charges the highest peaks in the different time zones during a month have to be identified and then multiplied with the respective dollar amount. As we can show in this example, this will be a significant portion of the entire electric bill:

-	Facility Demand	1,229 kW @ $13.15	$16,161.35
-	On-Peak Demand	1,008 kW @ $15.39	$15,513.12
-	Semi-Peak Demand	1,217 kW @ $4.33	$5,269.61
-	TOTAL DEMAND CHARGES		$36,944.08

The top graph at the right shows the entire month of June, each of the 30 lines represents on day. The bottom graph shows the remaining electricity to be purchased from the utility after solar. This estimate is generated using hourly generation data.





Now the calculation process as described above will be used to calculate the cost of the remaining electricity purchased from the utility. The savings is the difference between cost before and cost after solar. This is the only reliable method to estimate savings for complex tariffs.

Demand charges cannot be reduced at the same ratio as kWh energy charges. In our example the facility demand charge will stay almost the same based on the peak of 1,217 kW outside the sun-hours.

It is imperative to question the method that is used to estimate savings.

4. PV System Performance

The calculation and prediction of the performance of PV systems is little bit more complex than for example the performance of a generator that can operate 24 hours, seven days a week.

PV systems generation curve follows the curve of the sun radiation, which is a bell-shaped curve when not diminished by clouds. Thus we need to understand the capability of a PV system, independent of the actual sun radiation, as well as the actual generation based on the sun radiation.

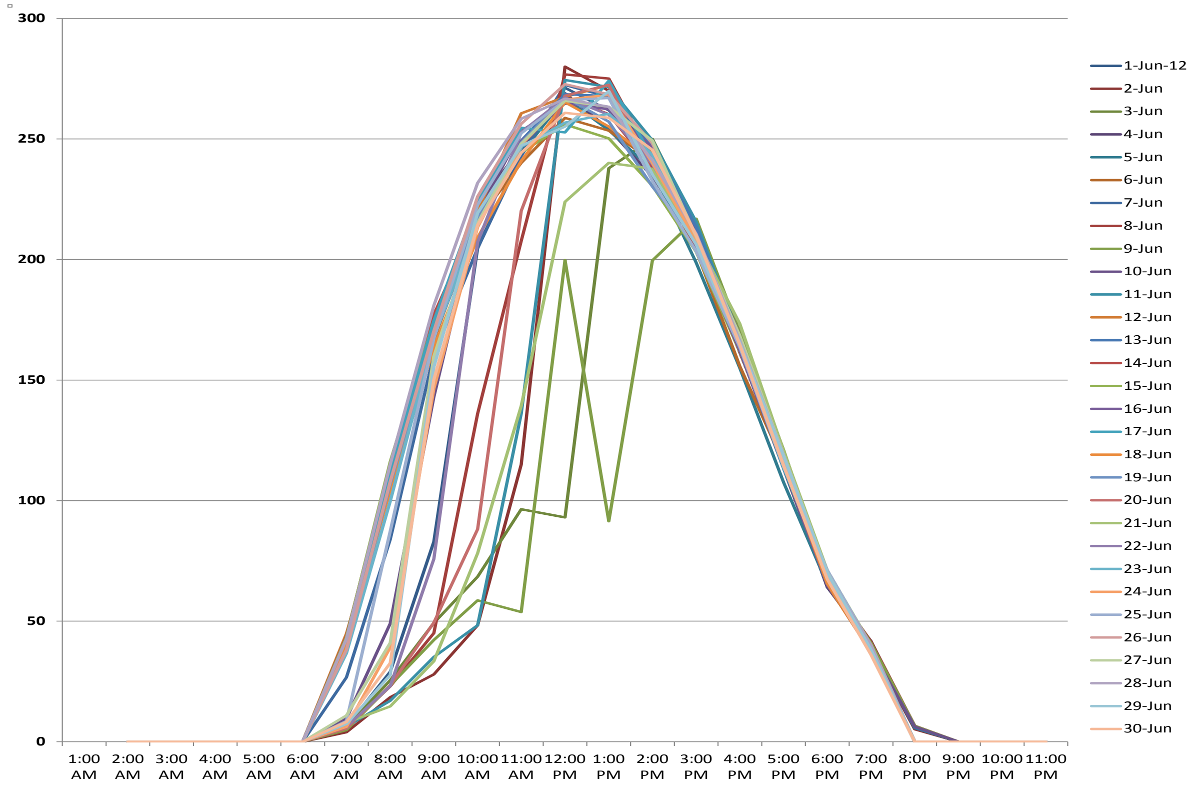


Figure 5: Generation of a 300 kW AC solar system in Ontario, California, USA. Every line shows the generation during one day in June. Courtesy of Mangan Renewables.

4.1. Performance of PV systems independent of solar radiation

The performance of a PV system specified independently of the actual solar radiation is a measurement of the capability of that PV system. Performance specifications are useful when comparing different systems, similar to comparing the horsepower of different generators. There are two main methods to specify this performance.

1. the performance of the solar array, that is the DC capability of array of solar panels, and

2. the performance of the entire system, that is the AC capability of the PV system including inverters.

The measurement units are respectively Watt DC (W DC) and Watt AC (W AC). To avoid big numbers, typically kilowatts (kW) or Megawatts (MW) are used, whereby 1 kW equals 1000 Watt, and 1 MW equals 1000 kW.

The most meaningful specification is kW AC, because it specifies what energy can be generated by the entire system; that is the energy available for usage. The DC specification is typically used to compare different solar panels.

It should be noted that there are two different DC units commonly used in the solar industry, DC STC and DC PTC.

STC stands for Standard Test Condition and is used world-wide to specify panel performance, shown on all data sheets for solar panels. The challenge with the STC method is that it is open to interpretation, so that panel manufacturers can be more conservative and others can be more aggressive with the Watt DC specification. In other words, comparing Watt DC of different panels can be misleading.

PTC stands for PV USA Standard Test Condition. Defined by the California Energy Commission (CEC) in cooperation with the solar industry, this method was developed to create a method that doesn't give solar manufacturers the "freedom" to be conservative or aggressive. The PTC condition also takes more realistic environmental values for temperature and wind into consideration. Thus a PTC value is a more realistic specification of the true performance of a system. PTC values typically are around 90% of the STC values. When comparing solar panel performance it is recommended to compare their Watt PTC.

4.2. Performance of PV systems based on solar radiation

The most important performance measurement of the PV system is the generation of power at the location where it is installed. The generation is based on:

- kW AC (see 4.1)
- Solar radiation at that location
- Tilt and Orientation of the panels
- Temperature at that location
- Panel temperature (based on ambient temperature and ventilation)

The actual generation of power is measured in kilo Watt hours (kWh), which is identical to the measurement of the electricity purchased from utilities.

The predicted generation is the most important performance number for the evaluation of a PV system before purchasing because the actual generation will define the actual savings.

Solar suppliers should be expected to explain the method for how they estimated the future generation. It may also be worth the extra cost to enter into a performance guarantee, which is a guarantee that the PV system will generate a guaranteed specified amount of minimum power based on actual solar radiation.

5. Solar Technologies

5.1. Solar Electricity/Photovoltaic

Solar panels (also called modules) convert solar radiation into electricity by exploiting the photovoltaic (or 'light-electric') effect. This is the same technology that is used by photocells to power small calculators and others small electronics. Solar panels are made up of a number of small Photovoltaic cells, which contain light-sensitive semiconducting material (usually silicon). These materials produce a voltage and electrical current (electricity) when exposed to light.

The performance of solar panels decreases with higher temperatures; the hotter the panel the lower the electricity generated.

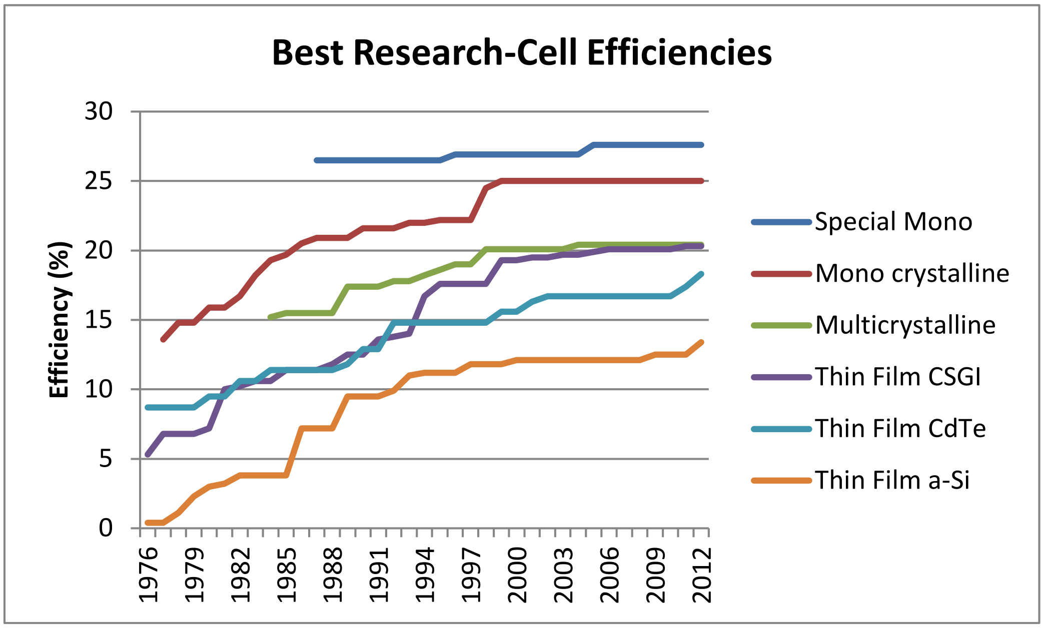


Figure 6: Abstract of NREL's "Best Research-Cell Efficiencies", published 12-2012

Over the past 10 years, main-stream Photovoltaic technologies have been close to their physical limits with CSGI Thin Film catching up. Paragraph 5.1.1 explains the different technologies. Figure 5.1 shows efficiencies of research cells. On general production efficiency is lower, and typically follows the research curve with 3 to 5 years offset.

The main research focus of the solar industry is focused on lowering the production cost. For example, a focus area of the research finds ways to decrease the amount of material required.

5.1.1. Solar Panel Technologies

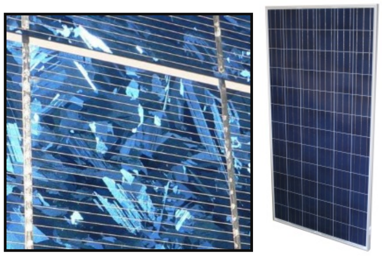
Several distinct types of photovoltaic (PV) cells are commonly used to make solar panels. While the principles behind their technologies are similar, their advantages and applications vary.

Crystalline

Crystalline PV cells are made from different types of silicon crystals. In a typical crystalline PV cell, layers of p-type (positive) and n-type (negative) silicon semi-conducting material are separated by a thin barrier. When exposed to sunlight, a voltage is generated between the two layers and electrons move across the barrier, creating electricity.

Polycrystalline (multicrystalline)

Polycrystalline cells are comprised of small, individual crystals with varying orientations. Polycrystalline panels are less expensive to manufacture, but are also less efficient than mono-crystalline panels (typical conversion rates are approximately 13 - 15%). Polycrystalline PV panels are most the commonly used type of photovoltaic technology.



Typical parameters for polycrystalline cells and panels:

- 12 – 13 Watt PTC per sq.ft.
- 0.15 – 0.25 lbs/Watt PTC
- 13.5 – 14.5 Watt STC per sq.ft.
- 0.13 – 0.23 lbs/Watt STC

Figure 7: Poly Crystalline Cell and Panel

Mono-crystalline (single crystalline)

Mono-crystalline cells are comprised of one single crystal with a uniform orientation. Mono-crystalline panels are more expensive than poly-crystalline, but they are more efficient (with typical conversion rates of approximately 14 - 16%). “Special Mono” is a technology the manufacturer SunPower uses, including special structure of the material itself as well as the glass, achieving up to 20% efficiency. Its higher efficiency comes with a significant higher cost in production.

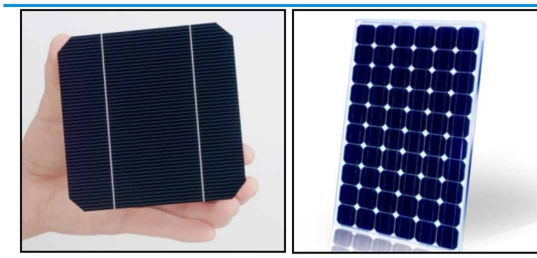


Figure 8: Mono Crystalline Cell and Panel

Typical parameters for mono-crystalline cells and panels:

- 12.5 – 13.5 Watt PTC per sq.ft.
- 0.15 – 0.25 lbs/Watt PTC
- 14 – 15 Watt STC per sq.ft.
- 0.13 – 0.23 lbs/Watt STC

Thin-Film

The common denominator of all thin-film PV technologies is that they utilize amorphous (not crystalline) semiconductors in a thin layer on a substrate such as glass, metal or plastic. Glass is commonly glass used. Plastic is used for application where flexible solar cells are needed. Thin-film cells are less expensive than traditional PV cells, but have lower conversion rates, typically between 10 and 13%. Typically, thin-film panels have wider tolerances than crystalline.

All thin-film panels have less performance reduction with rising temperature than crystalline panels. Thin-film panels also perform better in low light conditions than crystalline panels. Please note that the respective inverter has to support low light conditions (see 5.1.2).

The leading thin-film technology is based on the elements Cadmium and Tellurium (CdTe), which is a very hazardous material that must not be introduced into the environment. This makes recycling CdTe a particular challenge.

CIGS thin-film – Copper, Indium, Gallium, and Selenium is another available thin-film technology. CIGS film is more costly to produce than CdTe based thin-film and historically has lower efficiency. In recent years new developments have created CIGS modules that are catching up in efficiency and price.

The mounting cost using thin-film modules is typically higher than for crystalline panels because thin-film panels are typically only half the size of crystalline panels (up to 160 W) and thus many more panels have to be installed for the same performance.

Thin-film panel:

- Typ 9.0 – 10.5 Watt PTC per sq.ft.
- 0.30 – 0.50 lbs/Watt PTC
- Typ 10.0 – 11.5 Watt PTC per sq.ft.
- 0.27 – 0.45 lbs/Watt PTC

Figure 9: Courtesy of Solar Frontier

Hybrids

Hybrid PV uses both amorphous and crystalline forms of semiconductors. While more expensive than traditional crystalline and amorphous PV technologies, the combination of these two technologies makes hybrid PV cells more efficient (with conversion rates of approximately 18%) and allows them to perform better in higher temperatures.

Typical Warranties

All leading manufacturers offer a 25 year warranty for performance and 10 year warranty for workmanship. Flexible thin-film has significantly shorter warranties. The warranted performance typically is 20% degradation over 25 years, whereby the desirable warranty is a linear warranty with a guaranteed degradation per year rather than a warranty for degradation over 10 or 15 years.

Panel Frames

Panel frames deserve special attention. The frame has to protect the fragile cells from breaking as well as from corrosion; thus it has to be solid and the insolation between frame and cells has to be solid and long lasting. The quality of solar frames differs much more than the quality of the cells between different manufacturers.

Most panels have aluminum frames. The quality of the Aluminum is essential to avoid long term corrosion. Few thin-film panels are frame-less, causing extra caution and cost for mounting.

Pros and Cons

PV TECHNOLOGY	PRO'S	CON'S
Mono-crystalline	- Higher efficiency (14 - 16%) - requires less space	- More expensive
Poly-crystalline	- Less expensive	- Lower efficiency (13 - 15%)
Thin-film	- Inexpensive	- Low efficiency (11 -13%) - requires more space - higher mounting cost - wider tolerances causing more mismatch losses
Hybrid & Special Mono	- High efficiency (18 - 20%) - require least amount of space	- Expensive

Considerations

Here are some things to consider when choosing a specific PV technology:

- PTC-STC ratio
- Warranties
- Location specifics that impact panel frame
    - Corrosive environment

- Snow load
- Seismic

- Light conditions
  - Shading
  - Many days of low light
- Location specific cleaning requirements
- Temperature, ambient and predicted panel temperature

5.1.2. Inverters

Inverters convert the current generated in the solar panels into current that has the same features as the current that is delivered by the utility for the respective facility. The current generated is "Direct Current" (DC), and the current used in the facility is "Alternating Current" (AC). The inverter's task is to synchronize with the utility (Volt and Frequency) so that there is no difference between utility and solar generated electricity.

In case the solar PV system generates more power than used in the facility, typically the access will be fed into the grid and the customer gets compensated. For more information see the section on 'Excess Power'.

Standard inverters shut off immediately when the utility power is outside the utility approved values, in particular when the grid is down. This prohibits electricity to be contributed to the grid, when the grid is down for example for repair. There are special inverters available that can manage on- and off-grid connection, so that the PV system can work when the grid is down. However these inverters are small, thus typically used in residential applications, they are less efficient, and they need a battery back-up to function. Standard inverters can also be used in back-up systems; however this needs special additional equipment for power generation during power-outage and for control.

Each inverter has its window of operations; inverters don't start at zero and generate electricity immediately when light comes up. They need a minimum power generated by the solar panels to start generating. The minimum power varies significantly enough to be taken into serious consideration, in particular when low light conditions are essential, for example for thin film panels to benefit from their full potential and in regions with many clouds.

Inverters come in three categories: central inverters, string inverters, and micro inverters.

- Central Inverters: A typical commercial PV system needs one or two central inverters, located close to the main switchgear, easily accessible for maintenance and repair. Typical central inverters range from 50 kW to 500 kW; the bigger inverters are the most efficient inverters.

- String Inverters: They are directly connected to string of solar panels, thus the name “string inverters”. They are ideal for small commercial because they need the smallest amount of additional equipment.
- Micro Inverters: They are directly connected to solar panels, eliminating any DC wiring, simplifying the wiring for small systems, such as residential and small commercial. The benefit of eliminating DC wiring using hundreds, if not thousands of micro inverters on commercial roofs is questionable, because of two main reasons: maintaining inverters on the roof is more labor than in a single place on the ground; AC wiring for that many inverters on the roof is a challenge bigger than DC wiring. Micro inverters typically support 1 Phase AC current and are typically the lowest efficient inverters.

The examples shown are for illustration purpose only and don’t indicate in any way that the specific inverter and/or manufacturer is better or worse than others.

Figure 10: 500 kW Central Inverter, 90” wide, 3760 lbs. Courtesy of Advanced Energy.

Figure 11: 5 kW String Inverter, 16” wide, 49 lbs. Courtesy of Solectria Renewables

Figure 12: 0.215 kW Micro Inverter, 7” wide. 3/5 lbs. Courtesy of Enphase Energy.

Inverters are typically designed to work in temperatures up to 50^{0}C (122^{0}F) ambient temperature. Inverters should not be installed where exposed to direct sunshine because the additional heat lowers the efficiency and shortens the lifetime of the inverter. When mounted on a roof, the distance to the roof is critical; the closer to the roof, the higher the temperature. A good estimation is that the air 6 inches above the roof is 22^{0}F hotter than ambient temperature.

Another heating challenge can be the dissipation of the heat generated by the inverter, in particular when the inverter is installed inside of a building. When the location for the inverter is discussed, the specific heating dissipation requirements of the inverter have to be taken into consideration.

Most inverters have air ventilation heat dissipation systems. Small inverters can work with external heat dissipation panels. Medium and large size inverters have forced ventilation. A few inverters have integrated liquid cooling systems. This integrated “AC unit” ensures the right working temperature, however it requires more maintenance.

Most of the inverters can be installed inside and outside. As said above, a shaded place is preferred, for example outside at a North wall. Typically inverters are located close to the switchgear so that the main PV Disconnect (required by the utility) is close to the inverter and to the switchgear. The selection of the location also should consider wiring cost; the longer the run, the thicker the wires have to be to limit the power loss.

The typical inverter warranty is 5 to 10 years, with options of a 15 and 20 year warranty. Some inverter manufacturers also offer performance guarantee in the form of guaranteed uptime, typically 99% - at a significant additional cost.

5.1.3. Combiners

Solar panels are wired sequentially to form panel strings, and then the panel strings are wired parallel to be connected to the inverter. Typically 140 to 180 parallel strings are needed for a PV system on a 60,000 to 100,000 sq.ft. roof. That would be a lot of wires. To significantly reduce the number of wires ‘Combiners’ are used that electrically combine several panel strings, typically between 7 and 28, which allows the use of significantly fewer but larger wires (because of the combined power) to connect to the inverter.

Combiners can be “dumb” electrical combiners or they can be “smart”. Smart features are integrated monitoring and remote switch-off capability using contactors to switch-off power of the outgoing wires. In particular the remote switch-off capability is a significant safety means, switching off the power of all wires from the PV array, for example on the roof, to the inverter from one central switch. This feature is very welcome by fire departments across the U.S. and can be used by the facility management in any case of emergency.

5.1.4. DC-DC Boosters

Figure 13: 350 W DC-DC Booster, 3.5” x 3.5” x 1.1”. Courtesy of Tigo Energy

‘DC-DC Boosters’, also called ‘DC-DC Optimizers’ are a relatively new technology. The main feature is optimizing the performance of each panel while in panel strings the module with the least performance, the “weakest link”, defines the performance of the entire string. This optimization boosts the overall performance significantly when part of the system is shaded or if parts of the system have different orientation and thus different amounts of sun-shine to capture.

DC-DC Boosters typically come with two more features: monitoring and remote switch-off. Monitoring on the panel level obviously is the most comprehensive possible. The remote switch-off capability is the ultimate power switch-off any PV system can have, because it shuts off the power of each and every panel, leaving no wire under power. In the 2014 version of the National Electrical Code (NEC) the power shut-down of all panels after the inverter is out of operation will be mandated. It will take time until this requirement will be implemented in the respective State Codes; however, some fire departments may use it to enforce the highest safety standard possible.

DC-DC Boosters obviously have many positive features. The only problem is the price. At this time using this technology adds non-negligible cost to the PV system. It is expected that the cost for DC-DC Boosters will come down significantly in the next 5 to 10 years.

5.1.5. Electrical Components

Customers are typically less involved in the selection of other electrical components such as disconnects and combiner boxes. However it is a good idea to check if the qualification required by code as well as by the customer is met.

The most important code requirement is "UL Listing". The UL listing of any component can be found on the respective datasheet.

The other general code requirement is NEMA, specifying the use, for example:

- NEMA 1 – indoors only
- NEMA 3R – outdoor, weather-proof
- NEMA 4 – outdoor, water tight

The customer may want to further specify the material

- Galvanized: good for typical weather conditions, least expensive solution
- Stainless Steel: lasts "forever", should be required for corrosive environments such as coastal areas
- Fiber Glass: an alternative to stainless steel

5.2. Mounting Technologies

5.2.1. Roof-top

The most common place for solar PV systems for refrigerated warehouses is the roof. Roof-top mounting systems can be divided into three categories: penetrated systems, ballasted systems, minimal penetrated systems.

- Penetrated Systems shouldn't be considered for cold storages, but can be considered for dry storages and other kind of warehouses. Typically they are the lightest available mounting systems, typically around 3 lbs per sq.ft., thus they are usable for almost all roofs.
- Ballasted Systems are strongly recommended for cold storages. Typically they need 5 – 7 lbs per sq.ft., mainly dependent on the local wind speed. Some systems provide wind shields that can be additionally installed to reduce the necessary ballast. The required

ballast increases close to roof edges, which leads to either higher ballast, if the roof can carry it, or larger unusable areas of the roof.

- Minimal Penetrated Systems are used to leverage the benefit of ballasted systems for the most part of the roof and penetrate typically at the outside borders to limit the necessary ballast to a weight that the roof can carry. Minimal penetrated systems also are used to meet seismic requirements.

Mounting systems became so competitive over the last three years that there is no big price difference between the three system categories, labor and material combined. Price differences are mainly due to different material, galvanized steel, stainless steel, aluminum, and plastic. Galvanized steel and plastic typically are the least expensive, while stainless steel and aluminum are longer lasting and better for harsh environments. Plastic should be long lasting even in harsh environments, used in cars and boats since years, but there is no long field experience with plastic mounting system in the solar industry.

The kind of roof may define the mounting system. For example it is strongly recommended to use ballasted systems on membrane/TPO roofs. Standing seam metal roofs don't need any penetration using clamps that connect to the seams. Concrete roofs can be penetrated without any risk of water damage; however, typically the cost is higher than using ballasted systems. Corrugated metal roofs typically have to be penetrated because in many cases the metal roof cannot carry the weight of a solar system, thus the connection will be done to the underlying rafters. For all other roofs the available additional weight and the customer's preference will decide what system shall be installed.

Figure 14: Ballasted System, no penetration. typ 5 – 7 lbs/sq.ft. Courtesy of PanelClaw

Figure 15: Penetrated System, high tilt example. typ 3 - 4 lbs/sq.ft. Courtesy of Mangan.

Figure 16: Clamped System, standing seam metal roof. typ 3 lbs/sq.ft. Courtesy of Mangan

5.2.2. Ground Mount

Ground Mount Solar PV Systems typically are the most efficient solar PV systems at any given location. In order to achieve the high efficiency, panel rows have to be farther away from each other than typically is the case on roofs, thus the area required for the same system size is larger, typical 50% larger.

There are three commonly used types of ground mount systems: fixed tilt, horizontal 1-axis, and 2-axis systems. Fixed tilt systems have the benefit of virtually no maintenance. Horizontal 1-axis systems have the advantage of significantly higher efficiency than fixed tilt system at a reasonable cost (see 3.2.3). 2-axis systems have the advantage of the highest possible efficiency but it comes at a price.

Manually adjustable fixed tilt systems to adjust several times during the year didn't find its place in medium or large solar systems, most likely because of higher cost of the system plus significantly more cost for the manual adjustments. Tilted 1-axis systems are almost as expensive as 2-axis system at a significant lower efficiency.

Space requirement for a highly efficient 30^0 tilted ground mount system is around 180 sq.ft. per kW AC. Typical commercial ground mount systems are 500 to 1000 kW AC, requiring 2 to 4 acres. The space requirements for 1- and 2-axic systems are about the same.

5.2.3. Solar Carports

Solar carports have a dual purpose; they generate electricity and protect against the environment, in particular the sun creating shade for the cars. They make use of a space that otherwise cannot be used at all. Solar carports can be installed on parking lots as well as on top of parking garages.

5.2.4. Price Comparison

The price comparison can be a guideline only, because the actual price is dependent on the object the solar system is mounted on, that is the roof in case of roof-top systems and the soil in case of ground mount and solar carport systems. The price comparison below assumes identical systems in size, solar panels, inverters, and other electric components, and assumes typical roof or soil conditions. The price comparison below is made for the U.S. Price, as well as efficiency, will vary from region to region.

Price Comparison — Normalized on Roof-top Systems

Mounting Method	Tilt	Price	Efficiency [1)]
Roof Top	10^o	100%	100%
Ground Mount Fixed Tilt	30^o	101%	106%
Ground Mount 1-axis horizontal	0^o	115%	122%
Ground Mount 2-axis	N/A	147%	138%
Solar Carport	5^o	140%	97%

Notes 1) Efficiency for South facing panels
2) Actual numbers and relations may vary

5.2.5. Requirements for Different Locations

The main factors that influence the cost are wind-speed, height of the building, surrounding buildings that can deflect wind, snow load, and seismic requirements. It should be also considered if the system is built in a corrosive environment such as coastal areas or close to cement factories.

6. Electrical Connections

The interconnection of the PV system to the respective utility is the connection of the inverter output into the existing electric system of the facility, typically in the main switchgear. Through this interconnection the solar electricity will power the facility. In case solar doesn't generate enough electricity, additional electricity will be supplied by the utility, so that all power using equipment in the facility will have uninterrupted and sufficient power at any time. It is the physics of electricity that the solar electricity will be used first and the utility electricity is complimentary; and it is also the physics of electricity that there are no switches required to do so.

In case the PV system generates more power than consumed, typically the excess power will be automatically fed into the grid and the system owner will be compensated through a credit, called "Net Metering". There are utilities that don't provide Net Metering, but will pay for electricity fed into the grid ("Feed-in-Tariff"). For more details see chapter 6 "Excess Power".

In case the utility shuts down, standard solar systems shut down immediately, so that there will be no possibility of electricity fed into the grid that is expected to be off-line. In order to have the solar system work while the utility grid is down, additional back-up system equipment is needed on top of the standard solar Photovoltaic system (see also 5.1.2).

7. Wiring

It is imperative that wiring is done carefully so that no wire is damaged over time. Wires will move due to building movements (seismic), conduit movements (thermal expansion and contraction), wind (in case of exposed wires), and accidental push on conduits or components.

Wires cannot transport electricity without losses. It is very important to size the wires not only in compliance with the respective code but also to the specified power loss that is used to predict the system's generation.

Traditionally, wires are made from Copper. However, Copper is expensive. Aluminum wires had the problem of losing contact to lugs over time due to inefficient tensile strengths. Since the late '70's special Aluminum alloys have the necessary tensile strength. NEC, the National Electric Code, regulates the required specification for Aluminum wires. Potential problems with corrosion can be eliminated in both cases, Copper and Aluminum, by using anti-oxidant pastes while installing. Small wires typically are Copper wires, big wires, the wires running down from the solar array to the switchgear, can be chosen from Copper or Aluminum, whereby Aluminum wires typically are 25% of the cost of Copper wires.

Physical wiring is installed exposed when underneath solar panels, and typically in conduits or cable trays everywhere else. On big roofs cable trays have the advantage of smaller occupied areas, and no stress on the wires due to thermal expansion and contraction. Cable trays should have covers that are strong enough to step on them. Thermal expansion and contraction has to be considered for both, cable tray and conduits, and expansion parts have to be installed based on material and local temperature swings. Failures in conduit design and/or installation have caused several fires on roofs. Between roof and ground typically conduits are used, whereby outside on the building is less expensive, inside of the building is better looking.

8. Excess Power

Solar generated electricity and usage of electricity is not synchronized, and typically should not, because every kWh generated solar electricity ideally should be used. Thus there may be times when the solar system generates more electricity than consumed, mainly around mid-day and over weekends, when facilities work on 5 day weeks. The goal is to financially benefit from this excess power. There are two mainly methods used, “Net Metering” and “FiT – Feed-in Tariff.”

8.1. Net Metering

When utilities allow “net metering”, excess power will be fed into the grid and the customer gets a credit at the same rate at which he would have purchased the electricity at that time. The credit can then be used to offset the debit (the cost of electricity purchased). Most utilities have “roll-over” systems, thus a credit in one month can be used in another month, typically within a period of 12 months.

Net Metering almost everywhere is limited to a certain size of PV system, typically at 1 MW. Before purchasing any solar system, the utility’s requirements for net metering should be carefully analyzed.

8.2. FiT – Feed-in Tariff

Feed-in Tariffs specify the rate the utility pays the PV system owner for electricity generated and fed into the utility grid. Typically the rate is lower than the rate the customer has to purchase electricity from the utility, thus typically FiT is not as beneficial as Net Metering, exception exist where utilities or states are subsidizing solar heavily.

FiT can cover the entire solar electricity generated or only the excess power. And there is no common FiT method throughout the U.S.; if FiT is available at the location of the respective facility, a comprehensive analysis is required.

8.3. Non-Export

If a PV system is above the Net Metering limit and if there is no reasonable FiT available, a PV System need extra equipment that ensures that there will be no excess power fed into the grid, “Non-Export”. Not only is this extra equipment expensive, potential solar electricity will be “wasted”, not generating savings nor revenues. It still may make sense to install a big PV system, but the analysis of the usable solar electricity has to be very accurate in order to predict the financial results.

9. Monitoring

9.1. Energy Monitoring

Energy Monitoring tracks the electric power that is generated by the entire solar PV system. It is strongly recommended that every system has energy monitoring, even if not required by rebate or other rules. Energy monitoring gives the customer actual information about the overall system performance. Waiting for the next electric bill to find out that the bill is higher than expected because the system didn't work properly for a couple of weeks, is not a good method. Monitoring enables the maintenance team, to react immediately when the system underperforms. In case the system underperforms dramatically, for example when an inverter is down, the maintenance team should get an automatic warning.

9.2. Demand Monitoring

Demand Monitoring tracks the entire power consumption for the respective facility, including both; the utility and the solar electricity. Without the demand monitoring, there is no means to track the consumption; the utility meter tracks the electricity sold to the customer; the energy monitor tracks the solar electricity independent if consumed or fed into the grid. It is recommended though not mandatory to have a demand monitoring system installed so that the overall electricity consumption can be reviewed and action can be taken when more electricity is used than expected. Demand monitoring systems are not cost prohibitive.

9.3. System Monitoring

System Monitoring tracks the generation of individual parts of the system. System Monitoring should be part of each Photovoltaic system, so that the system's performance can be checked rather than having to wait for the next electric bill to try to figure out; if enough savings where generated. There are two major system monitoring available.

Energy Monitoring shows the total energy generated by the solar Photovoltaic system. In comparison with monitoring the sunshine, it is a first level analysis to check the system's performance by comparing energy and sunshine on one graph. Both curves have to me almost parallel.

DC Monitoring shows the performance of parts of the solar array, thus can be used for identifying low performing parts, most likely significantly before the lower performance would be identified using the Energy Monitoring.

Typical DC Monitoring systems are "string-level" and "sub-array-level" monitoring. String-level measures the output of each string of panels; sub-array-level measures the output of each combiner. Both systems enable maintenance personal to see when a component is underperforming, down to the panel level. In case of panel failures, string-level monitoring pin-points to the respective string, typically 10 to 14 panels, while sub-array-level monitoring pin-points to the respective combiner, typically 100 to 200 panels; thus the repair technician has to spent more time to find the defective panel. String-level monitoring is significantly more expensive, equipment and annual operation. In order to decide which system is more cost effective a life-time assessment should be done. Assuming low number of failures of the system, based on high quality components and high quality installation, typically the sub-array-level monitoring is the lower cost solution.

New technologies make system monitoring at the panel level possible (see 5.1.4). This technology still is the most expensive, thus benefits versus cost has to be analyzed very carefully.

9.4. Weather Station

Solar irradiation and panel temperature measured by a weather station are necessary parameters to calculate the expected performance at any given time.

A weather station can also give the customer a first-level indication if the solar system is working as expected by choosing a graph within the monitoring system that shows the solar irradiation and the system generation at the same time. System generation is dependent on the sunshine at any given time, thus it can change from day to day dependent on the weather conditions. If the two curves (radiation and generation) are parallel, the system most likely works well.

Additionally to the general observation about the performance of a solar system as described above, an engineering calculation comparing predicted generation with actual generation should be performed on a monthly basis to ensure that there is no general problem with the system's performance such as dirty panels or a problem with a system component.

10. Permitting

Permitting including Interconnection Applications is typically done by the contractor, or it can be done by the Engineering Company in case engineering and installation are decoupled. What should the customer look for?

The topics that caused most of the trouble getting a solar system permitted are:

- Zoning and visibility of solar panels
    - Discussions with the jurisdiction and may be even with the neighbors can help significantly
- Environmental specifics
    - Wind speed
    - Snow load
    - Seismic
        - For all environmental aspects it is a good idea to check with the responsible engineer hat he/she has considered all local environmental aspects
- Interconnection to the utility
    - The interconnection will not be approved before the system is completely installed. Thus it is mandatory to get a conditional approval by the utility that the system as designed will be approved when installed.

A permitting related topic is the choice of the electric rate including options such as Net Metering, Feed-in-Tariff (see chapter 8). It happened that customers based their financial model on specific rate and interconnection method, that wasn't approved in writing by the utility when the solar system should go online; and the expected savings couldn't be achieved. If it is not 100% certain that based on written rules of the utility the choice will be approved, a dialogue with the respective utility before the installation is strongly recommended, and any written statement very helpful; utilities in general are very reluctant to put anything in writing, so this is a challenge.

11. System and Contractor Selection

When selecting system components, the expected lifetime of the solar system should be taken into consideration. Typically a solar system is expected to last for 40 or more years, whereby typically the first 20 years are used for a life-time assessment. Thus it is important to have long lasting components and material installed. It may cost more at the beginning, but typically pays off multiple times over the lifetime of the system.

When selecting the two major components the following criteria can be used:

11.1. Solar Panels

- Warranties
  - Product warranty (labor and material) should be 10 years
  - Performance warranty should be 25 years or more
    - Performance warranty should be linear
  - Warranties should be honored by a US company; in case of foreign manufacturers, a US subsidiary
- Panel manufacturer's chances to stay in the business of solar panel manufacturing for at least the next 20 years should be as high as future can be predicted

11.2. Inverters

- Warranties
  - Product warranty (labor and material) should be 10 years
  - 20 year warranty extension should be available
    - Even if not used, it is a proof that the inverter has the expected lifetime
  - 99% uptime guarantee should be available
    - Even if not use, it shows the reliability of the inverter
  - Warranties should be honored by a US company; in case of foreign manufacturers, a US subsidiary
- Service: check the quality of the service
  - Feedback from installers
  - Feedback from customers
- Inverter manufacturer's chances to stay in the business of solar inverter manufacturing for at least the next 10 years should be as high as future can be predicted

The selected components also should be known as low maintenance products of the respective product category.

The selection of a contractor is more difficult but just as crucial. If the system is not designed correctly and/or installed correctly, bad things can happen. Here is one example that happened to a large retail chain: A fire destroyed a wide area of the roof. The fire was caused by two short cuts. In both cases insulation of a wire was damaged and a short cut to the metal conduit caused an arc. One of the conduits involved was not design correctly, too long section without expansion kit. The connection of two conduits for the other problem was not tightened per manufacturer specification.

Does a problem like this indicate that solar systems are risky? The answer is No. Cars are not seen as safety risks just because the pipe for the brake fluid can be designed and installed incorrectly so that the fluid escapes and the brakes doesn’t work. But similar to cars you wouldn’t buy from anyone or wouldn’t let the service be done by anyone.

Experience, expertise and competence of any contractor and engineering company should be checked, first be checking the respective license, second by references from customers. If possible a site visit to an existing installation is recommended.

In case the contractor will use subcontractors, it is a good idea to also check them out.

When selecting the contractor the following criteria can be used:

- Quality of Installation
    - Visit and check exiting similar installation(s)
- List of similar installations
    - References
- Generation Prediction
    - Price for kW DC or kW AC is a good comparison between offers, but not good enough. Price per kWh generated is the only reliable comparison between offers.
    - Check method of generation prediction
        - The most commonly used reliable generation prediction tools are PVsyst and NREL SAM
    - How does the installer back the generation prediction?
        - Performance guarantee has to be available even if not used
- Warranty
    - Request 10 year warranty (labor and material) for all major components
        - Mandatory in California for most of the rebate programs
    - Check if installer included a warranty reserve
        - The installer has to carry the product warranties when manufacturers go out of business

12. Maintenance

Figure 17: Automatic Panel Cleaning. Courtesy of Heliotex.

A good installation typically only requires annual maintenance to check and clean filters for the inverters, and check connections in all electric components. Performing the maintenance service by trained technicians ensures trouble-free system performance and avoids expensive repairs.

When guaranteed performance of the solar Photovoltaic system is required, beside others means, "up-time guarantees" supplied by inverter manufacturers ensure the required high level of performance. Up-time guarantees typically guarantee 99% up-time of the inverter of the period of 12 months for 10, 15 or 20 years. These guarantees typically are combined with inverter maintenance done by the manufactures.

Cleaning can also be seen as part of the maintenance, though dirty panels will function, technically, just with lower efficiency. Cleaning periods vary widely from areas where cleaning is almost unnecessary because of frequent rain to bi-monthly or even more in very dusty areas. A ball-park number for the labor of one cleaning is 6 to 8 hours for each 100 kW AC. Example: 6 labors clean a 500 kW AC solar Photovoltaic system in 6 hours.

Automatic cleaning also is available. The additional cost for installation, operation and maintenance has to be taken into consideration to decide if manual or automatic cleaning is less expensive. Typically automatic cleaning systems use soap. That may not be allowed at the specific location. It should be also checked if the additional use of water is justified.

13. Best Practice

Whenever a solar PV system is not designed and installed professionally following Codes and Best Practice, encountering problems is only a question of time. In this chapter the most common mistakes are discussed so that they will not occur again.

13.1. All Phase

- Rebate/Incentive milestones have to be met; otherwise the already conditionally approved rebate/incentive will be lost.
- One important deadline almost all rebate/incentive programs have is the deadline to start operation. Process control is essential, recommended at least bi-weekly. If necessary, serious actions have to be decided on and implemented.
- Many milestones are more administrative work. It is essential to specify in writing who is responsible for rebate/incentive administration, and in case of the installer, what are the financial responsibilities of the installer in case of missing a deadline.

13.2. Design Phase

- Wiring
    - Wire size has to be large enough to carry the maximum possible current including all possible fault conditions
        - Consider temperature (example: higher temperature on roof)
        - Consider number of wires inside a raceway such as a conduit
    - Temperature rating of wires AND of terminations such as lugs or terminal blocks has to be considered to avoid possible overheating
- Raceways, such as conduits, cable trays, etc.
    - Raceways expand and contract with temperature. Flexible expansion kits and grounding means have to be specified to avoid any mechanical and/or electrical break between sections
    - In regions that have ground movements such as earth quakes or vibrations caused by bypassing trucks the mechanical supports of all raceways have to be designed accordingly to avoid the raceways to move uncontrolled
- System Sizing
    - No electrical equipment shall be used outside of the specified parameter
        - Example: Oversized DC array can overload the inverter
    - Panel strings have to be designed to stay below the allowed maximum Voltage AND be large enough to start-off the respective inverter in low-light conditions
- Safety Means

- Ground Fault Detection means have to be designed at least per 2011 NEC. To avoid rare but possible events of two independent ground faults occur, preliminary information of 2014 NEC or equivalent papers should be taken into consideration
- The entire PV system should have one central switch-off for all wires coming from the solar array to inverter or recombiner. If required an even higher standard of safety can be achieved my switching off all panels from a central switch
- Adequate lightning protection has to be specified

13.3. Installation Phase

- Wiring
  - Pulling wires in particular long runs of thick wires have to be done using approved methods to avoid any damage of the insulation
  - Termination of wires have to be torqued per manufacturer's specification to ensure necessary electrical connection; otherwise overheating can happen
  - Insulation of wires at the termination means must be cut away long enough not to be heated nor leave bare metal more than necessary
  - Mechanical connections between raceways, raceways and enclosures etc. have to be tightened per manufacturer specification
  - Wire management has to ensure that no loose wires are hanging around, in particular wires have to be safely tied away from sharp edges of any object
    - It happened that loose wires between panels touched the sharp edge of a mounting structure, damaging the insulation over time, and caused a fire on the roof
  - When wiring for long wires is done in conduits, safety means have to be installed to avoid stumbling across the conduits, possibly insuring the person and damaging the conduits
  - When cable trays are used on roofs, walkable cable trays should be installed, because persons will step on it in spite of any warning signs
- Trenching and digging
  - A survey for all underground utilities has to be done before any digging
  - Additional pilot drillings have to be done to locate the exact location to avoid any damage of any underground line
    - It happened that the electrical underground line to a utility transformer was hit during trenching, leaving an entire block without electricity

13.4. Commissioning & Job Walks

- Job walks by customer/customer's representative and installer should be done at least at the beginning, once during construction, and at the end of the construction
- Comprehensive commissioning reports have to be handed over to the customer
- The ensure the highest probability to catch all possible problems a commissioning can be done by a professional third party

14. Evaluation Sheet

The Solar PV Evaluation Sheet is available below as an editable form. This is also available as a separate, downloadable form at www.gcca.org.

Building/Site Information

Ownership:	Own ☐ | Lease ☐
Occupancy Type:	
Age of Facility:	
Annual kWh Consumption:	
Average Cost per kWh:	
Wall Const.:	Masonry ☐ | Metal ☐ | Wood ☐ | Plastic ☐
Roof Deck Const.:	Steel Beams ☐ | Steel Purlins ☐ | Steel Truss ☐ | Steel Purlins ☐ Wood ☐ | Reinforced Concrete ☐ | Concrete on Steel ☐
Support Density:	Low ☐ | Moderate ☐ | High ☐
Number of Floors:	
Roof Height:	
Surrounding Area:	Urban ☐ | Suburban ☐ | Trees ☐ | Open Field ☐ | Water ☐ | Buildings ☐

☐ Pictures Away from Building (All Four Cardinal Directions)
☐ Pictures of Underside of Roof Deck
☐ Pictures of External Obstructions
☐ Structural Drawings Available

Roof Information

Age:	
Area (square feet):	
Warranty:	
Manufacturer and Model:	
Type:	BUR ☐ | Membrane ☐ Type:______________ | Metal ☐ Type: _____________ Modifed Bitman ☐ | Other ☐ Type: ______________
Securement:	Adhered ☐ | Mechanically Fastened ☐ | Ballasted ☐
Pitch:	Slope: _____________ | Direction: _______________

RTU Density	None ☐ | Low ☐ | Moderate ☐ | High ☐
Roof Dimensions	Length (NS): _____________ | Width (EW): ______________
Parapet	Yes ☐ | No ☐ | Height: _____________

☐ Pictures of Roof (from Each Roof Corner + 3 Pan Shots)
☐ Pictures of Tall Obstructions

Land Information

Available Acres:	
Access to 3 phase:	Yes ☐ | No ☐
Potential tie-in locations	
List obstructions / shading concernts	
General topography	Flat ☐ | Sloped ☐ | Rolling ☐
Rocky?	Yes ☐ | No ☐
Standing water	Yes ☐ | No ☐
Known easements?	Yes ☐ | No ☐ | If yes list in notes section
Local Utility	
Zoning	Agriculture ☐ | Commercial ☐ | Residential ☐ | Other ☐
NIMBY concern	Yes☐ | No ☐
Site Map / Platt available?	Yes ☐ | No ☐

☐ Pictures from north side of property looking south
☐ Pictures of possible tie-in points
☐ Pictures of utility pole number
☐ Pictures of tall obstructions

Electrical Information

Step-down Transformer :	Ground Mounted☐ | Inside ☐ | Pole Mounted ☐
Street Electrical Voltage:	
Number of Meters:	
Electrical Service:	3-Phase ☐ | 1-Phase ☐

Main Electrical Panel Voltage:	480/277 ☐ | 208/120 ☐ | 120/240 ☐
Main Electrical Panel Amperage:	
Emergency Generator?	Yes ☐ | No ☐

- ☐ Pictures of Step-down Transformer
- ☐ Pictures of Meter
- ☐ Pictures of Main Electrical Panel (Nameplate and Breakers)
- ☐ Location of Electrical Rooms and Meters Marked on PV Estimate
- ☐ Location of Probable Inverter Location Marked on PV Estimate
- ☐ One-line Electrical Drawing Available:

Notes

Building/Site Information

Roof Information

Land Information

Electrical Information

15. Acronyms

AC	Alternative Current (standard for all electric systems in buildings)
CdTe	Cadmium, Tellurium (semiconductor material for thin film solar panels)
CEC	California Energy Commission
CSGI	Copper, Indium, Gallium, Selenium (semiconductor material for thin film solar panels)
DC	Direct Current (current generated by sources such as batteries, Solar PV and others)
°C	Degree Celsius
°F	Degree Fahrenheit
FiT	Feed-in Tariff
IRR	Internal Rate of Return
ITC	Investment Tax Credit
kW	Kilo Watt = 1000 W (measurement of the potential of an energy source or consumer)
kW AC	Kilo Watt AC (measurement of the potential of a PV system that is available for usage)
kW DC	Kilo Watt DC (measurement of the potential of the solar panels of a PV system before consideration of wire losses, dust losses, inverter efficiency etc.)
kWh	Kilo Watt Hour (measurement of the electric energy generated or consumed in one hour)
lbs	Pounds
MACRS	Modified Accelerated Cost Recovery System
MW	Mega Watt = 1000 kW
NEC	National Electric Code
NEM	Net Metering
NIPSCO	Northern Indiana Public Service Company
OPALCO	Orcas Power & Light
PEC	Progress Energy Carolinas
PPA	Power Purchase Agreement
PTC	PV USA Standard Test Conditions (measurement method of the potential energy generated by a solar panel)
PV	Photovoltaic
REC	Renewable Energy Certificate
sq.ft.	Square Feet
STC	Standard Test Conditions (measurement method of the potential energy generated by a solar panel)
SREC	Solar REC
W	Watt (measurement of the potential of an energy source or consumer)

16. Glossary

AC (ALTERNATING CURRENT) The direction of electrical current reverses, usually many (60) times per second. Electricity transmission networks use AC because voltage can be controlled with relative ease.

AMPERE (amp) A unit of electrical current or rate of flow of electrons. One volt across one ohm of resistance causes a current flow of one ampere. One ampere is equal to 6.235 x 10^{18} electrons per second passing a given point in a circuit.

AMPERE HOUR (amp hr. or AH), a measure of current over time, used to measure battery capacity.

AMPERE HOUR METER An instrument that monitors current with time. The indication is the product of current (in amperes) and time (in hours).

ANGLE OF INCIDENCE The angle between the direct solar beam and the normal (90 degrees) to the active surface. (degrees)

ARRAY Any number of Photovoltaic panels connected together electrically to provide a single electrical output. An array is a mechanically integrated assembly of modules or panels together with support structure (including foundation and other components, as required) to form a free-standing field installed unit that produces DC power.

BALANCE OF SYSTEMS (BOS) Parts or components of a photovoltaic system typically other than the photovoltaic array and inverters.

BATTERY Two or more electrochemical cells enclosed in a container and electrically interconnected in an appropriate series/parallel arrangement to provide the required operating voltage and current levels. Under common usage, the term battery also applies to a single cell if it constitutes the entire electrochemical storage system.

BATTERY CAPACITY The maximum total electrical charge, expressed in ampere-hours (AH), that a battery can deliver to a load under a specific set of conditions.

BATTERY CELL The simplest operating unit in a storage battery. It consists of one or more positive electrodes or plates, an electrolyte that permits ionic conduction, one or more negative electrodes or plates, separators between plates of opposite polarity, and a container for all the above.

BATTERY AVAILABLE CAPACITY The total maximum charge, expressed in ampere-hours, that can be withdrawn from a cell or battery under a specific set of operating conditions including discharge rate, temperature, initial state of charge, age, and cutoff voltage.

BATTERY ENERGY CAPACITY The total energy available, expressed in watt-hours (kilowatt-hours), which can be withdrawn from a fully-charged cell or battery. The energy capacity of a given cell varies with temperature, rate, age, and cutoff voltage. This term is more common to system designers than it is to the battery industry where capacity usually refers to ampere-hours.

BATTERY CYCLE LIFE The number of cycles, to a specified depth of discharge, that a cell or battery can undergo before failing to meet its specified capacity or efficiency performance criteria.

BATTERY LIFE The period during which a cell or battery is capable of operating above a specified capacity or efficiency performance level. For example, with lead-acid batteries, end-of-life is generally taken as the point in time when a fully charged cell can deliver only 80% of its rated capacity. Beyond this state of aging, deterioration and loss of capacity begins to accelerate rapidly. Life may be measured in cycles and/or years, depending on the type of service for which the cell or battery is intended.

BLOCKING DIODE A semiconductor connected in series with a solar cell or cells and a storage battery to keep the battery from discharging through the cell when there is no output, or low output, from the solar cell. It can be thought of as a one-way valve that allows electrons to flow forwards, but not backwards.

CATHODIC PROTECTION Systems that protect underground metal from corrosion by running small electrical currents along the metal. Most often used to protect well heads, oil, gas, and water pipelines.

CELL (BATTERY) A single unit of an electrochemical device capable of producing direct voltage by converting chemical energy into electrical energy. A battery usually consists of several cells electrically connected together to produce higher voltages. (Sometimes the terms cell and battery are used interchangeably).

CELL (SOLAR) The smallest, basic Photovoltaic device that generates electricity when exposed to light.

CHARGE RATE The current applied to a cell or battery to restore its available capacity. This rate is commonly normalized by a charge control device with respect to the rated capacity of the cell or battery.

CHARGE CONTROLLER A component of photovoltaic system that controls the flow of current to and from the battery to protect the batteries from over-charge and over-discharge. The charge controller may also indicate the system operational status.

CONCENTRATOR A photovoltaic module which includes optical components, such as lenses, to direct and concentrate sunlight onto a solar cell of smaller area. Most concentrator arrays must directly face or track the sun.

DC (DIRECT CURRENT) A one way flow of electric current. Typical sources of direct currents are electric cells, rectified power units and direct current generators. This is the current flow produced by a solar system. To be used for typical 480 Volt switchgears in commercial and industrial facilities, it must be converted to AC (alternating current).

DEMAND The number of kilowatts or megawatts delivered to the load at a given instant.

DEPTH OF DISCHARGE (DOD) The ampere-hours removed from a fully charged cell or battery, expressed as a percentage of rated capacity. For example, the removal of 25 ampere- hours from a fully charged 100 ampere-hours rated cell results in a 25% depth of discharge. Under certain conditions, such as discharge rates lower than that used to rate the cell, depth of discharge can exceed 100%.

DIFFUSE INSOLATION The radiant energy from the sky incident upon unit surface area during a specified time period (Same units as for direct insolation).

DIRECT INSOLATION The radiant energy from the sun (and a small area of sky surrounding it, defined by the acceptance angle of the pyrheliometer) incident upon unit surface area during a specified time period. (W/m^2 per hour, day, week, month or year, as the case may be).

EFFICIENCY The ratio of power output of a Photovoltaic cell to the incident power from the sun or simulated sun sources under specified standard insolation conditions.

ELECTROLYTE The fluid used in batteries as the transport medium for positively and negatively charged ions.

ELECTRIC CURRENT The rate at which electricity flows through an electrical conductor, usually measured in amperes (amps).

ELECTRICITY Energy resulting from the flow of charge particles, such as electrons or ions.

ELECTRONS A negatively charged particle. The movement of electrons in an electrical conductor constitutes an electric current.

EQUALIZATION The process of restoring all cells in a battery to an equal state-of-charge. For lead-acid batteries, this is a charging process designed to bring all cells to 100% state-of-charge. Some battery types may require a complete discharge as a part of the equalization process.

EQUALIZING CHARGE A continuation of normal battery charging, at a voltage level slightly higher than the normal end-of-charge voltage, in order to provide cell equalization within a battery.

FLOAT SERVICE A battery operation in which the battery is normally connected to an external current source; for instance, a battery charger which supplies the battery load under normal conditions, while also providing enough energy input to the battery to make up for its internal quiescent losses, thus keeping the battery always up to full power and ready for service.

FREQUENCY Much like radio signals, electric generators can be "tuned" to produce power that vibrates at different frequencies. In the United States, virtually all electricity is generated and transmitted at 60-hertz or 60 cycles per second (cps). If the frequency fluctuates, it can damage all manner of electrical equipment. Frequency can be affected by a variety of factors and must be monitored closely by the ISO to make sure it remains very close to the 60 cps target.

FULL SUN The full sun condition is the amount of power density received at the surface of the earth at noon on a clear day - about 1000 W/m^2. Lower levels of sunlight are often expressed as 0.5 sun or 0.1 sun. A figure of 0.5 sun means that the power density of the sunlight is one-half of that of a full sun.

GASSING The evolution of gas from one or more of the electrodes in the cells of a battery. Gassing commonly results from local action self-discharge) or from the electrolysis of water in the electrolyte during charging.

GRID Transmission line network used to distribute electric power.

GRID LINES Metallic contacts fused to the surface of the solar cell to provide a low resistance path for electrons to flow out to the cell interconnect wires.

HERMETIC SEAL Being impervious to external influences. Typically associated with the sealing of a package so that oxygen, moisture, and other outside environments cannot enter the package.

HYBRID SYSTEM A power system consisting of two or more power generating subsystems (e.g., the combination of a wind turbine or diesel generator and a photovoltaic system.

INCIDENT LIGHT The incident light is the amount of light reaching an object.

INSOLATION (also called Irradiation and Solar Radiation) The amount of sunlight reaching an area. Usually expressed in Watts per square meter.

INVERTER A device that converts electricity from DC to AC.

IRRADIATION (also called Insolation and Solar Radiation) The amount of sunlight reaching an area. Usually expressed in Watts per square meter.

KILOWATT-HOUR Unit of energy used to perform work (energy and work are equivalent in units, energy being the potential value and work the achieved value)

Fuel equivalents:

One barrel of crude contains roughly 1700 kWh

One ton of coal contains roughly 7500 kWh

One gallon of gasoline contains roughly 37 kWh

One cubic foot of natural gas contains 0.3 kWh

One ton of uranium ore contains 164 million kWh 1.34 horsepower-hours.

Thermal unit:

One kWh = 3400 BTU. Can be compared to 860 calories (food value)

LOAD Refers to equipment that is powered by electricity. Usually expressed in terms of amperes or watts. In an electrical circuit, any devise or appliance that uses power (such as a light bulb or water pump).

MAXIMUM POWER The power at the point on the current-voltage characteristic where the product of current and voltage is a maximum (measured in watts).

MODULE also called PANEL: The smallest non divisible, self-contained and environmentally protected physical structure housing interconnected Photovoltaic cells and providing a single DC electrical output.

OPEN CIRCUIT VOLTAGE (V_{OC}) Voltage produced by a Photovoltaic cell with no load applied when the cell is exposed to standard insolation conditions, measured with a voltmeter.

PANEL also called MODULE: The smallest non divisible, self-contained and environmentally protected physical structure housing interconnected Photovoltaic cells and providing a single DC electrical output..

PARALLEL CONNECTION A wiring configuration used to increase current (amperage). Parallel wiring is positive to positive (+ to +) and negative to negative (- to -). Opposite of a series connection.

PEAK POWER POINT Operating point of the I-V (current-voltage) curve for a Photovoltaic cell, panel or array where the product of the current value times the voltage value is a maximum.

PEAK WATTS The measurement of electricity produced by a solar generator at noon on a sunny day, under predetermined standard conditions.

PHOTON The actual (physical) particle unit of light, as the electron is of electric charge and the atom and molecule are of matter. Light has both wave properties and particle properties. Violet light has relatively short wavelength and higher energy in its photons; red light has longer wavelength, lower-energy photons. The wavelength and/or energy spectrum of the sun extends in both directions beyond the visible range of light, of course, and the silicon module solar cell can capture some energy in both of these invisible zones. Photons not captured by the cell are either reflected or converted to heat in the solar array.

PHOTOVOLTAIC CELL A device composed of specially prepared semiconductor material or material combinations exhibiting the ability to convert incident solar energy directly into electrical energy.

PHOTOVOLTAIC EFFECT The phenomenon that occurs when photons, the "particles" in a beam of light, knock electrons loose from the atoms they strike. When this property of light is combined with the properties of semiconductors, electrons flow in one direction across a junction, setting up a voltage. With the addition of circuitry, current will flow and electric power will be available.

PHOTOVOLTAIC SYSTEM An installed aggregate of solar arrays generating power for a given application.

POWER CONDITIONER The electrical equipment used to convert power from a photovoltaic array into a form suitable for subsequent use. Loosely, a collective term for inverter, transformer, voltage regulator and other power controls.

POWER FACTOR The ratio of real power (watts) to apparent power (volt-amps) in an AC circuit. Displacement power factor is the ratio of fundamental watts to fundamental RMS volts times

RMS amps, excluding the effects of all harmonic exponents; it could be called fundamental power factor.

REGULATOR Prevents overcharging of batteries by controlling charge cycle-usually adjustable to conform to specific battery needs.

RENEWABLE ENERGY Flows of energy that are regenerative or virtually inexhaustible. Most commonly includes solar (electric and thermal), biomass, geothermal, wind, tidal, wave, and hydro power sources.

SEMICONDUCTOR A material such as silicon, which has a crystalline structure that will allow current to flow under certain conditions. Semiconductors are usually less conductive than metals but not an insulator like rubber.

SERIES CONNECTION A wiring configuration used to increase voltage. Series wiring is positive to negative (+ to -) or negative to positive (- to +). Opposite of parallel connection.

SILICON A non-metallic element, that when specially treated, is sensitive to light and capable of transforming light into electricity. Silicon is the basic material of most beach sand, and is the raw material used to manufacture most photovoltaic cells.

SINGLE-CRYSTAL STRUCTURE also called MONO CRYSTALLINE: A material having a crystalline structure such that a repeatable or periodic molecular pattern exists in all three dimensions.

SOLAR CELL The basic photovoltaic device which generates electricity when exposed to sunlight.

SOLAR RADIATION (also called Insolation and Irradiation) The amount of sunlight reaching an area. Usually expressed in Watts per square meter.

STAND-ALONE SYSTEM A system which operates independently of the utility lines. It may draw supplementary power from the utility but is not capable of providing power to the utility.

STORAGE BATTERY A device capable of transforming energy from electric to chemical form and vice versa. The reactions are almost completely reversible. During discharge, chemical energy is converted to electric energy and is consumed in an external circuit or apparatus.

STRING A collection of typically 6 to 16 panels serially electrically connected panels.

SULFATION The formation of lead-sulfate crystals on the plates of a lead-acid battery. Commonly used to indicate the large crystals which form in partially discharged cells as the result of temperature cycling. These large crystals are more difficult to reduce by the charging current than are the smaller crystals that result from normal and self-discharge reactions. Sulfating can be caused by leaving the battery in a discharged state for long periods of time.

SWITCHGEAR The electric equipment that distributes electric power. The typical source is the grid of a utility; the typical loads are the appliances within the facility.

TELEMETRY DEVICE Devices used to transmit or receive data in a digital form.

TILT ANGLE A fixed angle measured from the horizontal to which a solar array is tilted. The tilt angle is chosen to maximize the array output. Depending upon latitude, season and time of day this angle will vary.

TRACKING ARRAY An array that is mounted on a movable structure that attempts to follow the path of the sun. Some tracking arrays are single axis while others are dual.

VOLTAGE A measure of the force or "push" given the electrons in an electrical circuit; a measure of electrical potential. One volt produces one amp of current when acting against a resistance of one ohm.

WATT Unit of power. Power is the rate of using energy to do work.

17. Figures