Introduction to Small Hydropower Systems

PDH Credits:

1 PDH

Course No.:

SHS101

Publication Source:

US Dept. of Energy (EERE)

Pub. #DOE/GO-102001-1173

Release Date:
July 2001

DOE / GO-102001-1173
FS217
July 2001

ENERGY EFFICIENCY AND RENEWABLE ENERGY CLEARINGHOUSE

Small Hydropower Systems

If you're considering building a small hydropower system on water flowing through your property, you have a long tradition from which to draw your inspiration. Two thousand years ago, the Greeks learned to harness the power of running water to turn the massive wheels that rotated the shafts of their wheat flour grinders. And in the hydropower heyday of the 18th century, thousands of towns and cities worldwide were located around small hydropower sites.

Today, small hydropower projects offer emissions-free power solutions for many remote communities throughout the world—such as those in Nepal, India, China, and Peru—as well as for highly industrialized countries, like the United States.

This fact sheet will help you determine whether a small hydropower system will work for your power needs and whether your location is right for hydropower technology. It will also explain the basic system components, the need for permits and water rights, and how you might be able to sell the excess electricity you generate.

Uses of Hydropower

In the United States today, hydropower projects provide 81 percent of the nation's renewable electricity generation and about 10 percent of the nation's total electricity. That's enough to power 37.8 million homes, according to the National Hydropower Association.

Duane Hippe, NREL/PIX 04410

This small-scale hydropower system is helping an Alaskan community save money on their electricity.

This document was produced for the U.S. Department of Energy (DOE) by the National Renewable Energy Laboratory (NREL), a DOE national laboratory. The document was produced by the Information and Outreach Program at NREL for the DOE Office of Energy Efficiency and Renewable Energy. The Energy Efficiency and Renewable Energy Clearinghouse (EREC) is operated by NCI Information Systems, Inc., for NREL / DOE. The statements contained herein are based on information known to EREC and NREL at the time of printing. No recommendation or endorsement of any product or service is implied if mentioned by EREC.

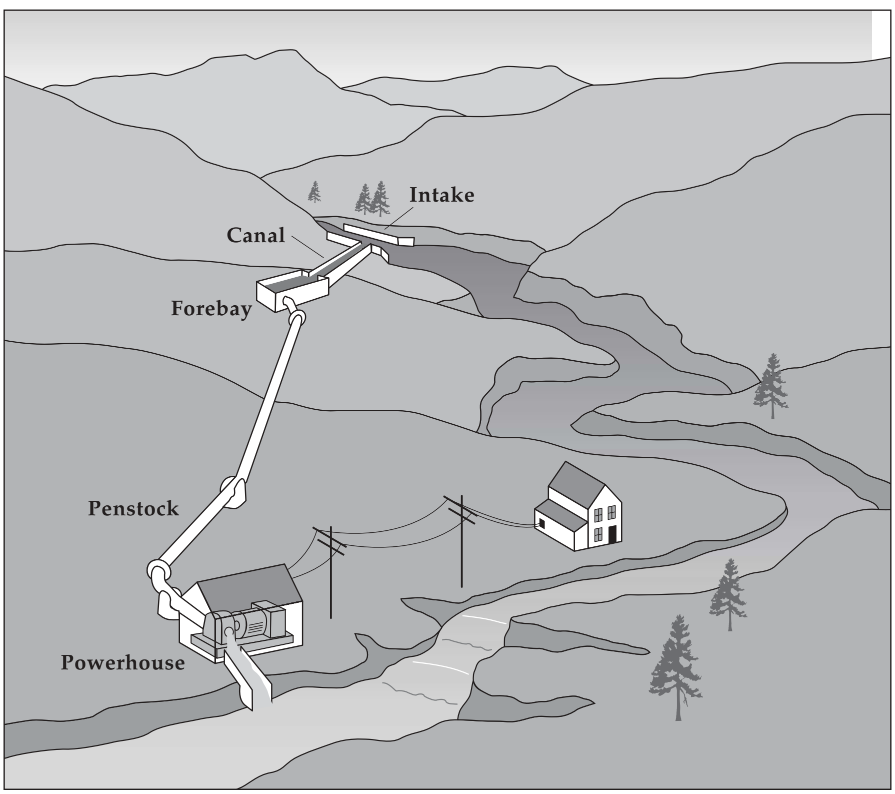
Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 20% postconsumer waste

The vast majority of the hydropower produced in the United States comes from large-scale projects that generate more than 30 megawatts (MW)—enough electricity to power nearly 30,000 households. *Small-scale hydropower systems* are those that generate between .01 to 30 MW of electricity. Hydropower systems that generate up to 100 kilowatts (kW) of electricity are often called *microhydro systems.* Most of the systems used by home and small business owners would qualify as microhydro systems. In fact, a 10 kW system generally can provide enough power for a large home, a small resort, or a hobby farm.

A 10 kW system can provide enough power for a large home, a small resort, or a hobby farm.

How Hydropower Works

Hydropower systems use the energy in flowing water to produce electricity or mechanical energy. Although there are several ways to harness the moving water to produce energy, *run-of-the-river systems,* which do not require large storage reservoirs, are often used for microhydro, and sometimes for small-scale hydro, projects. For run-of-the-river hydro projects, a portion of a river's water is diverted to a channel, pipeline, or pressurized pipeline (*penstock)* that delivers it to a waterwheel or turbine. The moving water rotates the wheel or turbine, which spins a shaft. The motion of the shaft can be used for mechanical processes, such as pumping water, or it can be used to power an alternator or generator to generate electricity. This fact sheet will focus on how to develop a run-of-the-river project.



In this microhydropower system, water is diverted into the penstock. Some generators can be placed directly into the stream.

Is Hydropower Right for You?

Of course to build a small hydropower system, you need access to flowing water. A sufficient quantity of falling water must be available, which usually, but not always, means that hilly or mountainous sites are best.

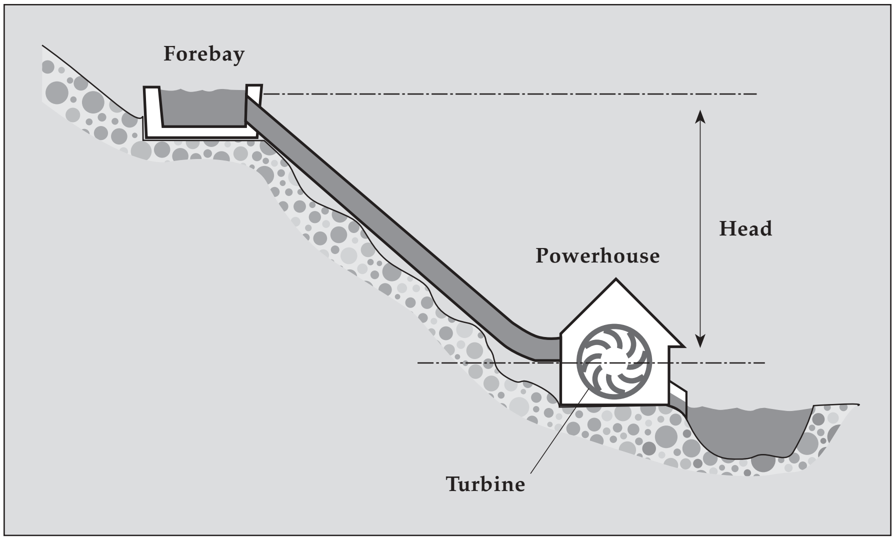
Next you'll want to determine the amount of power that you can obtain from the flowing water on your site. The power available at any instant is the product of what is called *flow* volume and what is called *head.*

Determining head

Head is the vertical distance that water falls. It's usually measured in feet, meters, or units of pressure. Head also is a function of the characteristics of the channel or pipe through which it flows.

Most small hydropower sites are categorized as low or high head. The higher the head the better because you'll need less water to produce a given amount of power, and you can use smaller, less expensive equipment. Low head refers to a change in elevation of less than 10 feet (3 meters). A vertical drop of less than 2 feet (0.6 meters) will probably make a small-scale hydroelectric system unfeasible. However, for extremely small power generation amounts, a flowing stream with as little as 13 inches of water can support a submersible turbine, like the type used originally to power scientific instruments towed behind oil exploration ships.

When determining head, you need to consider both *gross head* and *net head.* Gross head is the vertical distance between the top of the penstock that conveys the water under pressure and the point where the water discharges from the turbine. Net head equals gross head minus losses due to friction and turbulence in the piping.



Head is the vertical distance the water falls. Higher heads require less water to produce a given amount of power.

The quantity of water falling is called flow.

To get a rough estimate of the vertical distance, you can use U.S. Geological Survey maps of your area or the *hose-tube* method. The hose-tube method involves taking stream-depth measurements across the width of the stream you intend to use for your system—from the point at which you want to place the penstock to the point at which you want to place the turbine. You will need an assistant; a 20 to 30 foot (6 to 9 meters) length of small-diameter garden hose or other flexible tubing; a funnel; and a yardstick or measuring tape.

Stretch the hose or tubing down the stream channel from the point that is the most practical elevation for the penstock intake. Have your assistant hold the upstream end of the hose, with the funnel in it, underwater as near the surface as possible. Meanwhile, lift the downstream end until water stops flowing from it. Measure the vertical distance between your end of the tube and the surface of the water. This is the gross head for that section of stream. Have your assistant move to where you are and place the funnel at the same point where you took your measurement. Then walk downstream and repeat the procedure. Continue taking measurements until you reach the point where you plan to site the turbine.

The sum of these measurements will give you a rough approximation of the gross head for your site. Note: due to the water's force into the upstream end of the hose, water may continue to move through the hose after both ends of the hose are actually level. You may wish to subtract an inch or two (2 to 5 centimeters) from each measurement to account for this. It is best to be conservative in these preliminary head measurements.

If your preliminary estimates look favorable, you will want to acquire more accurate measurements. The most accurate way to determine head is to have a professional survey your site. But if you know you have an elevation drop on your site of several hundred feet, you can use an aircraft altimeter. You may be able to buy, borrow, or rent an altimeter from a small airport or flying club. A word of caution, however: while using an altimeter might be less expensive than hiring a professional surveyor, your measurement will be less accurate. In addition, you will have to account for the effects of barometric pressure and calibrate the altimeter as necessary.

Determining flow

The quantity of water falling is called flow. It's measured in gallons per minute, cubic feet per second, or liters per second. The easiest way to determine your stream's flow is to obtain data from local offices of the U.S. Geological Survey, the U.S. Army Corps of Engineers, the U.S. Department of Agriculture, your county's engineer, or local water supply or flood control authorities. If you can't obtain existing data, you'll need to conduct your own flow measurements.

You can measure flow using the *bucket* method, which involves damming your stream with logs or boards to divert its flow into a bucket or container. The rate at which the container fills is the flow rate. For example, a 5-gallon bucket that fills in 1 minute means that your stream's water is flowing at 5 gallons per minute.

Another way to measure flow involves measuring stream depths across the width of the stream and releasing a weighted-float upstream from your measurements. You will need an assistant; a tape measure; a yardstick or measuring rod; a weighted-

Whatever the upfront costs, a hydroelectric system will typically last a long time and is relatively maintenance free.

float, such as a plastic bottle filled halfway with water; a stopwatch; and some graph paper. With this equipment you can calculate flow for a cross section of the streambed at its lowest water level.

First, select a stretch of stream with the straightest channel and the most uniform depth and width possible. At the narrowest point, measure the width of the stream. Then, holding the yardstick vertically, walk across the stream and measure the water depth at one-foot increments. To help with the process, stretch a string or rope upon which the increments are marked across the stream width. Plot the depths on graph paper to give yourself a cross-sectional profile of the stream. Then determine the area of each section by calculating the areas of the rectangles (area = length x width) and right triangles (area = ½ base x height) in each section.

Next, from the same point where you measured the stream's width, mark a point at least 20 feet upstream. Release the weighted-float in the middle of the stream and record the time it takes for the float to travel to your original point downstream. Don't let the float drag along the bottom of the streambed. If it does, use a smaller float.

Divide the distance between the two points by the float time in seconds to get flow velocity in feet per second. The more times you repeat this procedure, the more accurate your flow velocity measurement will be.

Finally, multiply the average velocity by the cross-sectional area of the stream. Then multiply your result by a factor that accounts for the roughness of the stream channel (0.8 for a sandy streambed, 0.7 for a bed with small to medium sized stones, and 0.6 for a bed with many large stones). The result will give you the flow rate in cubic feet or meters per second.

Stream flows can be quite variable over a year, so the season during which you take flow measurements is important. Unless you're considering building a storage reservoir, you can use the lowest average flow of the year as the basis for your system's design. However, if you're legally restricted on the amount of water you can divert from your stream at certain times of the year, use the average flow during the period of the highest expected electricity demand.

Estimating power output

There is a simple equation you can use to estimate the power output for a system with 53 percent efficiency, which is representative of most small hydropower systems. Simply multiply net head (the vertical distance available after subtracting losses from pipe friction) by flow (use U.S. gallons per minute) divided by 10. That will give you the system's output in watts (W). The equation looks this: net head [(feet) x flow (gpm)] / 10 = W.

Economics of a small system

If you determine that your site is feasible for a small hydropower system, the next obvious step is to determine whether it makes sense economically to undertake building a system.

Add up all the estimated costs of developing and maintaining the site over the expected life of your equipment, and divide the amount by the system's capacity in watts. This will tell you how much the system will cost in dollars per watt. Then you can compare that to the cost of utility-provided power or other alternative power sources. Whatever the upfront costs, a hydroelectric system will typically last a long time and, in many cases, maintenance is not expensive.

In addition, there are a variety of financial incentives available on the state, utility, and federal level for investments in renewable energy systems. They include income tax credits, property tax exemptions, state sales tax exemption, loan programs, and special grant programs, among others. Contact your state energy office to see if your project may qualify for any incentives (see NASEO and DSIRE in "Resources").

Environmental Issues

Large-scale dam hydropower projects are often criticized for their impacts on wildlife habitat, fish migration, and water flow and quality. However, small, run-of-the-river projects are free from many of the environmental problems associated with their large-scale relatives because they use the natural flow of the river, and thus produce relatively little change in the stream channel and flow. The dams built for some run-of-the-river projects are very small and impound little water—and many projects do not require a dam at all. Thus, effects such as oxygen depletion, increased temperature, decreased flow, and rejection of upstream migration aids like fish ladders are not problems for many run-of-the-river projects.

System Components

Small run-of-the-river hydropower systems consist of these basic components:

- Water conveyance—channel, pipeline, or pressurized pipeline (penstock) that delivers the water
- Turbine or waterwheel—transforms the energy of flowing water into rotational energy
- Alternator or generator—transforms the rotational energy into electricity
- Regulator—controls the generator
- Wiring—delivers the electricity.

Many systems also use an *inverter* to convert the low-voltage direct current (DC) electricity produced by the system into 120 or 240 volts of alternating current (AC) electricity (alternatively you can buy household appliances that run on DC electricity). Some systems also use batteries to store the electricity generated by the system, although because hydro resources tend to be more seasonal in nature than wind or solar resources, batteries may not always be practical for hydropower systems. If you do use batteries, they should be located as close to the turbine as possible, because it is difficult to transmit low-voltage power over long distances.

Dams or diversion structures are rarely used in microhydro projects.

Channels, storage, and filters

Before water enters the turbine or waterwheel, it is first funneled through a series of components that control its flow and filter out debris. These components are the headrace, forebay, and water conveyance (channel, pipeline, or penstock).

The *headrace* is a waterway running parallel to the water source. A headrace is sometimes necessary for hydropower systems when insufficient head is provided. They often are constructed of cement or masonry. The headrace leads to the *forebay,* which also is made of concrete or masonry. It functions as a settling pond for large debris which would otherwise flow into the system and damage the turbine. Water from the forebay is fed through the *trashrack,* a grill that removes additional debris. The filtered water then enters through the controlled gates of the spillway into the water conveyance, which funnels water directly to the turbine or waterwheel. These channels, pipelines, or penstocks can be constructed from plastic pipe, cement, steel and even wood. They often are held in place above-ground by support piers and anchors.

Dams or diversion structures are rarely used in microhydro projects. They are an added expense and require professional assistance from a civil engineer. In addition, dams increase the potential for environmental and maintenance problems.

Turbines and waterwheels

The waterwheel is the oldest hydropower system component. Waterwheels are still available, but they aren't very practical for generating electricity because of their slow speed and bulky structure.

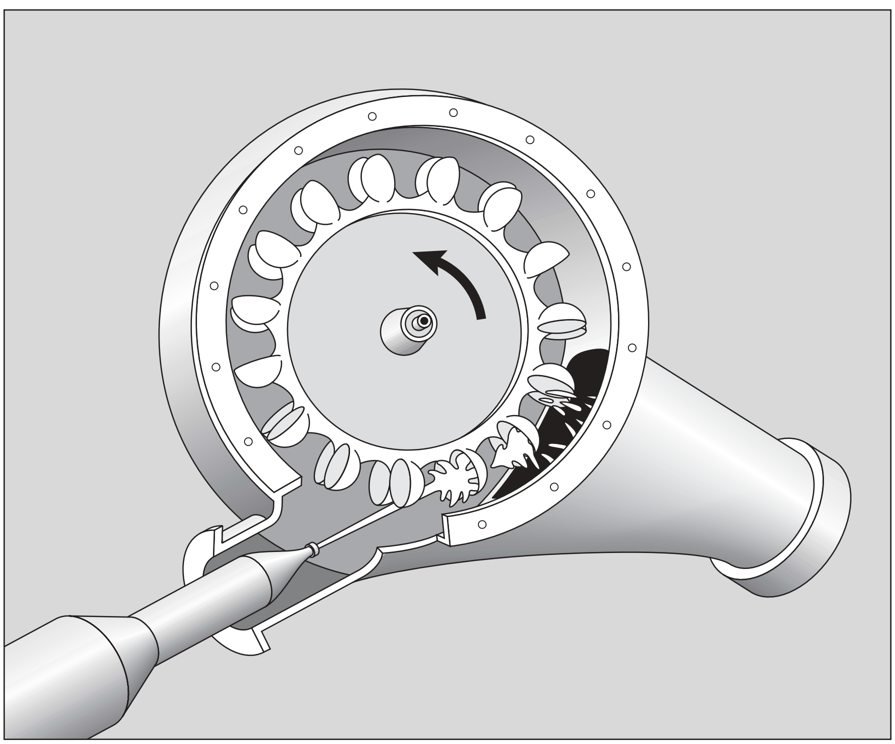
Turbines are more commonly used today to power small hydropower systems. The moving water strikes the turbine blades, much like a waterwheel, to spin a shaft. But turbines are more compact in relation to their energy output than waterwheels. They also have fewer gears and require less material for construction. There are two general classes of turbines: impulse and reaction.

Impulse

Impulse turbines, which have the least complex design, are most commonly used for high head microhydro systems. They rely on the velocity of water to move the turbine wheel, which is called the *runner.* The most common types of impulse turbines include the *Pelton* wheel and the *Turgo* wheel.

The Pelton wheel uses the concept of jet force to create energy. Water is funneled into a pressurized pipeline with a narrow nozzle at one end. The water sprays out of the nozzle in a jet, striking the double-cupped buckets attached to the wheel. The impact of the jet spray on the curved buckets creates a force that rotates the wheel at high efficiency rates of 70 to 90 percent. Pelton wheel turbines are available in various sizes and operate best under low-flow and high-head conditions.

The Turgo impulse wheel is an upgraded version of the Pelton. It uses the same jet spray concept, but the Turgo jet, which is half the size of the Pelton, is angled so that the spray hits three buckets at once. As a result, the Turgo wheel moves twice as fast. It's also less bulky, needs few or no gears, and has a good reputation for trouble-free operations. The Turgo can operate under low-flow conditions but requires a medium or high head.



Pelton wheels, like this one, can be purchased with one or more nozzles. Multi-nozzle systems allow a greater amount of water to impact the runner, which can increase wheel output.

Jack Rabbit Marine, NREL/PIX 09976

The submersible Jack Rabbit turbine was originally designed to power scientific instruments during marine oil exploration expeditions.

Another turbine option is called the *Jack Rabbit* (sometimes referred to as the Aquair UW Submersible Hydro Generator). The Jack Rabbit is the drop-in-the-creek turbine, mentioned earlier, that can generate power from a stream with as little as 13 inches of water and no head. Output from the Jack Rabbit is a maximum of 100 W, so daily output averages 1.5 to 2.4 kilowatt-hours, depending on your site.

Reaction

Reaction turbines, which are highly efficient, depend on pressure rather than velocity to produce energy. All blades of the reaction turbine maintain constant contact with the water. These turbines are often used in large-scale hydropower sites. Because of their complexity and high cost, they aren't usually used for microhydro projects. An exception is the propeller turbine, which comes in many different designs and works much like a boat's propeller. Propeller turbines have three to six usually fixed blades set at different angles aligned on the runner. The bulb, tubular, and Kaplan tubular are variations of the propeller turbine. The Kaplan turbine, which is a highly adaptable propeller system, can be used for microhydro sites.

Pumps as substitutes for turbines

Conventional pumps can be used as substitutes for hydraulic turbines. When the action of a pump is reversed, it operates like a turbine. Since pumps are mass produced, you'll find them more readily available and less expensive than turbines.

You can usually sell any excess power you produce to your local utility.

Grid-connected systems render additional electricity storage capacity, such as a battery bank, unnecessary.

However, for adequate pump performance, your microhydro site must have fairly constant head and flow. Pumps are also less efficient and more prone to damage.

Obtaining a Permit and Water Rights

If your hydropower system will have minimal impact on the environment, and you aren't planning to sell power to a utility, there's a good chance that the process you must go through to obtain a permit won't be too complex. Locally, your first point of contact should be the county engineer. Your state energy office may be able to provide you with advice and assistance as well (see NASEO in "Resources"). In addition, you'll need to contact the Federal Energy Regulatory Commission and the U.S. Army Corps of Engineers (see "Resources").

You'll also need to determine how much water you can divert from your stream channel. Each state controls water rights and you may need a separate water right to produce power, even if you already have a water right for another use.

Selling the Power You Produce

The great thing about producing your own power is that you can usually sell any excess power to your local utility. If you decide to sell, you'll need to contact the utility to find out application procedures, metering and rates, and the equipment the utility requires to connect your system to the electricity grid (it is generally best to do this before you purchase your hydro system). If your utility does not have an individual assigned to deal with grid-connection requests, try contacting your public utilities commission, state utility consumer advocate group, state consumer representation office, or state energy office. In general, utilities require a grid-interactive inverter listed by a safety-testing and certification organization such as Underwriters Laboratories, and the ability to disconnect your system from the utility's grid in the event of a power outage. The latter is necessary to prevent utility personnel working on the outage from accidentally being electrocuted.

Utilities in many states now offer a special incentive to small power providers called *net metering*. Net metering is a billing method that allows you, as a small power provider, to be billed only for the net amount of electricity you consume over a billing cycle. You effectively get the same value for the output of your system as you pay for electricity from the utility, up to the point where excess power is produced. Any excess power from your system is then bought by the utility, generally at the wholesale rate. For detailed information on net metering, contact your state's utility regulatory agency, typically the public utility commission or public service commission.

Aside from the advantages associated with selling power back to your utility, grid-connected systems also render additional electricity storage capacity, such as a battery bank, unnecessary. The grid will supply power when your hydropower system can't meet all your power requirements. However, if you live in an area where you can obtain higher rates for production during peak demand periods or for so-called "green power," it might be economical to include energy storage capacity to dispatch power to your utility on demand.

A Clean Energy Future

By investing in a small hydropower system, you can reduce your exposure to future fuel shortages and price increases, and help reduce air pollution. There are many factors to consider when buying a system, but with the right site and equipment, careful planning, and attention to regulatory and permit requirements, small hydropower systems can provide you a clean, reliable source of power for years to come.

Resources

The following are sources of additional information on small hydropower systems and related topics. The list is not exhaustive, nor does the mention of any resource constitute a recommendation or endorsement.

Energy Efficiency and Renewable Energy Clearinghouse (EREC)
P.O. Box 3048
Merrifield, VA 22116
Phone: 1-800-DOE-EREC (1-800-363-3732)
Fax: (703) 893-0400
E-mail: doe.erec@nciinc.com
Web site: www.eren.doe.gov/consumerinfo/

Energy experts and information specialists at EREC provide free general and technical information to the public on many topics and technologies pertaining to energy efficiency and renewable energy.

Organizations

Federal Energy Regulatory Commission (FERC)
Public Reference Room
888 1st St., N.E.
Washington, DC 20426
Phone: (202) 208-1371
Fax: (202) 208-2320
Web site: www.ferc.gov

Licenses and inspects private, municipal, and state hydro projects.

National Association of State Energy Officials (NASEO)
1414 Prince St., Suite 200
Alexandria, VA 22314
Phone: (703) 299-8800
Fax: (703) 299-6208
E-mail: info@naseo.org
Web site: www.naseo.org

Provides current contact information for state energy offices, including links to their Web sites.

National Hydropower Association (NHA)
One Massachusetts Ave., N.W., Suite 850
Washington, DC 20001
Phone: (202) 682-1700
Fax: (202) 682-9478
E-mail: info@hydro.org
Web site: www.hydro.org

Seeks to secure hydropower's place as an emissions-free, renewable, and reliable energy source.

Solar Energy International (SEI)
P.O. Box 715
Carbondale, CO 81623
Phone: (970) 963-8855
Fax: (970) 963-8866
E-mail: sei@solarenergy.org
Web site: www.solarenergy.org

Offers workshops on how to design fully functional microhydro systems.

U.S. Army Corps of Engineers
441 G. St., N.W.
Washington, DC 20426
Phone: (202) 761-0008
Web site: www.usace.army.mil

Can provide you with contact information for your local district office.

Volunteers in Technical Assistance (VITA)
1600 Wilson Blvd., Suite 710
Arlington, VA 22209
Phone: (703) 276-1800
Fax: (703) 243-1865
E-mail: vita@vita.org
Web site: www.vita.org

Provides publications on hydropower systems, including design guides for low-cost turbines and waterwheels.

Web Sites

Database of State Incentives for Renewable Energy (DSIRE)
Web site: www.dsireusa.org

Features information on state, utility, and local government financial and regulatory incentives, programs, and policies designed to promote renewable energy technologies.

U.S. Department of Energy Hydropower Program
Web site: hydropower.inel.gov

Provides information on current research and development of hydropower technologies, as well as environmental issues.

Energy Efficiency and Renewable Energy Network (EREN)
U.S. Department of Energy
Web site: www.eren.doe.gov

A comprehensive online resource for DOE's energy efficiency and renewable energy information.

Home Power
Web site: www.homepower.com

An online journal providing information on renewable energy power systems for the home.

Microhydro
Web site: www.geocities.com/wim_klunne/hydro/index.html

Features a discussion group and literature on small hydropower.

Books, Pamphlets, and Reports

Micro-Hydro Design Manual: A Guide to Small-Scale Hydropower Schemes, A. Harvey et. al, Intermediate Technology, 1993.

Mini-Hydropower, ed. J. Tong, John Wiley and Son, Ltd., 1997.

Motors as Generators for Micro Hydropower, N. Smith, Intermediate Technology Development Group, London, 1995. Available from Stylus Publishing, Inc., P.O. Box 605, Herndon, VA 20172-0605, (703) 661-1581, or styluspub@aol.com.