



Renewable Energy to Power Remote Communication Sites: A Guide for Law Enforcement Executives

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Executive Summary

One law enforcement challenge every executive faces is providing the officers of their agency with a reliable communications system. Many times the challenge of designing such a system is the location of the radio system sites. Oft times the perfect location for radio coverage may not be viable because there is no power utility infrastructure at the location. Many times, because of a lack of power infrastructure, multiple radio sites have to be established where there is power, to cover the same area that could be covered with one site if it could be powered. There are budget and safety implications when radio siteing is compromised because of lack of power in prime sites. Renewable energy systems, in particular solar photovoltaic (PV) and wind turbines deployed as stand-alone systems or, in some cases, in combination with fuel generators, are ideal for powering many remote communication sites used for public safety. This Guide addresses the uses, options and issues associated with renewable power systems at remote (i.e. off the traditional electricity grid) communication sites.

This Guide is organized into four parts: Part I describes the electrical load of a typical repeater communication site; Part II introduces renewable power sources and other considerations such as storage batteries, supplementary power sources and the impact of installation on performance; Part III offers four scenarios from throughout the United States, highlighting how the size and cost of a renewable energy system vary based on the solar and wind resources available at a particular geographic location and site; Finally, Part IV presents resources and tools for those that wish to explore the design and installation of a renewable energy system in greater depth.

The Power Challenge

A design goal for law enforcement communications systems is to optimize radio frequency (RF) coverage within a service area. However, often the ideal location for a communication site (i.e. one that optimizes RF coverage) may be in at a remote site that is not serviced by the traditional electrical grid. When this is the case law enforcement executives have a number of options:

Option 1: Locate the communication site in a sub-optimal RF coverage location that is serviced by the traditional electricity grid.

Option 2: Extend the traditional electrical grid to service the remote site.

Option 3: Power the remote site with a generator using diesel, propane, gasoline, or even an alternative fuel, like hydrogen.

Option 4: Power the remote site with renewable energy, in particular solar photovoltaic (PV) and/or wind turbines, and if necessary in combination with a fuel generator for back-up power.

Option 1 guarantees a steady supply of energy to a site, however, compromises the paramount goal of the communication system, namely RF coverage or it requires more sites to be built to meet the optimal RF requirement. Option 2 and Option 3 overcome the sub-optimal RF coverage problem; however they come with significant capital and maintenance costs. For example, extending the grid to a mountain peak requires significant initial capital. According to Sandia National Laboratories, this can range from \$8,000 to \$35,000 per mile depending on the terrain. And, supplying fuel solely to an on-site generator includes significant operation, maintenance, fuel and environmental costs, for example, getting fuel, spare parts and technicians to the site or dealing with environmental damage at a sensitive site as a result of storing large quantities of fuel on-site.

Option 4 offers a possible route around these problems. If the conditions are conducive to the use of renewable energy, this option can be significantly more cost effective allowing for optimal RF coverage while minimizing the operation, maintenance and environmental cost associated with a stand alone generator system, and the initial capital costs associated with a grid extension.

Renewable Energy System Basics

Not surprisingly, the attractiveness of using solar or wind energy to power a communication site is directly related to the size of the solar and wind resources at the particular site. However, the process of designing a proper renewable power system can be quite complex. This section provides an introduction to renewable power systems, highlights how certain factors impact system design, and offers insights of how to get the most out of a system.

Solar Energy

The Building Blocks of the Photovoltaic (PV) System

A photovoltaic (PV) system converts sunlight particles or “photons” into electricity. The foundation of a photovoltaic system is the PV cell. A PV cell generates DC electricity when exposed to sunlight. When photons strike a PV cell they excite and free electrons that induce a current and voltage (electricity). Typically, a PV cell produces .5 volts and up to 6 amps of current (i.e. 3 watts of power = .5 volts x 6 amps). PV cells are connected electrically to produce a higher voltage (volts), current (amps) and power levels (watts). A circuit of PV cells is known as a PV module. A PV module includes optics and other components that are packaged in an environmentally protective laminate and is the fundamental building block of the PV system. PV modules are fastened together to form PV panels and when combined with a foundation and support structure, as well as other necessary components form a PV array.

PV Module Power Output

Photovoltaic arrays are being deployed in ever increasing numbers throughout the United States. The majority of crystal silicon modules today have matured to a degree that they will produce power for 30 years or more. Most major manufacturers offer 20 to 25-year warranties for maintaining a high percentage (up to 80 percent) of initial rated power output. Evidence suggests life expectancy for these modules can be extended to as much as 50 years. Nonetheless, as the materials age over time module performance degrades.

Standard Test Conditions and Rated Power Output

PV modules are rated according to their maximum power output under Standard Test Conditions (STC). A module is operating under STC at a temperature of 25° C (77° F), a solar irradiance (intensity) of 1000 watts/meter², and an air mass of 1.5 spectral distribution. When these conditions are met, a “100 watt” module converts solar energy into 100 watts of direct current (DC) power output. Most of the time PV modules do not generate the amount of power that is listed on the manufacturer’s specification sheet since STC conditions are rarely encountered in the field.

Actual Module Power Output

In the field, environmental factors significantly impact the voltage and current and hence DC power generated by a PV module. First, variation in solar intensity or *irradiance* significantly affects the current (and in turn power output) of a PV module (interestingly it only has a small effect on the voltage). In general, irradiance is lower than that described in STC. This is the case for reasons that include the position of the sun relative to the angle of the module, clouds, shade, as well as obstructions on the module itself like dirt and dust and snow.

Temperature also has a direct and variable impact on performance. For example, variation in cell temperature affects power output, significantly impacting voltage and having a slight opposite impact on current. Concerning crystalline silicon PV modules, for every one degree Celsius increase in temperature, voltage is lowered approximately .45 percent and current increases approximately .1 percent.¹ Higher cell operating temperatures degrade power output, efficiency and lifetime. However, while colder environments result in higher operating voltages, they have significantly less peak sun-hours per day since solar intensity is less, lowering overall power output.

Sandia National Laboratories suggests amounts for reducing STC module output by to determine actual module output when designing your system. In the case of the 100 watt rated module, for example, diminish the actual power output by 15 percent due to losses from irradiance and temperature. A “100 watt” module then generates only

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85 Watts of DC power. Furthermore, taking into account dust and dirt losses, the “100 watt” module only generates 79.5 Watts (100 Watts X .85 X .93) of power output. In addition, mechanical losses due to module mismatching and resistance in interconnecting wires, and electrical losses due to DC to AC conversion (which is not necessarily required in repeater and microwave sites) will further lower power output to approximately 75 watts of DC power and 67 watts of AC power.

Wind Energy

Wind Speed and Wind Turbines

A PV system will not meet the load demand all of the time, requiring supplementary sources of energy. In terms of renewable sources this likely means wind. Like photovoltaic, the energy output and in turn attractiveness of deploying a wind turbine increases with the size of the renewable resource. In this case, it is the average wind speed at a particular site. In general, a site that receives an average of 12 miles per hour (or between 5 and 6 meters per second) of wind is considered a good resource.ⁱⁱ

Air has mass and air in motion, wind, contains the energy of that motion. Using a wind turbine, this kinetic energy can be turned into mechanical and eventually electrical energy. When in motion, the energy of the rotor blades turns a shaft in the turbine system, which in turn connects to a generator that converts the mechanical energy into electrical energy. The amount of power the wind transfers to the rotors depends on three factors: 1) air density, 2) rotor (blade) area, and 3) wind speed.ⁱⁱⁱ

Most wind turbines start operating at a speed of 4 to 5 meters per second and reach maximum power at about 15 m/s. Slight variations in average speed can mean large differences in power output. This is due to the fact that wind power is a function of its speed cubed. Therefore, while the difference between 4 m/s (9 miles per hour) and 5 m/s (11 miles per hour) wind speed at the same site may not seem like much, in terms of power, and all other things being equal, a turbine will produce twice as much power at a site receiving 5 m/s wind speed versus 4 m/s (since $V^3 = 125 \text{ m}^3/\text{s}^3$ versus $V^3 = 64 \text{ m}^3/\text{s}^3$).

Wind speeds are extremely variable from one site to the next. While a mountaintop location will generally have a good wind resource, as is demonstrated by the Southeast site described later in this Guide, height does not necessarily translate into increased wind speed. For example, obstructions like trees and rock formations can significantly decrease the wind that actually reaches the turbine. Therefore, knowing the local conditions is very important for determining if a site has a good wind resource, as well as the proper siting of a turbine.

Storage Batteries

Renewable power systems only generate electricity when the sun is shining or the wind is blowing strong enough. To power the load during nighttime, on cloudy days, and windless/marginally windy days, or to supplement power during periods when the renewable power being supplied cannot meet the load demand, a storage system is required. Batteries are used in renewable power systems to store the energy produced and to supply it to the electrical loads on an as needed basis. Batteries also serve to power electrical loads at stable voltages and supply surge currents to electrical loads and inverters. A charge controller regulates the batteries charge to guard against overcharge and over-discharge, and thereby protect the overall system.

Batteries used in renewable power systems, particularly in stand-alone systems powering remote sites, must be able to withstand harsh climates as well as supply power rapidly. As a result, batteries in these systems are normally lead-acid, deep-cycle batteries. These have thicker plates and can withstand discharges of up to 80 percent of their rated capacity. Another option is nickel cadmium batteries. These allow for an even greater depth of discharge, roughly 10 percent more of the rated capacity of the battery as compared to lead-acid batteries. Nickel cadmium batteries also require less maintenance, but they are more expensive.

Criteria for selecting the size of your battery bank (i.e. the number of batteries in the system), is highly dependent upon the required system availability and your budget. In the case of public safety, the system availability is

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“critical”. Therefore the battery bank must be quite large to store enough electricity to power the communication system when traffic is heavy for an extended period of time and the solar and wind resources are less.

Later in this Guide there will be examples of how the number of storage batteries required is impacted by the site location and other factors.

Hybrid System

A “hybrid” system combines renewable power with a fuel generator system. The addition of a generator provides an additional power source to meet the load demand. It is possible to control the timing of the generator to remain off when the PV and/or wind system or battery is providing charging and turn on when charging stops. Generators are generally fueled by diesel or propane. Increasingly, hydrogen fuel cells are being deployed. Please the Tools and Resource Section of this Guide for tools and resources to learn more about using hydrogen for back-up power.

Using a generator comes with added costs throughout the power system’s life. These include: 1) the cost of the fuel (including the cost of fuel delivery), 2) the cost of oversight and maintenance (including periodic tune-ups and rebuilds to maintain it for the life of the renewable power system); and 3) environmental costs (for example, some remote sites may be on public lands and diesel fuel spills may be hazardous to local flora and fauna).

The costs associated with generators make them unattractive when deployed in a stand-alone use, however if their use is limited to the supplementary role it plays in a hybrid system, these costs diminish substantially. With proper oversight, a generator is ideal to offset the availability issues associated with renewable power systems particularly in places where the solar resource in the summer is far greater than during winter and for sites requiring 100 percent system availability.

Balance of System Components

The balance of system (BOS) components literally refer to all of the system components not described in the sections above, but are nonetheless integral to having a complete operating system. These components can account for a significant portion of the system cost. Therefore, the greater the need for BOS components, the increased potential for added costs, and the increased importance of vigilance regarding component selection, system installation and regular maintenance.

BOS components consist of mounting structures, enclosures, wiring systems, switch gear, grounding, surge suppressors, fuses, ground fault detectors, charge controllers, and if needed, inverters. Most systems include a combiner board of some kind since most modules require fusing for each module source circuit. Some inverters include this fusing and combining function within the inverter enclosure. BOS components are fundamental to the successful deployment of renewable power systems. As is demonstrated in the section below on design and installation, improper selection can have serious consequences for system performance. The reader should refer to the Tools and Reference Section of this Guide for more information and consult with a knowledgeable professional when selecting the BOS components.

“Critical” Availability

System availability refers to the amount of time that a power system is capable of meeting load requirements. As noted above, in the case of a public safety repeater the system availability is “critical”, that is, a system failure may result in the loss of life or a significant amount of property. Critical system availability requires the system operate without any or at least with extremely minimal failure. It must meet power load requirements between 99 percent and 100 percent of the time (i.e. between 8,672 hours and 8,760 hours yearly).

Achieving 99 percent to 100 percent system availability is extremely expensive relative to achieving 90 percent to 95 percent availability. This is the case because of two factors: 1) the yearly variation in the fuel source, sunlight intensity used to power the PV system, or wind speed to power wind turbines, and 2) the fact that even if PV and/or This publication was funded by the U.S. Department of Justice, Office of Justice Programs’ National Institute of Justice under Cooperative Agreement #2007-IJ-CX-K013. Drakontas LLC served as the Administrator of the NLECTC Communications Technologies Center of Excellence from October 1, 2007 to September 30, 2010.

wind systems are designed to meet the “worst-case”, they are based on the “average” during these times. So, while a properly-sized PV and/or wind system with a large battery-bank is extremely good at meeting load demand most of the time, because it is dependent upon the environmental resources as well as other variables, it is challenging to meet all of the load demand all of the time. Therefore, during a year when the solar or wind resource is “below-average”, the system will not meet the load demand as often.

To approach 100 percent availability, one option is to simply increase the size of the PV or wind system to compensate for this variation. However, the addition of more panels or modules, or turbines (and batteries) to meet load demand during very specific times is not cost-effective or energy efficient overall. For example, a system designed to meet the worst-case when the solar resource is minimal in winter will waste a lot of energy in summer months, when the solar resource is relatively higher. As mentioned above, meeting critical demand can also be achieved through including additional sources of energy, either redundant renewable energy or a hybrid system that includes a hydrogen fuel cell or a traditionally fueled generator. As is the case with the electricity grid, drawing from multiple energy sources reduces the risk of system failure through increased diversification.

Get the Most Out of a Renewable Energy System

The Importance of Proper Design and Installation

A renewable energy system is not a single entity but a complex configuration of various parts. Ultimately, it depends on the ability of these parts to function together to ensure high conversion efficiency of the overall system at turning solar and/or wind energy into DC or AC power output. Therefore, those who decide which pieces to put together and put this into action, namely system designers, installers and integrators play an important role in the system meeting the load requirement. These individuals control the ability to optimize the performance and reliability of the system as a function of site-dependent environmental conditions.^{iv} While many renewable systems in use today perform exceptionally well, many do not. Improper design and installation is an important cause of system failure or degraded output. Inspections in California turned up numerous systems not meeting minimal construction requirements, and national electric and building codes. Many of the deficient systems also used unlisted equipment not compatible with other PV equipment, and ac devices used in dc circuits.^v In many cases improperly sized or installed conductors resulted in early failure of the conductors.

Beyond simply choosing proven products, numerous steps must be taken to maximize the energy being taken in by the system and being output from the system. The prevalence of system failures and degraded output does not demand public safety officials become design and installation experts. Rather, you should know the ultimate aim of your system and put the right people in place to make this a reality. This means purchasing products whose performance and reliability in your site’s environment is well documented, enlisting integrators and installers with significant experience designing and installing sites for similar application and locations, and ensuring that they follow the proper installation guidelines as laid out by the National Electrical Code (NEC). Finally, it also requires that they have some matrix to measure system performance to ensure the system is functioning properly. This means creating a performance estimate and monitoring actual performance.

Please consult Tools and Resources Section of this Guide for tools and resources related to the proper and improper design and installation of renewable energy systems.

Radio Repeater Site Case Studies

This section considers one radio repeater with a microwave relay at four distinct mountaintop sites in different regions in the United States with different solar and wind resources. Corresponding renewable energy systems were created using the National Renewable Energy Laboratory (NREL) software tool HOMER. To learn more about HOMER and where it can be downloaded, please consult Part IV of this Primer. For each site, system size and component configuration was determined by HOMER in order to minimize the net present cost of the system while still meeting the load demand.

The load is the power required to operate a communication site and its supporting components. To provide a simple illustration of how renewable energy can serve the needs of law enforcement, the type of load considered in this Guide is a single radio repeater with a microwave link. The more frequently the repeater is used the more power it demands. The duration and amount of use is referred to as the duty cycle. A renewable energy system is designed to not only meet the average load over time as defined by the average duty cycle, but also heavy loads during emergencies. The “critical” nature of law enforcement communications loads and its impact on system design is described in a later section of this Guide.

A site’s load can be broken into three components: the *peak power* in watts, the *peak current* in amps, and the *daily amp-hour load* during normal usage. Their relationship can be understood by the power equation: Power (watts) = Voltage (volts) x Current (amps).

Peak power and peak current are the watts and amps required by the site to transmit a communication. The following are examples of the stand by and peak power characteristics of a radio repeater:

The repeater in standby mode requires 5 watts of power.

The repeater in transmit mode requires approximately 500 watts of power.

The microwave radio requires 60 watts of constant power.

Peak power is the addition of the transmit power requirement and the constant microwave power requirement. In this case, the peak power is **560 watts**. And, as is highlighted by their relationship in the power equation, the peak current is simply the peak power (560 watts) divided by the voltage (24 volts), or approximately **24 amps**. The total standby power requirement for the repeater and microwave is **65 watts**, or roughly **3 amps**.

The amp-hour load per day is the amount of amps required to support the microwave radio and the repeater broken down by the average daily duty cycle of the communication site (i.e. the current when the repeater is in use and in standby mode) and taking into account system inefficiencies. This figure is integral in determining the size of the renewable system needed to meet the load.

There are a couple of lessons from this exercise. First, solar data and **especially wind data** are site specific. That is, they can vary significantly from one site to the next. Therefore, it is important to get the best available estimates of these at your particular site. If actual measurements at a site prior to installation are not possible, it is important to find a site with similar solar and wind characteristics and use this data for designing the system.

Second, there is no one solution to providing remote power to a site. Different variations of PV arrays, wind turbines, generators and batteries can all provide the necessary power to a site. For example, to provide more power, you can increase the PV array size, add another wind turbine, add another generator or increase the storage capacity through added batteries. Each solution serves a need; however the best solution will depend on site-specific factors like the solar and wind resource. Using a software tool like HOMER and consulting an expert in renewable energy at remote sites will help you develop an ideal solution to meet your need and your budget.

System Components	Cost Per Unit
PV Arrays	\$8.00/watt
Wind Turbine	
Batteries	
BOS Components	

Table 2. Inputs Used in HOMER System Design

Site Comparisons

Southwest Site – Tesuque Peak, New Mexico

Total Net Present Cost: \$28,903

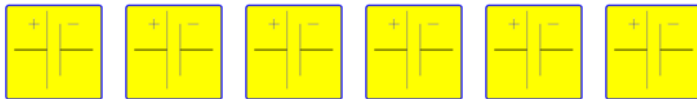
Latitude: 35.47 North
Longitude: -105.46 West
Solar Resource: Very Good
Wind Resource: Very Good



1kW



1kW



6 Batteries

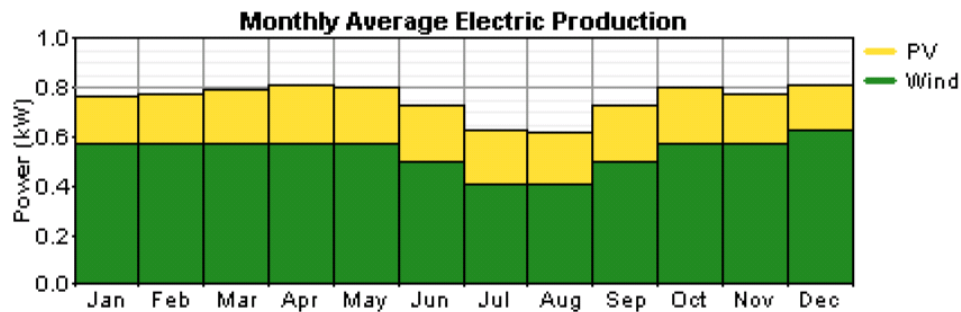
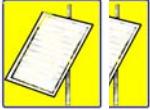


Figure 1. Average Monthly Kilowatts Produced by PV and Wind (Combined and Individually)

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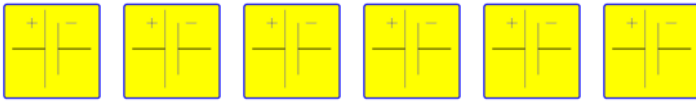
Northwest Site – Bend, Oregon
Total Net Present Cost: \$30,538
 Latitude: 44.-21-05 North
 Longitude: -121-41-30.2 West
 Solar Resource: Good
 Wind Resource: Very Good



PV System Size: 1.5 kW



Wind System Size: 1kW



Battery Bank Size: 6 Batteries

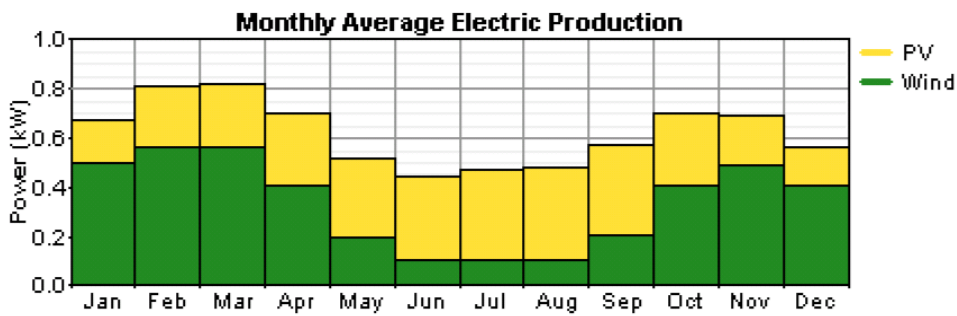


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Southeast Site – Sterling Mountain, North Carolina

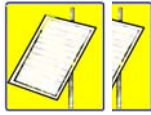
Total Net Present Cost: \$40,627

Latitude: 35.70264 North

Longitude: -83.12241 West

Solar Resource: Good

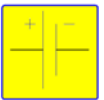
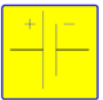
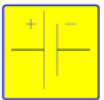
Wind Resource: Poor



PV System Size: 2.5 kW



Wind System Size: 1kW



Battery Bank Size: 6 Batteries

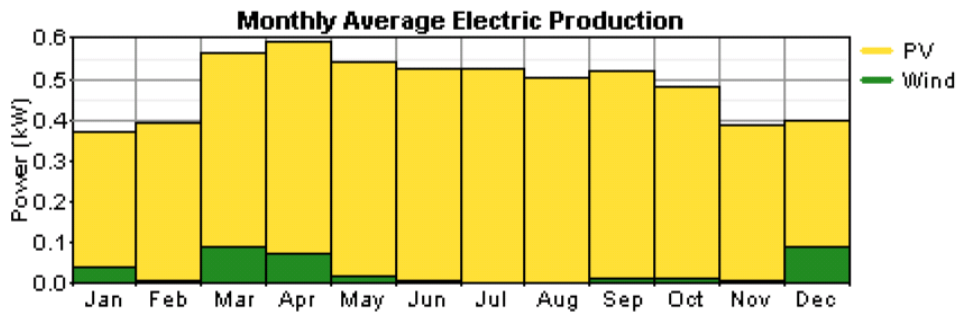


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Northeast Site – Irish Hill, Vermont

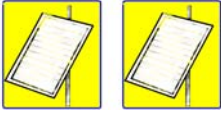
Total Net Present Cost: \$39,419

Latitude: 44.-11 -04 North

Longitude: -072-36-43.4 West

Solar Resource: Fair/Good

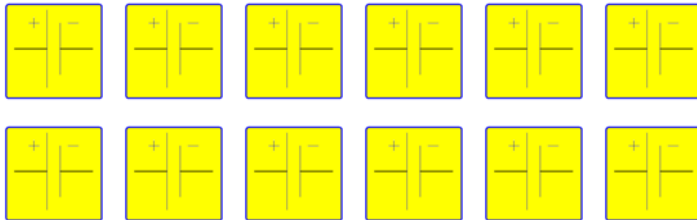
Wind Resource: Fair/Good



PV System Size: 2.0 kW



Wind System Size: 1kW



Battery Bank Size: 12 Batteries

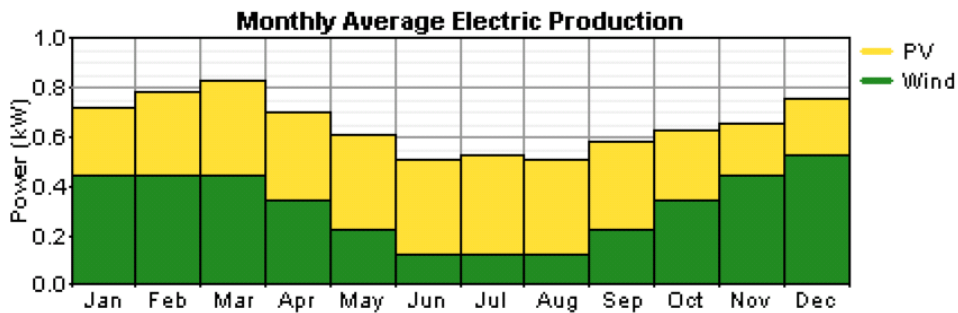


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Resources and Tools

Renewable Power

Sandia National Laboratories

http://www.sandia.gov/Renewable_Energy/renewable.htm

National Renewable Energy Laboratory (NREL)

<http://www.nrel.gov/>

Florida Solar Energy Center

<http://www.fsec.ucf.edu/en/>

PV Basics

http://www.fsec.ucf.edu/en/consumer/solar_electricity/basics/index.htm

US Department of Energy

http://www1.eere.energy.gov/femp/renewable_energy/index.html

American Wind Energy Association

Wind Basics

http://www.awea.org/faq/wwt_basics.html#What%20is%20wind%20energy

Danish Wind Industry Association

<http://www.windpower.org/en/tour/wres/enerwind.htm>

British Wind Energy Association

<http://www.bwea.com/index.html>

Batteries

Sandia National Laboratories

<http://photovoltaics.sandia.gov/docs/BattIntro.htm>

Hybrid

Sandia National Laboratories

<http://photovoltaics.sandia.gov/docs/Hybook.html#>

<http://photovoltaics.sandia.gov/docs/HybridSizing.html#AnchorMicrowave>

<http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/>

<http://www.plugpower.com/technology/overview.cfm>

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BOS Components

Sandia National Laboratories

<http://photovoltaics.sandia.gov/docs/BOS.htm>

Design and Installation

Sandia National Laboratories

http://photovoltaics.sandia.gov/docs/Design_and_Installation_of_PV_Systems.htm

North American Board of Certified Energy Practitioners

<http://www.nabcep.org/index.cfm>

http://www.nabcep.org/Monticello/userfiles/File/NABCEP%20Study%20Guide-Revised%20Version%209%20-%202030_06-FINAL.pdf

Wind Site Assessment

<http://www.nabcep.org/Monticello/userfiles/File/SmallWindTA1206FINALv1.0.pdf>

National Electrical Code

http://www.nfpa.org/freecodes/free_access_agreement.asp?id=7005SB

Documents and Research

Solar

<http://photovoltaics.sandia.gov/> (click on publications)

Wind

<http://www.sandia.gov/wind/TopicSelection.htm>

Hybrid Photovoltaic Case Studies

<http://www1.eere.energy.gov/femp/pdfs/24033.pdf>

<http://www1.eere.energy.gov/femp/pdfs/21237.pdf>

Batteries

<http://photovoltaics.sandia.gov/docs/battery1.htm>

Performance Optimization

http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=1190877

System Performance

http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=4104641

Tools

Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices, SAND87-7023. Albuquerque, NM: Photovoltaic Design Assistance Center, Sandia National Laboratories, March 1995.

Request a copy by emailing pvsac@sandia.gov or by writing:

Sandia National Laboratories

Solar Programs

P.O. Box 5800

Albuquerque, NM 87185-1110

General System Design Worksheets

<http://photovoltaics.sandia.gov/docs/Wkshts1-5.html>

<http://photovoltaics.sandia.gov/docs/Wkshts6-9.html>

Modeling Software

Hybrid Optimization Model for Electric Renewables (HOMER)

<https://analysis.nrel.gov/homer/>.

Getting Started Guide

<https://analysis.nrel.gov/homer/includes/downloads/HOMERGettingStarted210.pdf>

Solar and Wind Data

Solar Radiation Maps

NREL Renewable Resource Data Center

http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/

Dynamic Renewable Maps

<http://www.nrel.gov/gis/solar.html>

Grants

State Incentives for Renewables and Efficiency

<http://www.dsireusa.org/>

US Department of Energy

Financing (General)

<http://www1.eere.energy.gov/financing/>

State Financing Opportunities

<http://www1.eere.energy.gov/financing/states.html>

ⁱ *Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices*, SAND87-7023. Albuquerque, NM: Photovoltaic Design Assistance Center, Sandia National Laboratories, March 1995.

ⁱⁱ Hybrid Power Systems – Issues & Answers, Sandia National Laboratory

<http://photovoltaics.sandia.gov/docs/Hybook.html>

ⁱⁱⁱ Danish Wind Industry Association

<http://www.windpower.org/en/tour/wres/enerwind.htm>

^{iv} King, David, Thomas D. Hund, William E. Boyson, and Jay A. Kratochvil, “Experimental Optimization of the Performance and Reliability of Stand-Alone Photovoltaic Systems”, *Sandia National Laboratories*

^v Wiles, John C., Bill Brooks, and Bob-O Schultze, “PV Installations, A Progress Report”, Southwest Technology Development Institute, Endecon Engineering, and Electron Connection