

The Montana Consumer Guide to Grid-Interactive Solar Photovoltaic Systems



- ⚙ Capturing Solar Energy
- ⚙ Converting and Directing Power
- ⚙ Utilizing Produced Electricity
- ⚙ Making a Good PV Choice
- ⚙ Consumer Resources

The Montana Consumer Guide to Grid-Interactive Solar Photovoltaic Systems

Incorporating On-site PV Electricity Generation for Residential and Small-Business Consumers

Thank you for your interest in solar photovoltaic (PV) technology, and for taking the time to read this publication. It has been developed as a basic resource and practical guide for consumers who are considering a solar PV system.

The publication is focused on grid-interactive solar PV systems and has three primary sections with information essential to the understanding of solar technology. They are; capturing the sunlight, directing and transferring the produced PV electricity, and utilizing the electricity within a grid-interactive framework. It is not intended to be a technical manual, but instead is a representation of the factors, options, and decision steps important to the purchase and installation of a safe and productive PV system.

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The History and Science of Solar Photovoltaic Power

What is Photovoltaic Power?

In 1839, French physicist Edmund Becquerel found that when certain materials were exposed to sunlight, a small amount of electric current was produced. Albert Einstein described the nature and “science” of this interaction, and was awarded the Nobel Prize for Physics for his research on the “photoelectric” effect, which modern photovoltaic technology is based on.

The first photovoltaic (PV) module was developed by Bell Laboratories, and PV applications were advanced by NASA in the 1960’s space programs. Through those programs, solar PV performance improved and became available for non-space applications in the 1970s.

Costs were prohibitive for many people, but due to incentives, market transformation, competition, and production improvements, the price for PV systems declined significantly. Prices today for PV modules are approximately one-half of what they were five years ago.

How Does Photovoltaic Power Work?

As described by Einstein, the light from the sun contains energy. When sunlight contacts the PV cell, integrated materials within the cell (typically silicon) enable the light energy to produce an electrical field near the top surface of the cell. This electrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of current when the cell is connected to an electrical load.

Building Blocks (Cell, Module, Array)

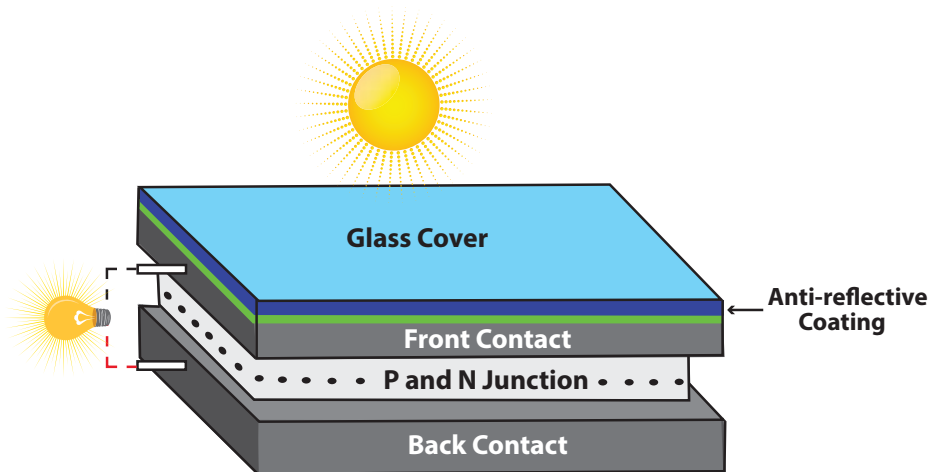
Each solar PV cell typically produces between one-two watts of power. Cells are connected together and form what is called a module or panel. Modules are then wired together to form the solar array.

The PV cells within modules are covered with a protective coating for safety and durability purposes. The electricity they produce is direct current (DC), which is usually converted to usable alternating current (AC), except when intended for DC designed appliances or battery storage.

The modules typically used for structural applications are rectangular and most often have dimensions of 3’3” x 5’5” and weigh in the 35-50 pound range. Depending on the manufacturer and specific cell composition and design, output is usually in the 150 – 400 watt range (per module).

The solar array is the complete group of modules present on the roof of a structure or on a ground mounted pole. Depending on the number and type of modules, the array will have a specific system power capacity, usually listed in watts. This rating is also called the “peak output” rating.

For consumers, the system capacity rating is important. This number provides the potential power output of the system when operating at full capacity, which in the case of photovoltaic production, is when the sun is providing the maximum amount of light energy. It does not mean that when the sun is obscured or not directly striking the panels, the output of the system will remain at rated capacity.



Solar Cell - Basic Function

P and N Semi-conductor

The Three Objectives of a PV System (Capture, Direct and Utilize Produced Power)

The three primary objectives of the grid-interactive PV system are to capture, direct, and utilize PV produced electricity in an efficient and safe manner. For the consumer, there are a number of variables and options within a PV system, beginning with the type of solar cell used, to variations in system components, to DC/AC conversion designs and mechanisms. All of these are integral to one or more of the “three objectives”.

This publication focuses on the three objectives, and specifically addresses the key components, variables and options that impact each objective. In this framework, solar PV system design and installation are easier to understand.

Capturing the Sunlight

Cells, Modules, Arrays, Mounting and Racks

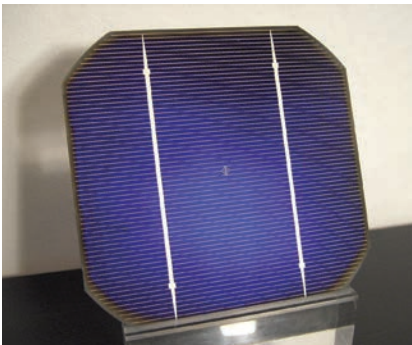
Crystalline Silicon Solar Cells

Between 90-95% of all residential and small scale commercial PV systems use a variation of silicon as the core of the solar cell. Crystalline silicon modules are available with either mono (single) or poly (multi) manufactured cells.

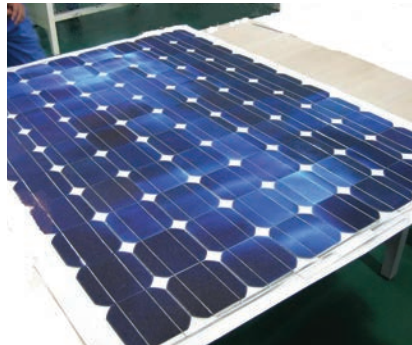
Monocrystalline cells have the highest efficiency rates (15-20%), and they are the most space efficient per produced watt. Research has also shown that they perform somewhat better in low-light conditions compared to polycrystalline cells, and often have a longer warranty period. The primary disadvantage to them is a higher cost per module.

Polycrystalline cells are rated at between 13-18% efficient, which translates into marginally higher space requirements compared to a monocrystalline module of the same rated capacity. However, they usually cost less, and many consumers favor the aesthetic appearance of them. Individual modules are more uniform in appearance when compared to monocrystalline silicon modules.

Solar dealers and contractors typically have both types of crystalline modules available. Depending on the specific installation, one of the types may be recommended by a contractor. Consumers should also recognize that there are other manufacturing variables relative to efficiency other than cell type. From a practical perspective, the most important efficiency consideration is the manufacturer rating of the panel. High quality, reputable, UL® listed panels will include the efficiency rating specific to the module.



Cell



Module



Array

Thin Film Solar Cells

Thin film solar cells are manufactured by depositing a fine layer of PV material onto a substrate of glass, plastic or composite material. Currently, thin film sales in America are between 5-7% of the residential and small-scale commercial market.

The three most common types of thin film solar cells are identified by their semi-conductive layer composition. They are; amorphous silicon, cadmium telluride, and copper indium gallium selenide.

Efficiency ratings of thin film photovoltaic cells are usually between 6-13%, with a common rating of between 8-9% for products available to consumers. This is also the efficiency rating of “solar shingles”, which are beginning to gain a market share in many areas of the country.

Because of the lower efficiency ratings, thin film arrays need more space per watt of output when compared to crystalline systems. They also usually require more wiring/electrical components and have higher labor installation costs per watt.

On the positive side, thin film modules are often flexible and can be used in specialty applications. Depending on the specific thin film type, they also can be relatively inexpensive.

Array Mounting

It is not safe to either mount solar modules directly to a structure without proper racking, or worse, to lean them on the side of a building or on the ground. Proper mounting components and techniques are necessary for both production, the integrity of the building, and safety.

Module racks are engineered and designed to be compatible with both the structure or pole they are fastened to, and the modules that are attached to them. They not only serve as the structural “backbone” of the array, but also are critical to the electrical safety of the system.

This section of the publication will address the three options for mounting (roof, ground, pole), and then overview array racks and variables.



Roof Mounts

Roof mounts are convenient because the “support” for the array is already in place, it can easily be tied into the existing electrical system, and the array can be mounted above most objects that cast shadows.

Modules are not mounted directly to the roof, rather the array sub-structure or racking is first installed, and the modules are attached to the racking. This is both a National Electrical Code (NEC) requirement and necessary to allow air movement for production.

In most cases, the solar contractor mounts the racking and modules with a minor offset, but at a comparable angle with the roof. There are engineered systems that change the angle and/or orientation of the modules compared to the roof. These are reliable and can boost performance, but add extra cost.

When considering a roof mount, there are some basic factors that the consumer should deliberate. They are:

- 1. The condition of the roof. The module lifespan will likely exceed that of most roof coverings. How will this impact “re-roofing” in the future? If the roof covering is in need of repair or replacement, should this be completed before the installation?**
- 2. The composition of the roof covering. As a general rule, wood shake or tile roofs are harder to mount racking on and seal. A good practice is to consult with a roofing contractor.**
- 3. What is the tilt angle and orientation of the roof? In addition, is there available space for the requisite system size?**
- 4. Are there existing obstructions impacting the roof that will result in shading? This includes vent pipes, chimneys, adjacent trees and structures, and wires. Can obstructions be moved or, in the case of trees, be trimmed?**
- 5. Can the structure adequately support the load increases of the array? This is an issue that is addressed in the building permit process.**
- 6. Can the array be installed and maintained safely? Is there adequate access to and around the proposed array? Does the system allow for access around the modules in the event of an emergency?**
- 7. Are there zoning or subdivision requirements that could affect a rooftop installation? This also includes consideration of neighboring properties, including trees that could impact the array production as they grow. Some jurisdictions have “solar access” statutes that address this.**

Ground Mounts

Ground mounts are different than traditional pole mounts in that they utilize multiple footings and supports, and are usually comprised of a row or rows of single height modules. They are popular in rural areas and agricultural applications where there is minimal shade and open spaces.

One of the primary advantages of ground mount systems is that they can be designed and sited for optimal tilt and orientation. In addition, there is adequate airflow and easily accessible components for installation and maintenance.

In urban areas, the issue of public accessibility and safety, as well as vandalism, can be a concern. Other considerations for the consumer are the need to trim vegetation, drifting snow on the modules, and “inter-row” shading if more than one row of modules is installed.

The National Electrical Code has provisions for addressing the majority of safety concerns. The solar contractor should be proficient in assuring the Code requirements including “readily accessible” electrical wiring and components are adhered to. This not only protects humans, but also pets and livestock.



Single Pole Mounts

A single pole system usually includes a large diameter (6”-8”) steel pole, designed and engineered to be mounted at a considerable depth in the ground, with concrete footings.

In a single pole system, the entire array is fastened to the pole at the desired tilt angle and orientation. A single pole can be quite tall, especially when including required ground and safety clearance as determined in the NEC.

Single pole systems take up less square footage than ground mounts. As a result, they are used in both urban and rural applications. Some designs also include a tilt adjustment mechanism that allows for seasonal modifications based on the sun’s altitude.

The cost of the pole, excavation and footings add to the overall cost of the system. Usually, a crane or lift is required to place the pole. Maintenance for single pole systems can also be an issue – in some cases, a mechanical lift needs to be utilized due to the height of the array.

Like ground mounts, the ability to achieve optimum tilt and orientation, coupled with the ability to avoid shading, can optimize production. System design and configuration can also include arrays that homeowners find aesthetically pleasing.

When considering a ground or pole mount, there are some basic factors that the consumer should deliberate. They are:

- 1. What is the likelihood of vandalism or accessibility by children, pets and livestock?**
- 2. What is the additional cost of the ground or pole mount footings, materials, and labor? How will the solar contractor assure cost-effective maintenance?**
- 3. Will the ground or pole mount be installed in a location where there might be “other plans” for the future, such as outbuildings or roads?**
- 4. Is it feasible and possible to connect the array electricity to the structure where the target electrical system is located?**
- 5. Are there zoning or subdivision requirements that might impact the installation? Of primary concern are restrictions relative to “edge of property” issues.**
- 6. Can trimming of vegetation and environmental considerations such as snow drift and/or flooding be addressed?**

Mounting Racks

Just as there are numerous options for solar modules, the racking, which attaches to the roof or pole and to which the modules are fastened, is available in a variety of designs, materials, and mounting options.

The primary factors a consumer should consider (and discuss) with the solar contractor are: the rack’s compatibility to the modules, applicability to the specific roof or pole type, the material design, engineering and weight, compliance to the NEC, aesthetics, and warranties.

Structural Attachments

The racking is fixed to the roof or pole. The attachment method and hardware varies based on the roof covering and/or substructure type. One of the most frequent failure points in an installation are roof leaks due to improper penetrations. Building inspectors in Montana are diligent regarding structural loading requirements for solar PV systems. In most cases, issues with roof mounting can be worked through, however, consumers shouldn't expect a rubber stamp on structural permitting of systems.

Fixed Versus Adjustable Racks

Fixed racks are permanently mounted to a structure or pole framework and are intended to be stable and stationary. Most contractors typically use what is called a "top-down" rail system. This contains four primary components:

1. Feet or what are termed "stand offs" that are mounted directly to the roof's substructure (typically, the rafter system).
2. Aluminum rails that are fastened to the "stand offs".
3. End clips which secure the modules to the racking.
4. Junction or mid-clips that manually join two modules to the mounting rail.

Top-down systems come in a variety of designs and are mounted at the same pitch as the roof, usually with a small gap between the racking/module and the roof's surface. The majority of problems with top-down systems are due to the limited air flow underneath the modules, and the fact that access to the back of the modules is difficult. The access and maintenance issues are usually solved by including "quick connect" electrical connections.

When solar modules were more costly, contractors and consumers commonly employed components such as manually adjustable racks to increase the production and ROI of arrays. Today, manually adjustable racks are used less often – instead, more modules are added to a fixed rack system.

Manufactured, adjustable racks are still available, and they do allow the array to capture more power, as well as providing for module maintenance access and increased airflow. They also can be used for awning type installations.

Adjustable racking can be harder to install – with smaller tolerances for rafter spacing and less layout flexibility. Seasonal adjustments also require contractor labor costs, which can reduce the extra production benefits resulting from the adjusted array.



Tracking Systems

Solar array tracking systems, similar to manually adjustable racking, were popular when solar modules were high priced. These trackers, designed for pole and ground mounts, either through passive or electrically powered technology, allowed the array to "track the sun". Solar contractors advertised between a 15-40% increase in production over fixed tilt systems.

Since that time, the popularity of tracking systems for residential and small-scale applications has dropped. Solar contractors usually recommend installing larger systems, which they advocate as both a cost and maintenance savings.

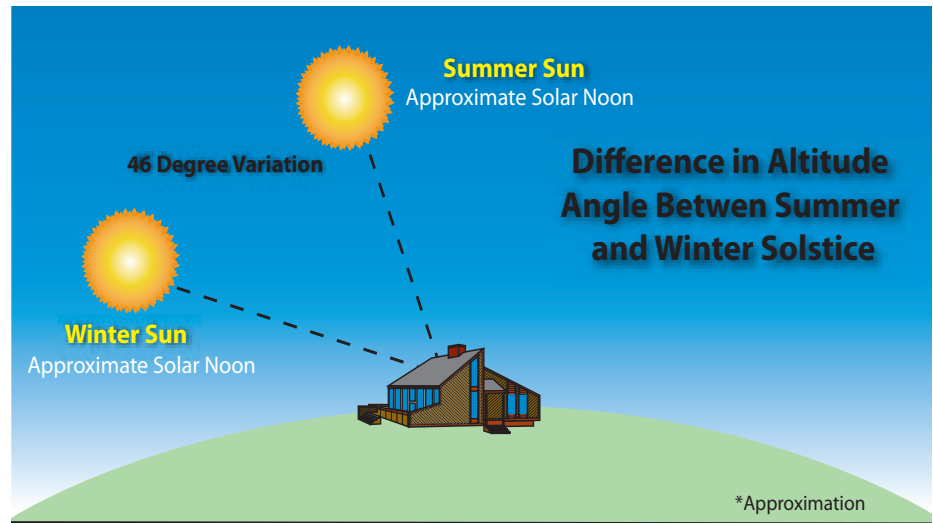
Passive trackers rely on chemicals, but consumers often had problems with adjustments and performance. Active trackers use motors, gears and/or hydraulics, which need both preventative and restorative maintenance. Increased complexity often introduces additional possibilities for failure, which can be a concern for consumers.

Residential single and dual-axis trackers have been improved and are still available. In specific applications they are still used, most notably in off-grid systems. Also, some consumers enjoy watching the array track the sun. Caution should be used to work with a solar contractor who is familiar with and can service the trackers.

Capturing the Available Power - "Siting" the PV System

For the consumer, determining where to mount a PV array is just as important as the system array and components. Without adequate sunlight, even the most efficient and expensive array will under perform.

The first goal of the system design relative to mounting (commonly called siting) is to have an array that is mounted to capture the greatest amount of light energy throughout the day. When the sun's rays are perpendicular to the array, the most power is produced – which is contingent on the position of the sun. Obstructions excluded, the two factors that impact the percentage of sunlight that hits the front surface of the array are orientation and angle (tilt)



Orientation and angle of the PV array are factors directly related to the sun's position in the sky, and rely on what are called the azimuth and altitude of the sun.

Azimuth is the sun's location on a horizontal plane, east to west, as it moves throughout the day. Altitude is the height of the sun in the sky. This varies throughout the day, and as important, is seasonal. This accounts for the longest day of the year on June 21st (summer solstice) and the shortest day on December 21st (winter solstice).

Orientation (in practical terms, the direction the array is pointed) corresponds to the azimuth. The optimum direction is "solar south", which has an azimuth of zero degrees, but this is not always possible. The good news is that an array that is mounted within 30 degrees of solar south will still produce at about 90% of an array mounted directly at solar south. On some installations, modules are purposely sited on southeast and southwest surfaces to either stand alone or complement a south facing array.

The tilt or angle of the array is predicated on a location's specific latitude. Montana's average latitude is 47 degrees North, which roughly splits the State in half. The northern border is at 49 degrees North, and the majority of the State's southern border is at 45 degrees North.

In theory, the desired angle or tilt of the array for year round production would be to match the latitude at the installation site. A steeper angle would favor winter production (because the sun is lower on the horizon), and a flatter angle would better advantage summer production.

In the case of roof mounting, most residential roofs have between a 4/12 and 8/12 pitch, which translates to a tilt angle of between 18 and 35 degrees. If mounted flush to the roof with a 4/12 pitch, a typical array will produce between 8-10% less compared to a similar system mounted at 47 degrees N. (the average for Montana). As discussed earlier, when modules were costly, adjustable racking (roof) or trackers (ground or pole mounts) were employed, but now the common practice is to add additional modules.

On a final note relative to the sun's azimuth and altitude, the term "solar window" is important. This term defines the optimum hours for production of a southerly facing array. Adjusted for all season, the hours from 9:00 am. - 3:00 pm. represent the average "ideal" year round time period for solar production.

Contractor Solar Site Assessment

Many residential sites are impacted by shading, and evaluation by sight alone requires observation over a year long period. Fortunately, reputable solar contractors can provide the consumer an accurate site analysis using specific equipment and software designed for PV installations.

Two of the most common site analysis devices are the Solar Pathfinder® and Solmetric Suneye®. Both of these devices are capable of determining the impacts of shading, as well as production improvements if obstacles are removed or minimized. They also provide monthly averages and other important information.

It is highly recommended that consumers request a site assessment that is more than a “walk through” or general production estimate. Solar PV systems are a substantial investment, and a realistic production estimate is important to the purchase and installation processes.



Solar Pathfinder

Converting and Directing PV Produced Power Inverters, Wiring, Batteries

Balance of System (BOS) Components

Photovoltaic cells produce direct current (DC). With a grid-interactive system, at some point between the module and structure’s electrical service, the conversion to alternating current (AC) must occur. An electronic device called an inverter accomplishes this. There can also be other electrical interactions within the system, for example, some of the DC produced electricity can be directed to battery storage (when applicable).

The industry term for the wiring and electrical components that support the PV array is called the “balance of system”. Depending on the specific design, the balance of system (BOS) components can include wiring, connectors, combiner boxes, disconnects, and most importantly, the inverter(s).

An understanding of inverter types, functions and applicability to specific siting applications is important for the consumer to understand. In the complete PV system, inverters are second only to modules in cost, and improper selection and installation of an inverter can have production and safety impacts.



What are Inverters?

America’s electrical power infrastructure is based on AC power. This includes not only the utility grid, but also the majority of appliances, lights and other loads used by consumers. Due to the fact that solar cells produce DC power, conversion from DC to AC, which is called “inversion” in electrical terms, is required for grid-interactive systems.

In a grid-interactive system, the essential (and sometimes only) required piece of electronics in the PV system is the inverter. Inverters are sized to meet or exceed the peak output of the array in string or central inverter systems, or the peak output of one or two individual modules in a micro-inverter design.

For use in a grid-interactive system, the inverter must be designed and specified for grid-interactive use. This is because it also serves other purposes, including integration of the utility grid and PV produced electricity. Utilities require consumers to use UL® listed, IEEE compliant inverters designed for PV applications. This is meant to ensure the reliability of the electrical grid and safety of utility workers.

There are two designs of inverters utilized in the PV industry. Both are applicable to residential and small commercial applications. They are string and micro-inverters.

String Inverters

In small-scale applications, the most common inverter type used is a string or central inverter. The modules are wired together in a series configuration, and the DC power produced by the modules is channeled into the inverter at a single point. In a series wiring design, voltages are additive, which results in up to 600 Vdc input voltage to the inverter in residential installations. After conversion, the output to the structure or grid is usually 120/240 Vac.

The primary benefit of string inverter systems is the cost and presence of a single component to maintain and service. There are a variety of inverter sizes to optimize the power rating between the array and inverter. The percentage of systems that use string inverters in Montana is approximately 80%.

In a string inverter configuration, the primary disadvantage is that overall system performance is impacted significantly by the poorest performing module. Several factors can contribute to decreased system performance, including a manufacturing defect in a single module, or partial shading from nearby structures, trees, or snow across portions of the array.

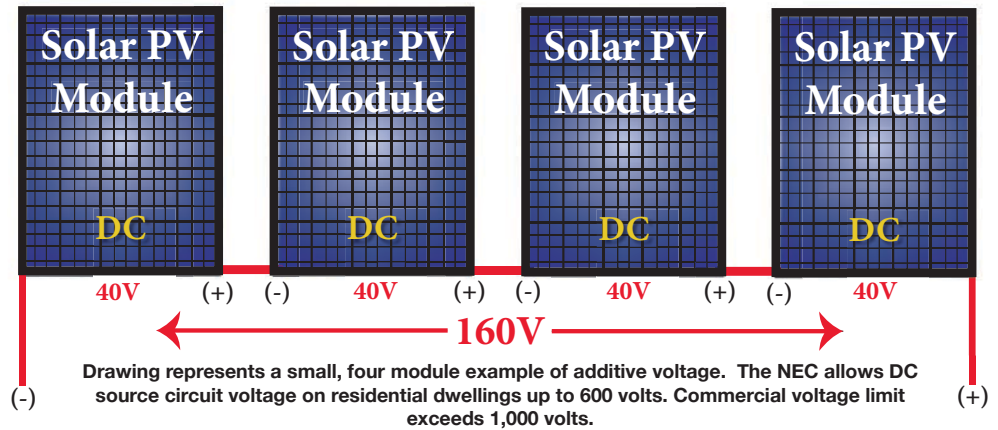
Micro-inverters

Micro-inverters are different than string inverters for two primary reasons. The first is that they perform the DC-AC conversion at or “attached” to the module, and the second is that they are parallel wired. The voltage remains constant, but the amperage (current) is increased with the connection of each module in the array. AC current is carried from the array to the PV electrical components and utility point of connection.

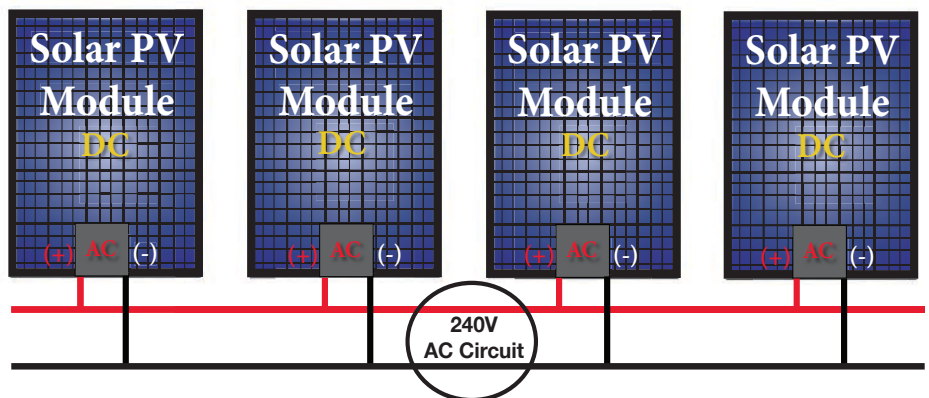
The primary benefit of micro-inverter systems is that the lack of performance in a single module (due to module failure or shading) does not impact the performance of the array to the same degree that occurs in a string inverter system. Micro-inverter manufacturers suggest that their systems can increase annual electricity production between 10-30%.

Micro-inverter systems are also popular with some home and business owners because they can be added onto without the need to buy additional, expensive equipment. The primary disadvantage with them is higher initial cost, and in some poorly designed roof systems, access for repairs and maintenance.

PV String Inverter System (Grid Interactive) Additive Voltage (Series Wiring)



PV Micro-inverter System (Grid Interactive) Additive Amperage - (Parallel Wiring)



AC Modules

The newest module on the market is what is termed an AC module. In an AC module, an integrated micro-inverter is “pre-installed”. This prevents the installer from having to perform two separate mechanical and electrical tasks in installing and wiring both the module and micro-inverter.

AC modules are advertised as the proverbial “plug and play” device, but a licensed electrician is still required for portions of the installation, including wiring the AC branch circuit and connections to the consumer’s existing electric system.

String Inverters (Positive Comparisons to Micro-Inverters and AC Modules)

1. String inverters are less costly (usually between 5-25% based on total component cost).
2. String inverters have more of a track record and common failure points in design have been fixed.
3. Because a string inverter is mounted at ground level (usually next to the main electrical supply), troubleshooting and maintenance is usually easier and more accessible.
4. String inverter systems typically have lower voltage loss due to the wire and component sizing. This is more critical with larger systems.
5. There are a variety of designs and features available to consumers, including system monitoring and feedback.

Micro-inverters (Positive Comparisons to String Inverters)

1. Failure of one micro-inverter only impacts production of the module it services. A string inverter failure impacts the entire system. Likewise, shading of or damage to a single module in a micro-inverter system had minimal overall impact when compared to shading or damage of a single module in a string system.
2. For non-conventional applications or situations where modules are placed on surfaces with different orientations, micro-inverters are more productive and can be orientated individually, rather than collectively.
3. Micro-inverter systems can be added to without the cost of purchasing a larger sized, costly inverter.
4. Individual power point tracking assures the optimum performance of each panel. With a string inverter, this is a more difficult task and, if done at the module level, can add significant costs.
5. Micro-inverters shut the system down at module level in the event of an emergency or utility disruption. String inverters need additional electrical safeguards to offer the same level of safety.

A Note on Wiring

Depending on whether the consumer decides on a string (central) inverter system, the wiring method of the array will be different. This is important for safety purposes, as it illustrates the high voltages with PV systems, including smaller residential installations.

Grid-interactive arrays utilizing string inverters are wired in a series configuration. In this scheme, the positive wire from one module is wired to the negative lead of the next, until they are combined to feed to the inverter. This results in voltages up to the NEC limit of 600 Vdc (at the inverter) for residential installations. For commercial applications, the NEC allows up to 1,000 Vdc.

Grid interactive systems using either micro-inverters or AC modules are wired in parallel. In this design, the positive wire from each module is wired to the positive lead of the next module. Amperage is increased with the connection of each module, but voltage remains constant at 220 Vac (which is the voltage level realized after the DC-AC conversion at each module).

Batteries and Generators for Grid-Interactive Systems

A small percentage of consumers have included battery or generator backup for their PV systems, even if they are grid-interactive. These systems are usually intended to service critical devices in the event of a grid power outage. The PV system might not be able to produce enough electricity or the outage can occur at night or during a storm, therefore storage batteries are used. The technical name for this type of system is an uninterruptible power supply (UPS).

The cost and complexity of designing and installing the UPS depends on the loads to be serviced and other factors. In most cases, it will add considerable costs, and will require compliant battery storage and safety devices.



Utilizing the Produced Electricity

Net Metering, Energy Efficiency

The final factor in successfully incorporating a grid-interactive PV system is the coordination and efficient use of the PV produced electricity. For the consumer, this includes understanding the process of utility net metering, and the employment of energy efficiency measures.

Net Metering

In a net metered PV system, the electrical production from the array will either be utilized to service the home or transferred to the utility grid through a process called net metering.

Net metering allows the homeowner to receive the benefits of generating electricity without the expense of installing expensive battery systems for storage; when not utilizing the power from the PV system, it is “fed” to the grid, and the consumer is credited for it. Conversely, when the consumer requires utility power, it is provided, and the consumer is charged for it. This is accomplished by the installation of a certified net meter by the utility, which in effect has controls that change direction as the result of either production or consumption.



At the end of the monthly billing cycle, if the consumer has generated more power than what was used, they are credited for the difference at the wholesale utility rate per kWh. If the consumer used more than they produced, the difference is paid to the utility.

The accounting cycle for many utilities extends for a twelve-month period and then starts over. If the consumer has excess credit at the end of the cycle, it is transferred to the utility without compensation and a new cycle begins. Consumers can often designate the beginning date of their cycle, choosing among January, April, July or October 1st. This allows the consumer to choose a cycle date based on seasonal usage and the estimated production patterns of their specific system. Check with the local utility to determine the details of their specific agreement.

Prior to installing the PV system (or attempting to connect an existing system), the homeowner must contact the applicable utility and begin the process of integrating the system to the utility grid.

Utilities also require consumers to sign and adhere to a net metering agreement. The net metering agreement has specific technical and safety requirements to ensure utility and public safety, as well as the integrity of the electrical grid.

Energy Efficiency

The complements to installing and producing PV electricity are energy efficiency and conservation. Consumers who combine efficiency and conservation with renewable production typically have a greater satisfaction with their PV system performance and complete energy “footprint”.

Both energy conservation and efficiency are directed towards minimizing the amount of loss (and waste) from the point of electricity generation to the end use application. Although the two terms are interchanged, there is a difference.

Energy efficiency is the ability to provide the same level of energy service using less energy. For example, if a light bulb had an output of 10 watts, 100% efficiency would mean that 10 watts of supplied electricity would power the bulb at its rated wattage. However, in using the example of an incandescent bulb, it would take 100 watts of power input to provide 10 watts of output (light), and the bulb would be considered 10% efficient. Both a compact fluorescent and LED bulb would provide the same level of light at a more efficient rate.

Energy conservation is focused on reducing the use or instances of use for energy services. Conservation is most often achieved through behavior changes or choices. The term, “energy conservation” was popular in the late 1970’s and early 80’s, and is often identified with turning down thermostats or shutting off lights. Energy conservation is still a valid control mechanism today – what has changed is the ability to mesh efficiency and conservation through the used of improved technologies.

From a “real world” economic standpoint, end use conservation and efficiency are considered to be of very high value. Professionals estimate that one dollar spent on conservation and efficiency has the same value as three to five dollars spent on production.

There are a variety of efficiency and conservation programs and services for Montana residential and business consumers. These can be found at the Database of State Incentives for Renewables and Efficiency (DSIRE), which also has a list of government incentives and tax credits. It can be accessed at dsireusa.org.

Making A Good Choice

Analysis Steps and Formulas

The preceding pages have highlighted the technical components, site considerations, and available options for PV systems relative to the capture, transfer and conversion, and use of PV produced power. Ultimately, the consumer must make a decision relative to the type, size and features of the PV system.

Following is a general guide to help in that process.

The decision making process has been broken down into three steps. These are: 1) determining the amount of electricity use and percentage the consumer wants to offset with PV production 2) analyzing the space requirements for the desired PV system, as well as other siting factors 3) determining the cost of and available funding for the system.

Step One - Determining Electricity Use and Desired Offset

- 1. Part One - Determine electricity use.** The average Montana consumer uses approximately 9,000 kWh of electricity per year. It is suggested that consumers review their specific electricity use for a one-two year period. This will provide the gross consumption number in kWh.
- 2. Part Two – Evaluate potential efficiency measures.** Inventory lights and appliances to determine where efficiency measures can be put in place (i.e. changing to efficient lighting), as well as conservation measures such as a family “lights on/off policy”.
- 3. Part Three – Choose the desired system size “on paper”.** Based on the numbers from parts one and two, estimate the average yearly amount of electricity the PV system will be designed to offset. In most cases, this is between 25-75% of the annual electrical use.

Example

Customer A uses 11,700 kWh of electricity per year, which was determined by reviewing utility bills for a 12 month period. **(Part One)**. Customer A then completed a self energy-audit and calculated that retrofitting lighting and removing several consumptive devices can reduce the annual electricity consumption by 1,000 kWh per year **(Part Two)**.

The estimated net electrical use, with the efficiency measures included, is reduced to 10,700 kWh annually. Customer A would like to offset 50% of that usage. $10,700 \text{ kWh} \times 50\%$ equals 5,350 kWh per year, which represents the required annual output of the PV system. **(Part Three)**.

Step Two - Sizing the System Based on Site Characteristics

The majority of siting factors and corresponding options have been highlighted earlier in this publication. Step two takes these into account and helps to place both objectivity and good science into the decision making process. For many consumers, the location and size of the system are determined by existing site characteristics such as available roof space. Limitations need to be accounted for – no matter the “wish list” of the consumer.

Generally, for crystalline modules, a good rule of thumb is to allow between approximately 100-150 square feet of roof (or ground/pole mount) space for each kilowatt of rated capacity, For thin film technologies, the space requirement is greater - usually between 150-300 square feet for each kilowatt of rated capacity.

Required square footage is directly correlated to the rated output production (listed in watts) of each module, as well as the specific module dimensions. Module technology improves continuously - several years ago, typical residential modules were rated from 80-120 watts. That has tripled with today’s technology, and is increasing. Solar module manufacturers understand space considerations and continue to put effort into increasing output per square foot.

When considering the variables, it is important to understand the siting considerations and issues, and some of the remedies for common problems. A qualified and reputable solar contractor should provide options and solutions for the consumer, and it is helpful and productive for the consumer to have an understanding of options.

- 1. Part One – Determine the system size based on Montana’s average production per rated kW.** For a typical, fixed mount PV system in Montana, the formula used to estimate annual production is to that **one kilowatt of installed, rated capacity will produce approximately 1,300 kWh of electricity per year**. This takes into account general environmental, seasonal and time of day factors - however it is a general estimate. For a more precise estimate, consumers should consult PVWatts®.

2. Part Two – Analyzing space requirements and other siting considerations. After determining the system size based on desired electricity production, the next task for the consumer is to evaluate the physical siting considerations and constraints.

For many consumers, the location and size of the system are determined by existing conditions such as roof space or the presence of obstructions that might not be able to be moved.

Example

Customer A has determined that he would like to offset 5,350 kWh per year. Using the one kilowatt expected annual output of 1,300 kWh, the required system size can be determined by taking the desired output (5,350 kWh) and dividing it by 1,300 kWh. $(5,350/1,300)$ equals 4.115. The size of the array would need to be approximately 4.1 kilowatts **(Part One)**.

Customer A has ample, south facing square footage to install a 4.1 kW system. The problem is that there is a tree in the front of the yard that will impact the west, bottom one-third of the array with shading to different degrees on a seasonal basis. The solutions could include downsizing the system, trimming part of the tree, or installing a micro-inverter system to minimize production losses.

Customer A also has an undeveloped, obstruction free space that used to be a garden. He is considering the option of splitting the system to include a smaller array on the roof and a 2 kilowatt pole mount. With a basic understanding of both his wishes and options, he has decided to contact two separate solar contractors to complete a site assessment and provide recommendations **(Part Two)**.

Step Three – Determining the System Cost, Available Incentives and Payback Period

The majority of Montana consumers rate the economic value of installing a system as the primary decision factor. Other reasons that impact the choice are environmental considerations, the need for production during outages, and a general interest with using the technology.

Step Three is focused on the economic value of the system. Consumers should consider that there are several accounting formulas utilized in solar PV sales relative to system payback. For the purposes of this document, simple payback on “non-borrowed” funding will be used. Other formulas include multipliers for factors such as the predicted increase in energy commodity prices, while some focus on valuations such as internal rate of return. The recommendation is that whatever formulas and factors the consumer uses, they should have a comprehension of them.

1. Part One – Determining the total system cost before incentives or tax credits. Although it might appear straightforward and easy, determining the total system cost (TSC) can highlight unexpected expenses. When working with contractors, it is highly recommended that consumers request a complete, detailed bid and specification sheet before the installation begins. (This is a standard offering from quality contractors).

The bid should include the costs for system components, design, permits, labor, maintenance contract fees, excavation or modifications to the structure, and other supplementary costs.

Part Two – Determine the available incentives/credits and calculate the net cost of the system. Research available incentives and/or tax credits for the system. These usually encompass system components and labor.

Both Federal and State tax credits are available for systems. Currently, for a household filing jointly, there is a \$1,000 Montana State Tax Credit for joint filers (\$500 for a single). The Federal Residential Renewable Energy Tax Credit (valid through December 31,2016) is 30%. Consumers should recognize that the Federal Tax Credit is calculated after incentives or State tax credits are deducted, rather than based on gross cost of the system.

Part Three – Determine the adjusted or net system cost. The Adjusted or Net System Cost (ASC) is obtained by subtracting incentives and tax credits from the Total System Cost (TSC).

Part Four– Determine the annual production value of the PV produced electricity. For Montana consumers, the average current charge for one kWh of electricity is approximately 11 cents(0.11). To determine the annual production value (APV) of the consumer’s specific system, the calculation is (Estimated Annual Production (kWh) multiplied by the Current Utility kWh Charge).

Part Five – Calculate simple payback. Divide the Adjusted System Cost (ASC) by the Annual Production Value (APV) to determine the simple payback (in years).

Example

Customer A ended up having a portion of his tree trimmed and the contractor was able to modify several vent pipes. He is expecting 15% production for his system and was able to have the contractor install the 4.1 kilowatt array. The total system cost was \$17,100. He is going to receive a \$2,000 utility rebate, a \$1,000 State of Montana Tax Credit, and is eligible for the 30% Federal Tax Credit for renewable energy systems.

The Math

ASC – Adjusted System Cost

1. 17,000 (TSC) minus 2,000 (Utility Incentive) -1,000 (State Tax Credit) = \$14,000
2. 14,000 x .30 (Federal Tax Credit) = \$4,200.
3. 14,000 - 4,200 = \$9,800 (ASC)

APV

Expected Annual Production (5,350 kWh) x Utility Credit of Eleven Cents (.11) per kWh = \$588.50

Simple Payback

\$9,800 (ASC) divided by \$588.50 (APV) = **16.74 (years)**

Resources and Important Things to Know

Definitions, Websites, Warranties, Safety

Following are resources that help to understand common questions and concerns about PV system installations. The ultimate goal is for the consumer to develop a secure and confident relationship with the solar contractor, and good contractors work well with competent consumers.

Solar PV and Applicable Electrical Definitions

Alternating Current (AC) - The flow of electricity that constantly changes direction between positive and negative sides. Almost all power produced by electric utilities in the United States moves in current that changes direction at a rate of 60 times per second.

Ampere (Amp) - The unit of measure that indicates how much electricity flows through a conductor. For example, a 1,200-watt, 120-volt hair dryer uses 10 amperes of electric current (amps = watts/volts).

Circuit - One or more conductors through which electricity flows.

Direct Current (DC)- The flow of electricity that flows continuously in one direction. Solar PV produced electricity is DC at the cell level.

Interconnection - The linkage of electrical lines between two utilities, or between a utility and an end-user, enabling power to be moved in either direction.

Insolation - The solar power density incident on a surface of stated area and orientation. It is commonly expressed as average irradiance in watts per square meter (W/m²) or kilowatt-hours per square meter per day (kWh/m²/day).

Inverter - A device that converts direct current electricity to alternating current either for consumer consumption or to supply power to an electricity grid.

Irradiance - The direct, diffuse, and reflected solar radiation that strikes a surface. Usually expressed in kilowatts per square meter. Irradiance multiplied by time equals insolation.

Kilowatt (kW) - 1,000 watts - A unit of measure of the amount of electricity needed to operate given equipment. For example, a one kW system provides enough power to illuminate 10 light bulbs at 100 watts each. (volts x amps = watts)

Kilowatt-hour (kWh) - The amount of kW produced over a period of time, or one kilowatt of electricity supplied for one hour. For example, a one kW system, if operating at full capacity for 5 hours will produce 5 kWh of electricity.

Maximum Power Point (MPP) - The point on the current-voltage (I-V) curve of a module, under illumination, where the product of current (amperage) and voltage is maximum.

National Electrical Code (NEC) - Contains guidelines for all types of electrical installations. The 1984 and later editions of the NEC contain Article 690, "Solar Photovoltaic Systems" which should be followed when installing a PV system. The NEC is adopted by the State of Montana under the Department of Labor and Industry.

Peak Sun Hours - The equivalent number of hours per day when solar irradiance averages 1,000 w/m². For example, six peak sun hours means that the energy received during total daylight hours equals the energy that would have been received had the irradiance for six hours been 1,000 w/m².

Solar Resource - The amount of solar insolation a site receives, usually measured in kWh/m²/day, which is equivalent to the number of peak sun hours.

String - A number of photovoltaic modules or panels interconnected electrically in series to produce the operating voltage required by the load.

Utility Grid - The interconnection of electricity generation plants through the transmission and distribution lines to consumers. The grid also refers to the interconnection of utilities through the electric transmission and distribution systems.

Utility Interactive Inverter – An inverter that can function only when tied to the utility grid, and uses the prevailing line-voltage frequency on the utility line as a control parameter to ensure that the PV systems output is fully synchronized with the utility power

Volt (V) - The amount of force required to drive a steady current of one ampere through a resistance of one ohm. Electrical systems of most homes and offices use 120 volts. (volts - watts/amps) (volts = amperes x resistance)

Watt (W) - Electric measurement of power at a single point in time, as either capacity or demand. For example, light bulbs are classified by wattage.

System Warranties

The warranty on your solar PV system is important and can be difficult to understand and contain “fine print”. For a PV system, it is important to consider that the primary components have separate warranties, and the contractor’s installation warranty, if offered, is distinct from those of the array and components.

At the contractor level, there is typically a one-two year warranty on parts and labor. In this case, even if there is a component failure warrantied by the manufacturer, the contractor will often repair or replace the problem with no labor charge – however, after this “parts and labor” time period, the manufacturer component warranty usually doesn’t include labor charges. Following are general component warranties.

Modules

Most UL® listed, quality modules have a warranty of between 20-25 years. This can be written relative to power output (usually 80% output for the life of the warranty or pro-rated per year of the warranty).

Module warranties usually cover both electrical performance and damage from normal environmental degradation. They do not cover vandalism or misuse. Module failure is rare – there are no moving parts included in the design, but electrical circuitry problems can occur.

Consumers opting for micro-inverters or AC panels should also check and understand the details of the module warranty. Because the modules and micro-inverters are integrated, there can be differences on what or what is not covered, as well as the duration of the coverage.

Inverters

Solar contractors are up-front with informing consumers that the point of failure in a grid-interactive PV system is often the inverter. A failed or improperly working inverter can be both a production issue and safety concern.

String (central) inverters are usually warrantied from 5-10 years. Quality manufacturers believe that a properly installed inverter has a life expectancy of up to 20 years.

Micro-inverter warranties are advertised by various manufacturers at 25 years. This has resulted in a debate among the solar community – some contractors believe that this is a marketing move and there has been inadequate real time performance data to justify the warranties. However, to date, contractors have experienced few issues with the micro-inverter manufacturers in fulfilling warranty obligations.

Battery Systems

Battery warranties vary between manufacturers and warranties are often limited or pro-rated. This is not because of unscrupulous manufacturers or contractors, rather it is due to other variables such as charge/discharge cycles (based on specific use patterns), as well as factors including the battery bank installation. Quality manufacturers will provide some level of warranty protection for the first years of battery life. This is primarily to cover manufacturing issues.

Questions to Ask the Contractor Relative to Warranties?

1. Does the installation contract include a parts and labor warranty from the contractor that is separate from the manufacturer warranty?
2. In the event of a component failure, is the consumer “on their own” after the contractor’s parts and labor warranty (but while still under manufacturer warranties)?
3. For manufacturer warranties, what is covered and to what degree? This includes troubleshooting, removing and replacing components, and shipping costs.
4. What guarantee is available if the manufacturer goes out of business while the warranty is in place (an issue that is plausible with the growth of and changes within the solar PV market)?

Consumer Safety Considerations

Even smaller residential, grid-interactive PV systems have the potential, if installed improperly, to cause serious injury to people or to structures. The DC voltage “on the roof” to the inverter is often three –five times that of 120 Vac household voltage. There are also other components and connections, if not designed and installed properly, that can be hazardous.

Montana Statute requires a licensed electrician to perform the work on circuits that are 90 volts and above; as a result, all grid-interactive systems meet the State licensing requirements. Some established, reputable solar contractors in the State are not licensed electricians themselves, but employ or sub-contract the electrical portion of the installation to a licensed electrician.

Consumers should understand that they are ultimately responsible for the safety and integrity of the PV system. Prior to hiring a solar contractor, the contractor should provide the consumer proof of liability insurance, workmen’s compensation insurance (for employees), and the ability to secure necessary structural and electrical permits. Consumer groups also suggest that consumers contacted the insurance providers and make sure the proof of insurance provided by the contractor is valid.

Two Essential Websites for Consumers

There are two useful consumer internet resources. They are PVWatts® and DSIRE™ – both of which are funded by the United States Department of Energy. The PVWatts® Calculator is very helpful in system planning and decisions, and DSIRE™ helps consumers understand the available incentives and tax credits for both renewable energy production and energy efficiency.

The PVWatts® Calculator

The PVWatts® Calculator is a useful and easy to navigate application for consumers interested in installing a Solar PV system. The user inputs the system’s location, design parameters and system economics. PVWatts® then calculates the output and monetary value of the produced electricity. It is important to remember that the application assigns standard production losses to factors such as shading and inverter efficiency, but these are not site specific.

The Calculator provides consumers the ability to quickly look at performance based on different options and sizes, and provides a base-line production estimate prior to a physical site assessment from a solar contractor. This helps consumers from being “oversold” on production estimates or features that can have a minimal ROI.

The PVWatts® Calculator can be accessed at pwwatts.nrel.gov. To get started, type in the address and zip code (or geographic location) for the system. The application guides consumers through the remaining steps.

DSIRE™ (Database of State Incentives for Renewables and Efficiency)

Established in 1995 and operated by North Carolina State University, DSIRE™ is the “go to” internet source for the scope of renewable energy and efficiency incentives and tax credits available to consumers. It is funded by the U.S. Department of Energy.

DSIRE™ also has resources that assist with understanding the specifics of the different types of tax credits/deductions, incentives and loans. Topics are communicated in a practical format, and links are provided to sites and providers with more detailed information. DSIRE™ can be accessed at dsireusa.org. Consumers can access Montana incentives and tax credits by simply clicking on the “MT” segment on the site’s home page.



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The Montana Consumer Guide to Grid-Interactive Solar PV Systems