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Inland Navigation Design Center

Standardization and Sustainability Initiative

Renewable Energy Applications for Locks and Dams

Standardization and Sustainability

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McNary Dam, Oregon

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Renewable Energy Applications for Locks and Dams

Standardization and Sustainability

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Abstract

This report provides a standardized approach for gauging the feasibility of potential solar, wind, and hydropower projects for application at U.S. Army Corps of Engineers (USACE) navigation sites in advancement of Federal sustainability goals for renewable generation and energy consumption. Federal renewable energy targets are identified, and background information is provided on each type of renewable energy. Guidance is provided for identifying and assessing site-specific conditions relevant to evaluating the suitability of each considered renewable energy type at a potential project location. Methodology is presented for system sizing, estimating project cost, and evaluating potential utility savings. Geographic resource availability and regulatory information is provided and discussed. The information provided within this report is a static snapshot of an evolving technology landscape. It provides a sound methodology for evaluation of each technology and, where possible, references outside sources that are maintained and updated by other parties. This report focuses on the scale of projects appropriate to use at USACE navigation sites.

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Preface

This study was conducted for Headquarters, U.S. Army Corps of Engineers (HQUSACE) by the Inland Navigation Design Center (INDC). The Inland Navigation Design Center Mandatory Center of Expertise (INDC-MCX) provides engineering, design, analysis, and review services for studies, new locks and navigation dams, major rehabilitation of existing inland navigation locks and dams, and significant inland navigation lock and dam Operations and Maintenance (O&M) projects. The INDC strives to deliver the highest quality products and services through design consistency, technical review, adherence to policy and regulation, standardization of design, risk analysis, collaboration with experts and stakeholders, and knowledge management of technical competency.

The Inland Navigation Design Center Mandatory Center of Expertise was tasked by HQUSACE to investigate opportunities across the enterprise for sustainability and standardization at navigation structures with emphasis given to mechanical and electrical components. This study and report was funded by HQUSACE and in part through the USACE ERDC Dredging Operations Technical Support (DOTS) program.

1 USACE Goals and Programs for Acquisition of Renewable Energy

1.1 Goals for renewable energy generation and sustainability

At the majority of installations, Federal renewable energy generation policy goals or requirements will be a principle motivator for evaluating the feasibility of a renewable energy installation project. Additionally, the specific requirements of current guidance will determine the target capacity for a given system. Identifying system size early in the process is important for evaluating the economic feasibility of the proposed system. Currently, Executive Order (EO) 13693, *Planning for Federal Sustainability in the Next Decade* (White House 2015a), directs Federal agencies to achieve specified reductions in building energy intensity that may be achieved in part through the use of renewable energy generation. Additionally, this order explicitly directs targets for renewable energy usage in terms of percent of total agency building electric and thermal energy consumed (Clean Energy Target) and percent of total building electrical energy consumed (Renewable Electric Target). These targets should be used as guidance when determining the generating capacity of any renewable energy installations being considered. At a minimum, 12 months of energy consumption data should be used to determine the average energy consumption at a site. Reductions targets in energy intensity should be based on the Fiscal Year 2015 (FY15) Baseline. Percentage generated towards the Clean Energy and Renewable Electric Generation Targets should be measured against the most recent 12-month consumption period.

1.2 Energy intensity target

EO 13691 section 3(a)(i) (White House 2015b), requires the reduction in energy intensity in Federal buildings by 25% by FY25 relative to the FY15 baseline, with milestones of 2.5% per year reduction in energy intensity relative to FY15. Efficiency improvements typically provide more economical means of achieving reductions in energy intensity. Renewable Energy generating capacity should be sized to cover the shortfall between the reductions achievable through efficiency measures alone and those specified by current or future requirements. Energy intensity is measured as British thermal units of energy used per gross square foot (BTU/GSF) of Federal building space.

Per the implementation instructions in EO 13693 (White House 2015a), on-site renewable electric energy contributes to energy intensity reduction. BTUs consumed from renewable energy systems installed on a Federal facility are also deducted from the numerator of the energy intensity equation, provided that the agency retains the renewable energy certificates (RECs), buys replacement RECs, or can otherwise confirm ownership of the beneficial environmental attributes. Certain Federal facilities may be excluded from Federal energy intensity goals. The exclusions of these facilities codified in the current statute, “Energy Management Requirements,” 42 USC § 8253(a)(2) and (c), apply under EO 13693 (White House 2015a). Even though some Federal buildings are excluded from the energy intensity reduction targets, EO 13693 encourages efficiency upgrades at goal-excluded buildings by allowing agencies to credit verified energy efficiency improvements toward the agency's progress on the energy intensity reduction goal. Measured and verified annual BTU savings from an efficiency improvement in a goal-excluded building are deducted from the total BTUs consumed by the agency's goal-subject buildings while holding gross square feet constant.

1.3 Clean energy target

EO 13693, section 3(b) (White House 2015a) requires agencies to ensure that, at a minimum, the percentage of the total amount of building electric energy and thermal energy that is clean energy, accounted for by renewable electric energy and alternative energy, meets the following specified targets:

- Not less than 10% in FY16 and FY17
- Not less than 13% in FY18 and FY 19
- Not less than 16% in FY20 and FY21
- Not less than 20% in FY22 and FY23
- Not less than 22.5% in FY24
- Not less than 25% in FY25 and each year thereafter.

Annual targets are measured against the total energy consumption in the respective year. Renewable energy projects should be sized to meet the intended clean energy target goal based on expected energy consumption for the target year (accounting for any planned efficiency improvements at that site).

1.4 Renewable electric target

EO 13693, section 3(c) (White House 2015a) requires agencies to ensure that the percentage of the total amount of building electric energy consumed by the agency that is renewable electric energy meets the following specified targets:

- Not less than 10% in FY16 and FY17
- Not less than 15% in FY18 and FY19
- Not less than 20% in F20 and FY21
- Not less than 25% in FY22 and FY23
- Not less than 27.5% in FY24
- Not less than 30% in FY25 and each year thereafter.

Annual targets are measured against the total electricity consumed in the respective year. Renewable energy projects should be sized to meet the intended renewable electric target goal based on expected energy consumption for the target year (accounting for any planned efficiency improvements at that site).

1.5 Funding programs for USACE sustainability projects

1.5.1 Calculating savings and net metering

Energy savings include all power generated and used on the site as well as any power distributed back to the grid, provided that the RECs are retained by the project. Cost savings include the avoided cost of generated energy consumed on site as well as any income generated by energy sold back to the utility grid. The actual savings must be determined from the expected reduction in energy use. Based on the rate structure and demand charges, this may vary substantially from the nominal cost per kilowatt rate. Reduction in metered charges at the rate band being affected and reduction in peak demand charges must both be investigated. The sale of excess generation back to the grid is typically facilitated by a net metering agreement. Net metering rules and availability vary widely and should be investigated early in a project because they determine the extent to which benefits may be derived for any excess generation capacity. Expected savings should be compared to system cost in terms of net present value and payback period.

1.5.2 Civil works appropriated funds for sustainability projects

Funding for U.S. Army Corps of Engineers (USACE) sustainability projects at civil works sites is set aside from general Civil Works appropriated funds. Annual funding set-asides for sustainability projects typically has been on the order of $10 Million. Project submissions received by the evaluation deadline are prioritized and funded in the order they are ranked. Submission information includes project description and cost, along with a quantification of expected energy savings and cost payback.

1.5.3 Alternative financing

Huntsville Engineering Center (HEC) supports USACE entities by securing third party financing for sustainability projects through both Energy Savings Performance Contracts (ESPCs) and Power Purchase Agreements (PPAs).

ESPC contracts leverage third party financing to engage approved Energy Service Companies (ESCOs) to make capital improvements, which are then paid for by the ensuing utility and/or maintenance savings achieved by the project. ESCOs are required to ensure a guaranteed savings with payback period of less than 25 years for an ESPC project to be considered awardable.

PPA contracts are intended to provide a means for the government entity to purchase power without acquiring any power generation assets. The PPA Program will focus on renewable alternative energy projects, but may include alternate energy sources that do not qualify as renewable, but do offer improvements or benefits in terms of greenhouse gas reductions, reduced energy costs, or improved energy security.

2 Hydropower

2.1 Process overview

If the Lock & Dam (L&D) facility wants to investigate the possibility of installing a non-spillway hydropower generating unit, there is no straightforward method of determining the best (or most appropriate) equipment to accomplish this task. The selection of the type and size of the turbine, generator, control system and electrical switchgear is a custom engineering process. However, the L&D and engineering staff can perform initial screening assessments to aid in determining the feasibility of a non-spillway hydro-generator project. The following sections aid in describing the requirements and process to conduct an assessment investigation, and Appendix B, “Hydropower Screening Procedure” provides a step-by-step procedure for working through the information presented in this chapter.

Additional reference information for initial assessment of hydropower applications can be found in TechNote 28, *Microhydropower* (2017), which was hosted and presented by Headquarters, U.S. Army Corps of Engineers (HQUSACE) and the Hydroelectric Design Center (HDC) in Portland, OR. This document provides more general information regarding small and micro-hydropower to aid in better understanding the equipment and site requirements for hydropower applications. The Permanent International Association of Navigation Congresses (PIANC) WG 197 is also a reference guide for installation of small hydropower. The WG 197 report is in progress as of the writing of this technical report.

The initial project screening assessment, as outlined in Appendix B of the report, will determine and indicate if a feasible project may be possible. The next step will require the project or assessment individuals to contact the USACE Hydroelectric Design Center (HDC) in Portland, OR. HDC will coordinate with both the L&D facility and with the facility’s parent District. HDC will collect additional information from the L&D and proceed with a more in-depth screening. Note that this entire investigation is a step-by-step process that may result in an unfavorable discovery at any point in the investigation. Note that HDC is a fee-for-service organization and their associated work to further the development and feasibility of any potential hydro-electric generator projects must be funded by the requesting organization. These costs are typically resourced by the local Corps of Engineers (COE) District with the interest in a specific project.

2.2 Hydropower overview

At a Lock & Dam site, there is always the potential for the installation of non-spillway hydropower. The questions that must be answered are:

- How much power is needed?
- What is the water flow rate needed to produce that amount of power?
- What is the cost of the machinery (turbine, generator, electric power transmission, controls and switchgear) needed to produce the power?
- Where can this machinery be located?
- How is the water conveyed to the turbine, i.e., what is the routing of the pipe?
- What is the routing to get the water from the turbine discharge back to the river?
- When all costs are considered, is the installation of a hydro-generator cost effective?

2.3 Power needed

To determine the appropriate size of a generating unit for the L&D, obtain 12 continuous months of electric utility bills and calculate the total electric energy (kilowatt hours) used during this period. Divide the total kilowatt hours by 8760 (the total number of hours in a year) to obtain the average power (kilowatt) usage. This average kilowatt usage is the size of generator that will provide the energy used by the L&D. Because a net export of energy is undesirable (see Section 2.5, Net metering), the generating unit should be sized to approximately 90% of this value.

2.4 Power availability at the site

To determine the power that is available from the site, or to calculate the amount of flow that is required to achieve a given power output, any one of the following equations can be used. The difference between these four equations is the manner in which head (i.e., pressure) and flow rate are measured.

$$\boldsymbol{P = \frac{HQ}{16.9}} \tag{1}$$

$$\boldsymbol{P = \frac{Hq}{7579}} \tag{2}$$

$$\boldsymbol{P = \frac{pQ}{7.31}} \tag{3}$$

$$\boldsymbol{P = \frac{pq}{3284}} \tag{4}$$

where:

- P = power in kW
- p = pressure (psi) , p= H*0.433 (psi/ft).
- H = head (ft) (upstream pool elevation minus downstream pool elevation)
- Q = flow rate (cfs)
- q = flow rate (gpm), q = Q*448.8 (gpm/cfs).

The above equations assume an energy conversion efficiency (generated power/ available hydraulic power) of 70%. Given the size of the installation and the equipment that will be used, this is a reasonable assumption and an appropriate starting point for the initial calculations. The efficiency will need to be refined/re-evaluated when site-specific assessments are performed. The above equations can also be used to calculate the water flow rate that is needed to produce a given power output.

The calculated water flow rate needs to be available to the turbine 100% of the time. If the L&D has a requirement to provide a minimum flow past the dam, the amount of water passing through the turbine will contribute to that minimum flow requirement. In other words, if the dam's minimum flow requirement exceeds the amount of water needed by the turbine, then there should be sufficient water available to power the turbine.

2.5 Net metering

The economic viability of installing generating capability at a facility cannot be fully evaluated until the local utility's rules for connection of generating equipment are understood. These utility rules include both: (1) how the generated electricity will be credited back on the facility's electric bill, and (2) the technical requirements for controls and connection of the generating unit to the grid. The following paragraphs discuss some aspects of these considerations.

Electric power usage at a facility will vary over time, both on a daily and on a seasonal basis. Net metering is the method of using all of the power generated at the facility, regardless of the time it was generated, to offset the facility's electric bill. In times of lower power usage at the facility, the excess generated power is exported to the local utility grid and the value of this exported power is credited to the facility's electric bill. At times of high power usage, power is imported from the grid. If more energy is exported from the facility than is imported into the facility, then from a commercial perspective the facility becomes a generation facility, which is generally not a congressionally authorized purpose of the facility. So on some average basis (typically a year) the goal is to generate slightly less energy than is used by the facility.

A variation of net metering is to measure based on cost, rather than energy. In addition to the simple energy (kilowatt hours) charge from the electric utility, there may also be additional electric usage charges based on: (1) time of day consumption, and/or (2) maximum (peak) power demand. The generating unit envisioned by this report has a constant output, regardless of either time-of-day or demand. This type of generation is considered base-load generation and is the least valuable type of generation. If one is to offset the billed (extra) charges for time-of-day consumption and/or peak consumption, then more base-load energy will need to be generated and the value of the extra generation will need to be credited to the customer's energy bill.

The local electric utility and the Corps of Engineer's Office of Counsel must determine whether net metering based on cost is allowed by the electric utility, and whether or not it is a legally acceptable Corps of Engineers' practice. Net metering rules, policy, and procedures are not uniform across the country, or even within individual states. The L&D staff will need to contact the local electric utility and obtain the utility's rules, requirements, and procedures for installing a net-metering generation unit. Key information that should be conveyed to the utility is:

- The unit will be installed "downstream" of the meter and is intended to generate slightly less than 100% of the total energy consumed on the facility.
- The unit will operate at a constant output. At times the facility will be exporting power to the grid; at other times the facility will be importing power from the grid.
- The generator can be either synchronous or induction, depending on the utility's requirements and/or cost considerations.

2.6 Types of turbines

Turbines are classically separated into two types: impulse turbines and reaction turbines. The rotating element (the runner) of an impulse turbine is driven by a jet of water passing through air and impinging on the blades of the runner. The rotating element of a reaction turbine is surrounded by water and is driven by the pressure differential across the runner's blades.

Different turbines can be used for the heads and power outputs that support the applications described here: Cross-flow turbines (Figure 1), which are a type of impulse turbine; and Francis (Figure 2) or Propeller turbines, which are reaction turbines. Francis turbines have a runner shape similar to a centrifugal pump impeller; propeller turbines have a runner shape similar to a ship's propeller.

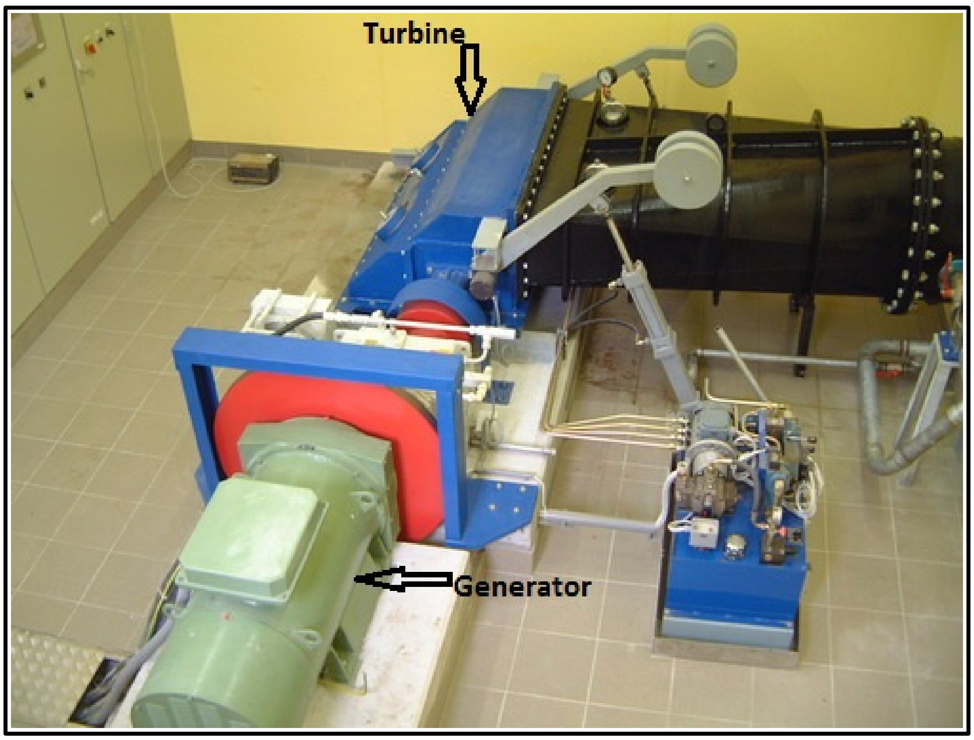


Figure 1. Crossflow turbine installation.

Figure 2. Skid mounted Francis turbine.

Hydrokinetic turbines, which use the velocity of flowing water rather than the pressurized water provided by a dam, are not the best selection for application at L&D sites because:

- Hydrokinetic units require a minimum water velocity of 6 ft per second, which will generally not be available.
- The mounting and anchoring requirements for the unit will be expensive compared to the installation of more conventional units.
- The technology is not mature and the reliability of the units is unproven.

Of the turbine choices available, there is no universal "best solution." There is no simple formula for choosing the "best" unit, or for calculating the cost of installing micro-hydro at an existing L&D since the process must consider complex combinations of many factors: the different turbine types, the variations in setting (elevation above tailwater), the differences in power output, and the differences in turbine control requirements.

2.7 Turbine characteristics

The power generation equipment envisioned for this application generates approximately 90% of the total energy used by the L&D facility in a year. Preliminary investigation of the power consumption at USACE L&Ds indicates that most L&D facilities will need between 20 and 50 KW of continuous generation to achieve this 90% goal. Note that generating more than 100% of the total energy used by the L&D turns the L&D into a hydropower generating facility, which is typically not an authorized purpose of the L&D.

The turbine envisioned in this report is an unregulated unit, which does not have wicket gates, and which has a power output that cannot be varied by control actions. At a given head (upstream pool elevation minus downstream pool elevation), the unit has a constant power output that cannot be increased or decreased. The use of an unregulated unit offers the following advantages:

- It has no need for a governor.
- It has no need for an oil hydraulic system to operate the wicket gates or rotate the runner blades.
- Since it has no wicket gates, the unit can use a less expensive, physically smaller turbine.

Use of an unregulated turbine, which cannot vary its power output, means that in its standard configuration the turbine cannot be used as a source of emergency backup power. In an emergency backup situation, the L&D facility will be disconnected from the power grid and any generator at the facility must: (1) produce only the power that is INSTANTANEOUSLY being consumed by the L&D facility, and (2) be able to instantaneously change its power output to match changing loads at the facility. If emergency backup capability is desired, then one of two changes must be made:

- The turbine must have adjustable wicket gates and a governor or
- A demand side variable load bank must be added to store the supplemental power generated. Demand side load banks are typically resistive electric heating devices, heating either water or air.

Of the two choices identified above, the demand side variable load bank is generally the preferred solution for the following reasons:

- Providing a demand side variable load bank has a lower initial cost than the combined cost of upgrading the turbine to a regulated unit and providing the governor system to control the turbine
- Maintenance costs for a demand side variable load bank will be less than for a regulated turbine and governor.
- The demand side variable load bank will provide more stable electric service, with less variation in voltage and frequency.

2.8 Space needed to house the generating unit

The physical arrangement of the turbine-generator will depend on the specific turbine selected to provide the power generation; thus the information provided here is approximate. If the Lock and Dam has a room that is within 50% of the dimensions identified below (Table 1), then a detailed study is appropriate.

The given dimensions are for skid mounted, non-embedded, horizontal shaft turbines and generators that are “set on the floor” of existing structures. These sizes are for turbines operating under 30 ft of head. For a given power output, turbines operating under lower heads will be physically larger and require a bigger space; turbines operating under higher heads will be physically smaller and require less space. For the larger units (generally 100 kW and larger) identified above, overhead crane access will be required. The smaller units can be installed and maintained using a forklift.

Table 1. Approximate room dimensions to house turbine-generator units (operating under 30 ft head).

Power Output (kW)	*Length (ft)*	*Width (ft)*	*Height (ft)*
12	12	10	8
25	16	10	8
50	20	12	10
100	26	14	12
200	30	16	16

2.9 Location of the turbine generator

In addition to having the physical space to place a generating unit, the location of the turbine will impact the cost, operability, and maintainability of the unit. While nothing precludes construction of a new building to house the turbine-generator, building a new structure will add to the cost. Considerations for location of the turbine include:

1. Piping to get water to the turbine.

   If water can be supplied to the turbine from an existing pipe that draws water from the upstream pool, this will decrease the cost of installing a unit. If a new pipe must be installed, the modifications of existing structures to install the pipe may be prohibitively costly. The pipe bringing water to the generator should be sized for a maximum water velocity of 7 ft per second. While higher velocities may work, water at higher velocity will have much higher head losses, thus reducing the amount of energy the turbine-generator can convert to electric power.

2. Both an isolation valve and a control valve must be installed in the pipe upstream of the turbine.

   The isolation valve will be used when maintenance is being performed on either the turbine-generator unit or on the control valve. The control valve will be used to control whether water is admitted to the unit. In other words, since there are no wicket gates, the control valve is the "on-off switch" for the turbine.

3. Turbine discharge water.

   The conduit that routes the water from the turbine discharge back to the river needs to be as short as possible. Ideal is to have a discharge pipe, or draft tube, the length of which is about four times the turbine runner diameter. For small units, this is about 8 ft long; for larger units, this will be about 40 ft long. The longer the discharge pipe, the more likely turbine power instability will occur.

4. Turbine Elevation.

   The elevation of the turbine needs to be near the elevation of the downstream pool. Ideally, the turbine will be less than 5 ft above the elevation of the downstream pool's normal operating elevation. The higher the turbine is above the downstream pool, the more susceptible the unit is to cavitation.

2.10 Electric power transmission

The electric power created by the turbine-generator will be Alternating Current (AC), as opposed to the Direct Current (DC) that is created by some other alternative energy sources. As such, the AC Generator can be connected directly to the L&D facility's distribution system.

The generator will be able to generate electricity at either 240 or 480 volts. It is assumed that the generator will be located very close to the L&D facility's primary distribution panel. A dedicated, heavy conductor will be needed to connect the generator to the distribution panel, but there should not be a need for transformers to step-up the voltage at the generator then step-down the voltage at the distribution panel.

2.11 Cost

The biggest variable in determining the cost of installing a turbine-generator is not the cost of the turbine-generator itself, but the cost of all the associated structural and facility modifications that will be required to support the turbine-generator. These structural and facility modifications include: piping to get the water to and from the turbine, modifications to the building to house the turbine-generator, and lines to transmit the electrical power. In some cases, these associated costs can be small; in other cases, they can be prohibitively large. A site-specific assessment is required to determine which of these two conditions prevails.

Generally speaking, the cost for the turbine-generator equipment will be a function of how much power is required. A 12 KW turbine-generator will cost on the order of $100,000. A 200 KW turbine-generator will cost between $250,000 and $500,000. Note that the cost of the equipment DOES NOT scale linearly as a function of power output (in other words, doubling the power output does not double the price).

2.12 O&M requirements

Operations and Maintenance (O&M) requirements for this type of turbine-generator should be minimal:

- Weekly maintenance requirements should be on the order of 1 to 2 hrs.
- An annual maintenance outage should require between 40 and 80 labor hours.
- The turbine-generator should have a minimum service life of 35 years, and many such installations have a 50-year service life.

Typical maintenance requirements may include:

- Turbine functional checks and inspection.
- Turbine bearing lubrication and inspection.
- Gearbox inspection (if gearbox is equipped).
- Gearbox oil condition analysis and oil changes.
- Gearbox bearing inspection and lubrication.
- Drive belt inspection and replacement (if equipped).
- Drive coupling inspection.
- Generator inspection.
- Generator bearing inspection and lubrication.
- Hydraulic system inspection.
- Hydraulic system oil condition analysis and oil changes.
- Check all sensors operate correctly.
- Check controller functions correctly.
- Inspection of intake area, impounding structures, pipeline, sluice(s).

2.13 Site attributes

2.13.1 Attributes of a good site

A good site will have:

- Existing water pipe providing water from the forebay.
- Existing water pipe large enough to have a max water velocity of 7 ft per second.
- Existing room or space large enough to house the turbine-generator unit.
- Proposed turbine location is at a low elevation with respect to downstream pool.
- Easy routing to return turbine discharge water to the river.
- Generator is located close to the dam's primary electric distribution center.

2.13.2 Attributes of a less than ideal site

A less than ideal site will be characterized by:

- A need to "breach" or penetrate the upstream face of the dam to obtain water for the turbine.
- Long, complicated routing for the pipe that provides water to the turbine.
- A generator location that is far from the dam's primary electric distribution center or from the electric load.
- Long complicated routing to get the water from the turbine discharge back to the river.

2.14 Sources of equipment

The generating equipment being considered for application at the L&D facilities will mostly be in the 20 to 50KW range, with heads of between 10 and 30 ft. There are relatively few world-wide suppliers in this range that have proven track records for providing quality products. Some of these suppliers are:

- Kossler (a subsidiary of Voith Hydro)
- Andritz Hydro
- Cornell Pump
- Toshiba (Hydro e-KIDS turbine)
- Ossberger Crossflow turbine.

2.15 Electric power interconnection

The electric connection of the generating unit to the L&D's electric load panel can be very straightforward. Since the turbine-generator being considered for this application is not a regulated (load following) turbine, the generating unit will be connected to the L&D's distribution system continually generating a constant amount of power. Most turbine-generator manufacturers offer a "standard" control package that will be adequate for the Corps' needs. The control system must provide the unit with an automatic disconnect and shutdown capability that will function when the grid system goes down. A standard isolation breaker (rather than the automatic disconnect and shutdown) should be a primary feature of the connection to the L&D's distribution panel.

2.16 Spillway installation

Most L&D sites within USACE cannot use the power produced by turbine-generating units that are made to be installed in the spillway. At a minimum, these turbine-generator systems will have an output of about 50 kW. Most manufacturers provide equipment with minimum outputs in the 200 kW to 500 kW range. However, there appear to be a few L&D's where the average power requirement falls within these larger ranges. These spillway-installed turbine-generating units are designed specifically for such applications. This work found only three manufacturers that provide such equipment:

- Andritz Hydro HydroMatrix turbine, https://www.andritz.com/products-en/group/products/hydromatrix
- Flygt's submersible turbine, https://www.xylem.com/en-us/brands/flygt/
- Voith Hydro Stream Driver, http://voith.com/corp-de/turbinen-und-generatoren/streamdiver.html

These three manufacturers' web sites contain additional information about the application and configuration of these offerings.

2.17 COE contacts

USACE Hydroelectric Design Center contact phone numbers are:

- Office of the Director: 503-808-4200
- Chief, Product Coordination Branch: 503-808-4225
- Chief, Mechanical/Structural Branch: 503-808-4250
- Chief, Electrical Branch: 503-808-4275.

3 Solar Power

3.1 Solar energy overview

The U.S. economy relies heavily on robust electrical generation and distribution systems. However, traditional electrical power generation has its drawbacks. Electrical power generation is the largest consumer of primary energy sources, and is currently responsible for 40% of global CO_2 emissions.

Renewable energy sources (solar, wind, geothermic, and hydropower), which are being developed and deployed as alternatives to more polluting technologies, have attracted much attention in recent years. The Energy Information Administration (EIA), for example, projects that the share of solar and wind power generation will increase from 5.4% in 2015 to 17.5% in 2040 (EIA 2016a). Of all renewable sources, solar energy has achieved the highest growth among the alternate energy use sector (Gencer and Agrawal 2017). Solar power offers the promise of an abundant low-temperature energy source.

However, the efficiency of solar power depends greatly on location. Solar systems are usually suitable for application in certain geographical regions with an average solar irradiation of over 2000 kWh/m^2yr and a significantly large solar collector area (Nizetic, Penga, and Arıcı 2017), normally in locations confined to lower latitude subtropical and tropical regions with limited cloudiness (Luderer et al. 2017). Moreover, some solar energy systems have extensive land requirements.

When developing solar energy systems for Federal projects and solicitations, refer to the following Unified Facilities Criteria (UFCs) for solar photovoltaic technical requirements;

- UFC 3-440-01, *Facility-Scale Renewable Energy Systems* (NAVFAC 2015)
- UFC 3-540-08, *Utility-Scale Renewable Energy Systems* (AFCESA 2017).

A utility-scale project has the interconnection point directly to the utility distribution grid. A facility-scale project has the interconnection point at the facility's service entrance equipment and generally provides electricity for the facility.

3.2 Existing technologies

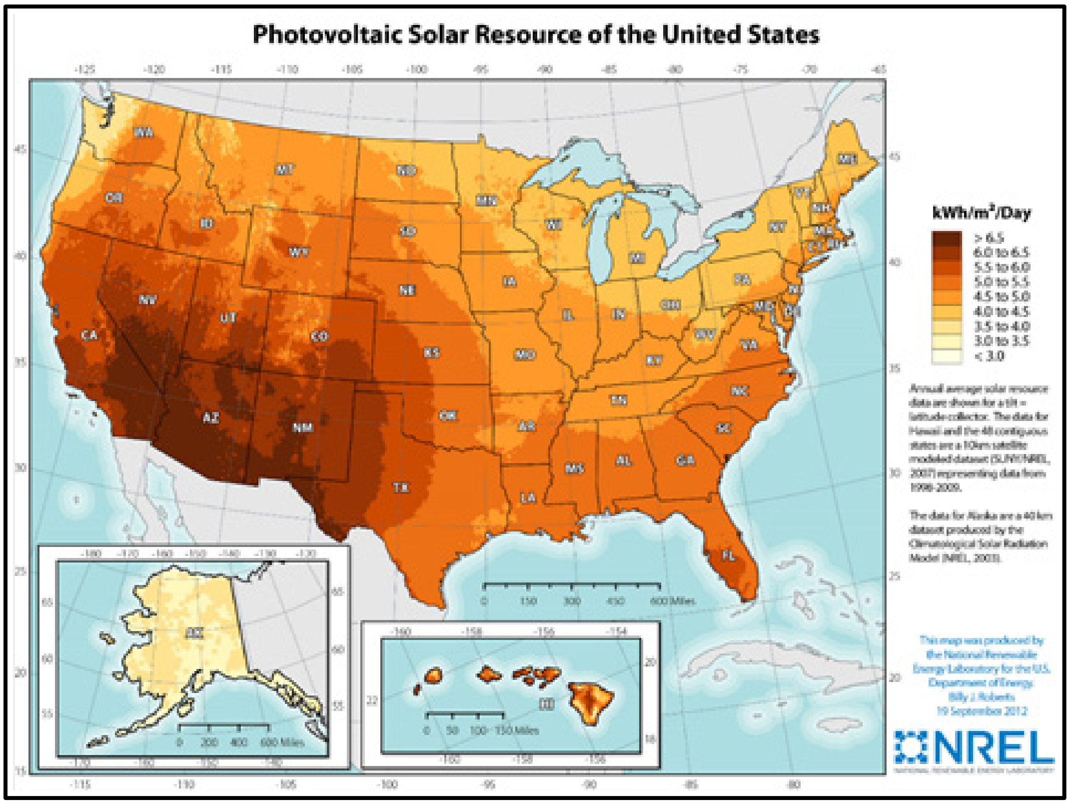
The two most common solar power generation technologies are: (1) photovoltaic (PV) solar, and (2) concentrating solar power (CSP). USACE Locks and Dams will most likely incorporate PV; therefore, CSP has not been included in this chapter.

The cost of providing the required energy to local and deployed military troops has been a relevant issue to the Department of Defense (DoD). The security and transportation burden of diesel fuel has incentivized the HQUSACE to investigate, develop, and implement alternative technologies to reduce conventional energy dependency. Solar cells or photovoltaic cells (PV) appear to be a potential candidate to diminish the use of conventional energy sources due to the low logistical support needed when compared to diesel fuel. PV technology has been characterized by rapid expansion and falling costs. From 1975 to 1985 the price of solar cells dropped from $30/Watt Peak (Wp) to $6/Wp. During the 1990s, the market increased by 17% per annum. At the end of the period, between 1996 and 1998, the growth rate averaged an impressive 33% (Andersson and Jacobsson 2000).

According to the *Renewable Energy Policy Network for the 21st Century* (REN21 2017), in 2015, the annual market was approximately 10 times the world's cumulative solar PV capacity of a decade earlier, increasing 25% over 2014 to a record 50 Gigawatts (GW) for a global total of 227 GW. At the end of 2016, the global installed capacity was 303 GW. Solar PV was reported to be the world's leading source of additional power generating capacity in 2016 with an annual market increase of nearly 50%, equivalent to more than 31,000 solar panels installed every hour (REN21 2017).

Operation and maintenance (O&M) cost is also fairly low for PV; the solar array component has a long lifetime (typically between 20 and 30 years), and a PV power station requires a minimal staff. However, PV cannot fully supply all power needs due to the variability of power output. Therefore, a hybrid power system or the combination of PV panels and other energy source, such as a diesel generator, could significantly reduce the amount of diesel needed by Army outposts (Severson and Leger 2013). According to a study performed by the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (Severson and Leger 2013), the incorporation of PV panels will significantly reduce the amount of diesel fuel used in deployed environments. Moreover, besides being a cost effective source, PV panels will also reduce generators' maintenance costs and increase generator lifetime due to longer shut off periods of operation. Different software (listed in Section 3.4.2) can be used to model the process to determine the feasibility of PV installation. To determine its feasibility, several components must be taking into account including solar resources availability (geographical location), load profile (electricity consumption), PV panel cost, and net present worth (to determine PV size).

Figure 3 shows the PV resources of the United States (NREL 2018). Section 3.4, "Solar energy on locks and dams," provides further discussion of this specific application of solar PV.



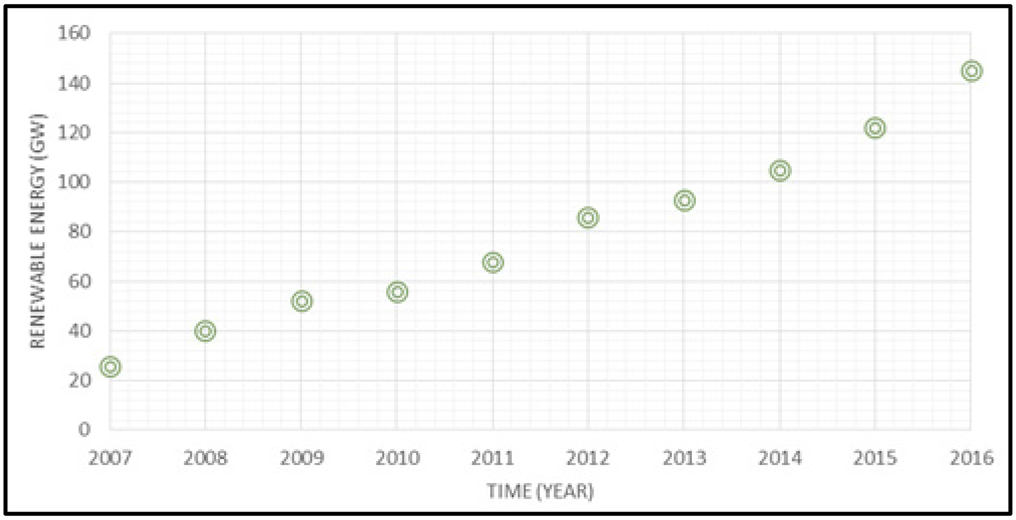
Source: www.nrel.gov

Figure 3. Photovoltaic solar resources of the United States.

3.3 Solar energy in the United States

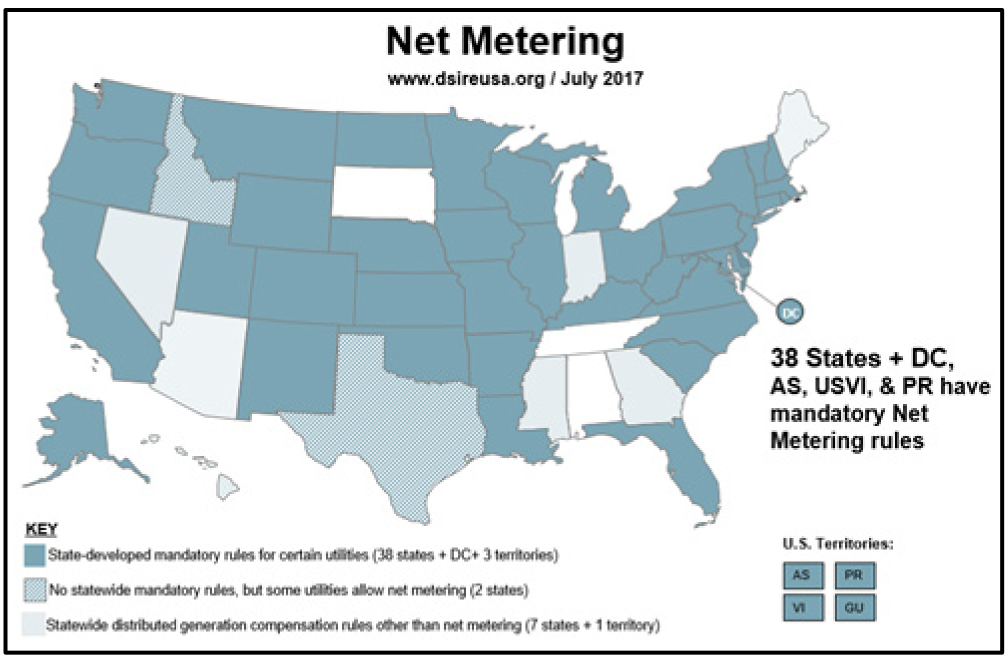
At the end of FY06, it was reported that the Department of Defense (DoD) consumed 80% of the total energy used by the U.S. Government, or almost 1% of the nation's total energy use (EIA 2007). Consequently, in January of 2007, President Bush issued EO 13423 (White House 2007), which required every Federal agency to improve its facility energy efficiency by 3%

annually, or by 30% total by 2015. As a result, the use of renewable energy has dramatically increased over the past decade. Figure 4 shows this growth as renewable energy usage per year (2007-2017), not including hydropower energy (Global Energy Reports 2007-2017). Moreover, most states have adopted net metering polices (Figure 5), which can assist each state in meeting their renewable portfolio standards (DSIRE® 2018).



Source: Global Energy Reports (2007-2017).

Figure 4. Renewable energy usage per year.



Source: DSIRE® (2018).

Figure 5. States with net metering policies.

In 2011, the U.S. Department of Energy (DOE) launched the SunShot Initiative, which consists of reducing the levelized cost of electricity (LCOE) to \$0.06/kWh by 2020 (EE&RE 2018). During that time, solar power comprised less than 0.1% of the U.S. electric supply with an installed capacity of 1.2 gigawatts (GW) and an average cost of \$0.23/kWh. Currently, solar power supplies 1% of U.S. electricity demand, and is growing. In 2016, solar power had an installed capacity of 30 GW and a LCOE of \$0.07/kWh. SunShot's current goal is to reduce the LCOE to \$0.03/kWh by 2030 (EE&RE 2018). The World Energy Council proposed the formula to calculate the levelized cost of electricity (Dowling, Zhen, and Zavala 2017). NREL provides an online calculator to estimate LCOE (https://www.nrel.gov/analysis/tech-lcoe.html). This formula allows the comparison of different energy technologies by comparing the combination of capital costs, operations and maintenance (O&M), performance, and fuel cost:

$$\boldsymbol{LCOE} = \frac{\sum_{t=1}^{n} \frac{(I_t+M_t+F_t-H_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{5}$$

where:

I_t = Investment expenditures in the year t
M_t = Operations and maintenance expenditures in the year t
F_t = Fuel expenditures in the year t
H_t = Avoided heat production costs in the year t
E_t = Electricity generation in the year t
R = Discount rate
T = Year
N = Assumed lifetime of system (integer, in years).

The result of the LCOE calculation can be used to compare the cost of electricity produced by the solar generation to the cost of electricity from the utility provider and other energy alternatives being evaluated.

The military has increasingly turned to solar energy to address vital DoD objectives and to meet its renewable targets. Portable solar provides the military with cost-effective energy that improves mission capabilities and mitigates national security issues associated with grid infrastructure and conventional fuel supply (EIA 2013). As of early 2013, more than 130 MW of solar PV energy systems powered Navy, Army, and Air Force bases in at least 31 states and the District of Columbia, with the Navy having the most facilities (Figure 6). Prehoda, Schelly, and Pearce (2017) revealed that about 17 GW of PV would be needed to fortify the U.S. military domestically.

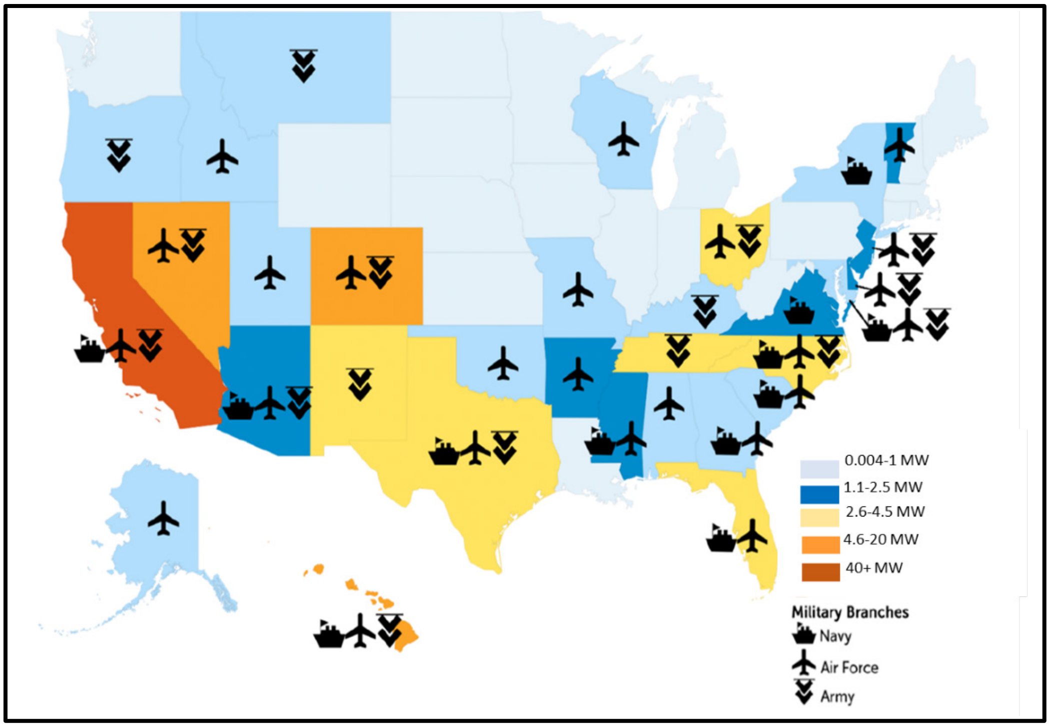
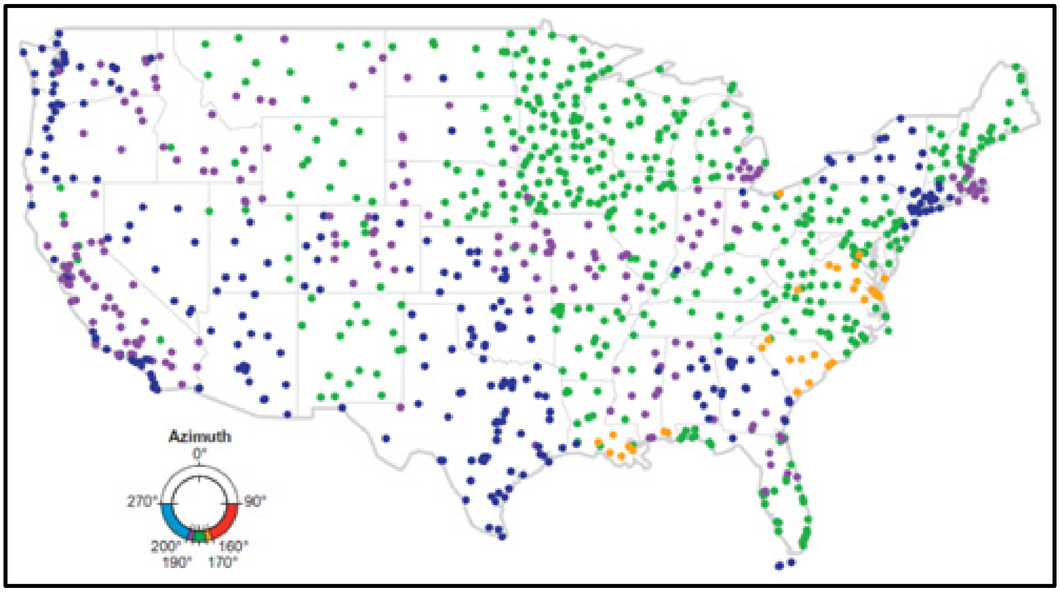


Figure 6. PV systems in the U.S. Department of Defense (DoD).

The average solar flux for the state is termed "*f*." In the United States, *f* is approximately 4.5 kWh/m²/day for non-tracking flat plate PV tilted south at the latitude to optimize yearly energy production (Figure 7). This value varies for different states from 3.34 to 7.5 kWh/m²/day, as measured at military installations within each state (Prehoda, Schelly, and Pearce 2017). However, depending on the location, i.e., on number of peak-equivalent hours per day (i.e., much usable sunlight is available in a given place), which averages 3.5-6.5 hrs in the United States (Appendix A), solar energy can pay for itself.

Since PV cells absorb only a portion of the solar spectrum, they are suitable for both diffused and sunlight applications; this allows them to be installed in diverse geographical locations (Bolton, Strickler, and Connolly 1985). Nevertheless, before installing a PV power station, a number of parameters must be evaluated to maximize effective energy generation, including: solar insolation, electric grid standards, energy transmission distance, site latitude, and regional energy load needs. The average solar radiance and the optimistic efficiency of the solar cell lifetime must also be accounted for to calculate the solar panel area required to supply a specified amount of energy.



Source: Rhodes et al. (2014).

Figure 7. U.S. optimal azimuth of solar PV systems when considering the value of solar energy produced.

Solar cell efficiency also depends on the color to which a cell responds, a characteristic that is fixed in the design of the photovoltaic layers. The color of sunlight changes with time and place; at sunset, light is redder and yellower so a blue PV cell cannot generate as much current at that time of day (Chen 2011). Concentrating the light to create higher incident intensity can increase cell efficiency, but the use of concentrated light can also cause a drop in cell lifetime (Abbott 2010).

3.4 Solar energy on locks and dams

Dams can have several functions. They are built to generate electricity, and also for downstream flood protection, irrigation, and improved navigation. For decades, hydropower has been the main renewable energy source for electricity generation in the United States. However, the increase in energy demand has led to the search for other renewable energy sources including wind and solar energy. In fact, it is expected that the wind and solar energy generation will be higher than that of hydroelectric power by 2040 (EIA 2016b). Although locks and dams efficiently generate hydropower, there is also a potential to use locks and dams to generate power from the synergistic integration of hydropower and other renewable energy sources. The area flooded by the dam can also be used for the installation of a photovoltaic power plant (Teixeira et al. 2015). This section focuses mainly on the combination of a hydropower plant and a solar array, also known as a "hydroelectric solar hybrid system," specifically on PV installation at locks and dams. PV arrays on Federal properties near a lock must closely follow UFC 3-440-01 (NAVFAC 2015) and other existing installation protocols. The California Energy Commission (CA.gov 2018) has also prepared a useful PV design and installation guide (http://www.energy.ca.gov/reports/2001-09-04_500-01-020.pdf).

The cost of solar energy technologies has drastically decreased in recent years, mainly due to government subsidies and to the fact that solar industries have achieved greater economies of scale (Carley and Andrews 2012). Thus, the combination of solar power with hydropower can greatly enhance energy generation without extra structural cost by using existing dams. Dams have a plane surface that can be used to accommodate solar PVs.

In addition to the installation of PVs on the face of existing dams, there has also been a proposal for the installation of PV floating systems in lakes, reservoirs, and other water bodies. However, the many disadvantages and limitations of these options must be considered before their implementation. For example, the efficiency of a PV module —or the maximum power output of the solar cells— gradually decreases as the temperature increases. These changes depend on the solar cell type and cell design (Kougias et al. 2016c). A standard crystalline silicon module loses about 0.4-0.5% of its rated power per degree Celsius increase (Wysocki and Rappaport 1960, Emery et al. 1996). Hence, placing PVs on a dam's (warm) plane surface may reduce solar cells lifespan. However, the temperature of the PV cells can be decreased by installing the combination of PV plant technology and floating PV technologies. The floating solar panel may be able to take advantage of the cooling effect of the water surface on the rear surface of the solar panels. On the other hand, the installation of floating PV requires an extensive area (depends on the desired power output), which could negatively impact aquatic life.

3.4.1 Floating PV systems

Even considering the constraints discussed in Section 3.4, dams can be used for solar power generation without affecting their primary functions. The goal of hybrid systems is to overcome seasonal minimum energy availability. The integration of solar energy into hydroelectric dams can improve a dam's capability to generate electricity (Melvin 2015). The PV floating plant (Figure 8) consists of a floating structure, mooring controls (directional control), PV panels, and underwater cables (Choi et al. 2013).

Source: www.solarbuildermag.com

Figure 8. Floating PV system.

A hydro-PV hybrid system will result in an initial cost of approximately $1715.83/kW installed, and an energy cost of $0.059/kWh. Moreover, the system could help reduce water evaporation, which, depending on local conditions, could increase the amount of water available for power generation (Teixeira et al. 2015). The following factors, which affect installation and maintenance, must be considered before integrating solar energy into a hydroelectric dam (Sharma and Kothari 2016):

- Water depth (water level fluctuation), frozen region(s), inflow of floating matter, accessibility, interference by dam facilities.
- Fishing prohibition area, marine leisure activity prohibition area, civil complaints, excessive compensation expense, and inducement of environmental problems. In the United States, applicable governing laws would be the National Environmental Policy Act (NEPA) of 1970, and the Endangered Species Act of 1973.
- Factors that directly affect power generation or efficiency (solar radiation, fog, and shade).
- Connection with power system, distribution line, distance to distribution line, distance to load.
- Legal restrictions: water source protection area.
- Risk of power loss in PV modules due to micro cracks caused by wind, waves, and external forces vibrations.

This innovative alternative is important to improve sun harvesting capabilities while reducing the land area needed for ground-mounted arrays, which in some cases is agricultural land. Floating PVs can also improve water quality by reducing algal growth by inhibiting photosynthesis. Since the dams are pre-existing structures, the cost of building new structures is negligible. Maintenance/cleaning requirements will be minimum since water for cleaning the panels is readily available, and panels can be easily rinsed off with a brush.

Nevertheless, unanticipated issues may occur, for example, problems related to the prolonged contact of the solar panels with water, or where systems are installed in coastal lines, the effect of brackish and/or saltwater on the lifetime of solar modules. Furthermore, installed floating systems should be able to withstand environmental factors such as maximum speed wind, water current, temperature variation, snow load, typhoons, and cyclones. Another disadvantage of using floating PV is the amount of arsenic (and other chemicals/heavy metals) used to build the cells. Each solar cell, for example, uses about 0.17 g/cm^2 of arsenic during manufacture (Lattin and Utgikar 2006), which can be harmful to humans and aquatic life if released.

To evaluate the performance of floating PVs, certain parameters involving the efficiency of the system must be calculated/estimated. For example, the PV effective conversion efficiency (Eq. 6) (Sahu, Yadav, and Sudhakar 2016) can be calculated by the ratio of the generated electrical power and the incident solar radiation intensity. The capacity factor (percentage) of the floating panels (Choi et al. 2013) can be expressed as the ratio of the generated duration analysis period and the product of the installed capacity and the analysis period (Eq. 7).Parameters that must be taken into account when installing PV systems include the PV dimensions and tilt angle (Tables 2 and 3), the distance between panel rows to prevent shade effects and access ways to ease operational maintenance (Ferrer-Gisbert et al. 2013), and very important, the payback period (Eq. 8) of the system (Sahu, Yadav, and Sudhakar 2016). Solar return on investment can be also calculated using the Solar Simplified (2017) Calculator, or by using the following formulas:

$$\boldsymbol{\eta_{el} = \frac{P_{max}}{S \times A_{pv}} \times 100} \qquad (6)$$

where:

η_{el} = the electrical efficiency (%)
P_{max} = power generated by PV module (W)
S = solar radiation intensity incident on the PV module (W/m^2)
A_{pv} = front PV module surface exposed to the solar radiation intensity (m^2)

$$\boldsymbol{Capacity\ factor}\ (\%) = \frac{\boldsymbol{Generated\ quantity\ duration\ analysis\ period}\ (\boldsymbol{kWh})}{\boldsymbol{Installed\ Capacity}\ (\boldsymbol{kW})\times \boldsymbol{Analysis\ period}\ (\boldsymbol{h})} \times \mathbf{100} \quad (7)$$

$$\boldsymbol{PB\ period} = \frac{\boldsymbol{Total\ cost\ of\ PV\ system\ with\ all\ auxiliary\ equipment}}{\boldsymbol{Total\ annual\ cost\ saving\ after\ installation\ of\ PV\ system}} \quad (8)$$

Table 2. Number of PV units and power installed depending on the tilt angle.

Tilt Angle	Number of Floating Modules (two PV panels)	Floating Module Sizes (W x L) (m)	Peak Installation (kWp)	Peak Power Density (Wp/m^2)	Energy Yield (kWh/m^{2}year)
30 deg.	652	3.40 x 2.00	260.8	55.46	82.49
15 deg.	787	2.20 x 2.55	314.8	65.55	104.27
10 deg.	908	2.20 x 2.20	363.2	74.16	114.89
Source: Ferrer-Gisbert et al. (2013).					

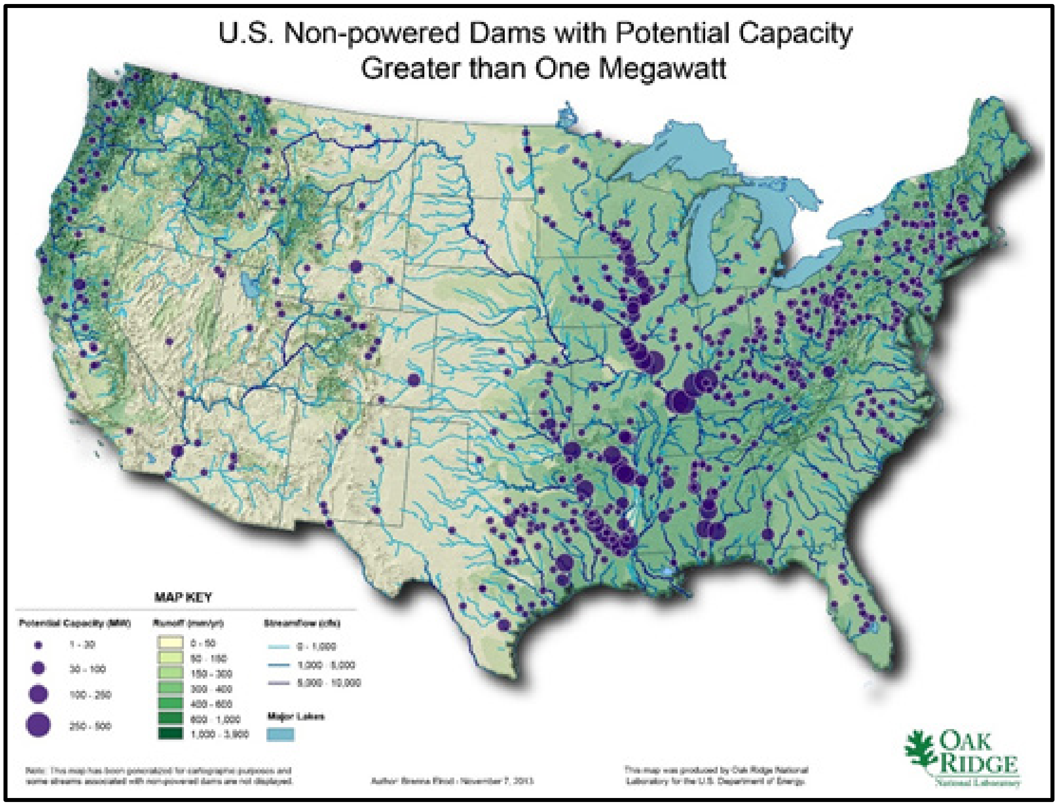
Table 3. Power loss vs. azimuth rotation.

Azimuth Rotation	Peak Sun-Hours (PSH)	Losses regarding 0-deg.azimuth
0 deg.	1800	–
10 deg.	1800	0.00%
20 deg.	1790	−0.56%
30 deg.	1780	−0.56%
40 deg.	1770	−0.56%
50 deg.	1750	−1.13%
60°	1730	−1.14%
Source: Ferrer-Gisbert et al. (2013).		

Although this technology has already been implemented in different parts of the world, some requirements need further research: the designing anchoring system to fix the buoyancy system, the effect of saltwater on the PV structure and module performance, and the development of a solar tracking device that can change the tilt and azimuth angle of the floating system (Sahu, Yadav, and Sudhakar 2016). The appropriate safety measures to transport the power from the water bodies to the land and structural design can be done by following the criteria in UFC 3-540-08, Chapter 3, "Design Criteria for PV Systems" (AFCESA 2017).

3.4.2 PV systems on dam plane surfaces

Another alternative for hydro-PV hybrid systems is the installation of PV systems on a dam's plane surfaces. An additional advantage of this type of systems is that it can be also installed on non-powered dams (Figure 9). For non-power water storage reservoirs, the produced solar electricity can be used to power other energy intensive operations; thereby, reducing the dam's energy dependence (Patsialis et al. 2014). At hydroelectric dams, PV equipment (i.e., transformer and circuit breakers) can increase capacity slightly (about 15%) by design (Kougias et al. 2016a).



Source: ornl.gov

Figure 9. U.S. non-powered dams.

It is recommended that PV modules be installed parallel to the dam's downstream surface to minimize obstruction and additional weight (Kougias et al. 2016c), and to ensure that the PVs are not mounted on spillways, gateways, or any other machinery. In fact, the additional structural weight of the PV installation may be negligible compared to the massive structure of the dam's body (Kougias et al. 2016a), which can vary accordingly with the type of dam. Therefore, the geometrical characteristics of each specific dam must be considered, including height, slope, and length of crest. Besides the geometrical shape, the construction methods, size, and materials of the dam must be evaluated as well.

Installation solutions differ for each specific dam. Different types of dams (Kougias et al. 2016a) include:

- *Gravity dam*, which is usually made of concrete or masonry with a vertical upstream face, and a downstream face that varies between 50 and

60 degrees. A gravity dam may impose some technical difficulties during the PV system's installation and maintenance, favoring regions with geographical latitude of 50-60 degrees, and dams that face south/north (depending on the hemisphere).

- *Buttress dams*, which are generally made of concrete with a watertight upstream side that is supported by triangular shaped walls or arches (buttresses). Due to downstream face and limited flat areas, buttress dams are not suitable for PV installation.
- *Arch dams*, which are curved in plan and carry most water load horizontally to abutment by arch actions. PV installation will require high investment capital. Arch dams are usually surrounded by shaded areas, which decrease the amount of insolation received.
- *Embankment dams*, which are created by the placement and compaction of a mound of soil, sand, clay, and rock. The two main types of embankment dams are earth-fill dams and rock-fill dams. Upstream and downstream faces may have different slopes (between 20 and 30 degrees). Embankments favor efficient PV installation on dams in regions with relatively lower geographical latitude. Moreover, an embankments' lower slope facilitates both installation and maintenance of PV systems.

Although some of these dams do not meet the expected criteria, it is still possible for some of them to be advantageous locations if they have a large flat area and an acceptable inclined surface. In the case of earth dams, an additional advantage of PV modules is that their installation protects the surface from direct solar radiation that might negatively affect the stability of low-head earth dams, especially during summer (Bortkevich et al. 2001).

In addition to these advantages, the installation of PV systems on dam faces does not impose the additional cost of grid extension (Kougias et al. 2016a). Some of the most commonly used methods for hybrid system optimization include the use of the Excel® based, linear programming, artificial intelligence, modeling language and optimizer (LINGO) and HOMER (Sopian et al. 2008, Kenfack et al. 2009, Kanase-Patil et al. 2010, Bakos 2002, Connolly et al. 2010). UFC 3-540-08 (AFCESA 2017) provides PV arrays sizing information. Specific information on PV sizing may also be found through:

- www.homepower.com (Home Power 2018)
- www.solardirect.com (Solar Direct 2018)
- http://aessolar.com/Resources/pvworksheet.htm (AES Solar 2018)

USACE studied the use of solar energy for ice control at locks and dams installations and concluded that solar energy (and wind energy) is not feasible because no solar power is generated at night when temperature drops (Nakato et al. 1992). Moreover, if a solar system should be installed on a dam's surface, it must follow UFC 3-540-08, Chapter 3, "Design Criteria for PV Systems" (AFCESA 2017).

3.5 Preliminary siting considerations

When performing a preliminary evaluation for solar potential the following steps will assist in the planning a preparation:

- Procure preliminary estimates of solar resource potential.
- Identify site-specific space requirements including physical sizes and space restrictions.
- Identify site-specific policies and incentives.
- Identify site-specific interconnection requirements including net metering.
- Determine the total annual energy consumption and average energy consumption of the potential site.
- Determine the percentage of the site annual energy consumption or average energy consumption to be supplied by the wind turbine.
- Estimate the required solar system and calculate a preliminary estimate of the annual energy output of the potential system

The document, *Working with the Department of Defense: Siting Renewable Energy Development (*NRDC 2013) identifies the following siting considerations that must be evaluated:

- Locations that adversely impact avian populations (especially migratory birds and raptors) and bats, or important habitat areas including flyways, migration routes and raptor concentration areas
- Areas that have been specially designated for conservation by land management agencies or other government agencies, including Areas of Critical Environmental Concern, Wildlife Habitat Management Areas, National Forest Roadless Areas, and Conservation Reserves that are included in proposed and final habitat conservation plans and other comparable plans
- Lands purchased for conservation, including those conveyed to the Federal government by third parties
- Landscape-level biological linkage areas required for the continued functioning of biological and ecological processes

- Proposed Wilderness Areas, proposed National Monuments, and Citizens' Wilderness Inventory Areas that are publicly noticed at the time the project is proposed
- Wetlands and riparian areas, including the upland habitat and groundwater resources required to protect the integrity of seeps, springs, streams, or wetlands
- Floodplains, especially 100-year flood plains
- Areas with limited water when siting solar panels that require water for washing the panels
- Sites that have been publicly identified as eligible for the National Historic Register at the time a renewable energy project is proposed
- Sites protected under the Archeological Resources Protection Act of 1979 (ARPA 1979)
- Locations directly adjacent to National or State Park units
- Native American and other cultural sites.

The California Energy Commission (CA.gov 2018) has also prepared a useful PV design and installation guide.

3.6 Preliminary estimation of solar resource potential

The office of Energy Efficiency & Renewable Energy provides state specific maps that detail direct normal irradiance, global horizontal irradiance, and maps that detail solar photovoltaics and concentrating solar power resource potential across the United States (NREL 2018). These maps can be used to estimate the solar potential at a specific site.

Appendix A includes a table that lists the high, low and average amount of sun hours per day for various cities and states across the United States. Locations with higher average sun hours per day will have a higher potential as feasible solar sites. This table can also be used to estimate the preliminary solar potential at a specific site in the following ways. The average sun hours per day can be multiplied by the size of the array to estimate the kWhs produced at the specific location, or the sites energy requirement can be divided by the average sun hours to estimate the size of the array to meet the site's energy requirement.

3.7 Physical size and space restrictions

For initial planning purposes, 100 square feet of available space is estimated to be needed per kilowatt or power required. Therefore, a 100kW solar array would require an estimated 10,000 square feet of available space to install the system.

If the specific host site has an acceptable estimate of solar potential, possible locations should be identified. Solar panels should be placed in unobstructed areas with few obstacles to that might shade the panels. Location of the panels must also consider grounds maintenance requirements and winter snow levels when determining mounting heights, spacing, and ground cover.

UFC 3-540-08 provides the following guidance:

> All structures and structural elements, including PV array structures must comply with UFC 1-200-01, DoD BUILDING CODE (GENERAL BUILDING REQUIREMENTS), including all referenced criteria and standards
> For optimum performance, orient the module true south in the northern hemisphere and true north in the southern hemisphere; however, slightly west of south or north (azimuth angle of true south or north plus 10 degrees) may be preferable in some locations if an early morning haze or fog is a regular occurrence.
> Tilt the array to the latitude plus or minus 10 degrees. It should be noted that as the tilt angle increases, the minimum spacing between rows must be increased due to shading. Do not allow inter-row shading between 9 a.m. and 3 p.m., when the bulk of the energy collection occurs.

3.8 Solar energy policies and incentives

Both regulatory policies and incentives must be examined for the specific site when investigating potential solar projects.

The DOE has funded the NC Clean Energy Technology Center at North Carolina State University to operate the Database of State Incentives for Renewables & Efficiency® website (DSIRE). DSIRE provides a comprehensive state by state database of policies and incentives for renewable technologies (DSIRE® 2018).

This searchable database provides information pertaining to financial incentives, technical resources, and regulatory policies that are useful in developing renewable projects, including those involving wind generation. This resource may be used to identify both net metering and interconnection requirements for the state being investigated, and to locate contact information for appropriate agencies.

In a preliminary test search, filters were applied to the DSIRE website to identify regulatory policies in the state of Iowa for solar technologies. DSIRE identified and listed 36 unique programs in the state of Iowa, including both policies and financial incentives. These site-specific policies should be reviewed during the initial development of any project.

3.9 Costs

Table 4 details the mean installed cost per kW of $2,667 with a standard deviation of $763/kW for photovoltaic systems. The usable lifecycle is 33 years with a 9-year standard deviation. The fixed O&M cost is $20/kW with a standard deviation of $10/kW. These numbers should be used for planning purposes when developing a project for the DoD.

3.10 O&M requirements

O&M may be performed in house, or as part of a warranty or service contract. Since PV technology uses highly specialized equipment, a service contract may be the most effective methodology for maintenance. UFC 3-540-08 (AFCESA 2017) directs DoD facilities to maintain installed solar technologies by complying with the requirements of UFC 3-560-01, *Operation and Maintenance: Electrical Safety* (NAVFAC 2018) and per manufacturers' documentation, as required. UFC 3-560-01 provides safety requirements and guidance for anyone working on or near electrical components rated at 50 volts or above in facilities and related infrastructure.

Table 4. NREL distributed generation renewable energy installed costs.

	Generator Type / Size System		
	PV 1–10 MW	**Wind 1–10 MW**	**Biomass Combined Heat & Power***
Mean installed cost $/kW	$2,667	$2,644	$6,067
Installed cost Std. Dev +/- $/kW.	$763	$900	$4,000
Fixed O&M $/kW-yr.	$20	$36	$91
Fixed O&M Std. Dev. +/- $/kW-yr.	$10	$16	$33
Variable O&M $/kWh	n/a	n/a	$0.06
Variable O&M +/- $/kWh	n/a	n/a	$0.02
Lifetime yr.	33	20	28
Lifetime Std. Dev. yr.	9	7	8
Fuel or water cost $/kWh	n/a	n/a	$0.04
Fuel or water Std. Dev. $/kWh	n/a	n/a	$0.02

*Unit cost is per kilowatt of the electrical generator, not the boiler heat capacity.
Geothermal cost breakdown not available. See Appendix F for planning factors and cost models.
Costs are NREL update of August 2013.

Source: UFC 3-540-08 (AFCESA 2017).

3.11 Environmental considerations

UFC 3-540-08 (AFCESA 2017) directs the evaluation of environmental requirements (e.g., noise, air pollution, wildlife, stormwater) be developed during the initial project planning stages in accordance with the National Environmental Policy Act (NEPA 1970).

3.12 COE contacts

The U.S. Army Corps of Engineers has a Solar Photovoltaic Center of Expertise (CXS) in Sustainability to provide information and help evaluate and implement the use of wind energy technologies at DoD locations. Further information on the Solar Photovoltaic (CXS) may be found through: http://www.usace.army.mil/Missions/Sustainability/Expertise-in-Sustainability/Solar-Photovoltaic/

The Solar Photovoltaic Knowledge Resource can be contacted through e-mail: SolarPV@usace.army.mil

4 Wind Power

4.1 Process overview

Developing a renewable energy project using wind turbine technology is a site-specific process. Several considerations must be met for a site to be an acceptable candidate for wind turbine installation. These considerations include the power requirements of the host facility, wind capacity/energy available at the site, and zoning requirements or restrictions, including grid interconnection requirements and net metering opportunities.

UFC 3-540-08, *Utility-Scale Renewable Energy Systems* (AFCESA 2017) should be used as the guiding document for all planning purposes when developing a wind project because it:

> … provides requirements for the planning, design, construction, and operations and maintenance of solar photovoltaic, horizontal axis wind turbine, waste to energy, landfill gas, and geothermal renewable energy power generation systems.

Two addition leading information resources on wind turbine technologies that provide invaluable resources for developing a wind power project are:

- The Department of Energy Office of Energy Efficiency & Renewable Energy (DOE EERE) Wind Energy Technologies Office website, https://energy.gov/eere/wind/wind-energy-technologies-office
- National Renewable Energy Laboratory's (NREL's) National Wind Technology Center's *Wind* webpage, https://www.nrel.gov/wind/

4.2 Power available

Wind turbines are typically built in two configurations, either horizontal axis or vertical axis. The horizontal axis configuration is the more commonly used type in commercial and industrial applications.

The horizontal axis configuration usually consists of two or three blades that rotate perpendicular to the wind direction. The blades facing into the wind convert the kinetic energy of the wind into mechanical power. This power runs a generator creating electricity. Power ranges for the horizontal axis configuration are typically grouped in two categories, small scale 1-100kW, and large scale >100kW. Size selection will be determined based on site-specific factors, including available space, wind resources, and power requirements of the host facility. Typically, lock and dam facilities could be reasonably serviced by small scale horizontal axis wind turbines.

Vertical axis wind turbine consist of a two or three blades with the rotor shaft set transverse to the wind. This design allows the generator and gearbox to be located close to the ground, also allowing for short tower heights. This type is far less common and will not be discussed in this document.

When performing a preliminary evaluation for wind potential, the following steps will assist in the planning a preparation:

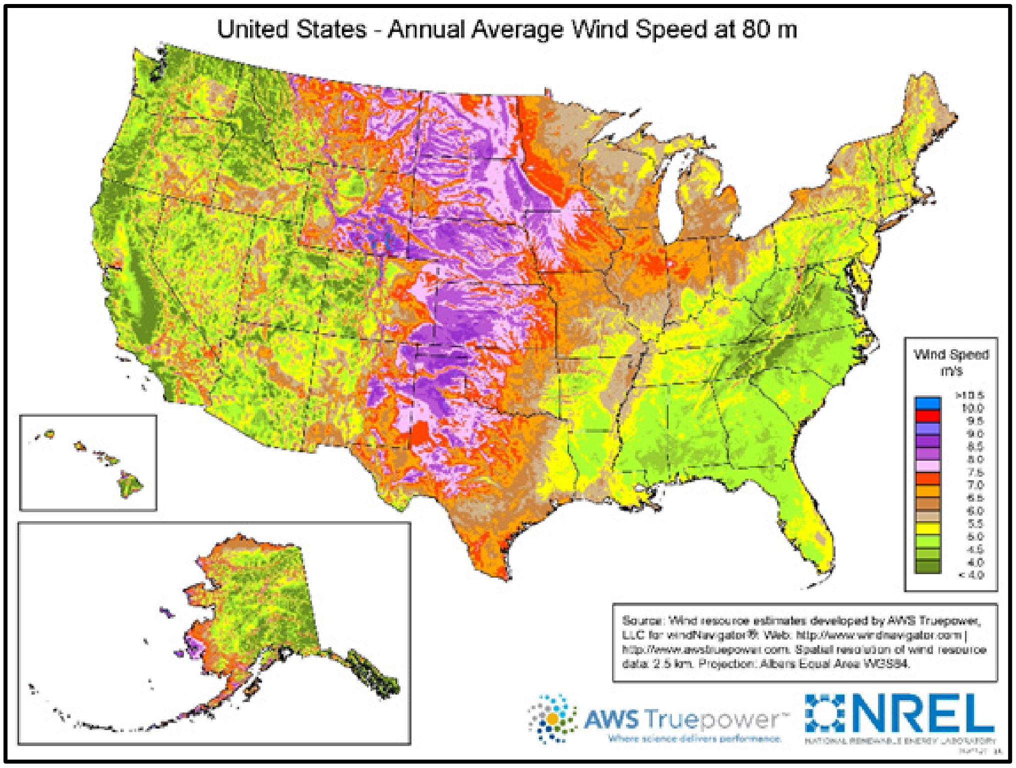
- Procure preliminary estimates of wind resource potential.
- Identify site-specific site space requirements, including physical sizes and space restrictions.
- Identify site-specific policies and incentives.
- Identify site-specific interconnection requirements, including net metering.
- Determine the total annual energy consumption and average energy consumption of the potential site.
- Determine the percentage of the site annual energy consumption or average energy consumption to be supplied by the wind turbine.
- Estimate the required turbine size and calculate a preliminary estimate of the annual energy output of the potential wind turbine.

4.3 Preliminary wind resource potential estimation

The DOE EERE *Wind Energy Maps and Data* website (https://windexchange.energy.gov/maps-data) lists categories of wind maps and allows the user to filter for specific turbine height. The categories of wind speed resources, based on turbine hub height, include:

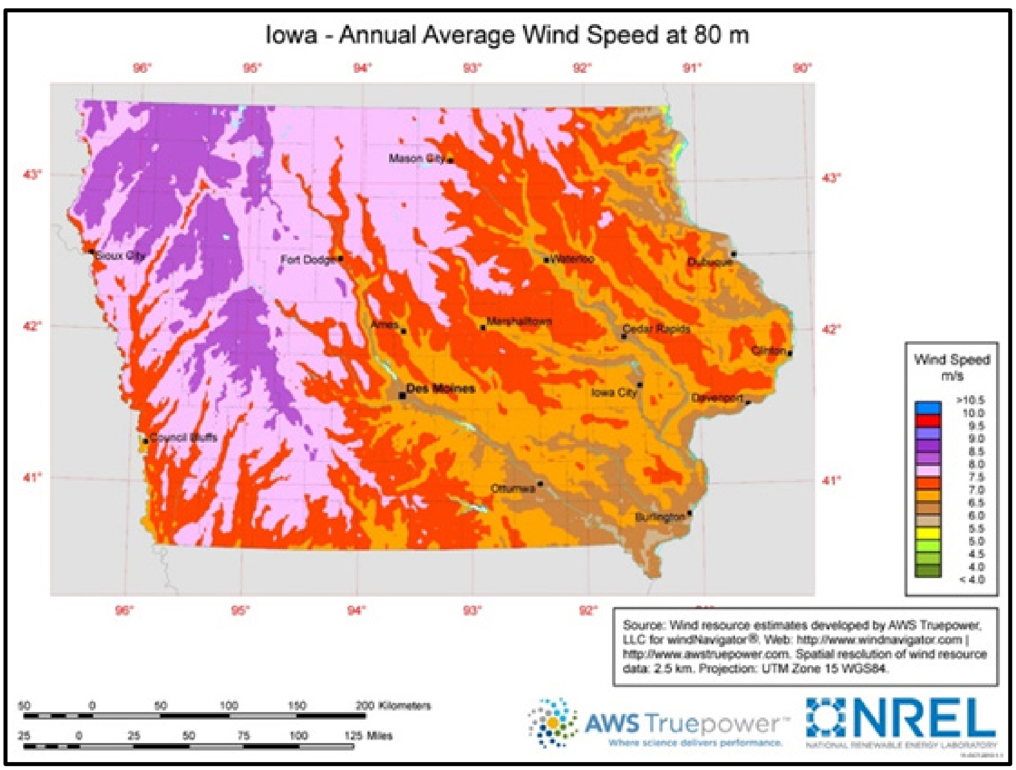
- 30 – Meter Residential
- 50 – Meter Community
- 80 – Meter Land-Based
- 90 – Meter Offshore
- 110 – Meter Potential
- 140 – Meter Potential.

The 80-Meter Land-Based map should be used in the initial evaluation of annual average wind speed to identify wind resource potential (Figure 10). Individual state maps are available for initial wind speed analysis (e.g., Figure 11 for Iowa).



Source: **www.windexchange.energy.gov**

Figure 10. U.S. annual average wind speed at 80 m.



Source: **www.windexchange.energy.gov**

Figure 11. Iowa annual average wind speed.

When evaluating for suitable wind speed, 6.5 m/s or greater are typically acceptable for further evaluation. If the site specific 80-Meter Land-Based map indicates sufficient wind resources, the 50 Meter and 30 Meter maps should also be reviewed, based on the hub height, and size of the potential wind turbine. For example, a 100kW wind turbine generally has a hub height of less than 50 meters so the lower altitude wind maps should be consulted.

4.4 Physical size and space restrictions

If the specific host site has an acceptable estimate wind potential, possible locations should be identified. Location of the turbines should be in unobstructed areas with few obstacles to disrupt air flow. Typically, good locations are on the tops of ridges or hills, in large open spaces, or near the edge of water. Poor locations include in valleys, at the bottom of hills, or where many obstructions occur.

Small scale wind turbines producing power less than 100kW generally have a hub height less than 50 meters and blades lengths less than 25 meters. For smaller turbines rated between 1-100kW the following rules of thumb are used for siting:

- Allow a 250-300 ft radius between the turbine and any obstacles.
- Mount the turbine at least 25-30 ft above any nearby wind obstructions.

NREL technical report NREL/TP-5000-63696, *Small Wind Site Assessment Guidelines* (Olsen and Prues 2015), details site assessment for small wind turbines with a power rating between 1-100 kW. NREL/TP-5000-63696 provides guidelines for developing a detailed site assessment for identifying the appropriate location of small wind turbines and calculating the energy production. The report provides the following considerations when identifying siting locations:

> The ability to site a wind turbine and tower in an ideal location that is completely free of obstacles and has access to unobstructed wind flow often clashes with the realities of land-use limitations, such as:
>
> - Property boundaries
> - Zoning setbacks and height limits
> - Owner or neighbor view impact
> - Soil conditions
> - Construction access
> - Interconnection requirements and wire run routing
> - Safety.

Typical large scale wind turbines producing power greater than 100kW can range in hub heights 80 to 100 meters with a tip heights of 130 to 225 meters. Blades can range from 40 to 60 meters in length.

For large scale turbines rated greater than 100kW, the following rule of thumb is used for siting: "Turbine location should be should be at least twice the turbine height from the nearest obstacle."

When installing large scale wind turbines, turbine providers will typically perform a detailed site assessment to facilitate location.

4.5 Wind energy policies and incentives

When investigating potential wind projects, both regulatory policies and incentives need to be examined for the specific site. Two websites created to provide information on these topics when developing wind projects are:

- WINDExchange website, https://windexchange.energy.gov.
  The Department of Energy, in conjunction with NREL, created the WindExchange to provide a searchable database of local ordinances that regulate the construction, permitting, and location of wind projects: https://windexchange.energy.gov/policies-incentives
- Database of State Incentives for Renewables & Efficiency® (DSIRE®) website (DSIRE® 2018), http://www.dsireusa.org/
  The DOE also funded the NC Clean Energy Technology Center at North Carolina State University to operate the DSIRE® website. DSIRE® provides a comprehensive state by state database of policies and incentives for renewable technologies.
  This searchable database provides specific information pertaining to financial incentives, technical resources, and regulatory policies that are important when developing renewable projects, including those using wind generation. This resource may be used to identify both net metering and interconnections requirements for the state being investigated, and to locate contact information for appropriate agencies.

In a preliminary test search, filters were applied to the DSIRE website to identify regulatory policies in the state of Iowa for wind turbine technologies (Figure 12). These policies should be reviewed during the initial development of the project.

Category: Regulatory Policy | Excluding SIR Programs | State/Territory: Iowa | Technology Category: Filter by Technology

Search... Subscribe Show 50 entries Apply Filter

Name	State/ Territory	Category	Policy/Incentive Type	Created	Last Updated
Green Power Purchasing Goal for Federal Government	US	Regulatory Policy	Green Power Purchasing	02/19/2004	12/13/2016
Alternative Energy Law (AEL)	IA	Regulatory Policy	Renewables Portfolio Standard	01/01/2000	12/09/2016
Interconnection Standards for Small Generators	US	Regulatory Policy	Interconnection	10/30/2007	07/27/2016
Mandatory Utility Green Power Option	IA	Regulatory Policy	Mandatory Utility Green Power Option	09/24/2001	01/29/2016
Small Wind Innovation Zone Program and Model Ordinance	IA	Regulatory Policy	Solar/Wind Permitting Standards	06/07/2011	01/29/2016
Interconnection Standards	IA	Regulatory Policy	Interconnection	06/18/2003	09/30/2015
Net Metering	IA	Regulatory Policy	Net Metering	01/01/2000	06/18/2015

Source: http://programs.dsireusa.org/system/program?fromSir=0&state=IA

Figure 12. Regulatory policies in the state of Iowa for wind turbine technologies.

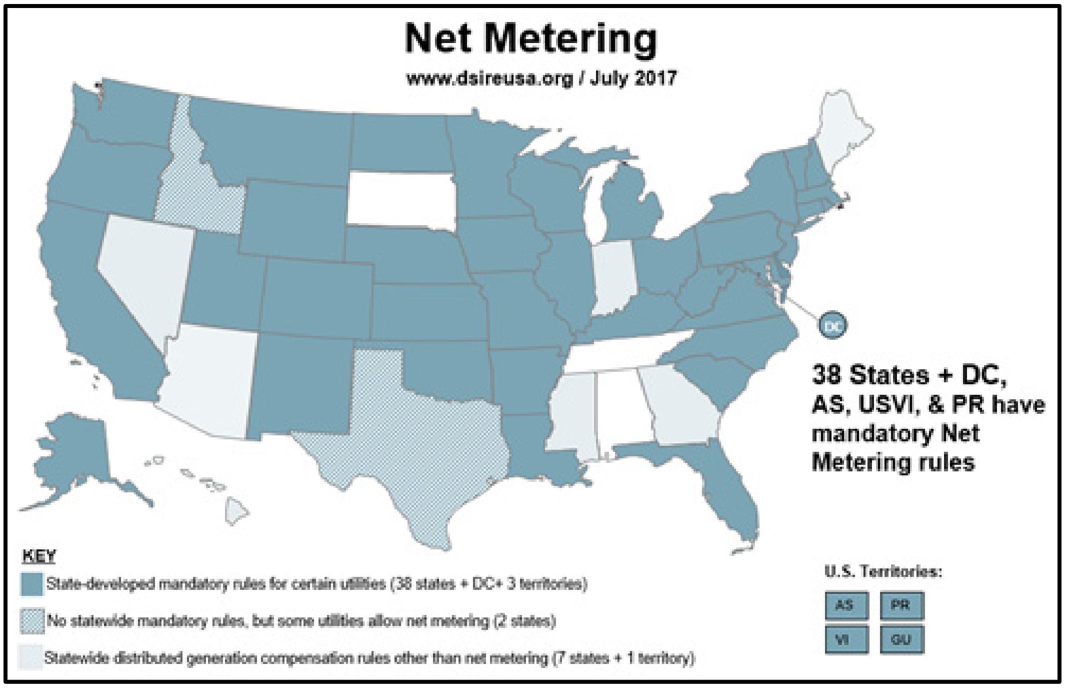
4.6 Electric power interconnection

Wind turbines may be installed as standalone power generators, or as generators that are interconnected to the commercial power grid and sized to be equal or less than the project's utility requirements. Interconnection rules and regulations are highly site specific and may be regulated by the state, or even by the individual utility company. One disadvantage to grid interconnection is that the host site may have to disconnect/shut down its turbine during utility grid outages for safety purposes to prevent energy from back-feeding onto the grid. Check with local utility provider for specific grid interconnection procedures and regulations.

With grid interconnection, the host site may be eligible for net metering. Net metering requires the utility provider to reimburse the host site for power generated by the wind turbine that is supplied to the commercial utility grid. DSIRE provides a comprehensive searchable database of net metering rules and regulations for the United States. Currently, 38 states and the District of Columbia have net metering rules (Figure 13).

Current net metering regulations may limit:

- the size of distributed generation that is allowed to interconnect
- the aggregate capacity of distributed generation on the utility grid
- the price paid for kW/hrs provided via net metering
- the duration of payments for kW/hrs provided via net metering.



Source: DSIRE® (2018).

Figure 13. Wind energy U.S. net metering.

When developing a wind project, it is essential to review state specific requirements for grid interconnection and net metering. For example, the state of Iowa allows investor owned utilities to limit the size of individual systems to 500kW, but requires the utilities to purchase the net generation at the utility's avoided cost rate, which is effectively the retail electric rate. This payment is in the form of a credit on the customer's utility bill that can be carried forward in time, but cannot be cashed out.

UFC 3-540-08 (AFCESA 2017) provides the following guidance on interconnection to the commercial grid:

> Individual states may have power connection limits. The Database of State Incentives for Renewables & Efficiencies (DSIRE) website (DSIRE® 2018), provides a summary of State interconnection policies and applicable State contact information. Coordinate with applicable State offices, local power company, and the International Standards Organization/Regional Transmission Organization (ISO/RTO) for limits and interconnection requirements.

Comply with requirements listed in UFC 3-540-08, Chapter 8, "Utility Interconnection" and Institute of Electrical and Electronics Engineers (IEEE) Standard 1547 (IEEE 2003).

4.7 Annual energy output potential

Calculate a preliminary estimate of the annual energy output of the potential wind turbine or estimate the required turbine size using:

$$AEO = 0.01328D^2V^3 \qquad (9)$$

where:

AEO = Annual Energy Output (kilowatt-hours/year)
D = Rotor Diameter (ft)
V = Annual average wind speed (miles/hour).

This calculation will provide an estimate of the expected annual energy output that can be used to estimate the size of turbine required to meet the site's needs. Once the estimated annual energy output and turbine size are determined, a more detailed estimate can be made using the specific turbine manufacture's detailed power curves. See the manufacturer's website for published power curves and calculators.

4.8 Cost

Table 5 details the mean installed cost per kW of $2,644 with a standard deviation of $900/kW for wind turbines. The usable lifecycle is 20 years with a 7-year standard deviation. The fixed O&M cost is $36/kW with a standard deviation of $16/kW. These numbers should be used for planning purposes when developing a project for the DoD.

4.9 O&M requirements

O&M may be performed in house, or as part of a warranty or service contract. Since wind turbine technology uses highly specialized equipment, a service contract may be the most effective methodology for maintenance.

UFC 3-540-08 (AFCESA 2017) directs DoD facilities to maintain installed wind turbines as detailed in the American Wind Energy Association document *Operations and Maintenance Recommended Practices* (AWEA 2013). This document provides the guidance for the following areas: balance of plant, blades/rotors, condition monitoring, gear boxes, generators, towers, data collection and reporting, and warranty.

Table 5. NREL distributed generation renewable energy installed costs.

	Generator Type / Size System		
	PV 1–10 MW	Wind 1–10 MW	Biomass Combined Heat & Power*
Mean installed cost $/kW	$2,667	$2,644	$6,067
Installed cost Std. Dev +/- $/kW.	$763	$900	$4,000
Fixed O&M $/kW-yr.	$20	$36	$91
Fixed O&M Std. Dev. +/- $/kW-yr.	$10	$16	$33
Variable O&M $/kWh	n/a	n/a	$0.06
Variable O&M +/- $/kWh	n/a	n/a	$0.02
Lifetime yr.	33	20	28
Lifetime Std. Dev. yr.	9	7	8
Fuel or water cost $/kWh	n/a	n/a	$0.04
Fuel or water Std. Dev. $/kWh	n/a	n/a	$0.02

*Unit cost is per kilowatt of the electrical generator, not the boiler heat capacity.
Geothermal cost breakdown not available. See Appendix F for planning factors and cost models.
Costs are NREL update of August 2013.

Source: UFC 3-540-08, Table 2-4.

4.10 Environmental considerations

Environmental considerations for installing wind turbine technologies include the visual impacts of the turbines on the landscape, the noise produced by the rotor blades, and deaths of birds and bats that may fly into the rotors.

When siting a wind turbine, the visual effects on the environment must be considered. Turbines are generally placed in exposed locations and therefore may be seen from long distances. Aesthetics are by nature subjective, but care should be taken to consider lines of site and neighboring communities.

Like all mechanical power generation systems, wind turbines produce some noise when they operate. Current wind turbines produce sounds of 55 dB (A) or less when measured at a distance of about 100 m. For comparison, a window air conditioner is has a sound level of approximately 50 dB (A). These sound levels decline based on distance from the wind turbine. On average, the sound declines following the inverse-square-law; if the distance from the turbine is doubled, the sound is reduced to one fourth the original level. Improved engineering designs have reduced the noise of current turbine models relative to older model types.

The impact of wind turbines on wildlife, including the effects on birds and bats, is widely being researched in the scientific communities, fish and wildlife agencies, and conservation groups. The research points to evidence that bird and bat deaths from collisions with wind turbines may be due to changes in air pressure caused by the spinning turbines. Habitat disruption may also change the behavior patterns of these animals. Results conclude that the impacts are relatively low and do not pose significant threats to species populations. Ongoing research is being performed on bird and bat behavior, and on migration effects and patterns to identify the safest turbine design and siting.

4.11 Equipment sources

According to the *Wind Technologies Market Report*. (USDOE 2016, p 7), the top three U.S. wind turbine manufacturers held 87% of the U.S. market: (1) General Electric (GE) held the largest share, 40%, (2) Vestas held 33%, and (3) Siemens held 14%:

- GE Renewable Energy, https://www.gerenewableenergy.com/wind-energy/turbines),
  GE Renewable Energy provides a variety of land-based horizontal axis wind turbines products ranging from 1.7MW up to 3.8MW with rotor diameters ranging from 100 to 137 meters.
- Vestas, https://www.vestas.com,
  Vestas provides a variety of land-based horizontal axis wind turbine products ranging from 1.8MW up to 4.2MW with rotor diameters ranging from 90 to 150 meters.
- Siemens, https://www.siemens.com/global/en/home/products/energy.html,
  Siemens provides a variety of land-based horizontal axis wind turbine products ranging from 2.3MW up to 4MW with rotor diameters ranging from 108 to 130 meters.

4.12 COE contacts

The U.S. Army Corps of Engineers provides the *Wind Energy Knowledge Resource* website to provide information to help evaluate and implement the use of wind energy technologies at DoD locations:
http://www.usace.army.mil/Missions/Sustainability/Expertise-in-Sustainability/Wind-Energy/

The Wind Energy Knowledge Resource can be contacted through e-mail:
wind@usace.army.mil

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Acronyms and Abbreviations

Term	Definition
AC	Alternating Current
AEO	Annual Energy Output
AFCESA	Air Force Civil Engineer Support Agency
ARPA	Archeological Resources Protection Act of 1979
AWEA	American Wind Energy Association
BTU	British Thermal Unit
BTU/GSF	British thermal units of energy used per gross square foot of Federal building space
COE	Chief of Engineers
CRREL	Cold Regions Research and Engineering Laboratory
CSP	Concentrated Solar Power
CSP	Concentrated Solar Power
DNI	Direct Normal Irradiation
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DSIRE	Database of State Incentives for Renewables & Efficiency®
EE&RE	Office of Energy Efficiency & Renewable Energy
EERE	[U.S. DOE] Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
EL	Environmental Laboratory
EO	Executive Order
ERDC	U.S. Army Engineer Research and Development Center
ESCO	Energy Service Company
ESPC	Energy Savings Performance Contract
ETSAP	Energy Technology Systems Analysis Programme
FY	Fiscal Year
GE	General Electric
GSF	Gross Square Foot
GW	Gigawatt
HDC	USACE Hydroelectric Design Center
HEC	Huntsville Center, Alabama
HOMER	Hybrid Optimization Model for Multiple Energy Resources
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
INDC	Inland Navigation Design Center
INDC-MCX	Inland Navigation Design Center Mandatory Center of Expertise
ISO/RTO	International Standards Organization/Regional Transmission Organization
KW	Kilowatt
L&D	Lock and Dam

Term	**Definition**
LCOE	Levelized Cost of Electricity
LINGO	Linear Programming, Artificial Intelligence, the Modeling Language and Optimizer
MW	Megawatt
NAVFAC	Naval Facilities Engineering Command
NEPA	National Environmental Policy Act
NREL	National Renewable Energy Laboratory
O&M	Operations and Maintenance
PCM	Phase Change Material
PIANC	Permanent International Association of Navigation Congresses
PPA	Power Purchase Agreement
PSH	Peak Sun-Hour
PV	PhotoVoltaic
QTE	Process Heat-to Electricity Efficiency
REC	Renewable Energy Certificate
SC	optical efficiency that accounts for optical losses associated with SC system (p23)
SEIA	p 25
STE	Solar Thermal Energy
TES	Thermal Energy Storage
TR	Technical Report
UFC	Unified Facilities Criteria
USACE	U.S. Army Corps of Engineers
USDOE	U.S. Department of Energy

Appendix A: U.S. Sun Hours/Day

State	City	High	Low	Avg		State	City	High	Low	Avg
AK	Fairbanks	5.87	2.12	3.99		MO	Columbia	5.5	3.97	4.73
AK	Matanuska	5.24	1.74	3.55		MO	St. Louis	4.87	3.24	4.38
AL	Montgomery	4.69	3.37	4.23		MS	Meridian	4.86	3.64	4.43
AR	Bethel	6.29	2.37	3.81		MT	Glasgow	5.97	4.09	5.15
AR	Little Rock	5.29	3.88	4.69		MT	Great Falls	5.7	3.66	4.93
AZ	Tucson	7.42	6.01	6.57		MT	Summit	5.17	2.36	3.99
AZ	Page	7.3	5.65	6.36		NM	Albuquerque	7.16	6.21	6.77
AZ	Phoenix	7.13	5.78	6.58		NB	Lincoln	5.4	4.38	4.79
CA	Santa Maria	6.52	5.42	5.94		NB	N. Omaha	5.28	4.26	4.9
CA	Riverside	6.35	5.35	5.87		NC	Cape Hatteras	5.81	4.69	5.31
CA	Davis	6.09	3.31	5.1		NC	Greensboro	5.05	4	4.71
CA	Fresno	6.19	3.42	5.38		ND	Bismark	5.48	3.97	5.01
CA	Los Angeles	6.14	5.03	5.62		NJ	Sea Brook	4.76	3.2	4.21
CA	Soda Springs	6.47	4.4	5.6		NV	Las Vegas	7.13	5.84	6.41
CA	La Jolla	5.24	4.29	4.77		NV	Ely	6.48	5.49	5.98
CA	Inyokern	8.7	6.87	7.66		NY	Binghamton	3.93	1.62	3.16
CO	Grandby	7.47	5.15	5.69		NY	Ithica	4.57	2.29	3.79
CO	Grand Lake	5.86	3.56	5.08		NY	Schenectady	3.92	2.53	3.55
CO	Grand Junction	6.34	5.23	5.85		NY	Rochester	4.22	1.58	3.31
CO	Boulder	5.72	4.44	4.87		NY	New York City	4.97	3.03	4.08
DC	Washington	4.69	3.37	4.23		OH	Columbus	5.26	2.66	4.15
FL	Apalachicola	5.98	4.92	5.49		OH	Cleveland	4.79	2.69	3.94
FL	Belie Is.	5.31	4.58	4.99		OK	Stillwater	5.52	4.22	4.99
FL	Miami	6.26	5.05	5.62		OK	Oklahoma City	6.26	4.98	5.59
FL	Gainsville	5.81	4.71	5.27		OR	Astoria	4.76	1.99	3.72
FL	Tampa	6.16	5.26	5.67		OR	Corvallis	5.71	1.9	4.03
GA	Atlanta	5.16	4.09	4.74		OR	Medford	5.84	2.02	4.51
GA	Griffin	5.41	4.26	4.99		PA	Pittsburg	4.19	1.45	3.28
HI	Honolulu	6.71	5.59	6.02		PA	State College	4.44	2.79	3.91
IA	Ames	4.8	3.73	4.4		RI	Newport	4.69	3.58	4.23
ID	Boise	5.83	3.33	4.92		SC	Charleston	5.72	4.23	5.06
ID	Twin Falls	5.42	3.42	4.7		SD	Rapid City	5.91	4.56	5.23
IL	Chicago	4.08	1.47	3.14		TN	Nashville	5.2	3.14	4.45
IN	Indianapolis	5.02	2.55	4.21		TN	Oak Ridge	5.06	3.22	4.37
KS	Manhattan	5.08	3.62	4.57		TX	San Antonio	5.88	4.65	5.3
KS	Dodge City	4.14	5.28	5.79		TX	Brownsville	5.49	4.42	4.92
KY	Lexington	5.97	3.6	4.94		TX	El Paso	7.42	5.87	6.72
LA	Lake Charles	5.73	4.29	4.93		TX	Midland	6.33	5.23	5.83
LA	New Orleans	5.71	3.63	4.92		TX	Fort Worth	6	4.8	5.43
LA	Shreveport	4.99	3.87	4.63		UT	Salt Lake City	6.09	3.78	5.26

State	City	High	Low	Avg		State	City	High	Low	Avg
MA	E. Wareham	4.48	3.06	3.99		UT	Flaming Gorge	6.63	5.48	5.83
MA	Boston	4.27	2.99	3.84		VA	Richmond	4.5	3.37	4.13
MA	Blue Hill	4.38	3.33	4.05		WA	Seattle	4.83	1.6	3.57
MA	Natick	4.62	3.09	4.1		WA	Richland	6.13	2.01	4.44
MA	Lynn	4.6	2.33	3.79		WA	Pullman	6.07	2.9	4.73
MD	Silver Hill	4.71	3.84	4.47		WA	Spokane	5.53	1.16	4.48
ME	Caribou	5.62	2.57	4.19		WA	Prosser	6.21	3.06	5.03
ME	Portland	5.23	3.56	4.51		WI	Madison	4.85	3.28	4.29
MI	Sault Ste. Marie	4.83	2.33	4.2		WV	Charleston	4.12	2.47	3.65
MI	E. Lansing	4.71	2.7	4		WY	Lander	6.81	5.5	6.06
MN	St. Cloud	5.43	3.53	4.53						

Appendix B: Hydropower Screening Procedure

Item Number	Description
1	Using 12 consecutive months of utility bills, determine the average power (kw) used by the facility. The target turbine size is 90% of the average.
2	Based on the turbine size (90% of average power used), estimate the cost of the unit from the information provided in Section 2.11.
3	What is the average annual charge for energy (KWH) usage? Does saving this amount of money justify investigating, and perhaps installing, a generating unit?
4	Contact the local electricity utility and obtain their rules and requirements for installing a generating unit. Key facts to tell the utility: (a)The unit will be installed “downstream” of the meter and is intended to generate slightly less than 100% of the total energy consumed on the facility. (b) The unit will operate at a constant output. At times the facility will be exporting power to the grid, at other times the facility will be importing power from the grid.
5	Using the power determined in Step 1 and the head of the L&D, calculate the water flow rate that is needed to produce the power. Confirm that this amount of water is available (minimum flow) 100% of the time. Determine the diameter of the pipe that is needed to provide this flow rate at a velocity of 7 ft per second.
6	For the pipe diameter determined in Step 5, does a pipe of this diameter or larger (slower water velocities are better) exist that can be used to provide water to the turbine. If the pipe does not exist, can one be installed (i) at a reasonable cost and (ii) without compromising the integrity of existing structures? The pipe must be able to be routed to the location described in Step 7
7	Identify a location for installing the turbine-generating unit. The overall size of the space should be as identified in Section 2.8. The elevation of the floor should be no more than 5 ft above the elevation of the downstream pool. The closer to the elevation of the downstream pool, the better. The location must be either (i) not subject to flooding or (ii) must be in a flood-proof building.
8	For the location identified in Step 7, determine how the water will get from the discharge of the turbine back to the river. Via a pipe Via a “tailrace channel” Will concrete need to be removed or placed to accomplish this?
9	Considering the costs of the generating unit, piping and structural modifications identified in Steps 2, 6, 7 and 8, and the benefit identified in Step 3, does it appear that further investigation is justified? If so, contact the Hydroelectric Design Center for detailed assistance.