

# RECLAMATION

*Managing Water in the West*

Technical Memorandum No. 8540-2017-012

## Powering Cathodic Protection Systems with Alternative Energy

Research and Development Office  
Science and Technology Program  
Final Report ST-2017-1718-01



U.S. Department of the Interior  
Bureau of Reclamation  
Research and Development Office  
Denver, Colorado

September 2017



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<b>T1. REPORT DATE</b> September 2017		<b>T2. REPORT TYPE</b> Research		<b>T3. DATES COVERED</b> Dec 2016 - Sep 2017	
<b>T4. TITLE AND SUBTITLE</b> Powering Cathodic Protection Systems with Alternative Energy				<b>5a. CONTRACT NUMBER</b> 17XR0680A1-RY15412017IS11718	
				<b>5b. GRANT NUMBER</b>	
				<b>5c. PROGRAM ELEMENT NUMBER</b> 1541	
<b>6. AUTHOR(S)</b> Kelly Ramaecker, Lise      Bureau of Reclamation Gentry, Atousa Plaseied      Denver Federal Center PO Box 25007 Denver, CO 80225-0007				<b>5d. PROJECT NUMBER</b> 1718	
				<b>5e. TASK NUMBER</b>	
				<b>5f. WORK UNIT NUMBER</b> 86-68540	
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b> Bureau of Reclamation Materials & Corrosion Laboratory PO Box 25007 (86-68540) Denver, Colorado 80225				<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b> 8540-2017-012	
<b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> Research and Development Office U.S. Department of the Interior, Bureau of Reclamation, PO Box 25007, Denver CO 80225-0007				<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b> R&D: Research and Development Office BOR/USBR: Bureau of Reclamation DOI: Department of the Interior	
				<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b> ST-2017-1718-01	
<b>12. DISTRIBUTION / AVAILABILITY STATEMENT</b> Final report can be downloaded from Reclamation's website: <a href="https://www.usbr.gov/research/">https://www.usbr.gov/research/</a>					
<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b> The goal for this study was to identify commercial and more cost effective alternative energy sources to the existing ones that will still allow ICCP systems to meet their operating requirements. Five commercially available alternative power sources as potential sources of power for ICCP systems at Reclamation were evaluated. Of all the alternative energy sources investigated, solar power appears to provide the best fit as the primary alternative power source, although it can be dependent on the site having good solar resources. The higher variability of wind power with low wind turbine elevations and the desire to minimize visual impact makes it less desirable in locations with good solar resources. TEGs, fossil fuel combustion generators, and fuel cells require significant staff involvement on an ongoing basis at the sites.					
<b>15. SUBJECT TERMS</b> Cathodic Protection, Alternative Energy, Solar, Wind, Thermoelectric Generator, Fuel Cell					
<b>16. SECURITY CLASSIFICATION OF:</b> U			<b>17. LIMITATION OF ABSTRACT</b> U	<b>18. NUMBER OF PAGES</b> 59	<b>19a. NAME OF RESPONSIBLE PERSON</b> William Kepler
<b>a. REPORT</b> U	<b>b. ABSTRACT</b> U	<b>c. THIS PAGE</b> U			<b>19b. TELEPHONE NUMBER</b> 303-445-2386



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## **Mission Statements**

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

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

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**BUREAU OF RECLAMATION**  
**Technical Service Center, Denver, Colorado**  
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**Technical Memorandum No. 8540-2017-012**

# **Powering Cathodic Protection Systems with Alternative Energy**

**Final Report ST-2017-1718-01**

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## Peer Review Documentation

From TSC Guidelines: <http://intra.do.usbr.gov/~tsc/guidance/operating/op-guide.pdf> (page 18)

### Project and Document Information

Project Powering Cathodic Protection Systems with WOID Z1718  
Name Alternative Energy

Document Powering Cathodic Protection Systems with Alternative Energy

Document Date September 2017

Document Author/Preparer Kelly Ramaeker, Lisa Gentry, P.E., Atousa Plaseied, Ph.D., P.E.

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## Executive Summary

The purpose of this scoping study is to identify commercial and more cost effective alternative energy sources to the existing ones that will allow impressed current cathodic protection (ICCP) systems to meet their operating requirements. This study is a comprehensive literature review containing:

- Requirements for ICCP system power sources, including component redundancy requirements and backup power requirements.
- Alternative energy sources which would meet the operating criteria for ICCP power sources.
- Cost evaluations for each alternative energy source and cost comparison against traditional utility provided electric power connections.

Providing utility supplied cathodic protection (CP) power sources can often be prohibitively expensive in rural and isolated areas. A need for more cost efficient power sources is pushing the Bureau of Reclamation (Reclamation) to consider alternative energy sources with new installations. It is important to understand the capabilities of the alternative energy source and needs of the CP system to prevent use of a system in an application for which it is not well suited.

While alternative energy sources are available, Reclamation does not have experience in installing or operating them for ICCP applications. This can cause problems in deploying these sources for the first time due to the unique challenges non-utility based power supplies can face. This study evaluates five commercially available alternative power sources (solar power supply, fossil fuel combustion engine generator supply, thermoelectric generator supply, wind turbine supply, and fuel cell supply) as potential sources of power for ICCP systems at Reclamation.

In addition to evaluating the power supply options based on the listed criteria, there is also a brief description of each power supply option and some of the general challenges that are faced in their implementation. We need to continue studying these technologies as Reclamation moves closer to deploying them.

## **Acknowledgements**

The authors are grateful for funding support from the Bureau of Reclamation Science and Technology Program.

## Acronyms and Abbreviations

°C	degree Celsius
°F	degree Fahrenheit
A	ampere
AC	alternating current
AGS	automatic generator start
Ah	ampere-hour
a-Si	amorphous silicon
ASTM	American Society for Testing and Materials
CdTe	cadmium telluride
CIS/CIGS	copper indium gallium selenide
C <sub>p</sub>	coefficient of power
CO <sub>2</sub>	carbon dioxide
CP	cathodic protection
CSP	concentrated solar power
DC	direct current
DOD	depth of discharge
gph	gallons per hour
GTEG	gas fuel thermoelectric generator
ICCP	impressed current cathodic protection
IEC	International Electrochemical Commission
IEEE	Institute of Electrical and Electronics Engineers
in	inch
kg	kilogram
kW	kilowatt
kWh	kilowatt hour
mA	milliampere
mA/m <sup>2</sup>	milliampere/square meter
mm	Millimeter
MPPT	maximum power point tracking
mV	millivolt

MW	megawatt
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NM	New Mexico
NREL	National Renewable Energy Laboratory
OPC	organic photovoltaic cell
PEM	polymer electrolyte membrane
PG&E	Pacific Gas and Electric Company
psi	pounds per square inch
PV	photovoltaic
PWM	pulse width modulation
Reclamation	Bureau of Reclamation
SGS	Small General Service
SiN	silicon nitride
SOC	solid oxide cell
SOFC	solid oxide fuel cell
TEG	thermoelectric generator
TFPV	thin-film photovoltaic cell
U.S.	United States
V	volt
V <sub>DC</sub>	volts direct current
VA	volt-ampere
VPC	volts per cell
W	watts
WA	Washington (State)

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## Introduction

The purchasing and installation of pipelines represent a significant portion of the project costs for water delivery and storage projects performed by the Bureau of Reclamation (Reclamation). Given these costs, it is important for the long term success of these installations to maximize the lifetime and use of the pipelines. For metallic components corrosion is a leading cause of premature failure and must be considered when designing the system. However, corrosion can be mitigated by many widely used commercially available products such as coating systems applied to the components and cathodic protection (CP) systems.

The purpose of CP is to reduce the corrosion current flow on a metallic structure's surface caused by the potential differences between local anodic and cathodic sites. This is accomplished by imposing current between the structure and an external electrode. The external current from the electrode polarizes the cathodic sites in the electronegative direction. Corrosion will halt when there is no longer a potential difference between the cathodic and anodic sites on a structure's surface [1].

Standard utility-supplied power sources are by far the most common and generally the most economical power supply used for the power requirements of impressed current cathodic protection (ICCP) systems. Alternative power supplies including solar, wind, thermoelectric generators (TEGs), combustion engine generators, and fuel cells are available when connections to the alternating current (AC) power grid are unavailable (the pipeline is far away from a power line) or are prohibitively expensive.

The goal of this scoping study is to identify commercial and more cost effective alternative energy sources to the existing ones that will still allow ICCP systems to meet their operating requirements.

## Components of the Impressed Current System

An ICCP system uses a power supply (rectifier) to generate large potential differences, enabling current to flow from the anode bed to the structure being protected. The components of an ICCP system are: anodes, a power supply (rectifier), structure, wiring, and connections (see Figure 1). A transformer-rectifier is a piece of equipment that steps down the AC voltage and then converts it to direct current (DC) voltage. If a DC power source with an appropriate current and voltage rating is supplied, then a rectifier is no longer required, and a variable resistor can be used.

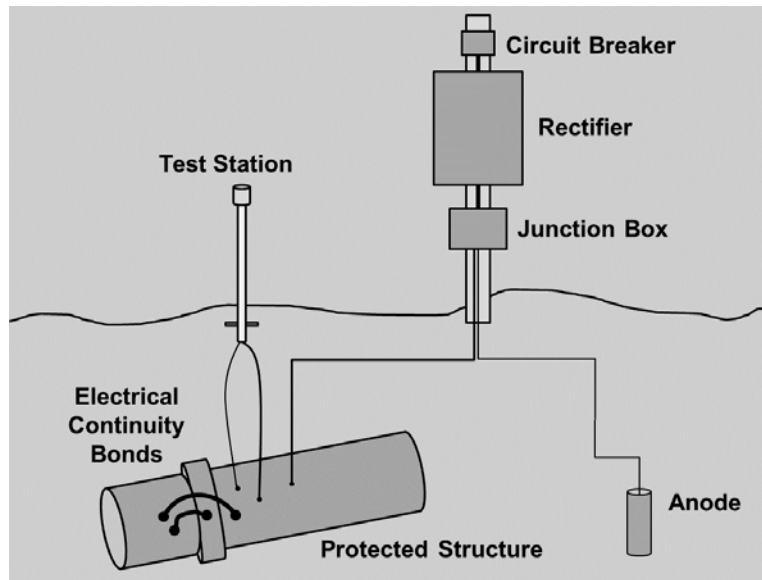


Figure 1.—Typical impressed current cathodic protection

ICCP operates with an external power source paired with inert anodes. This system is often required for the protection of large surface areas or if the resistivity of the electrolyte is high. In ICCP systems, the amount of protection does not depend on the anode activity because of the paired external power source. Typically, DC output will be in the range 12 to 30 volts (V) and 5 to 20 ampere (A) (generally 20 V and 15 A or smaller for Reclamation projects). To ensure that enough current is being supplied for the protection of the metal structure, the power source for the ICCP system should be optimized on a system-by-system basis. Typically, a structure current density in the range of 11-22 mA/m<sup>2</sup> is required for bare metal in soil. It is crucial to use ICCP systems continuously with a constant supply of electricity [2].

## Operating Requirements of Impressed Current Cathodic Protection Systems

In an impressed current system utilizing a rectifier, the power to the rectifier cannot be interrupted except when conducting maintenance or testing activities. Normally, a dedicated circuit is provided for the impressed current system so that the power cannot be inadvertently cut off [3]. Note that corrosion is not always going to happen without an ICCP system on, but is rather a possibility or probability. It means that there are pipes that have had the ICCP system off for years and a catastrophic failure has not occurred. However, at the same time there were failures in pipes in a short period of time with no ICCP on.

Power interruption (caused by utility power failure, equipment failure, vandalism, or maintenance requirements) can lead to extensive corrosion of metallic surfaces and metal reinforcement, especially in high corrosive environments and, thus, a reliable source of power for the CP current is essential. A detailed evaluation of the impact of short duration power outages is not included in this report and would require further investigation.

## **Power Sources**

Anything that can provide an electric power supply of 15 A at 20 V<sub>DC</sub> is capable of acting as an energy source for an ICCP system. The operating requirements of an ICCP system impose additional conditions on the power source so that it can be capable of providing reliable power with few interruptions of power. Different energy sources achieve this, either by having high reliability in the primary energy supply or by having a combination of components, which provide high overall power reliability.

A relative cost analysis is performed in this report for each of the energy supply options evaluated. The intent of this analysis to provide a general order of magnitude evaluation on the cost of the power supply installation. This evaluation does not include costs for the CP system, site preparation, or other installations on the site.

## **Utility Supply**

### **System Arrangement**

For utility supplied power the customer pays the electric power utility to bring a distribution power line to the location of the ICCP rectifier. If the location of the rectifier is near existing power lines, this cost might be minimal. If the location of the rectifier is a significant distance from available power lines, this cost can be extremely high. The cost to provide power to an individual location can be variable with connection costs anywhere from a thousand dollars to millions of dollars. This varies, based on the distance and amount of equipment required to be installed by the electric utility, as well as the pricing structure used by the utility. It is important when using utility supplied power to contact the utility company during the design process to evaluate the probable cost of the electrical connection.

Utility supplied power sources require little equipment for the customer to supply beyond the point of interconnection. Generally these installations only require an

electric disconnect switch and some cable to connect the power source to the rectifier. See Figure 2 for a typical utility supply arrangement.

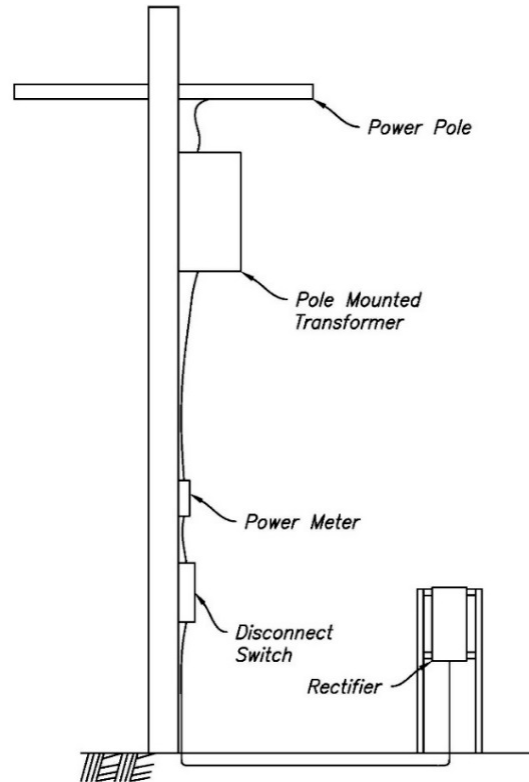


Figure 2.—Typical utility distribution arrangement

## Reliability

The reliability of a utility supplied power source is generally very high. As an example, electric utility Pacific Gas and Electric (PG&E) Company's customers experienced on average a sustained outage of 95.8 minutes in 2015 [4]. Due to the high level of reliability backup power equipment, like batteries, are rarely supplied for ICCP systems designed by Reclamation.

## Maintainability

Utility sources require monthly visits to the site to perform a visual inspection of the power components. The type of components required for this system allow it to withstand a wide variety of environmental conditions.

## Relative Cost

### *Installation*

As discussed earlier, the installation costs for utility power sources can be highly variable due to the cost of the utility connection.

### *Operation*

The operating costs calculated below are based on the charges for a 15 A, 20 V<sub>DC</sub> load and the 2013 electric rates for Black Hills Energy [5]. Costs for labor and maintaining the system are not included in this evaluation.

Electric load: 300 watts (W)

Utility charge (based on rate classification Small General Service (SGS) [5]):

<b>Customer fee:</b>	<b>\$16.50/month</b>
<b>Monthly rate:</b>	<b>\$0.1042/ kilowatt hour (kWh)</b>
<b>Total yearly electric bill:</b>	<b>\$472</b>

## Solar Power Supply

### System Arrangement

Solar power comes in a variety of different system configurations, types, qualities and levels of reliability. Two types that have been successfully implemented in large scale commercial installations are solar photovoltaic (PV) and concentrated solar power (CSP). The installed capacity of PV systems was 25,599 megawatt (MW) in 2015, while the installed capacity of CSP systems was 1,795 MW [6]. Due to PV systems being far more widespread and the lack of commercially available small scale (less than 500 W) CSP systems, the PV systems will be the focus of this evaluation.

The core of PV solar panel systems are the PV cells assembled together into mountable panels, which are in turn wired together to form a solar array. Apart from that core component there are a wide range of system configurations that are used. The choice of system configuration to use is generally based on the operating requirements of the connected loads to which it is supplying power.

In PV panel based systems energy production is limited to the solar radiation supplied which results in an intermittent power supply. For systems requiring a continuous power supply, an energy storage system is required to supply power when the PV system's power production is not sufficient. A solar panel system for an off-the-grid CP system would require a reserve power system to be able to ride through periods of time when the solar panels are not producing power. This is usually provided through a battery system. A diagram of a typical solar panel system for this type of application is shown in Figure 3.

For the type of system arrangement shown in Figure 3, the ICCP system would be supplied from the power panel shown in the diagram. This has the benefit of providing a location from which additional site AC electrical loads can be supplied, but has the downside of requiring the power to be converted between DC and AC power twice. These conversions happen once at the inverter to go from DC to AC power and then again at the rectifier to go from AC to DC power.

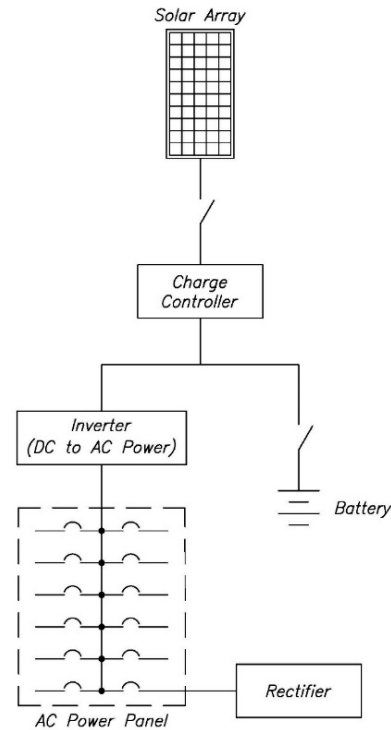


Figure 3.—Typical solar arrangement for CP application

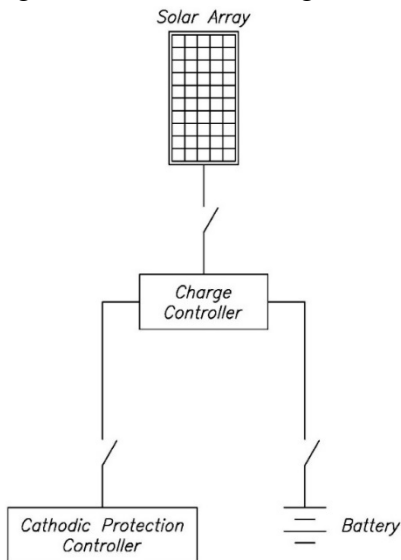


Figure 4.—Alternate solar arrangement for CP application

Figure 4 shows an alternate system arrangement for a system using solely DC power, without the conversions between AC and DC power. In this arrangement the PV charge controller and battery system produce DC power which is supplied directly to the ICCP system controller [7, 8]. The system shown in Figure 4 is the preferred alternative.

## Conditions Impacting Solar Photovoltaic Installations

One of the primary drivers impacting the design and suitability of solar PV installations is the amount and reliability of the solar radiation available at the site. This can be impacted by factors like the slope and direction of the site, cloudiness of the location, trees, or other structures that might block the sun and the solar resources generally available at the location. Figure 5 summarizes the annual average solar resource per day for a



tilt = latitude collector at various locations around the United States (U.S.). This map does not include factors that might impact specific local sites.

Another significant driver of the design of the solar array is the amount of cloud cover at the location of the solar panel system. Most of Reclamation's water delivery and storage projects are located in the Western U.S., so the cloud cover available at two locations in the west was chosen for comparison purposes. The mean monthly cloudy days for Albuquerque, New Mexico (NM), is shown in Figure 6, while the mean monthly cloudy days for Seattle, Washington (WA), is shown in Figure 7. The total annual number of cloudy days in Albuquerque, NM is 87 days, while the total annual number of cloudy days in Seattle, WA is 226 days [9]. Clearly this difference would have a significant impact on the design of the solar panel systems at these two locations.

The following additional conditions can also impact the viability and cost of installing a solar panel system at a given location [10]:

- Solar resource
- Available area
- Local climate
- Topography
- Land use
- Local regulations/land use policy or zoning
- Environmental designations
- Geotechnical conditions
- Accessibility
- Module soiling

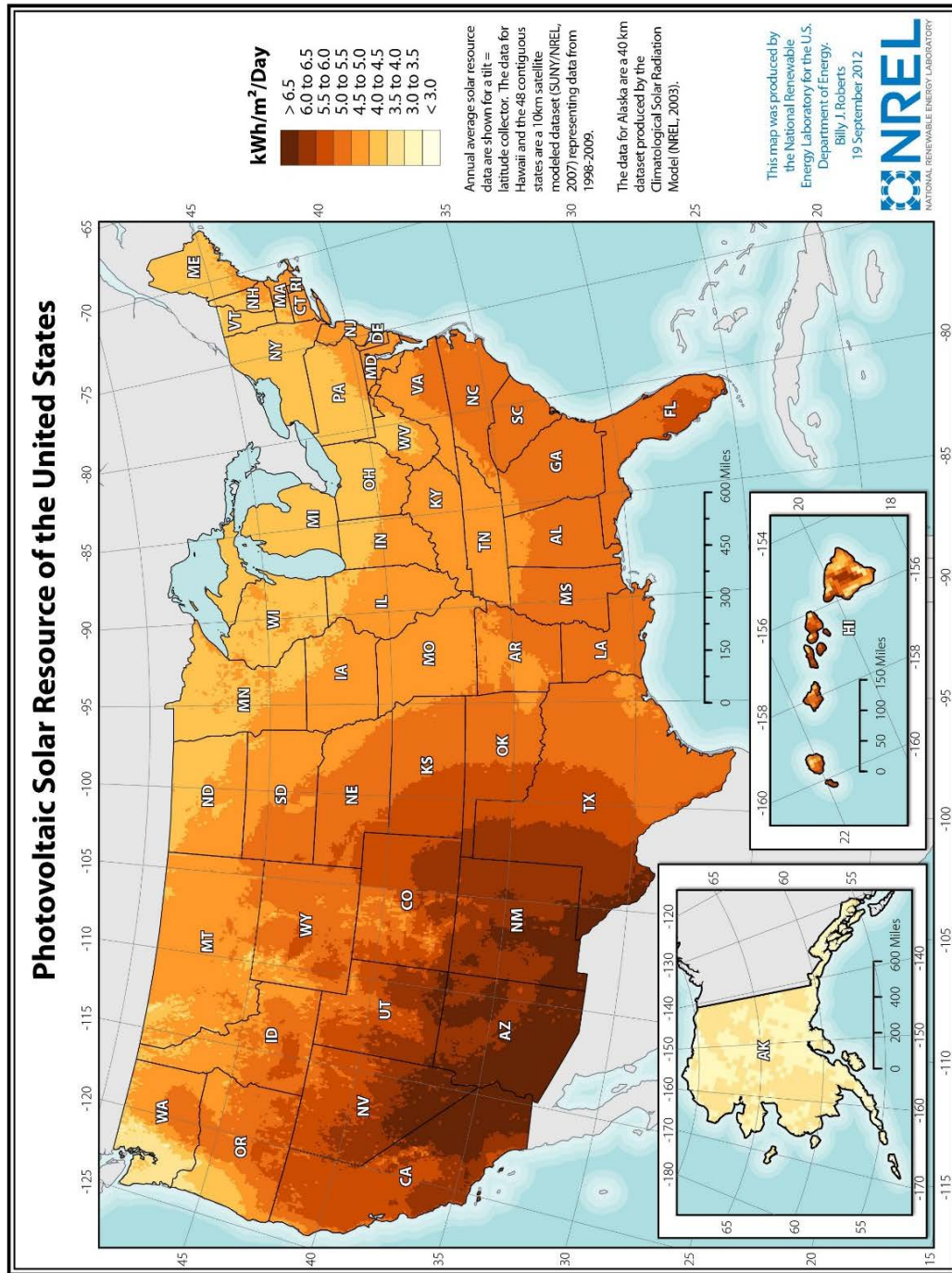


Figure 5.—PV solar resources of the U.S. [6]

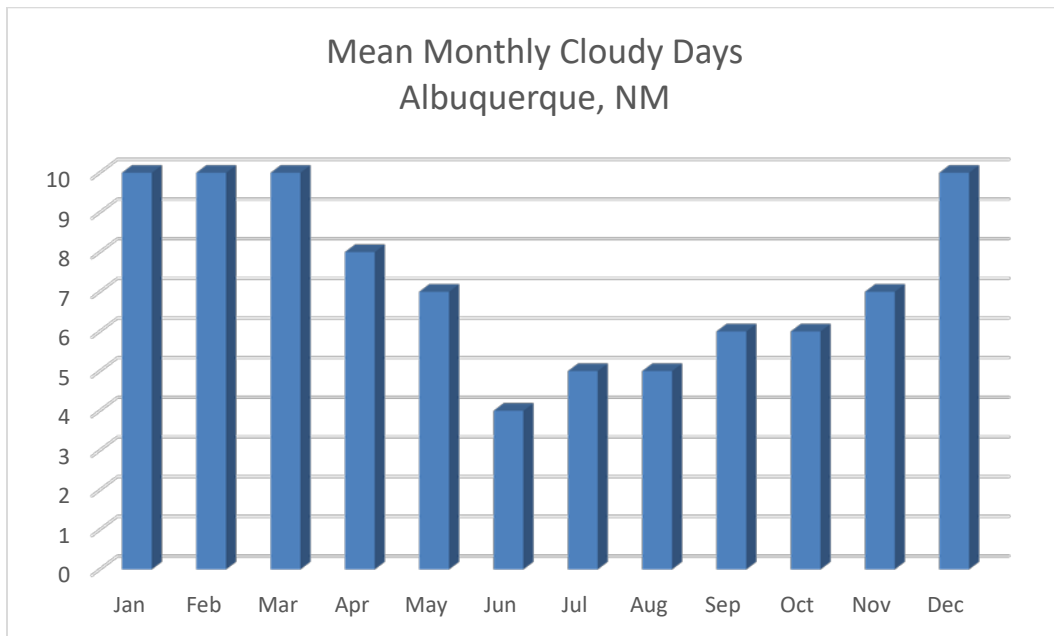


Figure 6.—Mean monthly cloudy days for Albuquerque, NM [9]

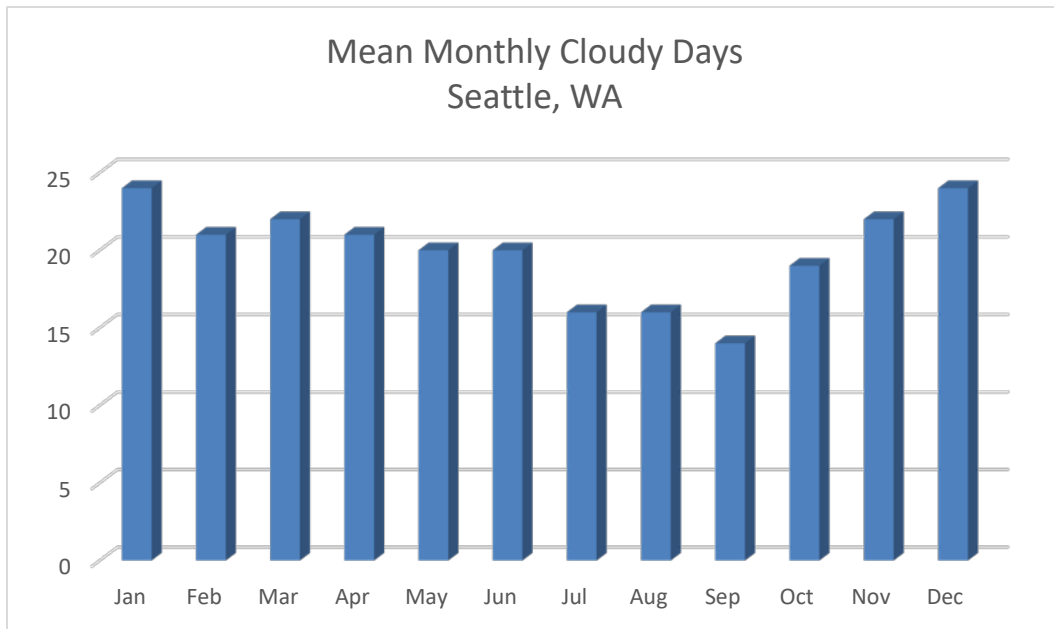


Figure 7.—Mean monthly cloudy days for Seattle, WA [9]

A final important consideration is site security and the impact of vandalism on the equipment. While many of Reclamation’s water delivery and storage project sites are located in rural or other sparsely populated areas they are still vulnerable to vandalism. For example, at some locations the equipment is routinely shot at and

damaged. These factors can influence equipment redundancy requirements as well as siting and decisions impacting equipment visibility and security measures.

## **Sizing Solar Power Supplies**

When a solar panel system is used as a primary energy source both the PV system and the reserve power system (batteries) should be sized based on the electrical load, reserve power requirements, and conditions at the installation location. This design can also be impacted by considerations like the criticality of the components being powered by the solar panel system and how long the reserve power system needs to last.

The simplest place to start when performing this evaluation is with the electrical load and the elements drawing power for immediate use. In the case of the system described in Figure 4, this would be the CP controller. For the purpose of this evaluation the assumed electrical load of the CP is approximately 300 W, the same electrical load used as the example in the Utility Supply section.

The next step is to determine the reserve power requirement. This is based on the electrical load to be supplied and the duration that backup power is required for the electrical load. Due to the importance of maintaining power to the ICCP systems the backup power duration should be chosen to minimize the power outages that the system will experience. This should include consideration of the location where the system will be installed and the length of time between charging periods where the solar panels will be able to fully charge the batteries.

In an example of a 300 watts (W) CP system located in Albuquerque, NM, the solar panel system would require a shorter backup power duration than one located in Seattle, WA, due to the reduced cloud cover that the location would experience. Given a mean of ten cloudy days per month in Albuquerque, a backup power for three days, or 72 hours, should provide a relatively reliable power source at this location. This duration along with the electrical load allows the battery to be sized according to the Institute of Electrical and Electronics Engineers (IEEE) 1013 [11] battery sizing criteria, including incorporating aging factors for the battery size. The down side of choosing a relatively high backup power duration is that it significantly increases the size of the batteries required. This also leads to higher output power requirements from the solar panels because they should be sized to fully recharge the battery within a single charging window.

Once the electrical load and the electrical load associated with recharging the battery system have been determined. The National Renewable Energy Laboratory (NREL) has an online tool PVWatts<sup>®</sup> Calculator [12], which can be used to estimate the size of the solar panels.

## **Components**

### ***Solar Panels***

About 90 percent of the world's PVs today are based on silicon. The efficiency of solar energy conversion to electricity depends on the purity of the silicon and the quality of its crystal structure. However, the manufacture of high purity silicon PV cells is expensive and must be balanced with other factors to achieve reasonable cost of the product [13].

In general, silicon-based PV cells can convert sunlight to energy at efficiencies between 8 and 20 percent and have a lifetime of no more than 30 years [10, 13]. A comparison of various types of solar cells can be found on the Energy Informative website [13].

### ***Charge Controller***

A charge controller supplies power to the battery to either maintain or recharge it while also supplying power to the electrical loads. The charge controller is also often used to regulate the voltage and charging current output from the controller to prevent supplying voltage or current outside of the battery's charging limits. The input and output power range of the charge controller should be coordinated with the solar array design and batteries purchased.

For instance GNB's Sunlyte 12-5000x battery is a 6 cell 12 V battery and lists a charge voltage of between 2.28-2.38 V per cell with a 30 A maximum current [14]. For use with these batteries the charge controller would need to be rated to supply power within this voltage range. The output of most solar panels used for solar panel systems of this type, supplying over 300 W, will not maintain a voltage within the window of charge voltage that the battery requires. Failure to maintain this voltage, for instance by supplying voltage that is too high, can prematurely age the battery or cause other damage.

Charge controllers are available in various shapes, sizes, features, and price ranges. They can be found as simple as 4.5 A controllers and can become as complex as 80 A controllers with a computer interface that can be used for system monitoring. For larger current requirements, multiple units can be wired in parallel. Generally, there are three types of charge controllers: 1 or 2 stage controllers that rely on relays or shunt transistors to control the voltage, the industry-standard 3 stage and/or pulse width modulation (PWM) controllers, and high-efficiency maximum power point tracking (MPPT) controllers [15].

## ***Batteries***

Batteries are rated in terms of Ah capacity, which is related to the amount of current a battery can supply for a specific time interval. Deep-cycle batteries designed for many charge/discharge cycles should be used for CP applications. A battery system must be able to supply the required output current before its replacement. The life cycle for lead-acid batteries varies depending on the quality of the battery purchased and how it is used, but temperature extremes can have a substantial effect on the longevity and output capacity of batteries.

## **Reliability**

The reliability of the solar panel system is impacted by both the reliability of the components that comprise the solar panel system and the reliability of conditions suitable to produce solar power. As discussed earlier, the availability of solar resources at the site must be evaluated to determine the duration of the backup power requirements.

## **Maintainability**

Solar panel systems in off-the-grid installations require routine maintenance to sustain operation. The solar panels and charge controllers will require periodic inspections to ensure that they are operating properly and have not been damaged. The battery systems require yearly testing and evaluation to monitor their health and current condition. Battery systems can fail relatively rapidly once they hit the point where aging accelerates. In addition, special maintenance activities may be required based on the weather conditions. These include periodically checking the arrays for things like snow or dust accumulation after weather events.

## **Relative Cost**

### ***Installation***

The equipment costs are based on purchasing a 5 kW solar panel array and a battery backup system to supply an ICCP system. The cost evaluation doesn't include the cost of the ICCP system components. This is intended for informational purposes only and does not include a detailed list of all components required for an installation of this type.

Electric load: 300 W

Solar panel array rating: 5 kW

- For this example a 5 kW solar array is used. This array uses 16 LG

NeON<sup>®</sup> 2, 33 W solar panels.

Solar panel system purchase price: \$359.99 [16] x 16 panels

**Total cost: \$5,759.84**

Battery system: 600 ampere-hour (Ah), 48 V

- This is based on a rough battery sizing estimate using a 300 W load at 48 V<sub>DC</sub> for approximately 72 hours with a 20 percent aging factor. It should be noted that actual battery sizing calculations should be done in accordance with the appropriate IEEE standard.
- For this example four GNB Industrial Power Absolyte<sup>®</sup> GP Model 6-90G11, 12 V, valve regulated lead acid batteries are used.

Battery purchase price: \$2,027.03 [17] x 4 6-90G11 batteries

**Total cost: \$8,011.96**

Charge controller:

- Suitable for recharging battery from a solar panel system.
- For this example a Morningstar Tristar MPPT 600 V 60 A charge controller is used.

Charge controller purchase price: \$1,599.00 [18] x 2 Morningstar Tristar MPPT 600 V 60 A charge controllers

**Total cost: \$3,198.00**

Power distribution components:

- Miscellaneous circuit breakers, electrical disconnects, etc.

**Purchase price: \$1,000.00**

Battery and inverter enclosure: National Electrical Manufacturers Association (NEMA) 250 type 3R enclosure

- Enclosure with internal racking system and cooling system.

**Enclosure purchase price: \$5,000.00**

Miscellaneous Components:

- Include cable, conduit, battery connectors, grounding components, etc.

**Miscellaneous components purchase price: \$2,000.00**

Labor

**Labor cost: \$3,500**

**Total: \$28,500**

## ***Operation***

Solar panel systems do not include consumable fuel sources or yearly utility fees. Costs for labor and maintaining the system are not included in this evaluation.

## **Standards for Solar Panel Systems and Specific Batteries**

### **Underwriters Laboratories Inc. Standards**

UL 1703-2002.–Standard for Flat-Plate Photovoltaic Modules and Panels

### **International Electrochemical Commission Standards**

IEC 61215-2005.–Crystalline Silicon Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval

IEC 61646-2008.–Thin-film Terrestrial Photovoltaic Modules – Design Qualification and Type Approval

### **The Institute of Electrical and Electronics Engineers Standards**

IEEE 1526-2003.–Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems

IEEE 1361-2003. –Guide for Selection, Charging, Test and Evaluation of Lead-Acid Batteries Used in Stand-Alone Photovoltaic Systems

IEEE 1562-2007.–Guide for Array and Battery Sizing in Stand-Alone Photovoltaic Systems

IEEE 937-2007. –Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic Systems

IEEE 1013-2007.–Recommended Practice for Sizing Lead-Acid Batteries for Stand-Alone Photovoltaic Systems

IEEE 1561-2007.–Guide for Optimizing the Performance and Life of Lead-Acid Batteries in Remote Hybrid Power Systems

## **Resources and Manufacturers**

**Invensun** produces solar panels ranging between 5 W and 300 W. They use a combination of grade A solar cells and a silicon nitride (SiN) coating to ensure that the solar panels are efficient and long-lasting. [19].

**Morningstar** provides solar controllers and inverters [20].

**Evergreen Solar** manufactures solar panels using “the string ribbon technology” [21].



**Ameresco Solar** manufactures solar panels, batteries, controllers, inverters, mounting, enclosures, pre-wired backplates, and wiring and cables. It also offers a variety of pre-packed off-grid solar kits to meet a range of power needs [22].

**SolarRay.com** installs solar-powered CP systems across Wyoming, Utah, and Colorado jointly with United Contracting. Figures 8a and 8b show two of their operational systems in Utah and Colorado, respectively [23].



Figure 8.—CP system installed for Chevron Oil with  
(a) 245 W modules, batteries, and charge controllers in Utah, and  
(b) 20 A output in Colorado, reproduced from [23]



Figure 9.—Sunpole solar panel system, reproduced from (Farwest Corrosion Control Company, n.d.)

**Farwest Corrosion Control Company** offers the Sunpole solar panel system (see Figure 9). This is up to a 24 V, 2 A preassembled pole-mounted system designed to provide 100% of daytime current during sunlight hours with a 50% cut at night [24].

**Solarcom France** offers solar micro-stations designed to power 12 V / 24 V or 48V low power loads [25].

**Solaire Powering Systems** manufacture solar panel arrays that can provide controllable 50 V and 50 A power [26].

**OkSolar** offers a variety of CP solutions using remote off-grid solar panel systems [27].

**Absolyte® GP Batteries** sells large valve-regulated lead-acid batteries [17].

**Sunlyte® Bloc Batteries** claim a “deep-cycle capability, long life, and low self-discharge rate” [28].

**Sonnenschein® Solar Batteries** are especially suited for small to mid - range power systems [29].

## Fossil Fuel Combustion Engine Generator Supply

### System Arrangement

Fossil fuel combustion engine generators generate power through combustion of fossil fuels and are commercially available in a variety of different arrangements, electrical ratings, and fuel options. Choosing a specific generator for an application is based on a variety of factors like availability of fuel sources and size of the electrical load the generator is supplying. When used in an off-the-grid application, like the ICCP system application, for a relatively small electrical load the generator is often used in combination with a reserve power system, like batteries, to reduce run time on the generator by charging the batteries. This prevents the generator from having to run continuously. A typical arrangement for these types of systems is shown in Figure 10.

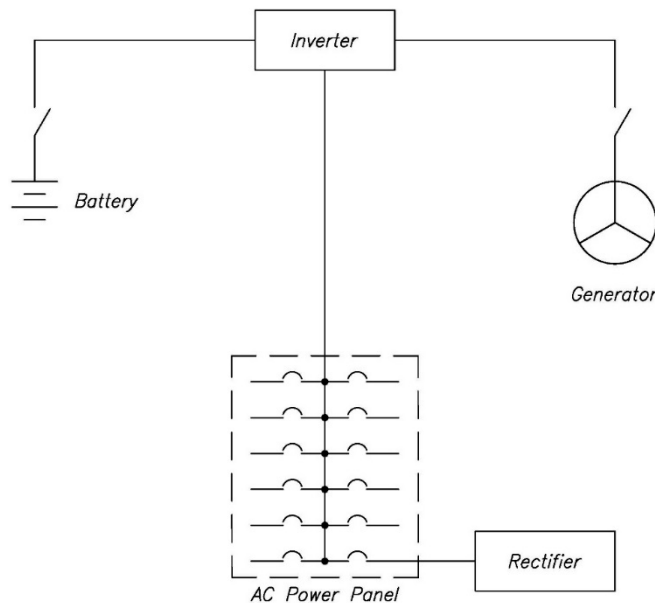


Figure 10.—Typical generator arrangement for CP applications

Similar to solar panel systems, generators should be sized for the electrical load that they are supplying and accommodate recharging the battery within the generator's rated output. This can be complicated when motors, or other electrical loads that experience a current spike on start-up, are connected to the electrical distribution system. In those cases, the chosen equipment rating needs to accommodate supporting those loads without allowing too high of a voltage drop. The arrangement shown in Figure 10 for the ICCP system does not include any loads with high current spikes on start-up, so this issue does not need to be accounted for and a relatively straight forward generator sizing evaluation can be performed.

Generator electrical ratings have two parts:

- the rated maximum real power output, often expressed in watts, and
- the rated power factor.

The generator should have an appropriate power factor to be able to start and run the electrical loads it is connected to. The power factor rating is not as important for generators that are running static (non-rotating) loads. Many locales require generators to have environmental permitting, particularly regarding emissions, depending on the size of the generator, functionality, and variety of fuel. These restrictions should be considered when selecting a generator.

## **Fuel Types**

Various types of fossil fuels can be used in generators, including: diesel, propane, gasoline, and natural gas. Gasoline is frequently used by small generators and natural gas is common in larger generators. However, small gasoline generators typically require frequent tank refilling and natural gas generators require access to a natural gas line, so these systems are rarely used by Reclamation for continuous service in remote locations where the water delivery CP systems are located. Generators using diesel and propane are the most common in Reclamation facilities, however due to the remoteness of the CP rectifier locations this can present problem with supply and inspection. Propane tanks can supply generators rated up to 200 kW, and are often supplied using propane tanks or cylinders. Diesel generators are available at higher power ratings than propane generators and use liquid fuel stored on-site in tanks.

The sizing of the fuel system is dependent on the fuel consumption of the generator and the amount of time needed for operation between refueling. In remote locations, several days or weeks of fuel may be supplied to limit the number of required refueling trips. Sizing fuel systems for long periods between refueling trips can significantly increase the size of the fuel tank or other fuel storage systems. The differences in delivery methods can lead to preferences between fuel types at some locations. The propane generators can be favored over other generator fuel types for remote systems of the size used for the CP systems. This is due to a general availability of propane in rural areas and because the delivery vehicles for propane cylinders are often smaller trucks and relatively maneuverable.

There are different national codes and local permitting requirements that can apply to generators with different uses and fuel sources. Permitting requirements also vary between fuel types based on fuel emissions. Since propane operates with less emissions than diesel, it is preferred in more stringent states like California. As permitting requirements vary by location this should be investigated with the proper permitting authority early on in the project planning stages.

The fuel choice can also affect some security considerations for the site with the generators. Diesel fuel can be easier to steal from tanks than propane, however propane is more combustible and is easier to blow up when vandals shoot at it.

## **Reliability**

Fossil fuel generators have a fuel source that can be highly reliable and, unlike wind and solar, is not dependent on the climate or other outside factors in the availability of its fuel source. The downside with these generators is that they

have many moving parts and components and can have relatively high maintenance requirements. These generators require routine maintenance and can quickly become unreliable when not adequately maintained. In addition, the fuel supply may have additional needs according to climate conditions. Items like fuel additives, heaters, or other equipment may be required to allow proper operation of the generator.

## Maintainability

These generators require a relatively high level of staff interface and effort. This is required both for the routine fuel deliveries to the remote sites and for the relatively high levels of maintenance that these generators and fuel systems require. Fuel deliveries can become more challenging during adverse weather conditions, like snow, which can impact the reliability of the power source if the fuel cannot be delivered.

## Relative Cost

### *Installation*

The equipment costs are based on purchasing an 8 kW propane generator and a battery backup system to supply an ICCP system, the cost evaluation does not include the cost of the ICCP system components. This is intended for informational purposes only and does not include a detailed list of all components required for an installation of this type.

Electric load: 300 W

Generator rating: 8 kW

- For this example an 8 kW Briggs & Stratton Standby Generator System, which operates by using liquid propane, is used. This generator includes an enclosure for outdoor installation.

**Generator purchase price: \$2,184.00 [30]**

Battery system: 430 Ah, 48 V

- This is based on a rough battery sizing estimate using a 300 W load at 48 V<sub>DC</sub> for approximately 48 hours with a 20 percent aging factor. It should be noted that actual battery sizing calculations should be done in accordance with the appropriate IEEE standard.
- For this example four GNB Industrial Power Absolyte<sup>®</sup> GP Model 6-50G13, 12 volt, valve regulated lead-acid batteries are used.

**Battery purchase price: \$1,746.20 [17] x 4 6-50G13 batteries**

Hybrid inverter / charger:

- Suitable for off-grid applications, intended for AC input from the generator. Includes an interface for automatic generator start.
- For this example a 6800 W Schneider Electric Conext XW+ hybrid inverter charger, a Schneider Electric Conext control panel and a Schneider Electric Conext Automatic Generator Start (AGS) module are used.

**Hybrid inverter/charger purchase price: \$3,629.80 [31] + \$249.47 for the control panel [32] + \$200.00 for AGS module [17].**

Power panel, circuit breakers, and electrical disconnects:

- Miscellaneous power panels, circuit breakers, and electrical disconnects.

**Purchase price: \$1,000.00**

Battery and inverter enclosure: NEMA 250 Type 3R Enclosure

- Enclosure with internal racking system and cooling system.

**Enclosure purchase price: \$5,000.00**

Miscellaneous Components:

- Include cable, conduit, battery connectors, grounding components, etc.

**Miscellaneous components purchase price: \$2,000**

Labor

**Labor cost: \$3,500**

**Total: \$25,000**

## ***Operation***

The operating costs calculated below are based on the fuel charges for operating the propane generator for a year. Costs for labor and maintaining the system are not included in this evaluation.

Generator rating: 8 kW

- This generator has a liquid propane consumption of 0.97 gallons per hour (gph) [30].

Battery discharge time:

- The battery is sized to support approximately 48 hours of run time for the ICCP system at maximum load [17].

Battery recharge time:

- The battery rating developed in the installation cost estimate was 430 Ah at 48 V. The inverter rating is 6,800 W, with a maximum

charge current of 140 A. It will take roughly 3.5 hours to recharge the battery when factoring in the continued current draw from the ICCP system during the recharge cycle [17, 32].

Total generator runtime (yearly):

- The total cycle, generator charging the battery and then the battery discharging, takes approximately 51.5 hours. Factoring the total hours in a year, 8,760 hours, the generator will run for approximately 595 hours a year. Based on the generator's fuel consumption of 0.97 gph this indicates that the generator will use approximately 577 gallons a year [30].

Generator fuel cost (yearly):

- Using a price for propane of \$2.169/gallon, from the U.S. Energy Information Administration Data on Petroleum and Other Liquids December 2017 data [33], and a yearly propane consumption of 577 gallons yields a rough cost of fuel of \$1,252 a year. This cost does not factor in additional fees, like the propane delivery cost to remote locations, and will experience variations over time and for localities.

## **Standards for Generators**

### **National Electrical Manufacturer's Association**

NEMA MG 1-2016: Motors and Generators

## **Resources and Manufacturers**

Major generator manufacturers include: Cummins Generators [34], Caterpillar Electric Power Generation [35], and Hyundai [36].

# **Thermoelectric Generator Supply**

## **System Arrangement**

Thermoelectric Generators (TEGs) run on fuel, like propane or natural gas, and convert heat energy directly to electrical energy by heating thermocouples in an internal burner. The heating creates small potentials across the thermocouple junction. These types of TEGs have three main components: heat source, thermopile, and cooling fins [37].

Typically, TEGs are rated based the amount of power produced. Generators with outputs of up to 48 V and 500 W can be purchased in conjunction with a variable power resistor to control the output of the TEG. These generators also require battery systems, fuel systems, and control systems to distribute fuel to the generators and coordinate the components.

National codes and local permitting requirements for TEGs require evaluation similar to the use of fossil fuel combustion engine generators. The impact of emission regulations on the generators may be different in some locations than those that impact the fossil fuel combustion engine generators, but the codes and standards for these fuel types still apply.

## **Reliability**

Thermoelectric generator systems operate by the use of fossil fuels, like natural gas or propane, so the fuel source can be independent of the climate or other outside factors. It is a relatively complex system and requires fuel, but does not have many moving parts, meaning that there is no significant maintenance required other than annual cleaning [38].

A downside is that current commercially available systems appear to be relatively limited in the amount of power that an individual unit can produce. The largest advertised unit found during a review of one of the manufacturer's product lines was listed as having a maximum power output of 550 W at 24 V [38]. If the product was paired with a battery system to power the CP system load, multiple units would be required.

## **Maintainability**

There are several challenges to these systems for maintainability. The first is due to the relatively small installed base for these types of generators in remote off-the-grid power generation applications. This small installed base would require additional time and planning for acquiring spare parts and training maintenance technicians. Another challenge is the need to provide routine deliveries of fuel to the site, which would require additional staff effort. These systems would also experience the same fuel system maintenance requirements as fossil fuel combustion generators.

## **Relative Cost**

Identifying a cost for deploying these systems across a project for ICCP systems is difficult due to the limited number of manufacturers currently making these



products for off-grid remote power applications. The fuel usage indicated for the largest 550 W Gentherm Global Technologies generator is listed on the datasheet as 20.1 gallons of propane a day [38]. This is roughly equivalent to the propane usage as the 8 kW generator used in the Fossil Fuel Combustion Engine Generator Supply evaluation (see section above).

## Resources and Manufacturers

**Farwest Corrosion Control Company** offers TEGs that are designed for impressed current for CP systems requiring between 10 VA and 1.5 kVA [39].

**Gentherm Global Power Technologies** supplies solid state systems to provide DC power to CP systems that operate on propane, butane, and natural gas [40].

**Kryotherm** offers gas fuel TEGs that can run on natural gas, propane or propane-butane mixture combustion [41].

## Wind Turbine Generator Supply

### System Arrangement

Wind turbine generators provide a small turbine energy source option that does not require periodic refueling. These turbines operate due to the kinetic energy of the wind, and are a possible energy source if a sufficient and steady source of wind is available. While there is a wide variety of wind turbines available (from very small up to large turbines used in utility wind farm applications) the turbines required for an ICCP system would generally be below 20 kW. This is due to the small size of the electric load for the ICCP system, 300 W, which would make it difficult to financially justify the use of a larger unit.

Due to the intermittent nature of the wind, a battery system would be required to provide backup power to the system when no power can be produced by the turbine. The backup battery system would be similar to those required for the solar application, although the battery sizing would need adjustment to account for the reliability of wind at the site.

Figure 11 shows a CP unit in Wyoming featuring both solar and wind power [23], while Figure 12 details an arrangement with a DC bus hybrid power system.



Figure 11.—A CP unit in Wyoming featuring both solar and wind power, reproduced from [23]

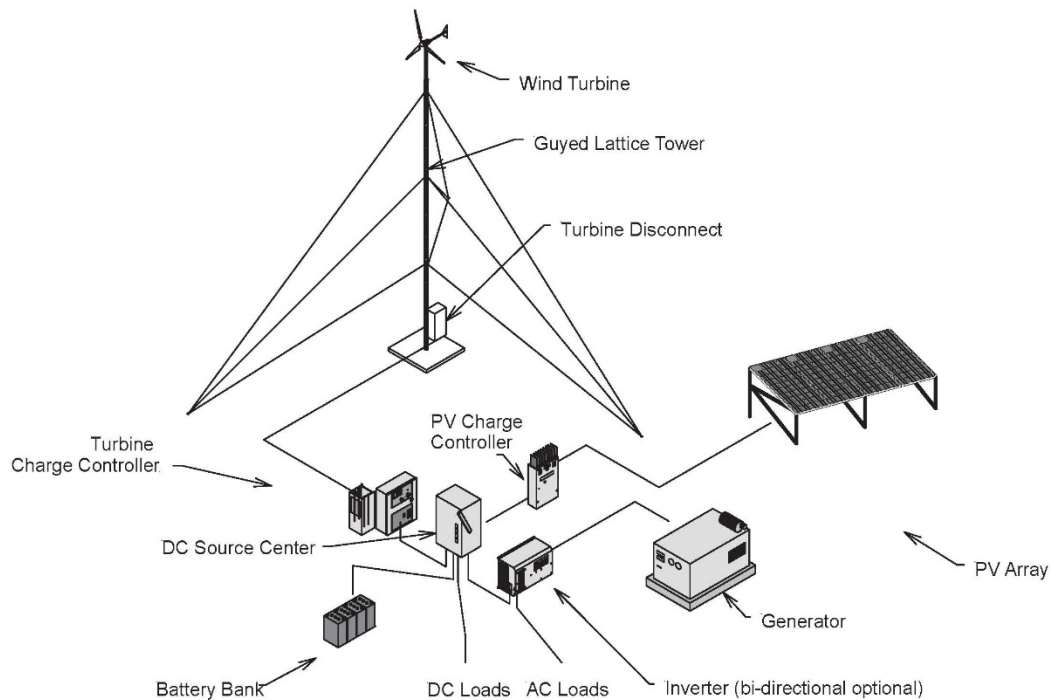


Figure 12.—Typical DC-bus hybrid power system, reproduced from [42]

## Conditions Impacting Wind Turbine Installations

Many of the same considerations that impact solar installations impact wind turbine installations too. Except where solar installations are concerned with the availability of solar resources, wind turbines are concerned with the availability of wind resources. Figure 13 summarizes the annual average wind speed at various

locations around the U.S. at a height of 80 m above grade [43]. Unfortunately, wind is significantly more variable than solar based on the elevation of the equipment above the ground. This can be seen when comparing Figure 13 to Figure 14, which shows the wind speed at a height of 30 m above grade. This variation in the wind based on the turbine elevation makes the height of the generator an important consideration. ICCP systems require small loads that would generally be paired with small turbines. This can put the wind turbines for ICCP systems on the low end of wind turbine elevation spectrum and impact their viability. The graphs shown in Figure 15 and Figure 16 from studies documented in a paper by Bowen, A. et al [44], provide preliminary power and coefficient of power ( $C_p$ ) curves for two small wind turbines.  $C_p$  is the electricity produced by the wind turbine divided by total energy available by the wind. As can be seen in the graphs, relatively significant levels of wind are required for much of the output from the turbines.

Individual sites can also experience variability in wind levels, which is not accurately reflected on the wind maps shown in Figure 13 and Figure 14. There can be geographic obstructions, which disproportionately impact shorter wind turbines, as well as other factors that can cause variability in the levels of wind. Due to the visual impact of tall wind turbines it would be unlikely to have a wind turbine for an ICCP application higher than 50 feet from grade elevation, although specific sites may get approval for a taller installation.

The following additional conditions can also impact the viability and cost of installing a wind turbine at a given location:

- Wind resource
- Available area
- Local climate
- Topography
- Land use
- Local regulations/land use policy or zoning
- Environmental designations
- Geotechnical conditions
- Accessibility

A final important consideration is site security and the impact of vandalism on the equipment. Similar to the solar panel systems, some locations are vulnerable to vandalism. Equipment is routinely shot at and can receive bullet damage. This has an influence on equipment redundancy requirements as well as locations and decisions impacting equipment visibility.

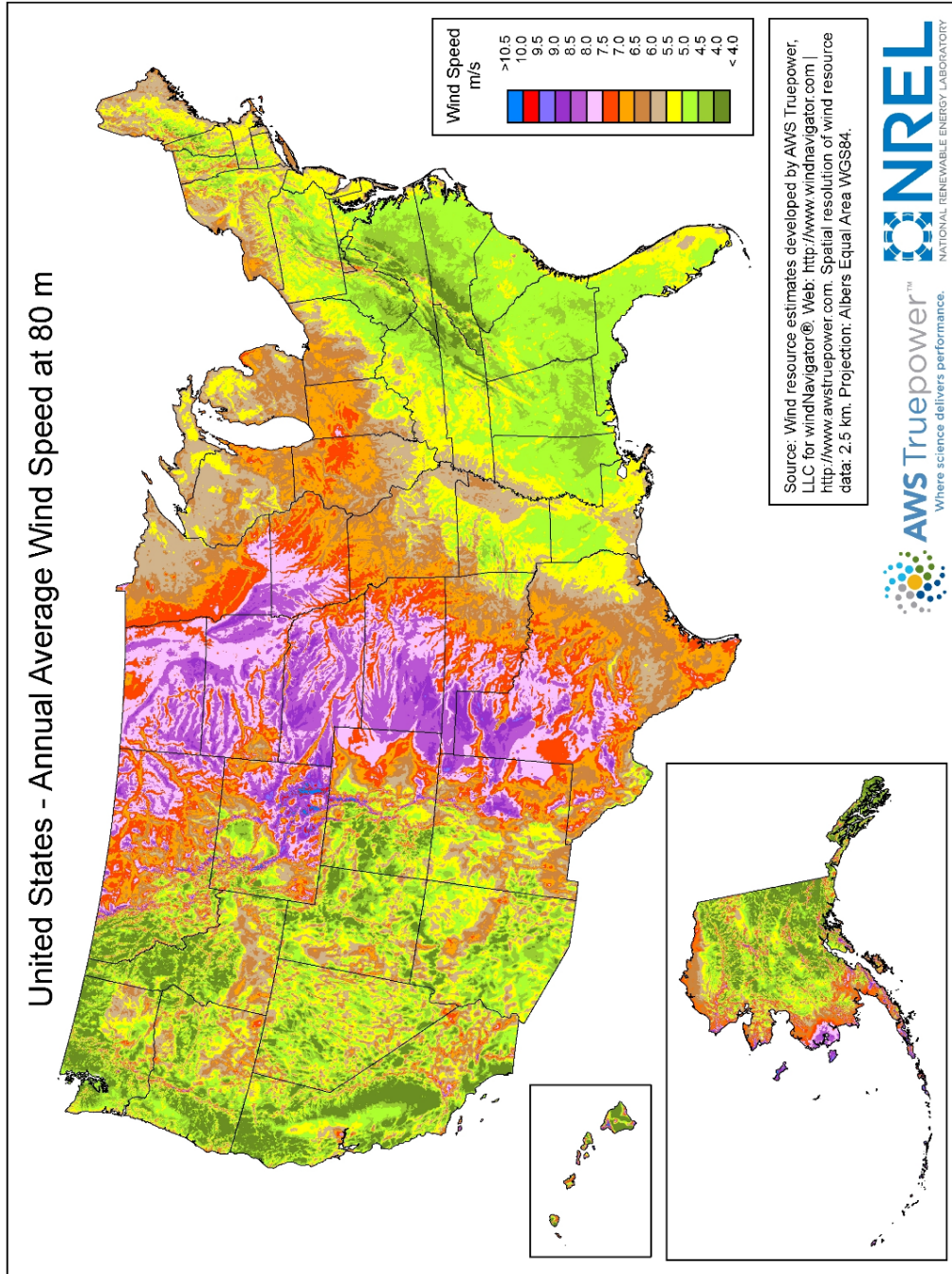


Figure 13.—Average annual wind speed at 80 m [43]

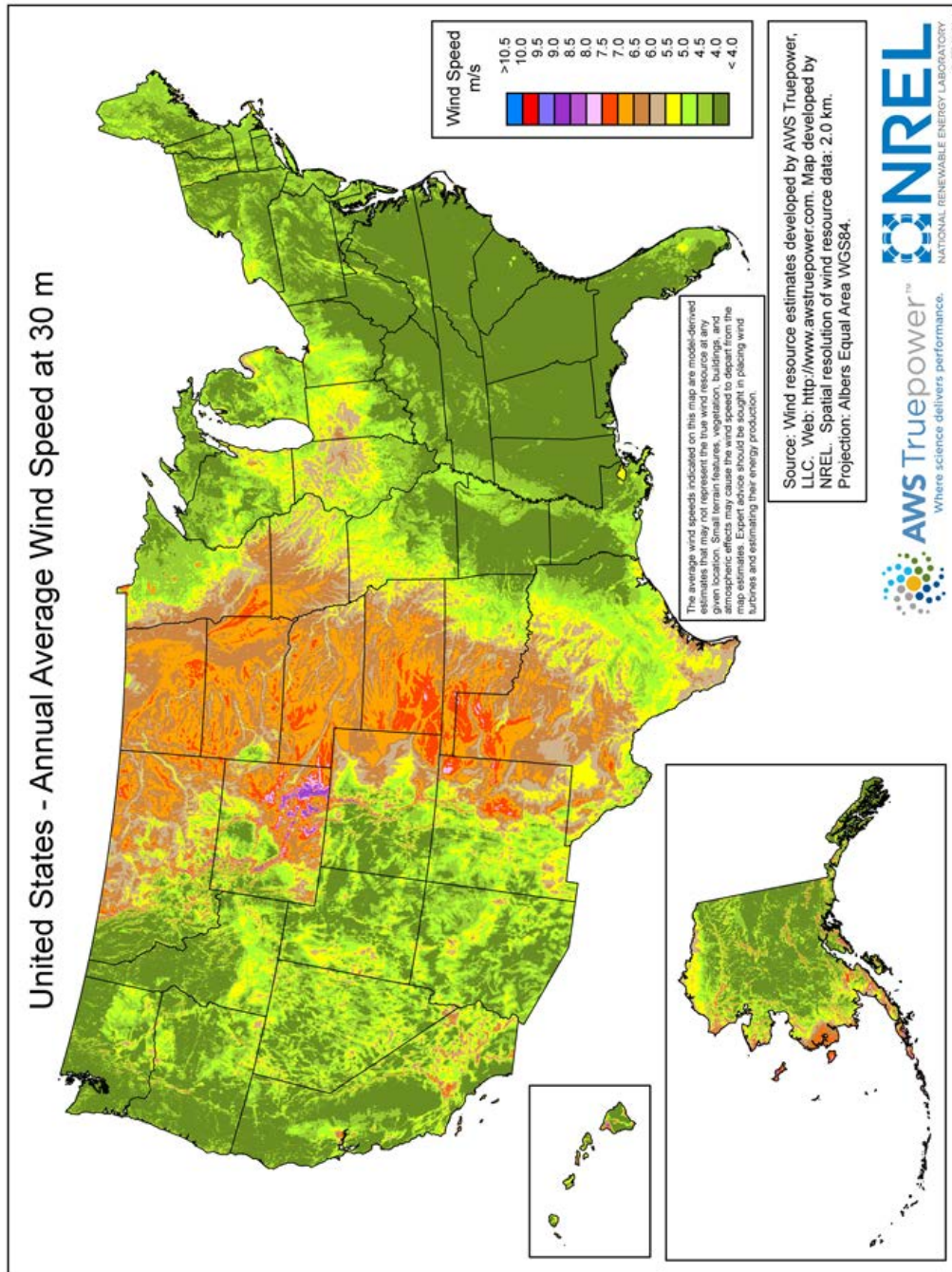


Figure 14.—Average annual wind speed at 30 m [43]



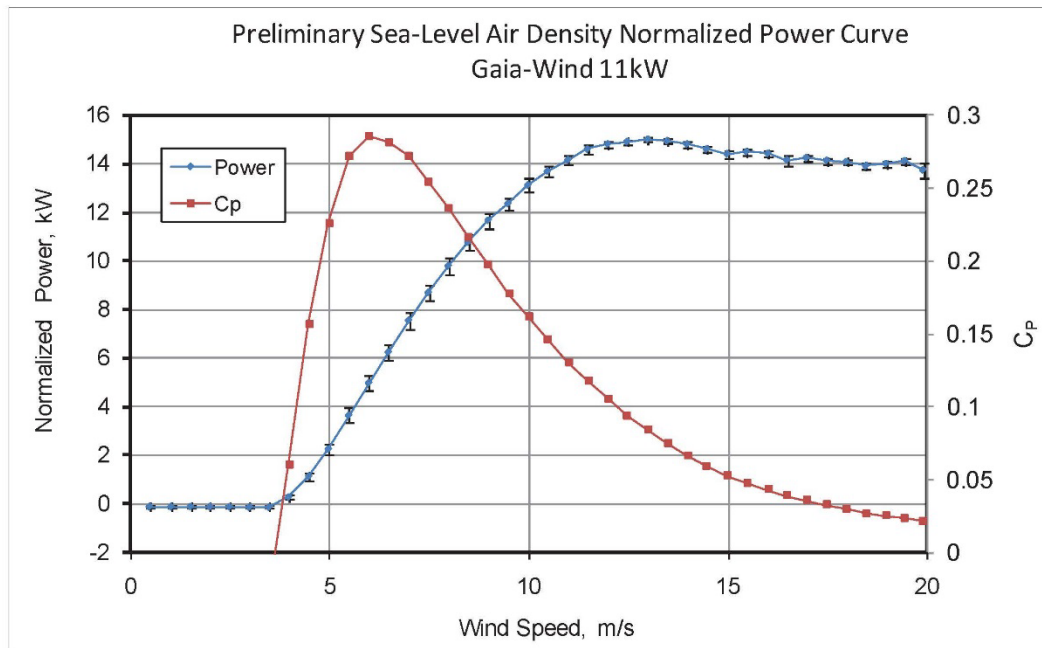


Figure 15.—Preliminary power and  $C_p$  curves for the Gaia-Wind 11 kW [44]

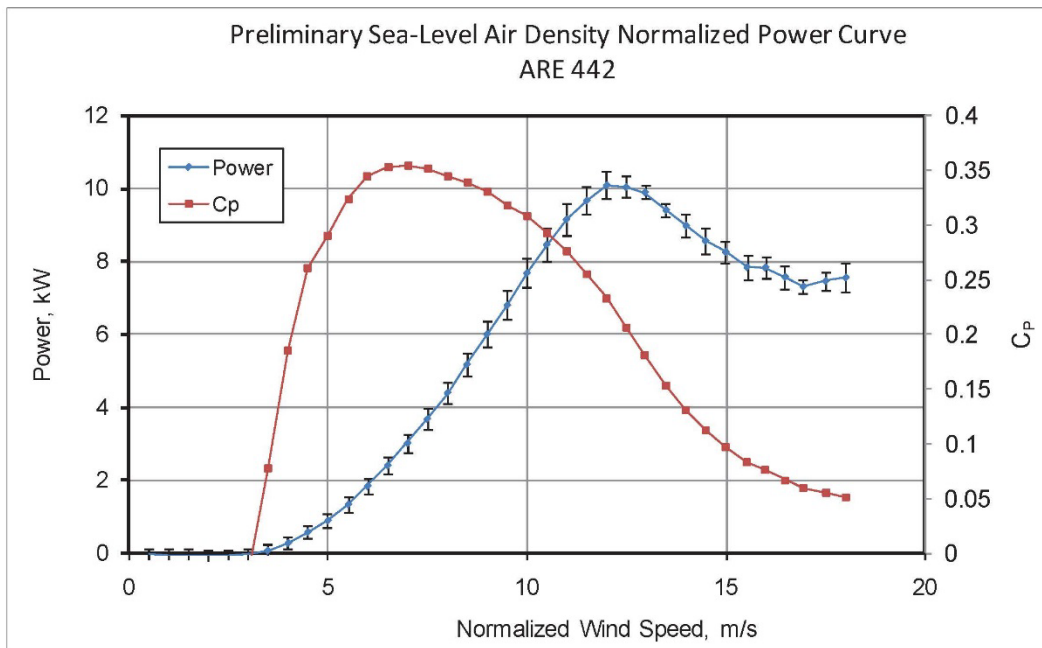


Figure 16.—Preliminary power and  $C_p$  curves for the ARE 442 [44]

## **Reliability**

Wind is a highly variable energy source and prone to abrupt changes in strength and power output. Wind turbine systems can also be susceptible to disruption based on both short and long term climate events. The reliability of wind systems is also highly dependent on the specific placement and height of the turbine to meet the estimated wind resources at the site. In addition, the wind resources at a given site may experience yearly cyclical events with months that routinely experience low and high wind levels. A comparison in the “Long-Term Wind Power Variability” by Wan, Y.H. [45], on the month by month power production at a wind farm located in Lake Benton in Minnesota, shows the yield of power production during the summer months that was 64 percent of the power production during the winter months.

There is also reason for concern that a wind turbine used in an energy capture installation with a battery bank may negatively impact the capacity of the wind turbine and battery system. Baring-Gould et al. [42] found that systems with weak or small battery loads can experience reduced system efficiency because of premature regulation by the charge controller and spilled energy when the battery bank appears full to the charge controller, while a surplus of energy remains. Furthermore, due to premature voltage regulation, the batteries do not become fully charged, leading to premature battery degradation.

## **Maintainability**

Wind turbines have a high number of moving parts and electronic components so they require a high level of routine maintenance. In addition, the battery systems used for wind applications require maintenance similar to the battery systems for solar applications.

## **Relative Cost**

### ***Installation***

The equipment costs are based on purchasing an 11 kW wind turbine generator with a battery backup system to supply an ICCP system. The cost evaluation does not include the cost of the CP system components. This is intended for informational purposes only and does not include a detailed list of all components required for an installation of this type.

Electric load: 300 W

Generator rating: 11 kW

- For this example a Gaia 133, 11 kW wind turbine is used. An

exchange rate of 1 British pound to 1.34 U.S. dollars is used to convert the purchase price from the source document.

**Wind turbine purchase price: \$46,890.00 [46].**

Battery system: 600 Ah, 48 V

- This is based on a rough battery sizing estimate using a 300 W load at 48 V<sub>DC</sub> for approximately 72 hours with a 20 percent aging factor. It should be noted that actual battery sizing calculations should be done in accordance with the appropriate IEEE standard.
- For this example, four GNB industrial power Absolyte® GP Model 6-90G11, 12 volt, valve regulated lead-acid batteries are used.

**Battery purchase price: \$2,002.99 [17] x 4 6-90G11 batteries**

Charge controller:

- Suitable for recharging battery from a wind turbine.
- For this example a Morningstar Tristar MPPT 600 V, 60 A charge controller is used.

**Charge controller purchase price: \$1,599.00 [18] x 2 Morningstar Tristar MPPT 600 V, 60 A charge controllers.**

Power distribution components:

- Miscellaneous power panels, circuit breakers, and electrical disconnects.

**Purchase price: \$1,000.00**

Battery and charger enclosure: NEMA 250 Type 3R Enclosure

- Enclosure with internal racking system and cooling system.

**Enclosure purchase price: \$5,000.00**

Miscellaneous components:

- Include cable, conduit, battery connectors, grounding components, etc.

**Miscellaneous components purchase price: \$2,000**

Labor

**Labor cost: \$3,500**

**Total: \$69,600**

## ***Operation***

Wind turbines do not include consumable fuel sources or yearly utility fees. Costs for labor and maintaining the system are not included in this evaluation.



## **Standards for Wind Turbines**

### **International Electrotechnical Commission (IEC)**

IEC 61400-2:2013.–Small Wind Turbines

## **Fuel Cell Supply**

### **System Arrangement**

Fuel cells are off grid technology under development. Fuel cells produce current electrochemically from a variety of fuels including: hydrogen, methane, propane, and gasoline. Fuel cell require minimal maintenance and boast pollution-free, high- operation. The Office of Energy Efficiency and Renewable Energy Fuel Cell Technologies Office lists the following types of fuel cells on their website [47]:

- polymer electrolyte membrane fuel cells
- direct methanol fuel cells
- alkaline fuel cells
- phosphoric acid fuel cells
- molten carbonate fuel cells
- solid oxide fuel cells
- reversible fuel cells.

Options currently exist for both polymer electrolyte membrane fuel cells and solid oxide fuel cells (SOFC) for off-grid remote applications. Diagrams of these two types of fuel cells are shown in Figure 17.

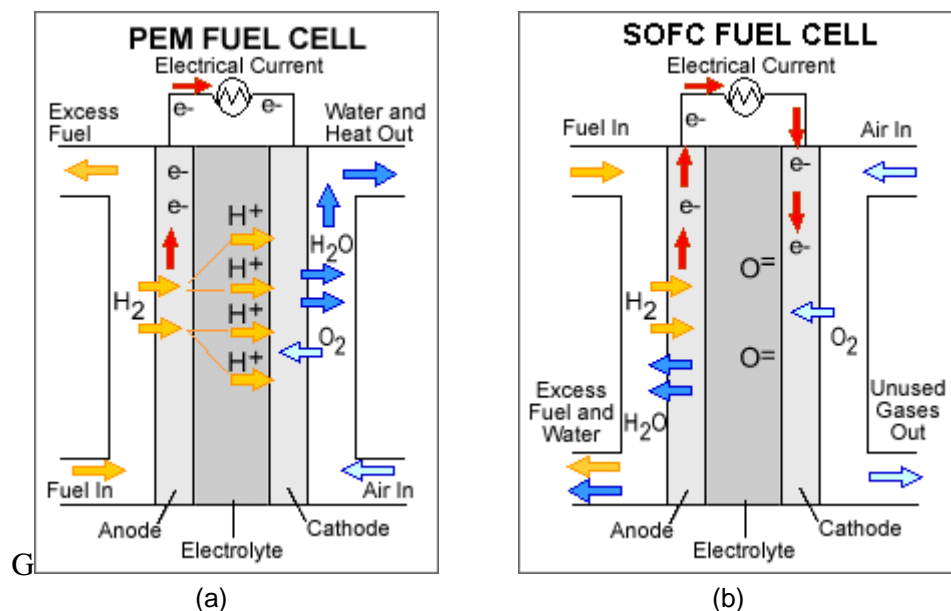


Figure 17.— Diagrams of (a) polymer electrolyte membrane fuel cells (PEM) and (b) solid oxide fuel cells (SOFC), reproduced from [47]

## Reliability

Reliability is a concern for fuel cells. Polymer electrolyte membrane (PEM) stationary fuel cells can experience major performance delay after 1,000 hours of operation [48]. Solid oxide stationary fuel cells have a longer lifetime than PEM fuel cells, although even their lifetime is relatively short. An International Energy Agency Technology Essentials report [49] compares the fuel cell lifetime for PEM fuel cells at 2,000 hours with a lifetime for SOFC at 6,000 hours.

## Maintainability

There are several challenges that these systems face for maintainability. The main challenge is due to the relatively small number of fuel cells currently installed in remote off-the-grid power generation applications. A small installed base means additional time and planning would be required for acquiring spare parts and training maintenance technicians.

## Relative Cost

Identifying a cost for deploying these systems across a project for ICCP operational requirements is difficult due to the limited number of manufacturers currently making fuel cells for off-grid remote power applications.

## Resources/Manufacturers for Fuel Cells

**Atrex Energy** has developed a SOFC (see Figure 18) to produce DC voltage for CP. The fuel cell is manufactured with inexpensive materials and can operate over a variable power range and provide a constant power output. This device can withstand harsh weather, extreme temperatures, and shock and vibration conditions [50].

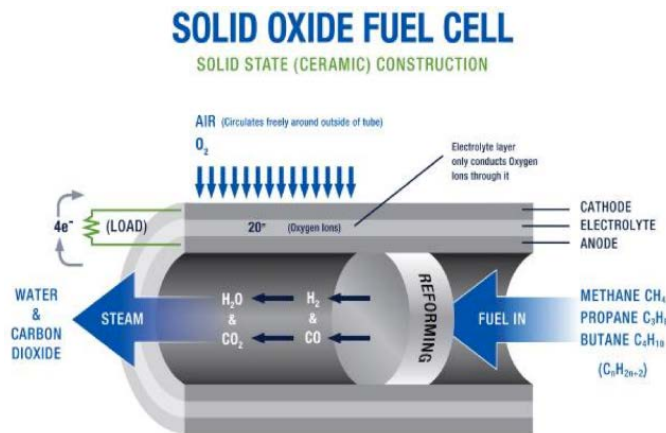


Figure 18.—Atrex Energy tubular SOFC technology, reproduced from [50]

**Ballard Power Systems** has a backup power systems line, the FCgen<sup>®</sup>-H2PM zero emissions fuel cell system that has been designed to integrate easily with existing power equipment [51].

**Plug Power** has the GENSURE<sup>®</sup> product line of stationary hydrogen fuel cell solutions meeting critical customer backup, grid-supplement and off-grid power needs [52].

**Sunfire** key technology is the Solid Oxide Power Core – a stack of high-temperature solid oxide cells. Operation gases are natural gas and liquid petroleum gas. These power generators have high efficiency and low maintenance costs [53].

## Summary

Table 2 summarizes the criteria for each of the energy sources with a brief evaluation. When evaluating these factors for each of the power supply options it is important to remember that many of these power sources are heavily impacted

by location and the specific conditions at the individual site where the system would be installed. At this time the primary option should generally be a utility supplied power source. When utility sources are in close proximity to the ICCP system they often provide an economical power source with high reliability and low cost of maintenance. It is only when the CP system location is farther from utility power and the power source becomes unavailable or un-economical that alternative power sources should be considered in lieu of utility supplied power. Of all the alternative energy sources investigated, solar power appears to provide the best fit as the primary alternative power source, although it can be dependent on the site having good solar resources. The higher variability of wind power with low wind turbine elevations and the desire to minimize visual impact makes it less desirable in locations with good solar resources. All of the other three sources, TEGs, fossil fuel combustion generators, and fuel cells require significant staff involvement on an ongoing basis at the sites.

Table 1.—Power Source Summary

Power Sources						
	Utility Supply	Solar Power Supply	Fossil Fuel Combustion Engine Generator Supply	TEG Supply	Wind-Driven Generator Supply	Fuel Cell Supply
<b>Ease of Use</b>	High	High	Medium	Low	Medium	Low
<b>Reliability</b>	High	Medium	Medium	Medium	Low	Low
<b>Maintainability</b>	Easy	Medium	Difficult	Difficult	Medium	Difficult
<b>Cost</b>	Low cost where power is available	Medium installation cost Low operating cost	Medium installation cost High operating cost	Low installation cost High operating cost	Medium installation cost Low operating cost	High installation cost High operating cost
<b>Best Fit</b>	Where utility power is available in proximity to site.	Where there are good solar resources and few cloudy days.	Where there are poor solar resources and support for significant fuel deliveries.	Where there are poor solar resources and support for fuel deliveries.	Probably best fit as a secondary power source.	Where there is support for high staff involvement at facility



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