PNNL- 22796

Renewable Resource Handbook for Feasibility Studies at Selected Air Force Bases

AE Solana, CA Antonopoulos, WM Warwick, SA Breithaupt, MI De La Rosa, SH Geerlofs, JA Horner, A Manning, AC Orrell, & BJ Russo

September 2013

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September 2013

Prepared for
the U.S. Air Force Civil Engineer Center[1] under a Work-For-Others Agreement with the U.S. Department of Energy

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[1] Formerly the Air Force Civil Engineering Support Agency

Executive Summary

Pacific Northwest National Laboratory was retained by the Air Force Civil Engineer Center (AFCEC) to conduct feasibility studies (FSs) of renewable energy potential for selected Air Force (AF) bases. The *Renewable Resource Handbook for Feasibility Studies at Selected Air Force Bases* (hereinafter "this handbook") presents general information about the cost of renewable energy, selected renewable energy resources and technologies, and the location requirements for each technology. The resources investigated were grouped into the following five categories:

- Biomass Power: woody wastes; agricultural wastes; landfill gas; municipal solid waste; and plant, animal, or waste-based oils and other biofuels used in combustion, thermal gasification, or plasma gasification facilities
- Wind Energy: horizontal-axis wind farms, vertical- and horizontal-axis distributed generation projects, and offshore wind farms
- Solar Energy: photovoltaic (PV) arrays, including thin-film and crystalline silicon roof- and ground-mounted systems
- Thermal Energy: geothermal power plants, ocean thermal power plants, concentrating solar thermal power plants, solar water heaters, solar air heating, ground source heat pumps, seawater cooling, biomass, and biofuels
- Ocean and Hydro Energy: tidal power converters, wave power converters, and hydroelectric dams

This handbook outlines and describes each of these renewable technologies and provides general information about each resource. The AF site-specific FS reports provide similar information, but only for resources that exist at each site. This handbook provides a single reference for general information on all renewable energy resources and helps site personnel understand more about resources and technologies that were determined to have no potential for development at their location.

Acronyms and Abbreviations

AC	alternating current
AD	anaerobic digestion
AEO	Annual Energy Outlook
AF	Air Force
AFCEC	Air Force Civil Engineer Center
BOP	balance of plant
CC	combined cycle
CCS	carbon capture and sequestration
COP	coefficient of performance
CSP	concentrating solar power
DC	direct current
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EGS	enhanced geothermal system
EIA	U.S. Energy Information Administration
EPAct	Energy Policy Act of 2005
FERC	Federal Energy Regulatory Commission
FS	Feasibility Study
FY	fiscal year
GCHX	ground coupled heat exchanger
gpm	gallons per minute
GSHP	ground source heat pump
GW	gigawatts
GW_{th}	gigawatts of thermal energy
HDR	hot dry rock
IPP	independent power producer
km	kilometer
kW	kilowatt
$kWh/m^2/day$	average daily kilowatt hours of insolation per square meter
LFG	landfill gas

m	meters
m/s	meters per second
MSW	municipal solid waste
MW	megawatts
MW_e	megawatts of electricity
MWh	megawatt-hours
MW_{th}	megawatts of thermal energy
mW/m^2	milliwatts of heat flow per square meter
O&M	operations and maintenance
OCONUS	outside of the continental United States
ORC	organic Rankine cycle
OTEC	Ocean Thermal Energy Conversion
PNNL	Pacific Northwest National Laboratory
psig	pounds per square inch [gauge]
PV	photovoltaic
R&D	research and development
RD&D	research, development, and demonstration
SAH	solar air heating
SDHW	solar domestic hot water heating
Si	silicon
SWAC	seawater air conditioning
TWh	terawatt hours
UK	The United Kingdom of Great Britain and Northern Ireland – comprises England, Scotland, Wales, and Northern Ireland
WEC	wave energy conversion
WSHP	water source heat pump
WTE	waste-to-energy

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1.0 Introduction

Pacific Northwest National Laboratory (PNNL) was retained by the Air Force Civil Engineer Center (AFCEC) to conduct feasibility studies (FSs) of renewable energy potential for selected Air Force (AF) bases.

The *Renewable Resource Handbook for Feasibility Studies at Selected Air Force Bases* (hereinafter "this handbook") is supplemental to the individual site analyses and was compiled to provide an overview of renewable energy technologies, location requirements, and other technological considerations for all resources in a single document. The information included provides a general overview and is not specific to any site. To access specific analyses, see the *Renewable Energy Feasibility Study* report for each location.

1.1 Background and Scope

The scope of this FS task includes detailed discussion of renewable energy resources, technologies, and feasibility for each site analyzed. For resources with no potential at a site, the detailed discussion distracted from the findings of the site-specific reports and recommended project descriptions. This handbook was created to better focus the site-specific reports and yet provide installation staff useful background on all renewable resources.

This handbook addresses the following resources, as listed in the FS scope.

- Biomass Power: woody wastes; agricultural wastes; landfill gas (LFG); municipal solid waste (MSW); and plant, animal, or waste-based oils and other biofuels used in combustion, thermal gasification, or plasma gasification facilities
- Wind Energy: horizontal-axis wind farms, vertical- and horizontal-axis distributed generation projects, and offshore wind farms
- Solar Energy: photovoltaic (PV) arrays, including thin film and crystalline silicon roof- and ground-mounted systems
- Thermal Energy: geothermal power plants, ocean thermal power plants, concentrating solar thermal power plants, solar water heaters, solar air heating, ground source heat pumps (GSHPs), seawater cooling, biomass, and biofuels
- Ocean and Hydro Energy: tidal power converters, wave power converters, and hydroelectric dams

This handbook outlines and describes each of these renewable energy categories and provides a description of each resource, applicable technologies, and location requirements. It provides a single reference for general information on all renewable energy resources considered.

1.2 Screening

PNNL conducted a screening of renewable resources at each site to determine which resources merited analysis. Along with resource availability, the site-specific screening analysis used information regarding energy costs; federal, state, and local incentives; regulatory initiatives; and/or market conditions, as applicable. The screening methodologies and results can be found in the *Initial Screening for Renewable Energy Potential at Selected Air Force Bases* (Solana et al. 2012).

The resources that clearly were not available at a specific location were excluded from further analysis and the corresponding overview details were not included in the FS reports. The resources that were deemed viable were analyzed to determine the resource availability and economic feasibility, and are discussed in detail in the individual FS reports.

1.3 Requirements and Goals for Renewable Energy

The Air Force needs to satisfy multiple goals and constraints while securing its energy supplies, focusing upon procurement of the lowest-cost energy that meets high reliability standards with minimum vulnerability to interruption from natural or intentional causes. Overlaid on this challenge is the need to comply with the major statutes and policies laid out in Table 1. It is important to note that all U.S. federal regulatory mandates and agency goals also apply to OCONUS[1] sites. These include:

- The Energy Policy Act (EPAct), Section 203. This law mandates the minimum contribution of renewable energy to an agency's total electricity consumption. The target fractions are the following: 3% for Fiscal Year (FY) 2007 through FY 2009, 5% through FY 2012, and not less than 7.5% beginning in FY 2013 (EPAct 2005).

- Executive Order 13423. The Executive Order reiterates the EPAct goals; however, it uses a different basis for measuring and crediting progress than EPAct (Executive Order 13423 2007).

- DOD Goal. A 2005 U.S. Department of Defense (DOD) memorandum establishing a goal of 25% renewable energy by 2025. DOD views this as an electricity goal, similar to that in EPAct. It also allows thermal energy from renewables to be credited toward the goal as electricity equivalent, as does the U.S. Department of Energy (DOE) for EPAct.

- 10 USC[2] 2911. This law codifies the DOD goal to increase renewable energy use to 25% by 2025 (10 USC Sec 2911 2009). The legislative language implied that it applied to all facility energy, thermal as well as electric. The Committee on Armed Services of the U.S. House of Representatives clarified their intent to mirror the original DOD goal in a letter to DOD dated May 13, 2010. Neither the DOD goal nor the statute includes any interim targets although DOD is required to develop one for 2018.

[1] Outside of the continental United States
[2] United States Code

Table 1: Legislated Renewable Energy Targets for DOD

	EPAct Section 203	Executive Order 13423	DOD's 25% by 2025 goal/ 10 USC 2911
Target/Goal	Increasing targets reaching 7.5% renewable content of electricity consumed	At least 7.5% of electric energy from renewable energy with 50% from new sources (after 1998)	At least 25% of electricity consumption from renewable sources
Target Dates	2013	2013	2025
Mandatory?	Yes	Yes	No
Considers thermal energy "renewable"?	No	Yes	Yes (counts toward electricity goal)

All three renewable energy goals are agency goals rather than goals for each facility. Air Force goals, based on data from 2012, are shown in Table 2.

Table 2: Air Force Energy Use and Renewable Energy Targets

FY 2012 Electricity Consumption	FY 2012 Total Energy Consumption (MWh Equivalent)	Electricity from Renewable Sources Required to meet EPAct Requirement (7.5% of 2013 Electricity Consumption)	Electricity from Renewable Sources Required to meet DOD Goal (25% of 2025 Electricity Consumption)
9,213,763 MWh	18,087,045 MWh	680,282 MWh	2,009,972 MWh

On April 11, 2012, the White House elaborated on comments made during the State of the Union address outlining DOD commitments to develop a total of three gigawatts (GW) of renewable energy, 1 GW for each of the three services. The commitment is part of the broader DOD goal of 25% renewable by 2025 and includes a commitment by the Air Force to meet its 1-GW goal by 2016. This 1-GW goal will likely mean the Air Force needs to exceed the DOD 25% renewable target.

1.4 Costs of Renewable Energy

Renewable energy sources and technologies to harness them span a very wide spectrum. For the purposes of the AF energy program, renewable technologies need to be sufficiently available and reliable to substitute for conventional energy sources that are both. Ideally, renewable energy technologies are available from multiple vendors with sufficient commercial experience to facilitate competitive procurements and head-to-head comparison with the conventional energy sources they may displace. The cost of bringing any technology to that stage is significant. The likelihood that a renewable technology can replace a conventional source will be a function of the size of the market. The renewable resources the AF desires to survey include resources and technologies for small as well as large markets, with prospective technologies that vary from being fully commercial to ones still in the research phase. Those that are available from multiple commercial vendors are the most likely to be suitable for AF projects.

Table 3 summarizes renewable resources and technologies of interest to the AF and sets the stage for reviewing the potential of renewable resources and technologies across the renewable resource categories identified by the AF. Table 3 is a qualitative assessment based on PNNL staff knowledge of renewable markets; utility, industry, and government research, development, and demonstration (RD&D) efforts; and vendor proposals.

Each resource listed in Table 3 is characterized elsewhere in this handbook. The market potential is based on a judgment of the global availability of the raw feedstock and the ability to generate energy from it. For example, woody biomass is readily available and can generate large amounts of power in areas with an active forestry industry, but harvesting does not occur in all forests. The commercial and RD&D status is unrelated to market potential, and considers only the status of the generating technologies.

Table 3: Summary of Renewable Resources/Technologies of Interest to the AF

Resource	Market Potential	Commercial Status	RD&D Status
Biomass Energy			
Woody waste fuels	Medium	Multiple vendors of combustion technologies, some vendors of thermal gasification technologies	Commercial
Agricultural crop wastes	Small	Multiple vendors of combustion technologies	Commercial
Landfill gas	Small	Multiple vendors of gas cleanup and generation technologies	Commercial
Municipal solid waste	Large	Multiple vendors of combustion technologies; thermal gasification technologies emerging	Plasma technologies largely pre-commercial except for hazardous waste processing
Biofuels	Medium	Compatible with existing combustion technologies for power generation	Focus is on production of biofuels as “drop-in” fuel for use with conventional equipment
Wind Energy			
Horizontal-axis turbine	Huge	Multiple vendors across wide size spectrum (1 kW to 2.5 MW)	Focus is on reliability, efficiency and size of existing technologies
Vertical-axis turbine	Tiny	Multiple vendors, but unproven market	Commercial
Offshore wind farms	Large	Major vendors have products but market is just developing in the United States	Focus is on larger turbines and tower systems
Solar Energy			
Photovoltaic	Large	Multiple vendors	Focus is on efficiency, cost reduction, inverters

Table 3: Summary of Renewable Resources/Technologies of Interest to the AF (Cont.)

Resource	Market Potential	Commercial Status	RD&D Status
Thermal Energy			
Geothermal power	Small	Multiple developers exist but resource is not widely available	Focus is on use of lower temperature resources and taking advantage of oil and gas wells
Ocean thermal power	Small	No commercial projects	Still in RD&D
Concentrating solar thermal power	Medium	Limited vendors in an emerging market	Commercial
Ground source heat pumps	Small	Multiple vendors	Commercial
Seawater cooling	Tiny	Few commercial projects for this niche market	Commercial
Biomass heating	Medium	Multiple vendors for various fuels (bulk and pelletized) and technologies (combustion and gasification)	Commercial
Biofuel heating	Medium	Liquid biofuels compatible with most existing conventional fuel boilers/furnaces	Focus is on production of biofuels as “drop in” fuel for use with conventional equipment
Solar water heating	Small	Multiple vendors	Commercial
Solar air heating	Small	Few vendors	Commercial
Ocean/Hydro Energy			
Tidal power	Small	Few commercial projects for this niche market	RD&D in demonstration phase of development with promising results
Wave power	Small	Few commercial projects for this niche market	RD&D in demonstration phase of development with promising results
Small hydropower	Tiny	Multiple vendors/technologies for this niche market	Commercial

1.4.1 Cost Comparison to Conventional Energy Sources

Renewable power is commonly viewed as being more expensive than conventional power. This comparison ignores potentially negative environmental and public health consequences from conventional power projects, or “externalities.” Nevertheless, actual costs are the most common metric used to compare the costs of alternative power sources.

The ultimate cost of power from a generator is a function of many variables, including the cost of the plant site; siting and permitting; transmission interconnection; and engineering, procurement, and construction (EPC) of the plant itself, in addition to operations and maintenance (O&M) costs, including fuel. There may also be costs for contracting and contract oversight and costs of project finance. A number of these variables lead to higher costs for renewable energy projects.

Utilities typically have reserved, or “banked,” sites for their planned generating projects. They also design their transmission system to access these sites as they are developed. The situation for non-utility developers, or independent power producers (IPPs), is different because they generally do not have sites banked and may not be able to secure sites near transmission lines, which would increase costs. Sites that have not been banked also require siting permits, again increasing costs.

Siting renewable energy projects is even more challenging because they need to be located where the renewable resource is available. Site-specific resource assessments are required, such as wind speed monitoring or test well drilling. This not only increases project costs and takes additional time, but it may also produce disappointing results that add to the cost of developing this type of resource.

The DOE Energy Information Administration (EIA) publishes an *Annual Energy Outlook* (AEO) and periodically provides surveys of U.S. plant costs that it uses in its energy price projections. The 2010 AEO included the full survey report as well as a summary table. The summary table was updated for the 2011 report and is presented as Table 4.

Table 4: U.S. Average Levelized Costs of Generation

(2009 $/MWh for plants entering service in 2016) (EIA 2010)

Plant Type	Capacity Factor (%)	Levelized Capital Cost ($/MWh)	Fixed O&M ($/MWh)	Variable O&M + Fuel ($/MWh)	Transmission Investment ($/MWh)	Total Levelized Cost ($/MWh)
Conventional Coal	85	65.3	3.9	24.3	1.2	94.8
Advanced Coal	85	74.6	7.9	25.7	1.2	109.4
Advanced Coal w/CCS[3]	85	92.7	9.2	33.1	1.2	136.2
Combined Cycle Gas	87	17.5	1.9	45.6	1.2	66.1
Advanced CC[4] Gas	87	17.9	1.9	42.1	1.2	63.1
Advanced CC w/CCS	87	34.6	3.9	49.6	1.2	89.3
Combustion Turbine Gas	30	45.8	3.7	71.5	3.5	124.5
Advanced CT[5] Gas	30	31.6	5.5	62.9	3.5	103.5
Advanced Nuclear	90	90.1	11.1	11.7	1.0	113.9
Onshore Wind	34	83.9	9.6	0	3.5	97.0
Offshore Wind	34	209.3	28.1	0	5.9	243.2
Solar PV	25	194.6	12.1	0	4.0	210.7
Solar Thermal Power	18	259.4	46.6	0	5.8	311.8
Geothermal Power	92	79.3	11.9	9.5	1.0	101.7
Biomass	83	55.3	13.7	42.3	1.3	112.5
Hydropower	52	74.5	3.6	6.3	1.9	86.4

Because this table is based on a cost survey, the average may mask a wide range of costs, especially for renewable energy projects that have widely varying site development costs and

[3] Carbon capture and sequestration
[4] Combined cycle
[5] Combustion turbine

resource potential (capacity factors). Nevertheless, geothermal and biomass power plants most closely match conventional power plants in cost. Onshore wind power is competitive as well; however, it is not an equivalent power resource because it is intermittent.

The costs represented in the last column of Table 4 reflect the minimum prices in wholesale power markets that would be profitable for an IPP developer. Wholesale power markets include bids from power plants that were constructed years ago and power from generators that may have excess generating capacity that can be sold for a profit as long as the price is greater than O&M costs. As a result, wholesale power markets rarely result in prices high enough to pay for new generators. Consequently, new plants are only built when the purchase of their output is secured through a long-term power purchase agreement (PPA).

Power projects constructed on DOD property to serve on-base loads compete against the cost of power from the local utility, not the wholesale market. As a result, new plants on DOD land may be economic when compared to utility power rates. Financial incentives for renewable energy projects, especially for solar, wind, and biomass projects, can also reduce project costs, further increasing the likelihood that these projects would compare favorably to utility power rates.

1.4.2 Using Annual Energy Outlook Costs for Renewable Energy

The costs in Table 4 are based on survey costs for 2009 that have been escalated to reflect expected costs of projects coming on line in 2016. They are based on costs of U.S. plants and are in U.S. currency. Project costs change constantly and final project costs typically depend on financial incentives and financing costs. Consequently, these costs are only a starting point for project cost estimating, but they are useful for comparing costs across generating technologies.

Translating these to OCONUS locations (including Alaska and Hawaii) will require locational cost adjustments and currency conversions, as appropriate. Projects included in this survey presumably relied on materials from U.S. sources. Other nations have firms that manufacture many of the same components in those nations or their respective regions, and will have costs that may not require a locational cost adjustment.

Table 4 is also a reasonable proxy for types of power technologies that are commercially available, with the exception of reciprocating engines. Reciprocating engines can operate on natural gas or liquid fuels, including biofuel. They can also utilize synthetic natural gas (syngas) and methane from landfills, sewage treatment plants, and anaerobic digestion as long as the gas is cleaned of excess moisture and contaminants beforehand. Reciprocating engines are common on DOD facilities and cost information should be readily available from local sources or the base Civil Engineer. Other technologies that are not included in Table 4 are generally not commercially available or are newly commercial such that cost and performance information is unreliable.

2.0 Biomass Energy

Figure 1: 21-MW Wood Residue Power Plant for the San Francisco Bay Area[6]

According to the Energy Policy Act of 2005, "the term 'biomass' means any lignin waste material that is segregated from other waste materials and is determined to be nonhazardous by the Administrator of the Environmental Protection Agency and any solid, nonhazardous, cellulosic material that is derived from—

(A) any of the following forest-related resources: mill residues, precommercial thinnings, slash, and brush, or nonmerchantable material;

(B) solid wood waste materials, including waste pallets, crates, dunnage, manufacturing and construction wood wastes (other than pressure-treated, chemically-treated, or painted wood wastes), and landscape or right-of-way tree trimmings, but not including municipal solid waste (garbage), gas derived from the biodegradation of solid waste, or paper that is commonly recycled;

(C) agriculture wastes, including orchard tree crops, vineyard, grain, legumes, sugar, and other crop by-products or residues, and livestock waste nutrients; or

(D) a plant that is grown exclusively as a fuel for the production of electricity."

In summary, "biomass" refers to renewable fuels used for electric power or thermal energy production and includes agricultural waste, forest and wood processing waste, animal waste, industrial waste, dedicated biomass crops, and urban wood waste (construction and demolition waste). Landfill gas and MSW are also considered renewable resources, but are considered

[6] Courtesy of DOE/NREL, Credit – Andrew Carlin and Tracy Operators.

waste-to-energy (WTE) rather than biomass (EPAct 2005). However, for the purposes of this report, the term "biomass" will encompass WTE resources.

Internationally, energy generated from biomass products (bioenergy supply) reached 50 EJ[7] in 2012, and could supply as much as 3,000 TWh (7.5% of total world energy consumption) by 2050 (IEA 2012). Figure 2 illustrates bioenergy supply by global region between 2000 and 2009.

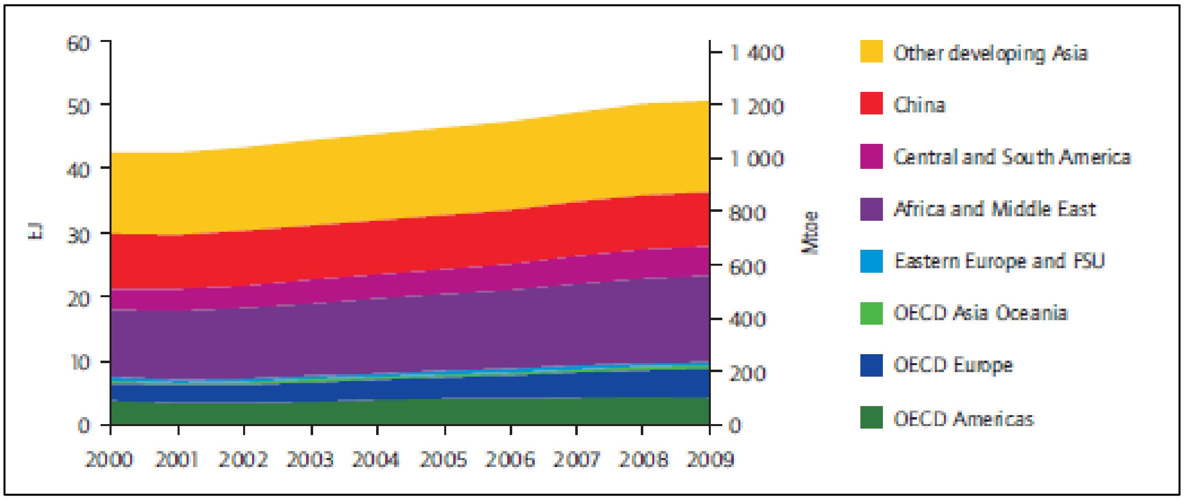

Figure 2: Global Bioenergy Supply by Region 2000–2009 (IEA 2012)

2.1 Biomass Resource Description

For biomass resources to be economically viable, biomass feedstock must be available in significant quantities within reasonable proximity to the plant. Collection and transportation of biomass material that is not co-located with an energy production facility is typically the limiting factor for economic energy production. The cost of transportation is a function of both the energy density of the material being transported and the hauling distance. In general, the materials described in sections 2.1.1 and 2.1.2 have relatively low energy density; accordingly, many trips are required to deliver sufficient material for a power plant of economic scale. As a rule of thumb, 50 to 60 mi (80.5 to 96.6 km) is the maximum range most materials can be hauled without the cost of the fuel, driver, and vehicle exceeding the practical value of the fuel, unless the material is already being hauled elsewhere, such as MSW, or disposed of in an undesirable way, such as through open burning. The transportation limit, therefore, limits the size of a viable power plant: no larger than the amount of biomass that can be collected within a 50 to 60 mi (80.5 to 96.6 km) radius. The transportation radius will vary with the cost of labor, fuel, and vehicle use, with fuel costs being the largest variable.

In addition, the supply of biomass must be consistent and reliable. Long-term availability of a biomass source is a large risk for energy generation facilities that need to operate for many years to gain a return on their investment. Therefore, the biomass supply for large plants is typically obtained through multiple different sources and contracts. This is common for plants operating

[7] EJ = exajoule, 10^{18} joules

on woody waste such as forest residue. Small plants can be built next to a single, long-term source of biomass, such as a landfill or food processing plant.

There are multiple types of biomass, as described below.

2.1.1 Woody Wastes

2.1.1.1 Forest Residue

Left from logging operations, forest residues include the non-merchantable portions such as branches, tops, and other materials removed during harvest. These materials are often not collected but left on the forest floor; therefore extra costs are often associated with collecting and transporting sufficient amounts.

2.1.1.2 Industrial Waste

Industrial biomass includes mill residue, food processing waste, textile waste, or waste (such as pallets) from other specialized operations or industrial activities. Mill residues can be categorized as primary or secondary residues.

Primary mill residues result from the processing of logs at manufacturing plants while secondary mill residues result from wood waste generated at woodworking shops or lumber yards. There are many types of mills that use wood to produce various products, including lumber; shake and shingle; pulp; veneer and plywood; log chips; and posts, poles, and pilings.

These processes generate primary residues in the form of sawdust and wood pieces, which are useful materials. In fact, most mill residue is currently used onsite for fiber, fuel, or other uses. Secondary residues from smaller woodshops and lumber yards are generally not used onsite and are disposed of as waste. The quantities produced are typically too small and variable to justify collection, although local residents may do so for home heating and similar uses.

2.1.2 Agricultural Wastes

Agricultural wastes include crop residues and animal wastes.

2.1.2.1 Crop Residues

Crop residues are the materials left in a field after a crop is harvested. Wheat, corn, barley, and cotton are among the most common crops that leave a residue after harvest. Many of these are left in place as soil amendments. Variables that affect the feasibility of using the residues for energy production include climate, crop type, growing practices, and soil characteristics. Competing uses for the residues may exist, which can increase costs. For example, baled straw has much higher value for animal bedding, garden mulch, erosion control in construction projects, and even as a building material.

2.1.2.2 Animal Wastes

Animal wastes, or manure, from cattle, swine, and poultry farms can be used to produce energy. The manure is typically used in small-scale, onsite systems because it is often collected as a liquid after washing down holding areas. Logistics and costs of collection, drying, and transportation are major barriers to using animal waste in offsite systems. If wastes are captured nearby, piping methane from a plant to an energy user may be practical.

2.1.3 Municipal Solid Waste

Solid waste is customarily disposed of in landfills. Landfills across the globe are reaching capacity, resulting in an increasing need for alternative waste disposal options. Recycling is one way to reduce the strain on landfills; using the waste to generate energy is another. Some recyclables, like metals, must be removed before waste is used for energy generation; otherwise, they will become byproducts of energy production. All carbon-based materials, however, can be used to generate energy.

The economics of MSW projects are typically more attractive than other biomass projects because MSW is often delivered free or even accompanied by payment in the form of a tipping fee, which would otherwise go to the landfill operator. Most landfills are operated or franchised by a local government, and many of these organizations derive operating revenues from fees that are in addition to the actual operating costs of the landfill. These fees may support recycling and other local government programs. As a result, the landfill tipping fee may be inflated over the payment that could be received at a WTE plant, and should be carefully evaluated if considering an MSW project that diverts waste from a landfill.

In rural areas of the United States, landfill operations cost about $20/ton. In urban areas, landfills are reaching capacity with no expansion options, which results in higher tipping fees and an increasing need for alternative waste disposal options. The most common alternative to urban landfills is transporting waste long distances to rural landfills.

2.1.4 Landfill Gas

Methane is generated in landfills as the organic content of MSW is broken down by microorganisms (a process called anaerobic digestion or AD). Methane is a potent greenhouse gas as well as a combustible pollutant that must be controlled, and is typically collected and flared to avoid buildup and danger of explosion. Collected methane can be used as a fuel to generate heat or electricity. The most economic opportunities for landfill methane capture and use are cases where the landfill already has a collection system in place, is active or recently closed (methane production tapers off as landfills age), and has sufficient waste (typically at least 1 million tons) in place to generate a significant amount of methane. The landfill must also be lined in order to prevent the migration of methane into the surrounding soil.

Methane is the primary component of natural gas, but raw landfill gas has about two-thirds the energy content of pipeline natural gas. Raw landfill gas typically contains moisture and other impurities that can interfere with power generators; consequently most landfill gas is processed prior to use in a generator, although it can and is used in raw form for simple heat applications. Landfill gas cannot be injected into natural gas pipelines for transport unless it is cleaned to pipeline gas specifications. Production from most landfills is too small to justify that expense.

2.1.5 Biofuels

Biofuels can come from many different sources, including both plant and animal sources. For instance, waste oils such as yellow grease (from restaurants) and algae oils are most often used for biodiesel production purposes. Fish oil residue that cannot be utilized for human consumption or developed into marketable products is another source of oil. Other biofuel feedstock includes cellulosic materials such as those discussed in the sections on forest residue and agricultural residue. Methane produced from landfills or AD processes can also be converted into a biofuel. Processes using these materials are targeted toward "drop-in fuels" for direct replacement of gasoline, diesel, and jet fuels.

Biodiesel and ethanol biofuels are produced commercially using a variety of techniques. Biofuels are rarely used directly in power production technologies, but instead are first converted to a more useful form of fuel that has the potential to replace fuels in a standard power generation device. Nevertheless, some biodiesel fuel can be used in power generation units such as diesel power engines, and other biofuels have potential for use in standard or modified gasoline engines, depending on the level of fuel cleanup required. However, use as a generating fuel is generally impractical in areas where other conventional fuels or renewable power resources are available. Currently, the highest value for biofuel is as a transportation fuel. This is likely to remain the case until production reaches a fully commercial scale and costs are competitive with conventional vehicle fuel. Although ethanol is produced in large-scale facilities, it is only competitive with conventional fuels if it is either subsidized, as in the United States, or utilizes waste materials that can be readily converted to ethanol, as is done with waste from sugar production in Brazil.

The U.S. military is experimenting with the use of biofuels for vehicles, aircraft, and ships. Use of biofuels as a drop-in fuel for military applications requires testing and certification. To the extent it becomes available in these applications it will also be more readily available for use as a generation fuel. The most likely uses will be in remote sites or in theater where use of a single fuel for both vehicles and power generation has logistical value.

2.2 Applicable Technologies

There are a number of different technologies used for converting biomass into useful energy. The primary technology types used with solid biomass include combustion and gasification. Liquid and gas biomass, including LFG and biofuels, are used in other fuel-specific conversion technologies, as described below. Other technologies exist for use with various forms of biomass, but these are not discussed here because they are inappropriate for use by the Air Force.

2.2.1 Combustion

Combustion, or direct-fired, systems burn biomass to produce steam in a boiler, turning a turbine connected to a generator (in systems producing electricity). This method of producing electricity is relatively inefficient, at about 20 to 30% efficiency. Complex combustion boilers will have multiple steam pressures (up to 1,800 psig[8]) as well as economizers and water preheaters to maximize the efficiency of the steam cycle. These steam cycles require water treatment systems as well as heat rejection using either once-through cooling or cooling towers.

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[8] Pounds per square inch [gauge]

Large combustion systems usually have significant air pollution controls including baghouses, scrubbers, and other controls to reduce air pollution and other undesirable emissions. Certain components of the feedstock tend to form deposits on the heat transfer surfaces, increasing maintenance requirements and decreasing the lifetime of these surfaces, as a result of corrosion and ash buildup. Ash (both fly ash and bottom ash) has to be collected and removed from the system. Excessive ash and corrosion are more of a problem with biomass and MSW projects than with coal due to the variability of the incoming feedstock in terms of its composition and moisture content. Systems that use a homogeneous feedstock benefit from more complete combustion, thereby increasing efficiency, availability, and reducing combustion waste products and emissions.

Various boiler designs try to address these ash deposit issues. Typical designs include pile burners, stoker boilers, fluidized bed boilers, and suspension burning. Pile burners use a traditional design that includes a two-stage combustion chamber and an air feed from the bottom and sides. Feedstock is piled into the bottom to be combusted, and ash is collected when the system is shut down. Stoker boilers use a pneumatic stoker to spread the feedstock, and a moving grate allows ash to fall out for continuous collection. Fluidized bed boilers use a stream of gas to circulate the feedstock particles, allowing more efficient heat transfer and reduced emissions. Suspension burning may use fluidized beds, but requires special burners and considerable feedstock preprocessing, including drying and pulverizing into tiny particles, but the efficiency is higher than with other designs and the furnace is smaller.

2.2.2 Gasification

Gasification is more efficient than combustion, but the technologies employed are more variable and thus not as mature or common in commercial operation. Gasification uses oxygen, steam, heat, and pressure to break down organic materials to form syngas, which is composed primarily of hydrogen and carbon monoxide. After it is cleaned to remove impurities, syngas can be used to generate electricity in a gas turbine, internal combustion engine, or fuel cell, or used to form transportation fuels or useful chemicals. There are various gasification designs that use different amounts of oxygen and steam at different stages and temperatures, producing different amounts of heat, syngas, and solids. Figure 3 depicts a gasification plant that can handle up to 200 tons per day of wood, enough for generating 8 MW. Figure 4 is a diagram of a fixed-bed updraft gasification system.

Figure 3: Biomass Gasifier at the McNeil Generating Station, Burlington, Vermont[9]

[9] Courtesy of DOE/NREL, Credit – Warren Gretz.

Figure 4: Nexterra Fixed-Bed Updraft Gasification System (Nexterra 2012)

Plasma gasification and plasma-assisted gasification are versions of gasification in the early stages of commercialization. Plasma technologies are much more expensive than combustion or thermal gasification because they are newer and more complicated. They also have a high parasitic load due to the need to provide a high-temperature operating environment; however, they break down waste much more thoroughly than other technologies. Plasma gasification systems operate at over 1000°C (1832°F) and are capable of safely handling many hazardous wastes that are difficult to dispose of as well as biomass feedstocks. Because of the more thorough conversion process, there are far fewer emissions with plasma gasification than with other systems. Plasma systems are newer to the U.S. market, but large-scale systems are already in operation in some international markets. Figure 5 shows a diagram of a plasma gasification system and Figure 6 is a demonstration plasma gasification system.

Figure 5: Westinghouse Plasma Gasification Vitrification Reactor (Westinghouse Plasma Corporation 2012)

Figure 6: Plasma Enhanced Melter® System (Photo credit: Amy Solana, PNNL)

2.2.3 Landfill Gas Generators

Because LFG production is diffused across a landfill, special conditions are necessary to increase the LFG concentration and make collection economic. Methane production from landfills is fairly low; as a result, power facilities that use it are typically small systems located onsite using fuel cells, microturbines, or reciprocating engines for power production. These types of generators must either be specifically engineered to handle the impurities inherent in LFG, and/or must be paired with a gas cleanup system. Figure 7 depicts a generator that burns LFG.

Figure 7: GE[10] Jenbacher Gas Engine for Use with Landfill Gas (GE 2012)

2.2.4 Cogeneration

Cogeneration, or combined heat and power, is the most efficient way to operate any power plant. In cogeneration, waste heat from electricity generation is used as thermal energy. Cogeneration with any of the technologies described above significantly increases the overall system efficiency. Another way to operate a cogeneration plant is to split the thermal output, so that part is used directly as steam or gas and part is used for electricity generation. The challenge in cogeneration is identifying an appropriate location where both electricity and thermal energy could be used. A year-round, consistent, large thermal load is needed.

2.2.5 Biofuel Technologies

Biofuels (bio-oil and ethanol) for use in transportation or power/thermal energy generation are produced primarily through pyrolysis or fermentation. The use of liquid bio-based feedstocks to produce higher quality fuels can be accomplished through esterification or catalytic cracking, but these processes are not yet commercial.

2.2.5.1 Pyrolysis

Pyrolysis is a thermal decomposition process that occurs at temperatures greater than 850–1,110°F in an oxygen-depleted environment. The products of this process include char, gas, and a liquid product primarily consisting of oxygenated hydrocarbons. All three products can be useful, but the primary interest is in the liquid "bio-oil," which can be used to fire a boiler or a generator or be de-oxygenated to yield hydrocarbon fuels. Pyrolysis has only been proven for use with uniform feedstocks (preferably clean, ash-free wood). Pyrolysis of plastics is

[10] General Electric

acceptable if the plastics are not halogenated or fluorine based. Other waste types may be acceptable, but mixed waste is not yet a proven feedstock.

Pyrolysis is a newly commercial technology. Worldwide, there are a few commercial pyrolysis plants generating energy in Europe and Canada. There is one permitted pyrolysis plant located in the UK, in Cambridgeshire (EA 2010). An electricity generation pyrolysis plant is being designed for a village in Tuscany, Italy, with plans to process 150 tons per day (Ensyn 2012).

2.2.5.2 Fermentation

Fermentation refers to the biochemical conversion of a carbon source by a dedicated organism into alcohols, lipids, or other small molecules. Fermentation has the potential to produce exact non-oxygenated molecules, which are more aligned with current transportation fuels and less significant in the power production processes. Ethanol production through fermentation is a well-known industrial process in the corn ethanol industry. Using cellulosic material for production of alcohol, hydrocarbons, and other products is still in the demonstration stage. However, most of the larger fuel production companies such as British Petroleum, Exxon, Shell, and Chevron have established research and development (R&D) teams as well as some pilot-scale operations for cellulosic fuel production. Operational and emissions regulations for cellulosic fuel production have not yet been specified.

2.2.5.3 Esterification

Esterification is the process by which biodiesel is produced from vegetable oil or animal fats. Alcohols such as methanol or ethanol are reacted with an oil feedstock, and a methyl or ethyl ester fatty acid chain is produced with glycerol as the byproduct. The properties of such a molecule closely mimic those of petroleum diesel with some noticeable differences, such as higher cloud point (temperature at which solids precipitate). Biodiesel has been shown to work in both transportation and power-producing diesel engines. Esterification and subsequent biodiesel production is popular as a grassroots movement, with some dedicated producers supplying regional communities; however, national initiatives and mandates for uses other than transportation are still in the early stages of development.

2.2.5.4 Catalytic Cracking

With the help of catalysts to promote the breakdown of complex polymers, catalytic cracking can be used to produce fuel. Polymers are cracked to form monomers (simple, shorter molecular units) which can then be then refined through classic refinery cracking processes to produce gasoline and diesel fuels. This process is more aligned with production of transportation fuels. Catalytic cracking is a well-established technology in the petroleum industry and production of the catalyst and subsequent petroleum processing is covered by federal regulations. However, use of this technology for alternative fuel production is still in the R&D stages.

2.3 Location Requirements

A biomass plant typically requires cleared land near an access road and utilities but away from residential or commercial areas. Biomass plants are best located near the source of biomass to reduce costs. In the case of siting on an Air Force base, where on-site feedstock is often limited, the plant would ideally be located on the edge of an installation where off-site feedstock can be easily delivered to the plant with minimal interruption to the base's daily activities and minimal security requirements for the delivery drivers. Regular, uninhibited feedstock delivery is key to plant operation, and therefore ease of access to the plant is important.

For each of the biomass technologies discussed, a plant will require feedstock storage space, feedstock preparation equipment, feed equipment, processing equipment, product cleaning and collection equipment, electricity generation equipment, ash and waste storage space, and emissions control equipment. The specific infrastructure and space required for each of these depends on the type and amount of feedstock used, the process used, and existing site conditions. As an example, one plasma gasification project processes 250 tons of MSW per day in an 80 ft by 175 ft (24 m by 53 m) area, not including storage space. However, permanent systems with infrastructure typically need 5–10 acres. Landfill gas projects are an exception since the feedstock comes directly from the landfill via the collection system embedded in the landfill. As a result, only space for a power house is needed.

Some feedstocks require year-round storage because they are only available seasonally (e.g., agricultural residue). Other feedstocks are almost continuously available and require less storage space (e.g., MSW), typically about 3–5 days of fuel. Storage areas are typically much larger than the processing area, and may have to be located some distance away due to site constraints. However, nearby storage is preferred to reduce operational costs. The same pile of feedstock cannot sit unused for extended periods of time because the material begins to break down, which reduces energy content and may produce unpleasant odors. Therefore, it is best to first use the feedstock that has been in storage the longest and store new incoming feedstock. This method requires constant transportation between the storage site and plant.

Required utilities for a plant include natural gas, fuel oil, or propane for system startup, electricity to run the plant, and water and wastewater for cooling and boiler operation (for systems using boilers). In addition, distribution systems for generated energy will be needed: a substation and/or distribution lines for electricity, and steam, hot water, or gas pipes for thermal energy. Sites that already have access to these utilities are preferred; costs will increase with increased distance to existing utility distribution systems.

3.0 Wind Energy

Figure 8: Wildhorse Wind Project in Kittitas County, WA, Owned by Puget Sound Energy (Photo credit: Jennifer States, PNNL)

By the end of 2011, global wind capacity had reached almost 238 GW, representing a six percent growth over 2010 (GWEC 2012). The 40.5 GW of new wind resources brought online in 2011 represent a total global investment of approximately $68 billion (GWEC 2012). Additions of wind generation outpaced additions of all other generating resources in the United States in 2012 (AWEA 2013). Table 5 provides specific information about 2011 wind power additions and total capacities for nations with U.S. AF bases analyzed in the FSs.

Table 5: Wind Power Additions and Total Capacity in 2011 (GWEC 2012)

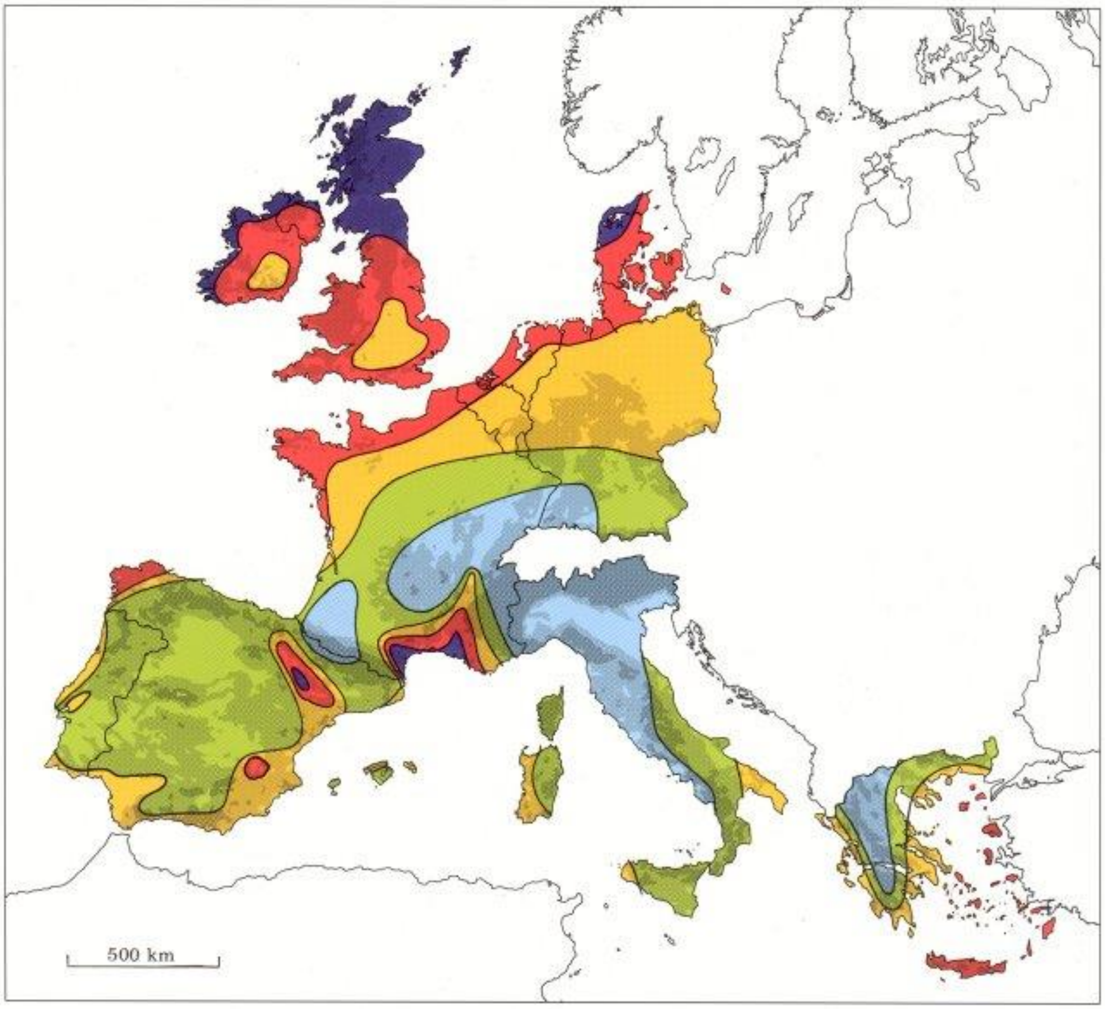
Country	Wind Capacity Added in 2011 (MW)	Total Wind Capacity (MW)
Germany	2,086	29,060
Italy	950	6,737
Japan	168	2,501
South Korea	28	407
Turkey	470	1,799
United Kingdom	1,293	6,540
United States	6,811	46,919
Global Total	40,564	237,669

3.1 Resource Description

According to U.S. standards developed as part of the *Wind Energy Resource Atlas of the United States* (PNNL 1986), there are seven main classes of wind power, as shown in Table 6. Wind speeds are at 50 m (164 ft) above ground level. Referencing this classification system is a way to benchmark wind resources across installations. This wind power classification system is applied outside of the United States as well. For example, the European Wind Atlas (Riso National Laboratory 1989) provides a comparable, color-coded, tiered resource classification for Europe, also at 50 m (164 ft) above ground level, for five different types of topographic conditions, as shown in Figure 9.

Table 6: Classes of Wind Power Density at 50 Meters

Wind Power Class	Wind Power Density (W/m^2)	Average Speed, m/s (mph)
1	< 200	< 5.6 (12.5)
2	200 – 300	5.6 (12.5) – 6.4 (14.3)
3	300 – 400	6.4 (14.3) – 7.0 (15.7)
4	400 – 500	7.0 (15.7) – 7.5 (16.8)
5	500 – 600	7.5 (16.8) – 8.0 (17.9)
6	600 – 800	8.0 (17.9) – 8.8 (19.7)
7	> 800	> 8.8 (19.7)



Wind resources[1] at 50 metres above ground level for five different topographic conditions										
	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

Figure 9: European 50 m Wind Resource Map (Riso National Laboratory 1989)

A strong Class 3 resource, preferably Class 4, is generally required to achieve an economic project on a large, commercial scale. However, a wind resource class rating alone is insufficient to determine a potential project's energy production potential.

Wind turbines generate power when wind causes a turbine's blades to rotate. This rotational energy is converted into electrical energy by a generator. The ultimate goal for a wind energy project is to maximize energy production by deploying the most appropriate turbine for the site and wind resource available. The horizontal-axis wind turbine has evolved as the most cost-efficient design for power production from sustained winds of reasonable velocities. This design is able to capture approximately one-third of the available energy in the passing wind stream, which is similar to the fuel conversion efficiency of a simple cycle natural gas or oil-fired combustion turbine.

Wind speed is the critical factor for wind power production because power generation is based on the cube of the wind speed: if the wind speed *doubles*, the power output from the turbine increases by a factor of *eight*. In general, wind speeds are greater and more consistent at higher elevations. This is one of the reasons that turbine hubs are very high. Higher hubs also allow turbines to be above surface obstacles that interfere with wind flow.

Wind turbines are designed to produce a maximum amount of power under optimal wind conditions. Winds that are highly variable or turbulent produce less energy than those that are sustained within an optimal range. This means that a site with a consistently high wind speed is preferable to a site with only seasonal, high gusts.

Estimates of wind power production are based on wind resource data (wind speed, wind direction, and other factors) and a "power curve" specific to the turbine design. A turbine's power curve allows for the calculation of the amount of power a turbine will generate at a specific wind speed. The distribution of a site's wind speeds, i.e., how often a site experiences any given wind speed, thus dictates its total energy production potential.

Net energy produced is gross energy minus any losses. Losses from a single, isolated turbine arise from turbine outages for maintenance and repair, power disruptions, and icing or other detrimental weather conditions. When multiple turbines are combined to form a wind farm, losses arise from reduced availability as above, but also from wake and array effects (i.e., the inter-turbine interference with wind flow). The net capacity factor, given as a percentage, is the turbine's (or wind farm's) net energy generation at a given site divided by the turbine's or farm's maximum possible generation, typically its nameplate capacity. The capacity factor is an indication of the quality of the wind resource, the efficiency of the project's layout, and the quality of the turbine design.

3.1.1 Offshore Wind

Offshore wind potential is enhanced by the more consistent winds offshore, fewer structures and geographic features that affect surface winds, and fewer limitations on turbine height. Offshore wind farms can be larger than onshore systems and more consistent maritime wind results in higher capacity factors, theoretically near 50%.

Development of offshore wind is also hampered, however, by the maritime environment; the corrosive atmosphere and turbulent weather and extreme ocean conditions threaten to damage turbines and reduce associated output as well as limit access for routine maintenance. Infrastructure to construct and maintain turbines in a marine environment is also not as readily available as it is for onshore projects. Highway networks onshore allow for flexible staging of equipment and personnel to construct onshore wind farms; similar staging facilities do not exist offshore. Further, there is a network of high voltage transmission lines onshore that can be used to interconnect terrestrial wind farms. Not only is there no such transmission grid offshore, the onshore transmission system along coastlines is typically much less robust than in the interior. As a result, interconnecting offshore wind farms may require significant investment in transmission upgrades onshore as well as new facilities in the ocean.

The UK leads the world in offshore wind development with over one GW of installed capacity and leases in place for many more. Experience in the UK is that offshore wind projects cost roughly twice as much as onshore projects. Much of the additional expense is associated with the immaturity of coastal facilities to construct and maintain offshore wind farms. Significant reductions in cost are projected as permanent, new facilities to support wind development are added. Another observation from the UK is that actual capacity factors are much lower than originally assumed. In fact, offshore UK wind farm performance is lower than onshore project performance. The difference has been attributed to the difficulty maintaining turbines offshore. If a turbine malfunctions, it takes longer to repair and the longer shutdown significantly reduces output (Greenacre et al. 2010). Offshore wind potential in the United States has yet to be developed, although the potential appears to be significant.

3.2 Applicable Technologies

Wind projects, often referred to as wind farms, can be categorized by scale. Large, utility-scale projects tend to be at least 50 MW and typically rely on turbines 1.5 MW in size and larger, with hub heights of 80 m (262 ft) or taller.

The standard turbine design used for large turbines (1 MW and larger in size) is the horizontal-axis, three-bladed rotor with an upwind orientation and an active yaw system to keep the rotor oriented into the wind.

Some smaller turbines, typically those used for distributed generation purposes, can instead have a downwind design, a vertical axis, or only two blades. Distributed generation projects are designed to offset the owner’s retail electricity purchases by producing energy that is consumed onsite. Distributed generation projects typically have just one or two turbines, often small turbines, but the wind project size varies depending on the power requirements of the customer, the available resource and land, and local and utility regulations.

Vertical-axis wind turbines have been used for distributed generating projects, but have had limited commercial success and often underperform compared to manufacturers’ estimates, usually because of less-than-ideal siting.

Onshore wind turbine size is constrained by the size and weight of materials that can be transported on public roadways and also by the size and reach of land-based cranes. Currently that limits land-based turbines to around 2.3 MW, with towers around 100 m (328 ft) tall. Turbines for offshore wind projects do not have the same constraints and can be very large. Turbine manufacturer Vestas is currently constructing a 7-MW offshore prototype in the North Sea, and is aiming for commercial European production by 2015 (Vestas 2012).

The typical life expectancy of a wind turbine is 20 to 30 years, assuming periodic maintenance outages and one major overhaul. To support this lifespan estimate, turbine manufacturers have been forced to address the problem of premature gearbox and drivetrain failures. As turbines get larger, the design of the gearbox must be adjusted to avoid overloading. The industry continues to innovate and develop strategies to address this issue in response to some problems with earlier generations of larger (over 1.5 MW) turbine models.

3.3 Location Requirements

The primary siting considerations for grid-connected wind projects are wind resource availability, transmission availability, the capacity of those transmission lines, and sufficient land area. Projects ideally need to be located close to existing transmission lines that can handle additional load. Otherwise, accommodations, such as new lines or substation upgrades, will be needed, potentially at considerable cost.

The land required for a single utility-scale (MW-size) wind turbine is typically three acres, which includes access roads, the turbine base, and other equipment. The actual footprint of a turbine is small compared to the amount of land required to site a wind farm. A wind farm can require 20 to 60 acres per MW, but the project's facilities generally occupy only two to five percent of this acreage. The rest of the land is needed to provide adequate space between turbines. The area between wind turbines can be used for agricultural and many other uses without interfering with power production.

Smaller turbines, such as those 100 kW in size, require less land area than large ones because they can be spaced closer together and have smaller foundation bases. However, production from a wind farm composed of 100-kW turbines is much less than if the same area was developed with larger, but fewer, turbines. In fact, early wind farms developed in California often used 100-kW turbines. Almost all of these have been removed and the sites reconfigured using 1.5-MW machines.

The proper spacing of turbines is essential to reduce wake interference and optimize the wind resource. Terrain and prevailing wind direction(s) ultimately dictate the layout of a wind energy project. On flat, open land, a row of wind turbines is ideally laid out perpendicular to the prevailing wind direction. Spacing between the turbines within a row and between different rows of turbines is typically defined in terms of rotor diameters. Two turbines in a row may be three to four rotor diameters in length apart and that row may be separated from another row by six to ten rotor diameters in length. On complex terrain, the orientation of the ridgelines will dictate the project's layout.

Turbine height restrictions may be imposed to mitigate visual impact concerns, radar interference, and interference with airport operations. In addition, each Air Force base will have its own siting restrictions and issues. Height and location restrictions to minimize impacts to air operations are the most common.

Figure 10 provides a visual of the turbine and transmission layout requirements for a typical large-scale wind project.

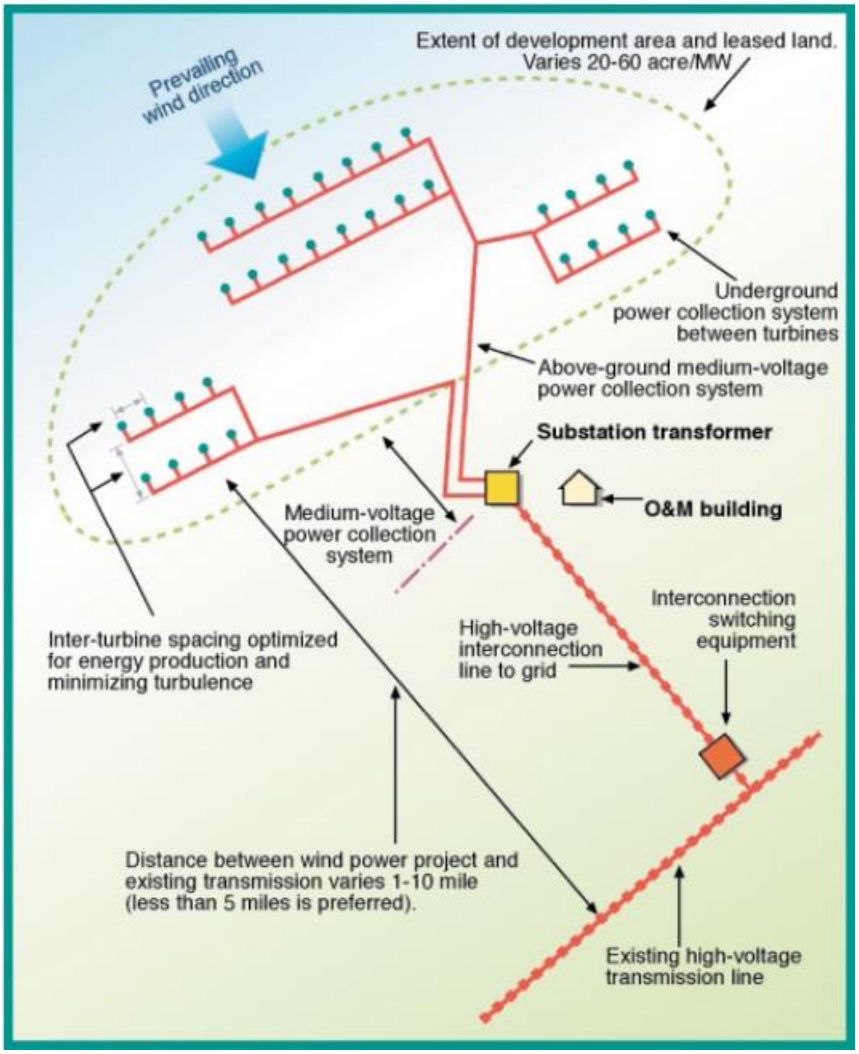


Figure 10: Typical Turbine and Transmission Layout for Large-Scale Wind (PNNL 2008)

4.0 Solar Photovoltaic Energy

Figure 11: Energy Northwest's 30 kW White Bluffs Solar Project in Richland, WA (Photo credit: Jennifer States, PNNL)

PV technologies convert sunlight (global radiation) into a stream of electrons to produce electricity. When sunlight strikes a semiconductor in the solar cell, electrons are released, thereby generating current. PV energy is often considered one of the most reliable forms of renewable energy because it can produce power without moving parts. Between 2000 and 2011, growth in solar PV technology and projects grew faster than any other renewable energy source worldwide. By the end of 2011, an estimated 65 GW of solar PV was installed globally, up from 1.5 GW in 2000 (IEA 2012).

Use of solar technology on military installations has been underway for over a decade—typically smaller projects, mobile power solutions, and demonstration programs. However, several large-scale PV systems have been installed, such as a 14-MW system located on Nellis Air Force Base in Nevada and a 2-MW array at Fort Carson, Colorado.

Naturally, PV systems produce power only during daylight hours and the output varies seasonally. These systems can be configured to provide reliable, secure power when sunlight is not available and during power outages by adding energy storage, typically in the form of batteries.

4.1 Resource Description

The solar energy resource varies by location, elevation, and microclimate. Solar radiation is measured two ways. The first is "global" solar insolation, which includes direct insolation (sunlight that travels directly from the sun to the surface) and indirect insolation (insolation reflected from clouds, structures, the ground, and other reflective bodies). It is commonly measured in units of energy delivered to an area by the sun over a period of time and is often presented in units of kWh/m^2/day. Global insolation is a useful measure for estimating production from PV arrays, solar thermal systems, and daylighting applications. The second way to measure solar radiation is by direct insolation only. Direct insolation, also known as beam radiation, is used to estimate the output of concentrating solar power systems (CSP) including concentrating solar photovoltaic arrays.

4.2 Applicable Technologies

Solar cells produce direct current (DC) electricity, which can be used to power equipment or to recharge a battery. In order for PV arrays to be used for power generation, an inverter is required to convert DC to alternating current (AC), and a transformer is required to convert the power to the appropriate voltage.

Figure 12 illustrates a typical solar cell consisting of semiconductor layers that produce energized electrons when exposed to sunlight, a front contact to allow the electrons to flow to a load, a back contact to allow electrons to complete the circuit by returning to the semiconductor, an antireflective coating, and a glass cover.

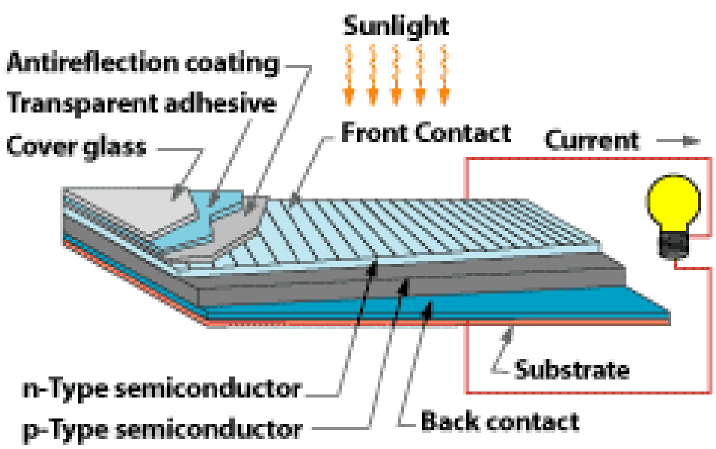


Figure 12: Solar Cell Construct (DOE 2013)

Many individual *solar cells* make up a *solar panel*, also referred to as a module. The panel is protected in a flat-plate assembly constructed of a substrate of metal, glass, or plastic to provide structural support in the back; an encapsulant material to protect the cells; and a transparent cover of plastic or glass to safeguard the entire module. Figure 13 illustrates typical solar panel construction.

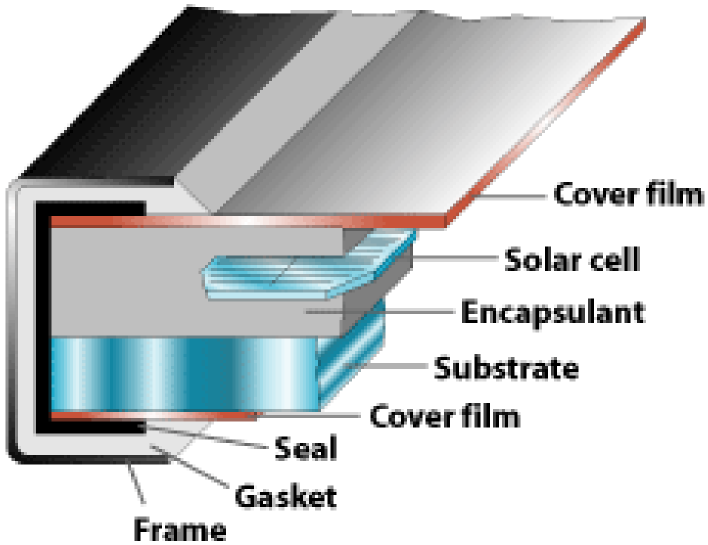


Figure 13: Solar Panel Assembly (DOE 2013)

A *PV array* is constructed by assembling a single or several modules into a unitary system that is connected to the balance of plant (BOP), which is the ancillary equipment that allows the produced power to safely and effectively integrate into an electrical distribution system. In Figure 14, a single PV module is connected to the BOP, thusly creating a PV array that is connected to a load such as a house. In part (a) of the figure, a stand-alone PV system uses battery storage, which is part of the BOP, to provide DC electricity day and night. In part (b), the home is connected to the grid and the PV array is paired with an inverter (represented as the power conditioner), which is also part of the BOP and produces AC power during the day. Excess electricity beyond the needs of the load can then be sold to a utility. In turn, the utility can provide electricity when the array does not produce sufficient power or energy (DOE 2013).

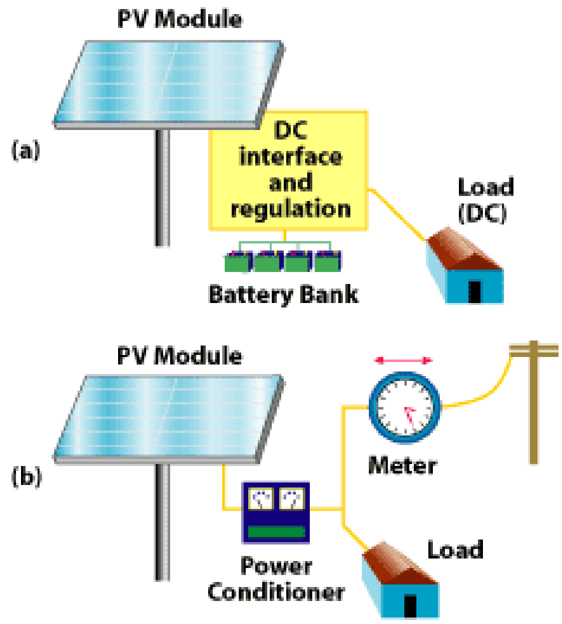


Figure 14: Solar Power System (DOE 2013)

The method by which modules are mounted onto the ground or structures is also important as it influences power and energy production. For instance, the modules in Figure 14 are ground-mounted, fixed-tilt modules; the pitch of the module is fixed. Fixed-tilt modules are typically installed at an angle equal to the latitude of the installation location, facing south (in the Northern Hemisphere). PV modules can also be mounted on single-axis tracking and dual-axis tracking mounts. Single-axis tracking systems allow the array to follow the sun's path across the sky throughout the day along one axis, which is typically the north-south axis. In other words, the panels are tilted to face the sun as it travels from east to west and the entire assembly is often tilted at an angle equal to the site latitude. Dual-axis tracking systems rotate along two axes to follow the path of the sun daily from east to west as well as its daily and seasonal vertical migration across the sky. Arrays can also be sited on buildings and generally employ fixed-tilt mounting techniques, although select axis-tracking systems are available. Figure 15 illustrates fixed-tilt, one-axis, and two-axis sun-tracking PV systems.

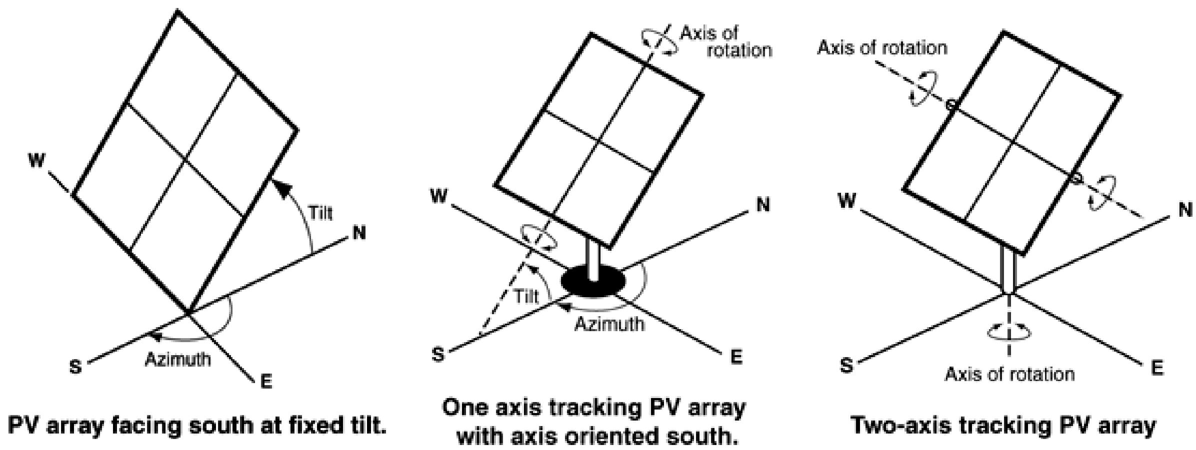


Figure 15: Fixed, One-Axis and Two-Axis PV Arrays (NREL 2011)

Fixed-tilt modules are inherently simpler and therefore less expensive to purchase and operate than the tracking versions. However, the tracking increases the PV panel's energy output, which is more cost-effective in select environments.

4.2.1 PV Cell Materials

A wide range of semiconducting materials are used to fabricate PV modules, including silicon (Si), cadmium telluride, gallium arsenide, and copper indium gallium selenide. In general, more exotic materials are used to produce PV cells that more efficiently convert available solar energy into electricity, or have a higher capacity factor. Nevertheless, significant efficiency gains have been achieved with Si-based panels. Consequently, Si panels produce power for less than panels using exotic materials because Si is generally much less expensive. Unless the area for siting PV panels is constrained, Si panels are preferred.

The efficiency of solar panels can be improved in other ways. These include fewer connecting wires between individual solar cells on the panel surface to increase the energy-producing surface area, better conduction of heat away from the panel (overheating reduces efficiency), and near-seamless connections across an array. The result of these and other innovations has been a steady decrease in the cost per unit output of solar panels. DOE's SunShot program[11] has a goal of bringing installed costs down from around $2/watt today (under ideal conditions) to just $1/watt by 2020. Experts in the industry believe this goal may be achieved before 2020.

4.3 Location Requirements

Compared to most renewable energy technologies, PV panels have a fair degree of siting flexibility. As previously mentioned, an array can be mounted on the ground or upon existing buildings and structures. A potential site needs to be free of any objects, such as trees or buildings, that may cast a shadow on the array.

[11] http://www1.eere.energy.gov/solar/sunshot/

A typical 1-kW PV array may range in size from 8 to 9 m^2 (86 to 97 ft^2); however, a larger array requires access space as well as spacing between the rows of panels to avoid self-shading, and will subsequently require a greater amount of space per installed kW. For example, a 30-kW array would likely require 550 m^2 (5,920 ft^2), and a 100-kW array may require nearly 2,000 m^2 (21,528 ft^2), assuming that the PV array occupies 50% of the space. Panels mounted on slanted roofs can usually be more tightly grouped because of a decrease in self-shading potential.

Large arrays can produce considerable amounts of energy and require siting near existing high voltage power lines. Smaller systems could be integrated into lower-voltage lines where such lines exist. Systems that are on or near buildings can be integrated into the power grid through the building power panel if the PV system isn't too large. This facilitates use of the PV system for power within the building during power outages, if the correct equipment is in place and all utility interconnection requirements are met.

5.0 Solar Thermal Energy

Figure 16: National Solar Thermal Test Facility at Sandia National Laboratory (DOE 2010)

In 2011, an estimated 48.1 GW_{th} of solar thermal collector capacity was installed worldwide, bringing the total installed capacity to 234.6 GW_{th} (Weiss and Mauthner 2013); 1,318 MW_e of solar thermal power capacity was installed in 2010 (DOE 2011a). The majority of installed thermal energy is in China and Europe, which combined represents 78.5% of all installed solar thermal system capacity. Table 7 below outlines total installed capacities of water and air heating technologies in specific countries analyzed in the FSs.

Table 7: Installed Solar Thermal Capacity, 2011, MW_{th} (Weiss and Mauthner 2013)

Country	Collectors for Water Heating			Collectors for Air Heating	Total (MW_{th})
	Unglazed	Flat Plate Collectors	Evacuated Tube Collectors	Glazed	
Germany	428.1	9,107.6	1,174.0	22.6	10,732.2
Italy	29.4	1,796.6	268.5		2,094.5
Japan		3,216.0	58.6	332.6	3,607.3
South Korea		1,108.3			1,108.3
Turkey		9,229.8	933.8		10,163.6
United Kingdom		358.1	101.8		459.9
United States	13,986.5	1,723.5	73.7	52.6	15,836.4
Global Total	21,496.4	65,397.2	146,132.3	451.4	233,477.3

5.1 Resource Description

Solar thermal systems harvest solar radiation (i.e., insolation) in the form of heat to perform air and water heating and power generation via heat engines. Direct insolation, also known as beam radiation, is used to estimate the output of CSP systems. Irradiance is another common measure of solar energy and is often presented in units of W/m^2, which can be converted to insolation by accounting for the duration of the irradiance intensity.

The solar energy resource varies by location, elevation, and microclimate, including the orientation of the solar energy collector. While there is no default collector orientation for reporting insolation values, the three most common orientations are flat, latitude-tilted, south-facing, and vertical. A flat-mounted collector is placed flat on even ground and the solar energy that strikes such a collector is often referred to as global insolation. A latitude-tilted, south-facing collector is orientated to face south (in the Northern Hemisphere) and is tilted at an angle equal to the site's latitude. This orientation helps optimize solar energy collection as this orientation allows the collector to collect more energy over the year. Solar air heating (SAH) systems generally employ vertically mounted solar thermal collectors to maximize winter energy production.

5.2 Applicable Technologies

Although both solar air and water heaters collect solar thermal energy, the collector technology differs.

5.2.1 Solar Water Heating

There are three common, commercially available solar domestic hot water (SDHW) technologies: *unglazed* solar collectors (collectors without glass covers), *glazed* collectors (collectors in glass-covered frames), and *evacuated tube* solar collectors. Unglazed solar collectors are only used in low temperature hot water applications, such as pool heating. Glazed collectors are insulated, weatherproofed boxes that contain a dark absorber plate under a glass cover. These collectors are able to efficiently heat water to temperatures of 160ºF and are well suited for domestic hot water production. Evacuated-tube solar collectors feature parallel rows of transparent glass tubes. Each tube has a glass outer tube and a hollow inner absorber tube that contains a heat transfer medium. These collectors are most often used in high-temperature (>160ºF or 71ºC) hot water applications or in cold climate regions where heat loss needs to be minimized and operational runtimes maximized to achieve useful output temperatures. The FSs assume glazed SDHW collectors will be used, because domestic hot water heating is the intended application.

SDHW systems are also either direct or indirect. Direct systems directly heat the potable water intended for domestic consumption in the solar collectors. Indirect systems circulate a working fluid through the solar collectors and employ a heat exchanger to transfer the heat to the potable water intended for domestic consumption. This working fluid is often an antifreeze solution (10% to 50% glycol mixed with water) that allows the SDHW system to operate in lower ambient temperatures.

Systems that do not utilize a glycol mixture but encounter freezing conditions require a drainback or draindown tank to prevent freezing of working fluids. Draindown systems are also used to prevent damage caused by overheating the working fluid. For this reason, these tanks are often used for both direct and indirect systems.

5.2.2 Solar Air Heating

Transpired SAH systems draw outdoor air through a space between a building's exterior wall and metal panels attached to the wall, which are perforated to allow the air to pass through. The sun heats the metal panels and the panels warm the air as the air passes between the metal panel and exterior wall, as illustrated in Figure 17.

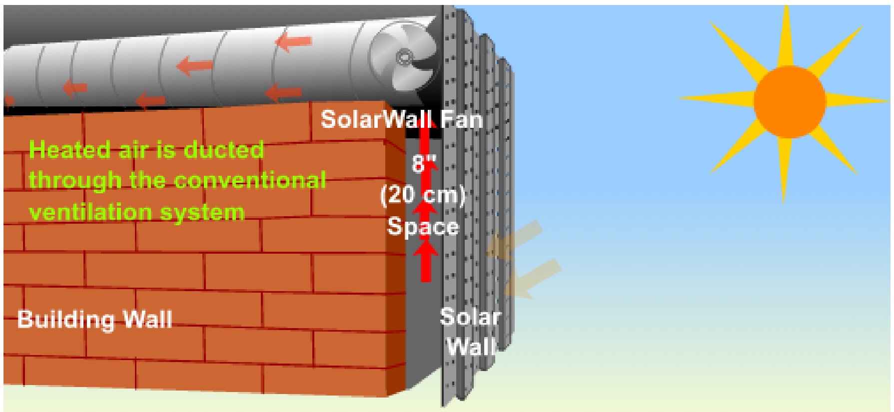


Figure 17: Solar Air Heater Operation (Conserval Engineering 2013)

After collecting heat from the solar collector, the warmed air enters the building through an existing fresh air intake or a dedicated blower and/or diffuser system. A dedicated diffuser system is generally a cloth duct that traverses the building interior along the ceiling. Alternatively, a SAH system can deliver heat to a system of blowers that force the warmed air downward toward occupants. Both approaches can assist with temperature destratification while improving air circulation.

SAH systems can be configured as single-stage or two-stage heating systems. Two-stage SAH systems employ an additional layer of glazing on the upper portion of the heater to avoid heat loss, whereas single-stage systems lack the additional glazing.

Under ideal conditions, an SAH system can provide a majority of the space heating needs for a building or space. When no heating is required, such as during the summer, a damper closes and prevents hot air from entering the building. In addition, the presence of the SAH system provides an additional layer of insulation, which can help lower the building's space conditioning costs.

5.2.3 Concentrating Solar Power

Concentrating solar power systems use mirrors to focus the sun's rays and a heated fluid to produce power rather than directly converting solar energy to electricity. There are three primary types of CSP systems: solar dish, power tower, and solar trough technologies.

A solar dish system employs dual-axis tracking reflective dishes that concentrate thermal energy onto a central point that houses an electricity-producing heat engine. Stirling engines are the most frequently used heat engine in solar dish applications. A Stirling engine uses heat flow to expand and contract a working gas, which then drives a piston and produces electricity. Multiple solar dishes are required to produce utility-scale (multiple MW) power.

Power tower systems use large arrays of mirrors, or heliostats, to concentrate the sun's energy on a central receiver tower that transfers the heat to a working fluid; the heat can then be used to produce steam to drive a generator (see Figure 16 above). The heliostats can be configured to be either single- or dual-axis tracking, though dual-axis systems tend to be more popular and cost-effective. Cogeneration and thermal storage are options for this technology.

Solar trough arrays concentrate the sun's energy on a pipe containing a working fluid, which is used to generate steam to drive a generator. These systems employ curved, single-axis tracking mirrors or reflectors and are highly sensitive to the slope of the ground due to the need to pump the liquid through the collector tubes. A newer variation of the solar trough system employs rows of less expensive flat mirrors (as compared to parabolic mirrors) to heat tubes surrounded by a concentrating Fresnel lens. Each tube is served by several mirrors. As a result, these new systems may be more economical to construct and operate. Cogeneration and thermal storage are also options for this technology.

Both power tower and solar trough systems heat large quantities of a working fluid that is then used to drive a conventional thermal generator. The working fluid can be stored so that variations in sunshine availability have less impact on power production, resulting in more predictable output. Storage for several hours is also possible so that electricity can be produced during peak demand periods and even at night.

5.3 Location Requirements

Solar thermal technologies each have unique siting requirements, which are described below.

5.3.1 Solar Water Heating

SDHW systems are integrated into a building's water heating system. Consequently, the characteristics and properties of the building are as important, and often more so, than the intensity of the available solar resource when estimating SDHW system potential. Buildings suitable for SDHW systems frequently have the following characteristics:

- relatively large water loads supplied from a centralized water heating system (e.g., a boiler vs. point-of-use heaters),
- high levels of makeup water heating and low levels of return water reheating,
- consistent and regular water draws throughout the day,
- seven-days-per-week occupancy, and
- modest hot water temperature set points (e.g., 120°F or 48.9°C).

A range of building types is generally suitable for SDHW systems, including dining facilities, dormitories, barracks and billets, transient housing, buildings with shower rooms such as physical fitness centers and pools, child development centers, laundry facilities, and buildings with restaurants such as club houses. Certain building types are generally less suitable, including administrative buildings, mechanical shops, retail services, and small or mixed-use buildings, due to their irregular and generally small consumption of hot water as well as smaller or crowded rooftops, impeding collector placement.

Another important requirement for SDHW systems is the ability to site additional hot water storage tank(s). The space required for additional tanks can be challenging to secure in densely occupied mechanical rooms. Consequently, existing buildings need to be carefully examined to make sure that space is available for these tanks. For new buildings, supplemental space can be reserved during the design phase.

SDHW systems also require free and open space for collector installation. Collectors are typically installed on rooftops; ground-mounted systems are possible but uncommon. Both flat and pitched roofs are suitable for collectors. Standing seam metal roofs are typically preferable as they allow for simpler and generally less costly panel mounting via clips that attach to the standing seams. Regardless of roof type, an ideal roof provides an area that faces south, or largely south. Other roof types can be considered given the age and roofing material on a case-by-case basis. For instance, flat roofs can be suitable provided the roof can accommodate the mounting racks. SDHW systems typically feature latitude-tilted or flush, roof-mounted collectors at an angle generally matching the roof angle. The closer a site is to the equator, the closer the latitude-tilted insolation value will equal the global insolation value (because the latitude of an equatorial site is 0°).

Systems can be installed on historic buildings, but the collectors must be selected, arranged, and installed in such a way that they are not visible from ground level.

5.3.2 Solar Air Heating

As with SDHW systems, SAH systems are installed on buildings, and consequently the characteristics of the buildings and the space heating system play a critical role in SAH system feasibility. Buildings suitable for SAH systems frequently have the following:

- large, open floor areas,
- high ceilings,
- forced-air heating systems (e.g., air handling units, fan coil units, forced-air furnaces) rather than radiant systems (e.g., infrared or radiant floor heating),
- outdoor/make-up air requirement, and
- ample space available on exterior walls facing south, east, west, and/or intermediate orientations for collector installation.

Buildings suitable for SAH systems typically have large, open floor areas and high ceilings (>15 ft [4.6 m]) to allow for straightforward heated air distribution. SAH systems are occasionally suitable for highly partitioned buildings (e.g., administrative), provided the existing air handling system is particularly amenable to an SAH system and the energy cost savings are relatively large. Examples of amenable distribution systems include air handling systems with a fresh air intake on the south wall or roof, or buildings that require 100% outdoor air or high numbers of air changes, such as laboratories and medical facilities.

Buildings with high ceilings and roofs are particularly suitable as these buildings typically have ample space for SAH system siting on exterior walls. Additionally, such buildings generally have considerable heating needs due to their large interior volumes and frequently suffer from temperature stratification issues, which SAH systems can mitigate. Furthermore, as with SDHW systems, SAH systems are generally more economic for buildings heated seven days a week. These are typically buildings occupied seven days a week, but may include buildings occupied fewer days where interior temperature is not automatically reduced when the building is not occupied.

The nature of the building's space heating system can have tremendous influence on system economics. Buildings that employ space heating by delivering heated air via air handing units are the most suitable to this technology as SAH systems can easily be integrated into the existing system. Buildings with fan coil systems also directly heat the air, but in different manner. In some cases, SAH systems combined with destratification systems can be successfully deployed at buildings that use fan coil systems. Radiant floor heating and infrared heating systems have become increasingly popular in buildings generally considered ideal for SAH systems (e.g., hangars) since these systems can more effectively provide heat to building occupants. Such buildings may have limited or nonexistent air heating systems or outdoor air delivery systems, which poses a challenge to SAH system installation. Since radiant heating technologies provide and deliver space heating in a fundamentally different nature than SAH systems, great care must be taken to estimate the thermal energy savings of a SAH system. To account for this, sophisticated building modeling must be employed to determine true thermal energy savings for subsequent economic analyses.

Every considered structure must have a suitable mounting surface. SAH systems are generally installed on walls, which require vertically mounted collectors; this orientation helps maximize winter energy production. Generally, the ideal mounting surface is a south-facing exterior wall. East- and west-facing walls can also be considered provided economic analyses prove positive. The mounting surface must be largely free of shading from neighboring buildings, structures, and geographical features and, ideally, have little to no surface irregularities or windows, though such features can often be accommodated. SAH systems can also be integrated into the walls or roofs of a building to help mask their appearance.

A range of building types is suitable for SAH systems, including hangars, gymnasiums, warehouses, and mechanical bays. Other building types can be considered provided they have an appropriate wall to mount the system and have amenable space heating systems. Remote buildings that provide space heating via expensive fuels such as propane or fuel oil may be small, have poor southern exposures or other characteristics that are not ideal for SAHs, but may have sufficiently strong economic drivers to result in cost-effective projects.

5.3.3 Concentrating Solar Power

CSP systems require high levels of direct normal solar insolation to be cost-effective, generally at least 6.75 kWh/m^2/day of direct normal insolation. Consequently, sites are generally limited to deserts and other arid ecologies. In the case of solar trough systems, the slope of the land must be less than 1% to minimize the energy expended to pump the working fluid through absorber tubes. Solar power towers and solar troughs require hundreds of contiguous acres, whereas individual solar dish systems require tens to a few hundred ft^2 per system depending on the system capacity. Proximity to transmission lines and ease of access for construction and O&M staff also play a large role when considering potential power plant locations. This presents challenges for CSP because the ideal desert environment is often not near a population center or served with transmission lines. Lastly, unlike photovoltaic power systems, CSP systems are generally not suitable for installation on buildings and structures, with the exception of small-scale (i.e., multi-kilowatt) solar dish systems.

6.0 Geothermal Energy

Figure 18: Geothermal Energy Plant at The Geysers near Santa Rosa, California (DOE 2012a)

The International Geothermal Association reported that in 2010 there were 10,715 MW of geothermal resources online globally, producing a total of 62,246 GW—an increase of 20% since 2005 (Holm et al. 2010). By 2050, geothermal resources could supply 3% of electricity and 5% of heating and cooling demand worldwide (Goldstein et al. 2011). Table 8 outlines 2010 installed capacities and planned geothermal additions for countries included in the FSs.

Table 8: Installed Geothermal Capacity, Current and Planned (Holm et al. 2010)

Country	Installed Geothermal Capacity in 2010 (MW)	Planned Capacity Additions by 2020 (MW)
Germany	8.11	240
Italy	843	84.3
Japan	536	30
Turkey	1,177	N/A
United States	3,086	N/A

6.1 Resource Description

Geothermal energy is produced from the heat of the Earth and has several forms. Geothermal energy from deep within the Earth is hot enough to use in power plants. Geothermal energy from shallower wells may only be suitable for thermal applications, such as space and water heating. This includes use of hot water from geothermal wells or hot springs as well as use of the thermal inertia inherent in the surface soil that creates a temperature differential between the soil and the surrounding air.

The process of generating electricity from steam, whether from boiling water using fossil fuels or using natural geothermal sources, involves a process referred to as a Rankine cycle. The steam rotates a turbine connected to a generator that produces electricity. Geothermal power plants use steam produced from heat reservoirs found deep below the Earth's surface.

Geothermal resources are available at varying levels, and the level of availability typically determines the technology and application. Conversely, the desired application determines the requirements for the geothermal resource. Geothermal resources, known as reservoirs, are usually found in areas where the Earth's tectonic plates meet. These boundaries are located in the same areas where deep-Earth geologic structures are closest to the surface, and are also the cause of most volcanoes and earthquakes. One of the most active geothermal areas is the Ring of Fire that encircles the Pacific Ocean (EIA 2012a).

6.2 Applicable Technologies

The geothermal resource can be used for electricity generation, direct heating and drying applications, or the ground source temperature differentials can be used for heating and cooling. The technologies used to harness the geothermal resource vary across the different applications.

6.2.1 Geothermal Power Plants

There are three basic types of geothermal power plants used to generate electricity: dry steam, flash steam, and binary cycle. The type of plant depends on the state of the geothermal fluid at the surface (whether it is steam or water) and its temperature.

6.2.1.1 Dry Steam

Dry steam power plants use underground steam resources. The steam is created when water enters hot structures in the Earth, creating subsurface steam. When tapped with wells, the steam is piped directly from the wells to the power plant, where it passes through separators to remove small particles before it is directed into a turbine-generator unit. Figure 19 illustrates the process of producing power using dry steam.

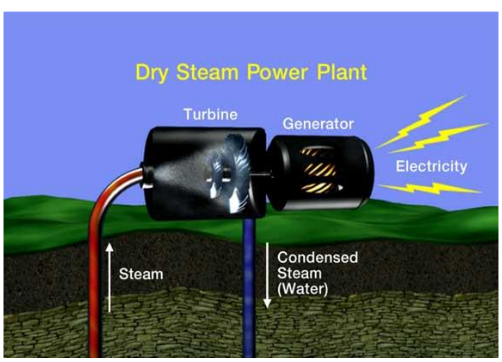


Figure 19: Dry Steam Power Plant (Geothermal Education Office 2000)

6.2.1.2 Flash Steam

Flash steam power plants use geothermal resources that produce high-temperature hot water or a combination of steam and hot water. This very hot water (reservoir temperatures higher than 360°F or 182°C) flows up through wells in the ground under its own pressure. As it flows upward and the pressure decreases, some of the hot water boils (flashes) into steam. The steam is then captured, separated from the water, and used to power a turbine-generator; Figure 20 illustrates this process. Leftover water and condensed steam are injected back into the reservoir, making this a sustainable process. Depending on the temperature of the resource, it may be possible to use a second flash tank where more steam at a lower pressure is separated for generation (double flash plant).

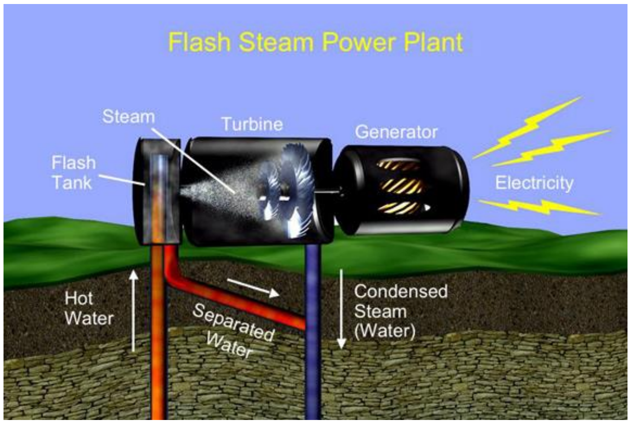


Figure 20: Flash Steam Power Plant (Geothermal Education Office 2000)

6.2.1.3 Binary Cycle

Binary cycle power plants utilize a second fluid in a closed cycle to operate the turbine, instead of direct geothermal steam. These plants operate on water at lower temperatures of about 225–360°F (107–182°C), which is piped to a heat exchanger near the surface. As shown in Figure 21, the heat from the hot water is used to boil a working fluid with a lower boiling point than water, usually an organic compound. Current machines use hydrofluorocarbon-type refrigerants (e.g., isobutane, pentane). The working fluid is vaporized in the heat exchanger and used to turn a turbine. The water is then injected back into the ground to be reheated. The water and the working fluid are kept separated during the entire process. The ability to operate with lower temperature water is a distinct advantage of the binary cycle plant over other geothermal electric technologies. Binary power plants are also becoming available at smaller scales. Two firms are marketing units in the 200-kW to 10-MW range.

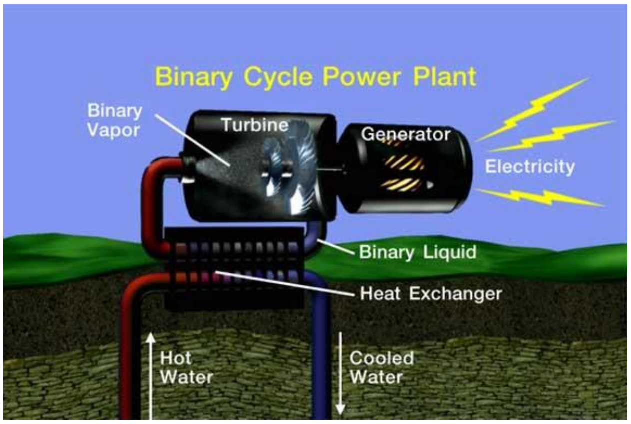


Figure 21: Binary Cycle Power Plant (Geothermal Education Office 2000)

6.2.1.4 Emerging Technologies

Hot dry rock (HDR) geothermal production utilizes high-temperature rocks found deep (several km) below the surface by pumping high pressure water down a borehole into a heat zone. The water captures the heat of the rock by traveling through fractures until it is forced out a second borehole and used to generate electricity. Once the water has cooled, it is pumped back underground to heat up again. This process is most easily utilized in natural geothermal systems with existing cracks or pore spaces. In a location where there are some cracks and connected pore spaces, or few to no cracks or connectivity, cracks can be created or enhanced. This process is referred to as engineered or enhanced geothermal systems (EGSs). The advantage of HDR or EGS is that geothermal resources can be captured for production in tectonically inactive regions. However, this technology is still very new and expensive. Future use of EGS may be assured because the basic process of increasing porosity borrows from fracturing techniques now widely used by the oil and gas exploration industry. DOE has funded a number of RD&D efforts to see whether these techniques can be adapted for geothermal power production.

A new application for binary cycle geothermal power plants is the organic rankine cycle (ORC) engine. The ORC engine utilizes a heated organic gaseous chemical instead of superheated steam. The organic chemicals used by an ORC engine include freon and most of the other traditional refrigerants—isopentane, chlorofluorocarbons, hydrofluorocarbons, butane, propane, and ammonia. ORC engines are best applied with waste heat recovery at temperatures between 302°F and 392°F (150°C to 200°C). Chena Hot Springs Resort in Alaska has entered into a partnership with United Technologies Corporation to demonstrate their geothermal ORC power plant technology. At well temperatures of 170°F (77°C), this plant demonstrates the application of low-temperature geothermal resources near the surface primarily because it can increase the effective temperature differential by using the frigid Chena River for cooling the working fluid.

New research is emerging on the potential to develop geothermal energy from co-produced hot waters from oil and gas operations. Hot water is a byproduct of hydrocarbon production, as oil and gas are typically commingled with geologic water. This high temperature "waste water" could be used in a binary plant to produce power for use on-site or to supply to the power grid. This process would take advantage of existing infrastructure and on-site high temperature fluid flow. The additional revenue path from potential geothermal generation could allow low-yield producers with high water volume to keep the well equipment running.

These systems are now sized to fit single wells or multiple wells with an approximate fluid temperature differential of 120°F (50°C) or more between the ambient temperature of production and the resource. It can be difficult to find existing oil and gas wells with high enough fluid flow because of smaller well casing diameters. A 50-MW_e plant would require about 117 wells with 5-inch casings, drilled 12,000 ft (3,658 m) deep, with temperatures at 300°F (149°C) to generate enough fluid (Petty and Porro 2007). Well completion history and production data are needed to determine the potential for geothermal energy production at individual sites.

6.2.2 Direct-Use Geothermal

Direct-use geothermal involves using the heat of the water directly for applications without the use of a heat pump or power plant. Space heating, aquaculture, heating spas and pools, greenhouses, agriculture drying, and snow melting are some of the applications in operation today with direct use of geothermal fluids.

Space heating systems can be built for individual user applications or for district heating systems with many buildings and many users. Some systems use the geothermal fluids themselves for heating. Alternatively, water can be pumped through heat exchangers while the geothermal fluid remains in the ground.

Direct-use systems typically include three components (DOE 2012a):

- a production facility that brings the hot water to the surface (typically a well)
- a mechanical system to deliver the heat to the space or process (piping, heat exchanger, controls)
- a disposal system to receive the cooled geothermal fluid (storage pond or injection well).

Geothermal heating systems are different from ground source heat pumps in that they tap into heat sources that are hotter than the surrounding earth. Ground source heat pumps utilize the difference between the ambient temperature of the earth and a working fluid, typically air or water.

6.3 Location Requirements

Geothermal power projects are located according to resource availability, rather than by the location of the electrical power demand. Consequently, a critical part of most geothermal projects is the provision of transmission lines and associated electrical systems to deliver the power. Therefore, it is essential that transmission and power market studies be part of the preliminary siting and investigation phase of any project.

Geothermal power plants typically require much less land than fossil fuel energy sources; however, exactly how much land is needed is difficult to quantify prior to exploration because the properties of geothermal reservoir fluids and the options for waste stream discharge (typically reinjection) are highly site-specific (MIT 2006). According to the Massachusetts Institute of Technology (MIT 2006), a typical 20-MW binary power plant (excluding wells) requires approximately 1.5 km^2/MW. Well fields can cover large subsurface areas of more than 10 km^2 (3.86 mi^2) that require water and pore space rights, but directional drilling technologies enable multiple wells to be drilled from a single drill pad, reducing the surface impact to less than 1 km^2 (0.39 mi^2).

6.3.1 Geothermal Power Plants

Some key considerations for geothermal power plants include considerations about existing plant operations or developer activity. Sites must have the following:

- one or more wells tested with temperatures in excess of 212°F (100°C) logged downhole at depths less than 3,000 m (9,842 ft),
- demonstrated high fluid flow rates, on the order of 1,000 gpm (gallons per minute) per MW,
- heat flow rates greater than 80 mW/m^2 (or milliwatts per square meter), and
- any other exploration data and information available from other drilling in the area.

Typically, geothermal wells are drilled to depths of 200 to 1,500 m (656 to 4,921 ft) for low- and medium-temperature systems, and up to 3,000 m (9,842 ft) for high-temperature systems. However, drilling depths vary with site-specific circumstances. The high cost of drilling wells means there is an economic trade-off between the number of wells drilled and well depth. The hope of EGS is that it will require less well drilling to tap geothermal reservoir capacity.

For commercial use, it is necessary to have a geothermal reservoir capable of providing hydrothermal (hot water and steam) resources at sufficiently high flow rates. Successful geothermal electrical power generation requires fluid flow rates equal to or greater than 1,000 gpm per MW. For example, 1.5 MW of electricity at a reservoir temperature of 300°F (149°C) requires a flow rate of about 1,000 gpm (McKenna 2006).

Geothermal plants also operate in regions with high heat flow rates. Heat flow values above 80 mW/m^2 are considered characteristic of a geothermal system. Productive heat flows are generally greater than 150 mW/m^2 (Blackwell et al. 2003).

6.3.2 Direct-Use Geothermal

Direct-use projects generally use resource temperatures between 100°F (38°C) and 300°F (149°C), depending on the application. Geothermal space heating typically requires water temperatures of at least 120°F (about 50°C). Space cooling (using geothermal fluids to run a refrigeration cycle for air conditioning) typically requires higher water temperatures (at least 230°F or 110°C). Agricultural or industrial drying and aquaculture heating uses require the lowest temperatures, from 77°F to 194°F (25°C to 90°C) (Lund 2005).

7.0 Ground Source Heat Pumps

Figure 22: Piping for Ground Source Heat Pump Systems (DOE 2012b)

Unlike other renewable energy technologies, GSHPs do not generate energy. Instead, GSHPs transfer heat from one location to another to provide cooling and heating. In the cooling mode, the GSHP system will remove heat from the building and deposit it into the ground (or another heat sink). In the heating mode, the GSHP reverses this process and removes heat from the ground (or another heat source) and deposits it in the building. In any GSHP system, the renewable resource being used is the constant temperature of the heat sink/source. This can be used to improve the coefficient of performance (COP) of heating and cooling applications for buildings compared to other heating and cooling systems.

GSHPs can be used in almost any building with heating and cooling needs, regardless of the size of the building. Under some circumstances, the same ground loop can be shared between buildings. If the load of a single building is large, multiple GSHPs can be used to meet the load.

GSHPs are used worldwide in many applications. In 2008, the U.S. GSHP industry shipped 121,243 units globally, with a total capacity of 416,105 tons (NREL 2009). Outside of the United States, GSHPs are primarily concentrated in Europe, with more than 100,000 units installed by 2009, followed by China, which installed almost 1.5 million tons by 2009 (NREL 2009).

7.1 Resource Description

GSHPs tend to perform better in climates with balanced heating and cooling needs, although other situations can be accommodated. The systems are most cost-effective compared to other heating and cooling systems when both the heating and cooling loads are large; this allows the higher efficiency of GSHPs to generate more energy savings.

These systems generally require ground temperatures of 4°C–38°C (40°F–100°F). Open-loop systems are once-through systems that use water as an exchange fluid and therefore need a source of water and a location for the used water. Shallow groundwater or a large body of nearby surface water signifies good potential for open-loop GSHPs. Water requirements are typically 1.5 to 3 gpm per cooling ton. This high water use greatly affects the feasibility of open-loop systems in some areas, as do local codes and regulations. Many locales do not want to risk groundwater depletion or contamination.

Closed-loop systems perform best with high soil conductivity, which can vary significantly by location and should be tested at each proposed building prior to designing a GSHP system. Closed-loop systems can also be affected by regulations related to concerns of groundwater contamination; drilling beyond a certain depth is sometimes prohibited.

Because GSHPs can be employed almost anywhere, site-specific and building-specific circumstances need to be considered. One consideration is availability of the technology and designers and installers with experience. If not properly designed and installed, GSHPs do not perform well and are often soon replaced with standard heating and cooling equipment. Other considerations are described below in Location Requirements.

7.2 Applicable Technologies

GSHPs generally consist of two main technical components that differ from traditional heating and cooling systems: a water source heat pump (WSHP) and a ground coupled heat exchanger (GCHX). The WSHP operates on the same principle as a typical air conditioner, but has been modified to allow it to work in two directions. Essentially, it can either cool the interior of a building or the outside air (which in turn heats the air inside a building); depending on its operating mode. Another characteristic of WSHPs that differentiate them from standard air conditioners is the fact that the exterior coils are designed to interact with water rather than air. This interaction occurs with the GCHX.

The GCHX portion of GSHP systems allows the WSHP to exchange energy with the earth and take advantage of the consistent annual temperatures found below the earth's surface. There are a number of different configurations of GCHXs, including open-loop, horizontal closed-loop, vertical closed-loop, coiled closed-loop, and hybrid systems. In general, closed-loop systems are more efficient than open-loop systems because of the lower pumping requirements.

7.2.1 Open-Loop Systems

Open-loop systems use wells or open bodies of water as direct heat transfer mediums. Heat transfer is only needed once, at the building, because groundwater is used directly. The water is used once and then discharged to a stream or lake or injected into a second well. The limited drilling and trenching necessary for this system results in a lower initial cost. However, to avoid contamination, the water source and sink need to be closely monitored and the WSHP at the building sealed and maintained. Figure 23 illustrates an open-loop system.

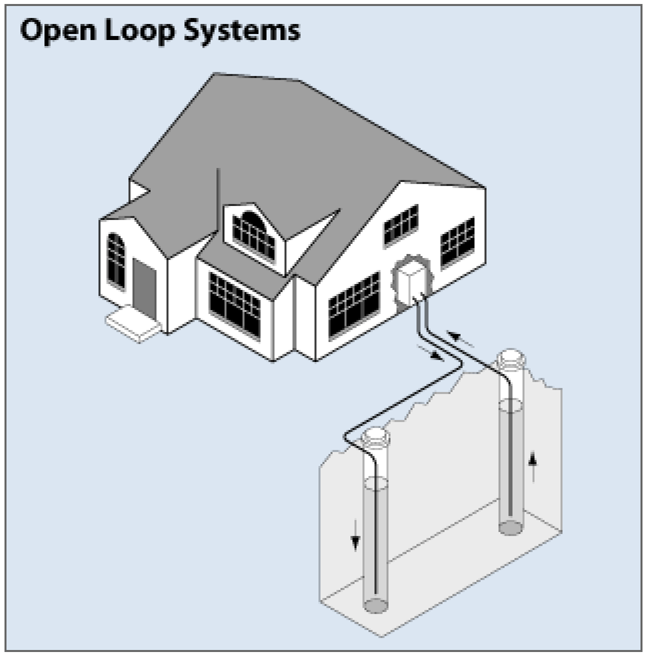


Figure 23: Open-Loop Ground Source Heat Pump (DOE 2012c)

7.2.2 Horizontal Closed-Loop Systems

Horizontal closed-loop systems, illustrated in Figure 24, use heat transfer fluid inside a sealed pipe to exchange heat with the earth. The heat exchange pipe is buried in a trench dug about 6 ft (1.8 m) below the surface. Some pipe configurations are long straight loops, while others spiral around like a slinky. Heat transfer occurs twice in this system: in the ground between the heat transfer fluid and the soil, and in the building between the heat transfer fluid and the WSHP refrigerant.

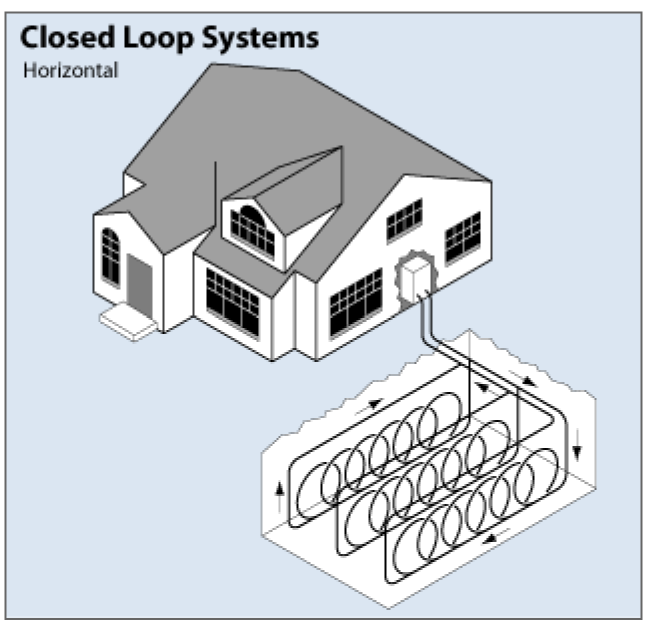


Figure 24: Horizontal Closed-Loop Ground Source Heat Pump System (DOE 2012c)

7.2.3 Vertical Closed-Loop Systems

Vertical closed-loop GSHPs operate on the same principle as horizontal loops, with a sealed ground loop and heat transfer occurring twice. An example is shown in Figure 25. However, in this case, the heat transfer piping is installed vertically in boreholes about 300 ft (91 m) deep. The depths reached with this configuration allow access to more constant ground temperatures and make it a more efficient system when compared to horizontal loops.

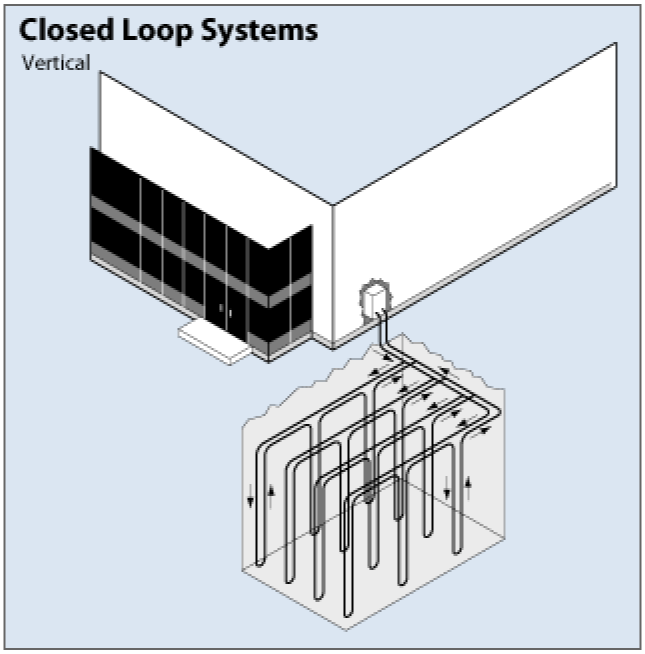


Figure 25: Vertical Closed-Loop Ground Source Heat Pump System (DOE 2012c)

7.2.4 Coiled Closed-Loop Systems

Closed-loop systems can also be used with open bodies of water, where piping is installed near the bottom of a pond or lake and generally coiled to reduce area requirements (see Figure 26). These systems operate similarly to other closed-loop systems, but utilize the constant temperature of the water at the bottom of the pond or lake instead of the ground. The pond or lake must be large enough to provide a sustainable heat source and sink year-round, under various weather conditions, and over the life of the GSHP.

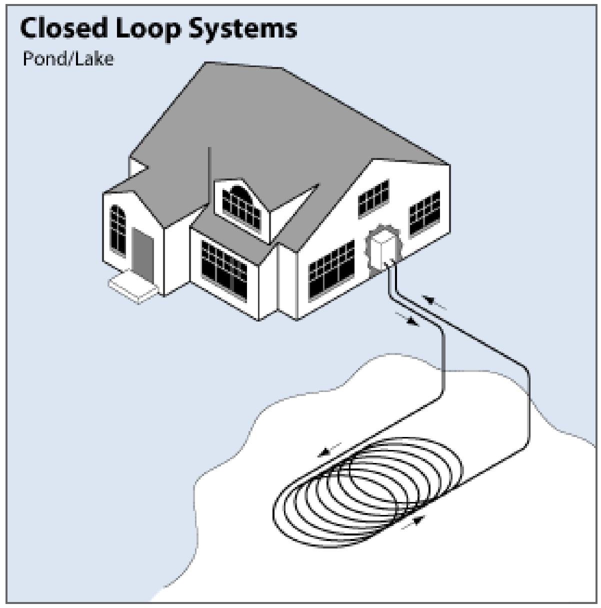


Figure 26: Closed-Loop Coiled Ground Source Heat Pump System (DOE 2012c)

7.2.5 Hybrid Systems

Hybrid systems incorporate additional heating or cooling components into the system to reduce ground loop requirements (and therefore cost) when heating and cooling loads are unbalanced. These components may be an additional cooling pond, cooling tower, boiler, or solar water heating element.

7.2.6 GSHP Efficiency

The efficiency of heat pumps is usually measured by a system's COP. A system's COP is simply the heat delivered by the system divided by the energy consumed to deliver the heat.

$$COP = \frac{Quantity\ of\ Heat\ Delivered}{Energy\ Required\ by\ Heat\ Pump}$$

Most GSHP systems have a COP of about 2.0 to 5.0. Heat pumps have COPs greater than 1.0 because the energy transferred by the heat pump is greater than the energy required to run the heat pump. The COP of a GSHP system will depend on many factors, including ground temperature, system design, and building characteristics such as insulation and air tightness. In addition to the COP, GSHP systems include an energy efficiency ratio (EER), which measures cooling efficiency using the ratio of heat removed to the electricity used to power the unit.

7.3 Location Requirements

GSHPs are applicable in almost any building with heating and cooling, and are most effective in buildings that have large, balanced heating and cooling loads. They can be used in buildings as small as 100 ft^2 (30 m^2) or as large as 1,000,000 ft^2 (over 300,000 m^2). Multiple GSHPs can be used in a single building to meet the load, or the same ground loop can be shared between buildings.

To install GSHPs at a building, the surrounding area will have certain prerequisites, depending on the type of GSHP. Open-loop GSHPs need a water source and sink. The source can be a well or open body of water. The sink can be a secondary well, the same open body of water used as the source, or another body of water. The source and sink should be located near the building to reduce drilling and installation costs of open-loop systems.

Horizontal loops are laid parallel to the surface, and therefore require a large area of land for heat exchange adjacent to the building being served. Horizontal pipes are laid in trenches 100 to 400 ft (30.4 to 121.9 m) long per cooling ton, with spacing of 6 to 12 ft (1.8 to 3.7 m) apart. The soil characteristics and number of pipes per trench determine the pipe length; more pipes (up to six) per trench save land space but require more piping per ton of cooling capacity. An area approximately four to five times a building's floor area can be required for a horizontal ground loop serving that building.

Vertical closed-loop heat transfer pipes are placed vertically in the ground at depths of 200 to 800 ft (61 to 243.8 m), with spacing of 15 to 20 ft (4.6 to 6.1 m) apart. The piping length needed is 200 to 600 ft (61 to 183 m) per cooling ton. Approximately half the size of a building's floor area can be required for a vertical ground loop serving that building.

8.0 Ocean, Hydrokinetic, and Hydroelectric Energy

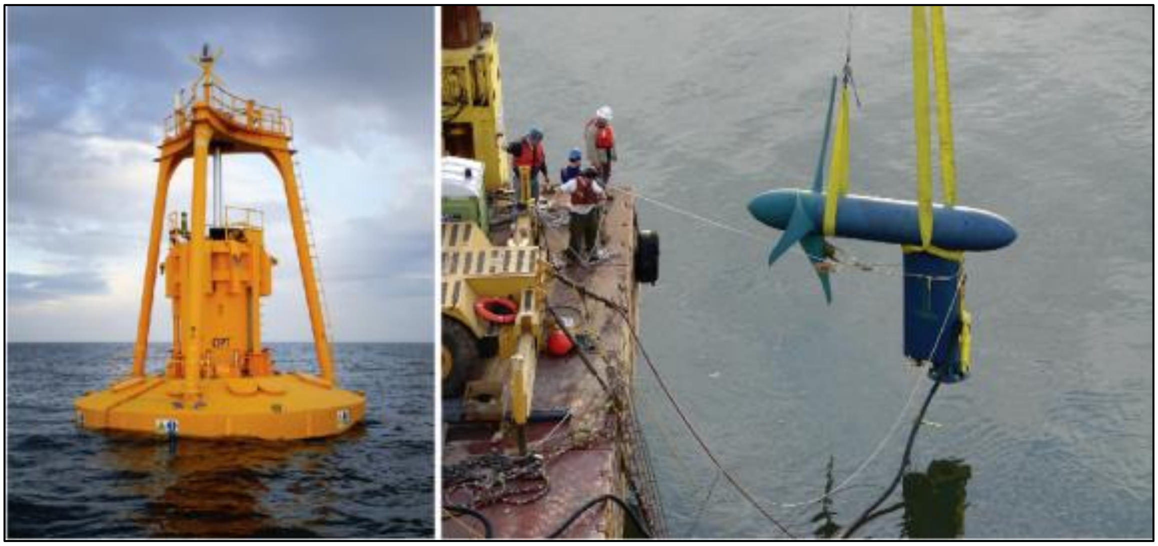


Figure 27: Ocean Wave Power off the Oregon Coast (Left), Underwater Turbine Entering New York's East River (Right) (EIA 2012b)

Energy from oceans comes in various forms. The oceans act as the world's largest solar collectors, capturing thermal energy from the sun and (along with the rotation of the earth) causing ocean currents. The gravitational pull of the moon powers the ocean's tides while wind drives the ocean waves. Technologies used to harness the ocean's currents to generate energy are still in their infancy.

The UK has traditionally been the pioneer of ocean energy and currently has eight operational facilities, which include five tidal and three wave systems (SETIS 2011). In the United States, advancement of hydrokinetic projects is being pursued by a variety of entities, and two large commercial projects were approved by the Federal Energy Regulatory Commission (FERC) in 2012. These projects include the Roosevelt Island Tidal energy project, which will install hydrokinetic generators in New York's East River, and the Reedsport Wave Park power station off the Oregon coast, with the potential generation capacity of 1.5 MW (EIA 2012b).

Ocean wave and tidal technologies are not as mature as many other renewable energy systems, but research is rapidly expanding these technologies. Worldwide, capacities of ocean energy did not grow significantly over the past decade, remaining at approximately 502 MW (REN21 2011). However, in 2010 a number of projects were under development, and estimated capacity was expected to jump to 520 MW by the end of 2011 (REN21 2011).

Hydroelectric power represents the largest share of global renewable energy capacity, with systems installed in over 150 countries. In 2010, global hydro increased approximately 5%, bringing the total installed capacity to an estimated 1,010 GW (REN21 2011). In total, hydroelectric power comprises 16% of global energy production (REN21 2011).

Table 9 outlines hydroelectric power potential (measured in TWh per year) in countries analyzed by the FSs accompanying this handbook. For each country, the theoretical capacity based on the entire country's resource is presented, followed by technically exploitable and economically viable production amounts.

Table 9: Hydroelectric Energy Capability by Country, 2002 (UN 2006)

Country	Gross Theoretical Capacity (TWh/yr)	Technically Exploitable Capacity (TWh/yr)	Economically Exploitable Capacity (TWh/yr)
Germany	120	25	20
Italy	340	105	65
Japan	718	136	114
South Korea	52	26	19
Turkey	433	216	126
United Kingdom	40	3	1
United States	4,485	1,752	501

8.1 Resource Description

This section provides an overview of each hydro resource by technology type. Sections 8.1.1 through 8.1.4 contain specific descriptions for ocean energy resources, and Sections 8.1.5 and 8.1.6 contain descriptions for river/stream energy resources.

8.1.1 Ocean Thermal Energy Conversion

Ocean Thermal Energy Conversion (OTEC) requires very warm and very cold seawater to drive a thermodynamic cycle and produce electricity. A temperature difference of 36°F (20°C) between warm and cold water is understood to be the cutoff for a viable OTEC facility. Thermodynamic efficiency of the OTEC cycle is very low, even in tropical oceans where this relatively large temperature gradient exists between deep and shallow waters. Because of this, very large seawater flows are required, on the order of several cubic meters per second per megawatt (Nihouse 2007).

8.1.2 Seawater Cooling

Seawater cooling, or seawater air conditioning (SWAC), systems utilize cold, deep seawater (or lake or river water) to replace energy intensive air conditioning or refrigeration systems. SWAC systems can reduce electrical cooling loads by as much as 80–90 percent in geographical locations where cooling is a major energy consumer (Makai Ocean Engineering 2011).

8.1.3 Wave Power

Uneven solar heating of the Earth's surface causes winds. When winds blow over a distance of water (a fetch), waves are created. Wave energy conversion (WEC) devices convert the energy contained within waves into useable electricity. Wave power resources are greatest in areas with open coastlines exposed to waves driven by a long fetch. The Pacific coast of North America is considered one of the world's premier locations for wave energy. Wave energy is predictable, with highest energy availability in the northern Pacific in months when energy demand is highest (winter, for heating).

8.1.4 Tidal Hydrokinetic Power

Tidal in-stream energy conversion devices exploit the ebb and flow of coastal waters. When tidal waters pass through narrow constrictions, such as headlands, channels, straits or other geographic features, currents are concentrated and accelerated, making energy harvest and conversion to electrical power possible.

8.1.5 In-Stream Hydrokinetic Power

In-stream hydrokinetics utilizes the power of a stream's discharge for generation directly, with power generation depending on the depth and velocity of the stream. In these types of systems, power generation occurs in open channels without the benefit of dams or conduits to direct flow through the turbines.

8.1.6 Hydroelectric Power

Hydropower (hydro) is generated when flowing water is diverted through a conduit to produce electricity. The different types of hydroelectric facilities are all powered by the kinetic energy of flowing water as it moves downstream. Turbines and generators convert the energy into electricity.

Small hydro generation refers to renewable energy that converts the energy of flowing water routed through a conduit with a drop in elevation from the upstream to downstream ends of the conduit. This technology is similar to that used for conventional hydro but at a smaller scale. Small hydro is typically defined as producing <30 $MW_{average}$ (Hall 2006; Kosnik 2010); generation potential <1 $MW_{average}$ is classified as low-power hydro (Hall 2006) and generation potential <0.2 $MW_{average}$ is classified as microhydro (Kennas and Barnett 2000). For simplicity, in this document small hydro is considered to incorporate small, low-power, and microhydro.

8.2 Applicable Technologies

The technologies used to harness ocean and tidal energy include thermal energy systems and electrical power generation systems. Each of these technologies, along with traditional hydroelectric power, is described in detail below.

8.2.1 Ocean Thermal Energy Conversion

OTEC produces electricity through a thermodynamic cycle that utilizes a working fluid (such as ammonia) and heat exchangers operated between warm (shallow) and cold (deep) ocean waters. OTEC systems may be either closed-cycle (where a working fluid is utilized and reused in a closed cycle) or open-cycle systems (where water is used as the working fluid and cycled back to the ocean).

In order to achieve a 20°C (68°F) gradient and the flows necessary to drive the cycle, a typical OTEC facility requires a very long, large-diameter cold-water intake pipe to reach water cooled to approximately 5°C (41°F), typically at depths of 1,000 m, as illustrated in Figure 28. A similar diameter warm-water intake pipe is needed to draw warmer surface water at approximately 25°C (77°F).

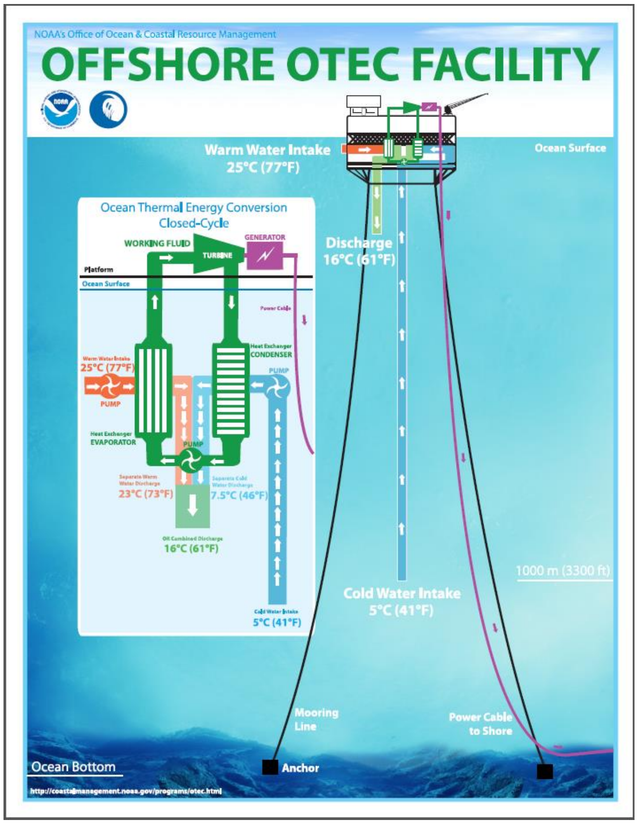


Figure 28: Diagram of Offshore OTEC Facility (NOAA 2011)

8.2.2 Seawater Cooling

SWAC systems pipe cold sea, lake, or river water through heat exchangers coupled to a cold-water loop. The chilled water in the cold-water loop is then moved through buildings in a similar manner and temperature as with a conventional air conditioning system. The seawater is discharged from the heat exchangers at a higher temperature into the water body from which it was drawn. Systems are designed to the specifics of the geographic location.

8.2.3 Wave Power

Wave power is an emerging industry in both the United States and abroad; similar to the wind industry three decades ago, there are many different WEC device designs with no clear technology "winners" at this point. Interest in wave power has increased over the last decade as utilities have sought new forms of predictable, reliable electrical generation close to coastal load centers. In the last five years, R&D in wave energy has increased in both the United States and abroad, and devices have progressed from conceptual stages through deployment at the pilot scale.

The U.S. DOE maintains a database of marine and hydrokinetic technologies that is searchable by technology type, location, and technology readiness level.[12] The database lists 137 different technologies or site development efforts for wave devices worldwide. Of these, only nine are considered to be at a development phase suitable for open water testing and deployment.

The U.S. DOE maintains a glossary describing the main classes of tidal and wave energy devices (DOE 2011b). Descriptions below are adapted from that glossary and the European Marine Energy Centre's description of device types (EMEC 2012):

- Point Absorber: A floating structure that absorbs energy in all directions through its movements at or near the water surface.
- Submerged Pressure Differential: Functions similarly to a point absorber, but fully submerged; a pressure differential is induced within the device as waves pass overhead, driving a fluid through a pump to create mechanical energy.

Point absorber and submerged pressure differential technologies are shown in Figure 29.

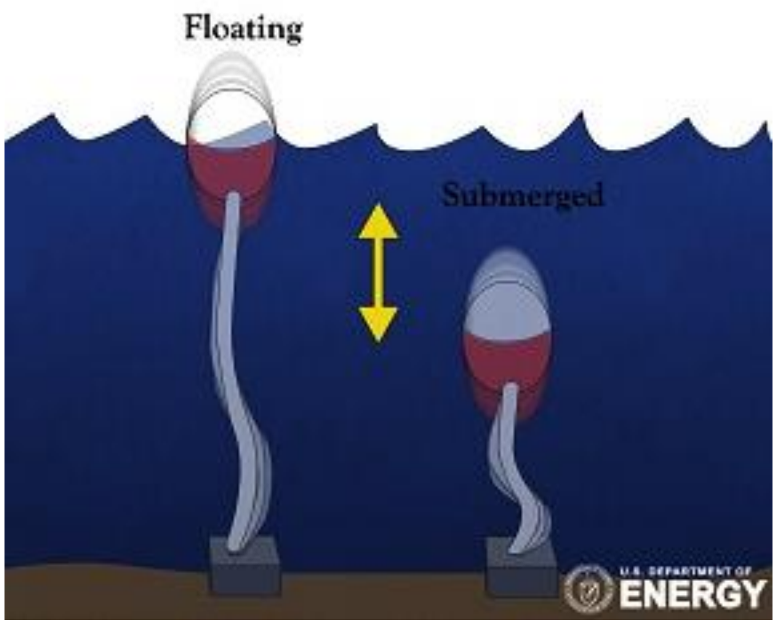


Figure 29: Point Absorber Technologies (DOE 2011b)

- Oscillating Water Column: A partially submerged structure encloses a column of air, which rises and falls with the passing of waves. Pressurized air is driven through an air turbine. Oscillating water columns may be shore-based or floating. The concept is illustrated in Figure 30.

[12] The U.S. DOE technology database may not include all technologies that are under development. This is a rapidly evolving technology space. Figures cited here are intended to provide a sense of the diversity of technologies worldwide.

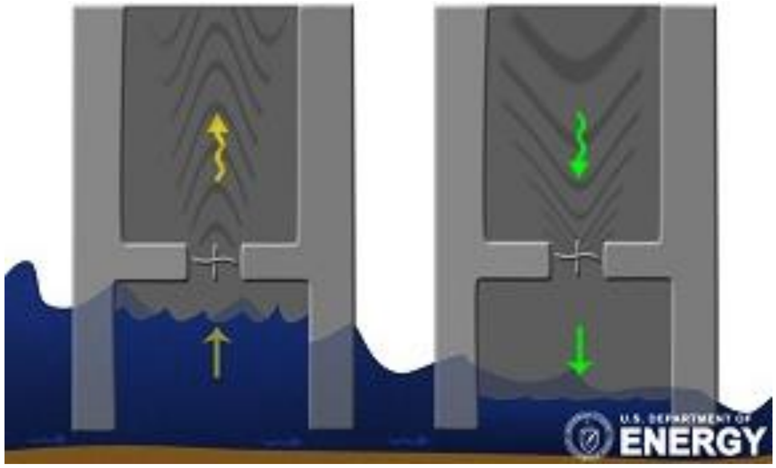


Figure 30: Oscillating Water Column Technologies (DOE 2011b)

- Overtopping Device: Waves are funneled through a collector into a reservoir, and as the water runs back to sea, it passes from the reservoir through a turbine, as shown in Figure 31. Overtopping devices may be shore-based or floating.

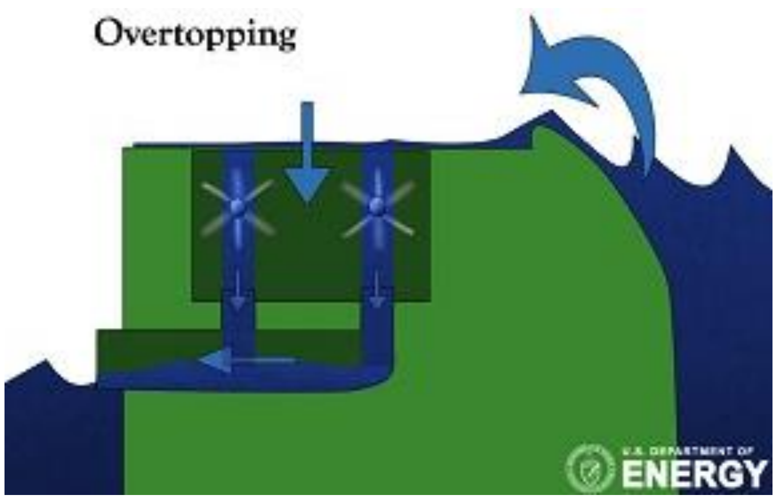


Figure 31: Overtopping Technologies (DOE 2011b)

- Attenuator: The device is aligned parallel to the direction of the incoming wave. Relative motion of the segments of the device drives a fluid through hydraulic rams, producing electricity in a generator. Attenuator technology is shown in Figure 32.

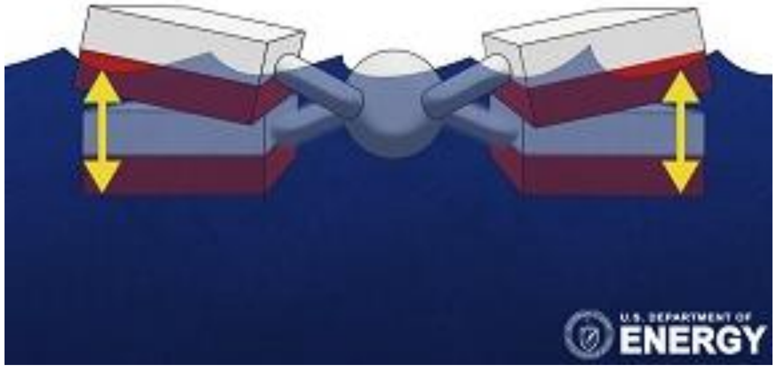


Figure 32: Attenuator Technologies (DOE 2011b)

- Oscillating Wave Surge Converter: A flap or float oscillates along a fixed axis in response to wave surge. Energy is extracted from the relative motion of the flap or float to a fixed reaction point. One type of oscillating wave surge converter is illustrated in Figure 33.

Figure 33: Oscillating Wave Surge Converter (DOE 2011b)

8.2.4 Tidal Hydrokinetic Power

Tidal power is at a developmental phase similar to that of wave energy in the United States and worldwide, with many different device designs and no clear technology "winners" at this point. Interest in tidal power has increased over the last decade as utilities have sought new forms of predictable, reliable electrical generation close to coastal load centers. In the last five years, R&D in tidal energy has increased in both the United States and abroad, and devices have progressed from conceptual stages through deployment at the pilot scale. No commercial-scale tidal power development yet exists, though smaller-scale commercial projects were approved by FERC in 2012 (EIA 2012b).

The U.S. DOE database of marine and hydrokinetic technologies lists 95 different technologies or site development efforts for current tidal devices worldwide. Of these, only seven are considered to be at a development phase suitable for open water testing and deployment (OpenEI 2013).

Descriptions, below, of the main classes of tidal energy devices are adapted from the U.S. DOE glossary (DOE 2011b) and the European Marine Energy Centre's description of device types (EMEC 2012):

- Horizontal axis turbines (or axial flow turbines): These turbines function similarly to an underwater wind turbine, with blades mounted on a horizontal shaft oriented to the direction of the tidal flow, as shown in Figure 34. Movement of water past the blades creates lift, causing the rotor to turn, driving a generator to produce electricity.

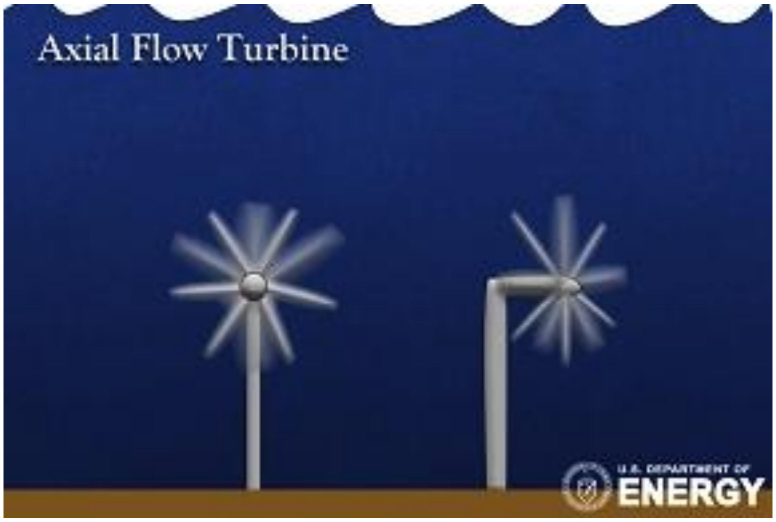


Figure 34: Axial Flow Turbine (DOE 2011b)

- Cross-flow or cross-axis turbines: These turbines extract power in a similar manner to horizontal-axis turbines, but the turbine blades rotate on an axis, which may be oriented vertically or horizontally in the water column (see Figure 35). These are similar to the "egg beater" style wind turbines tested in the 1980s.

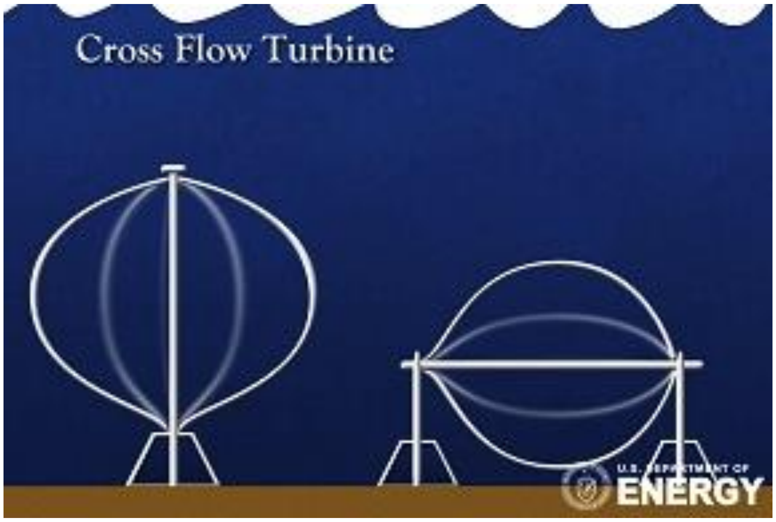


Figure 35: Cross Flow Turbine (DOE 2011b)

- Oscillating hydrofoil (or reciprocating devices): Oscillating hydrofoils employ a wing-like structure mounted to an oscillating arm, as shown in Figure 36; when the tidal flow moves past the wing it creates lift. As the arm moves up and down it drives hydraulic fluid through a power conversion system, creating electricity.

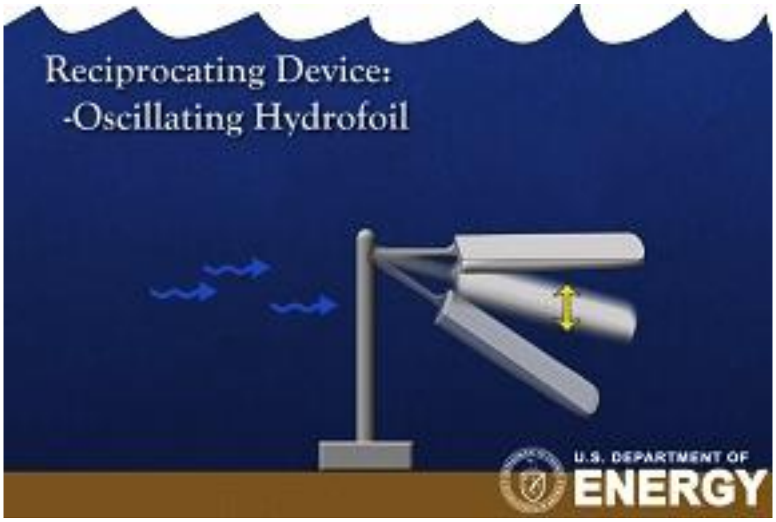


Figure 36: Reciprocating Device (DOE 2011b)

- Venturi, shrouded, or enclosed tip turbines: These devices utilize a shroud or duct to concentrate the flow of tidal waters past the turbine. Shrouds may also serve to mitigate potential environmental effects of blade strike. There are many different designs that utilize a shroud or venturi. Figure 37 below illustrates an OpenHydro turbine during construction. Note the shroud around the blades and the open center, which serve to reduce potential environmental effects of the device as well as concentrate tidal flow over the blades.

Figure 37: OpenHydro Turbine during Construction (OpenHydro 2012)

8.2.5 In-Stream Hydrokinetic Power

The development of in-stream hydrokinetic power has followed tidal power, with similar companies and technologies involved. Free Flow Power has made the largest investment to date, and is in the process of negotiating FERC licenses for 25 projects on the Mississippi River. Because in-stream hydrokinetic technologies do not use dams or impoundments, deployment and licensing may be faster than for conventional technologies. In the United States, an in-stream hydrokinetic system has been installed on the Yukon River in Alaska, while in Canada, systems have been installed at several locations with approvals being sought at several more locations (NEC 2011). FERC (2012) is currently considering 65 permit applications for inland in-stream hydrokinetic power generation in the United States.

In-stream hydrokinetics directly utilizes the power of the stream for generation. The turbine has blades fixed to a rotor and the turbine is mounted on a platform with the rotor shaft aligned perpendicular to the stream flow. The power generation unit is fixed in place in the stream, with the velocity of the stream supplying the power to rotate the blades of the turbine.

Five- or 10-kW systems from New Energy Corporation, shown in Figure 38 below, are used as typical generation units for in-stream hydrokinetic feasibility analyses.

Figure 38: Examples of In-Stream Hydrokinetics (NRN 2009)

8.2.6 Hydroelectric Power

The technology for hydro is relatively mature, though improvements in small and micro-sized turbines are ongoing. There are two general types of turbines: impulse and reaction. Impulse turbines are suspended in air within the turbine housing and utilize the force of a jet of water. Reaction turbines are immersed in water and utilize the lift generated by the pressure difference between the water upstream and downstream of the turbine blades.

To drive the turbines, an intake and penstock are installed to provide water from an upstream reservoir (or holding basin) located at a higher elevation. The elevation difference between the water surface of the reservoir and the turbine provides the head. The size of the penstock determines the discharge allowed to flow through the turbine. The turbine and power generator are housed in a powerhouse downstream of the dam. The tailrace conveys the discharge from the turbine and powerhouse to the water body downstream via a pathway that is armored to prevent erosion. The powerhouse should be located to prevent or reduce flooding potential. In the case of a reaction turbine, the water level in the tailrace would need to be high enough to keep the turbine blades immersed, possibly by including a weir over which tailwater discharges to the water body downstream. A transmission line to the electrical system conveys power from the generator. Figure 39 illustrates the major components of a small hydro electrical generation system.

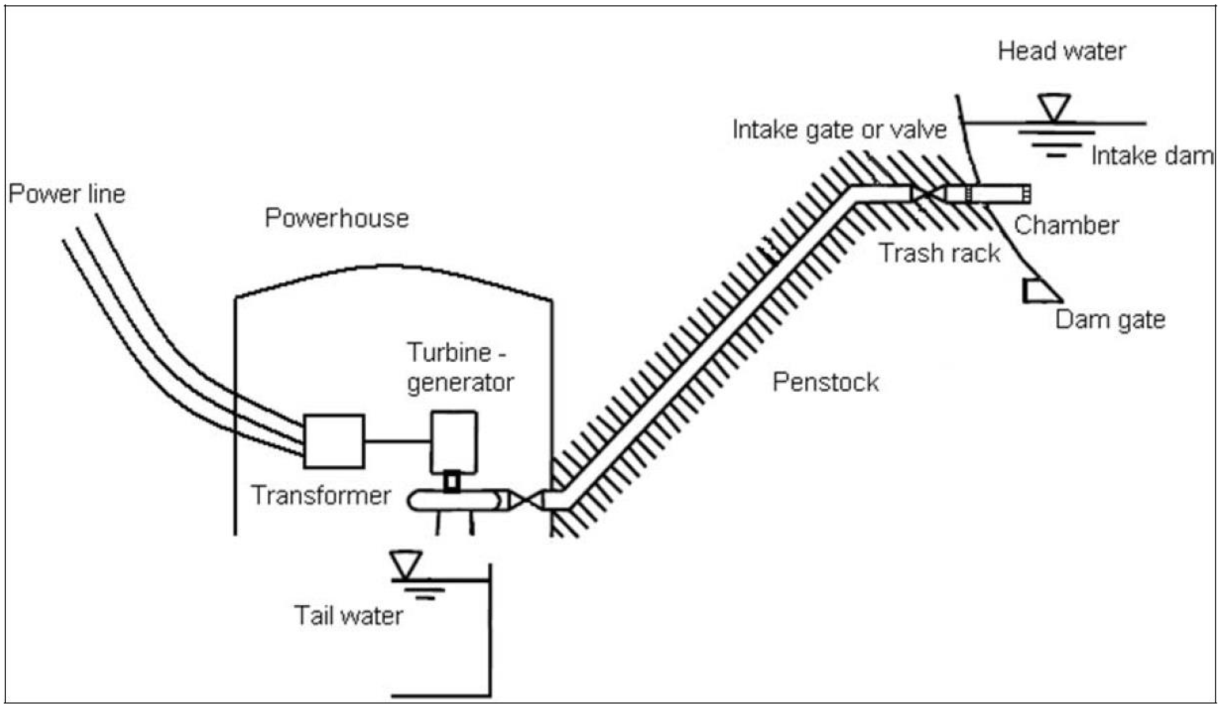


Figure 39: Schematic Diagram of a Small Hydropower Electrical Generation System (Verdaguer et al. 2010)

In the case of retrofitting an unpowered dam, the penstock would need to be excavated and placed so that the intake is located below the minimum pool elevation of the reservoir. Drawdown of the reservoir or construction of a cofferdam would be required for installing a penstock through the dam. Another possible route for the penstock would be to install it as a siphon, so that the conduit lies on the face of the dam. In this case, thrust blocks/anchors would need to be installed to hold the conduit in position.

In the case where the water supply is a stream or river (without an existing dam and reservoir), the intake is installed behind a weir or small dam, with a trash rack to prevent large debris from entering the penstock. The penstock is typically installed in an excavated trench adjacent to the stream to a point downstream where the powerhouse is located. Other features are similar to those already discussed for hydropower systems.

8.3 Location Requirements

Power potential for marine energy is greatest on the western coasts of continents because of the circulation of major ocean currents. In Europe, energy potential peaks at Ireland and Scotland, and in North America, energy potential peaks at Oregon, British Columbia, and Alaska. In the southern hemisphere, the highest energy potential is along the coasts of southern Chile, South Africa, and the southwest coasts of Australia and New Zealand (Mork et al. 2010). Wave resource stability is an important factor when considering energy potential. Seasonality affects stability and is a more important factor in the Northern Hemisphere (Mork et al. 2010). Specific requirements by technology type are described below.

8.3.1 Ocean Thermal Energy Conversion

OTEC is only feasible where the ocean temperature difference between warm surface water and cold deep water is at least 36°F (20°C). This temperature gradient exists typically between the Tropic of Capricorn and the Tropic of Cancer, and between 0 and 1,000 m (0 and 3,280 ft) of water depth.

8.3.2 Seawater Cooling

The primary location requirement for a SWAC system is in close proximity to a source of cold water. Oceans, rivers, and lakes have all been utilized for SWAC systems. As described above, economic feasibility of a SWAC system is tied both to distance from the source of cold water and to demand for cooling. An ideal application would be for a densely populated area or facility in a warm climate adjacent to a source of cool water (typically 5°C [41°F] or cooler), either deep ocean or deep lake water that stays cool in summer months.

Factors that determine the feasibility of a SWAC system include:

- distance of facilities from a source of cold water (typically 5°C [41°F]). Piping cost is a driver of economic feasibility. The depth necessary to reach cold water and the distance the water must be moved overland are both factors.
- size of the cooling load. SWAC systems benefit from large economies of scale; if cooling loads are not high, SWAC systems are difficult to justify economically.
- percent utilization of the air conditioning system. SWAC systems are more economically feasible in warmer geographic locations where AC is operated throughout the year.
- local cost of electricity. The higher the local cost of electricity, the more savings can be obtained from a SWAC system.
- complexity of the distribution system onshore. SWAC systems work best in a district arrangement, where multiple buildings can utilize the resource, and the district is compact.
- availability of marine construction infrastructure (Makai Ocean Engineering 2011.

8.3.3 Wave Power

In general, WEC devices require exposure to a wave climate that is suitable for the type of device being deployed. As described in the “Applicable Technologies” section, there is a great diversity of WEC devices that can be used in many types of locations and at many depths.

8.3.4 Tidal Hydrokinetic Power

Criteria for tidal power viability include tidal velocities greater than approximately 1 m/s, suitable depth to allow turbines to be deployed without interfering with navigation, suitable bathymetry (i.e., channels that are not too steep, rocky, sandy, etc.), proximity to transmission and power markets, and proximity to deep-water ports for operations and maintenance.

8.3.5 In-Stream Hydrokinetic Power

The placement of turbines in stream has a minimum depth requirement equivalent to the unit's shaft length because the shaft is placed vertically in the water column. The stream velocity determines the power generation, with greater velocities producing more power. A power output of approximately 1 kW is obtained with a velocity of 5 ft/s (1.5 m/s). A velocity of 9.8 ft/s (3 m/s) is required to achieve 5 kW (with a 1 m rotor length) or 10 kW (for a 2 m rotor length).

8.3.6 Hydroelectric Power

Hydro generation potential varies with the available head and stream/river discharge. The available head depends on the topography of the site, while discharge varies seasonally with precipitation and resulting runoff from the watershed. Preferred locations have larger watersheds, which produce more runoff than small watersheds; larger watersheds also produce higher base flows during low precipitation periods than small watersheds. A large head is also preferred, because a larger change in water surface elevation from upstream of the dam to downstream of the dam (head) creates more potential energy to be utilized for hydro generation. Conventional hydro calls for the construction of a dam with significant water storage in the reservoir upstream of the dam to provide an adequate, regular flow for electrical power generation.

9.0 Sources of Information

Section 1.0 Introduction

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Section 2.0 Biomass

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