



Welcome to Hydro and Hydrokinetic Power, one of a series of online natural gas and electricity training modules from Enerdynamics. In this module you will become familiar with how hydro and hydrokinetic power work, the various attributes by which they are compared to other renewable fuel sources and technologies, and the future potential for hydro and hydrokinetic power.

If you encounter an unfamiliar term in this module, you can look it up in our glossary. Just click the link in the upper right hand corner of your screen. The course will pause and the glossary will pop up.

Objectives

By the end of this course, you will be able to:

- Describe what hydro and hydrokinetic power are
- Describe the methods and technologies used to generate hydro and hydrokinetic power
- Describe how the movement of water is converted to electricity
- Discuss the current role of hydro and hydrokinetic power in the U.S. electric mix
- Define key attributes that determine the benefits, costs, and challenges associated with hydro and hydrokinetic power
- Evaluate the potential role of hydro and hydrokinetic power in a region's overall electric generation resource mix
- And finally, discuss key issues for the future growth of hydro and hydrokinetic power

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Describe the methods and technologies used to generate hydro and hydrokinetic power.

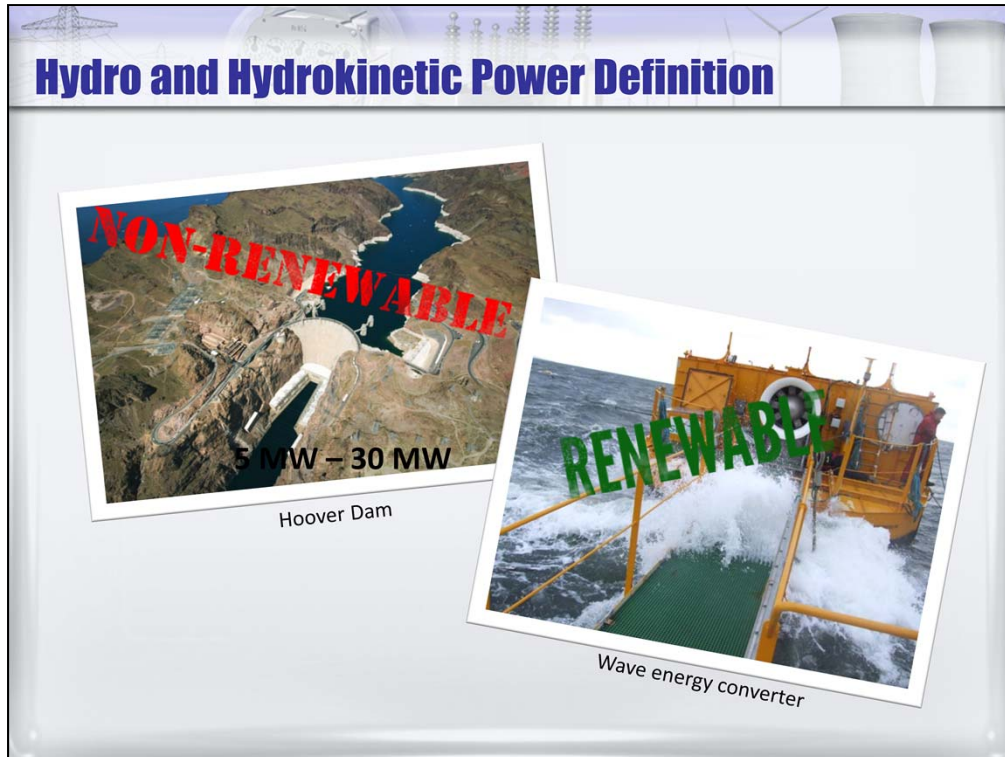
Describe how the movement of water is converted to electricity.

Discuss the current role of hydro and hydrokinetic power in the U.S. electric mix.

Define key attributes that determine the benefits, costs, and challenges associated with hydro and hydrokinetic power.

Evaluate the potential role of hydro and hydrokinetic power in a region's overall electric generation resource mix.

And finally, discuss key issues for the future growth of hydro and hydrokinetic power.



Both hydropower and hydrokinetic power describe electricity derived by converting the kinetic or potential energy of water into electricity. The two differ by the method that is used to capture the energy of water.

Hydropower uses either impoundment of a river behind a dam or diversion of a river flow through a penstock or canal to direct moving water over a turbine. Hydropower depends on the potential energy possessed by a body of water due to its positioned height above the turbine that captures the energy.

Hydrokinetic power uses natural flows in ocean currents, tides and inland waterways including rivers or the motion of waves without impoundment or diversion. Hydrokinetic power depends on kinetic energy of moving water.

Hydrokinetic is also sometimes called marine power, but marine power also includes ocean thermal energy conversion, which is power generated by a heat engine taking advantage of temperature differences between layers of water. We will not discuss ocean thermal power in this module.

Both hydropower and hydrokinetic power fit the definition of renewables as sources of electricity that are naturally replenishing. However, large hydropower is often excluded from definition of renewable energy for regulatory purposes due to the significant environmental impacts of large hydro projects. The size of hydro projects defined as renewable vary from 30 MW or less in some states to 5 MW or less in other states.

Types of Hydro Power



Hydro power facilities are classified by size, by the method used to contain the water, by whether the water can be pumped back uphill for reuse, and in the case of tidal hydro by the source of water.

Hydro plants are often classified as large, small or micro based on their maximum output, or capacity. Exact definitions of what is large, small or micro differs a bit, but for the purposes of this class we will call plants with capacity greater than 30 MW large hydro, plants with capacities ranging from 100 kW to 30 MW small hydro, and plants with capacity less than 100 kW micro hydro.

Hydro plants are also classified by whether or not a reservoir is available to store water above the power plant.

Types of Hydro Power – Impoundment



Hoover Dam and Lake Mead

Units with large dams used to contain water in a reservoir are called impoundment facilities. The ability to store water is useful because the unit can then be controlled so that power is generated at times most advantageous to the system operator. Impoundment facilities often have large enough reservoirs to store water across months or even years and often significantly alter downstream river flow.

Types of Hydro Power – Diversion



John Day Dam and Columbia River

A second type of unit is called a diversion facility, also sometimes called run-of-the-river. Diversion facilities funnel a portion of the water flow either through a pipe called a penstock or through a canal. Diversion facilities may or may not use a dam to direct the water. They may have a small amount of storage, called pondage, but the storage capability is much less than an impoundment facility. In most definitions for diversion or run-of-the-river facilities, storage is limited to daily or weekly fluctuations in water flow and does not materially alter downstream river flows.

Types of Hydro Power – Pumped Storage



Seneca Pumped Storage Station and Kinzua Dam

A third type of hydro plant is a pumped storage plant. Pumped storage plants are like impoundment facilities, but with reservoirs both above and below the turbine and have the capability of pumping water back uphill to refill the upper reservoir. This capability allows the same water to be reused many times to generate electricity.

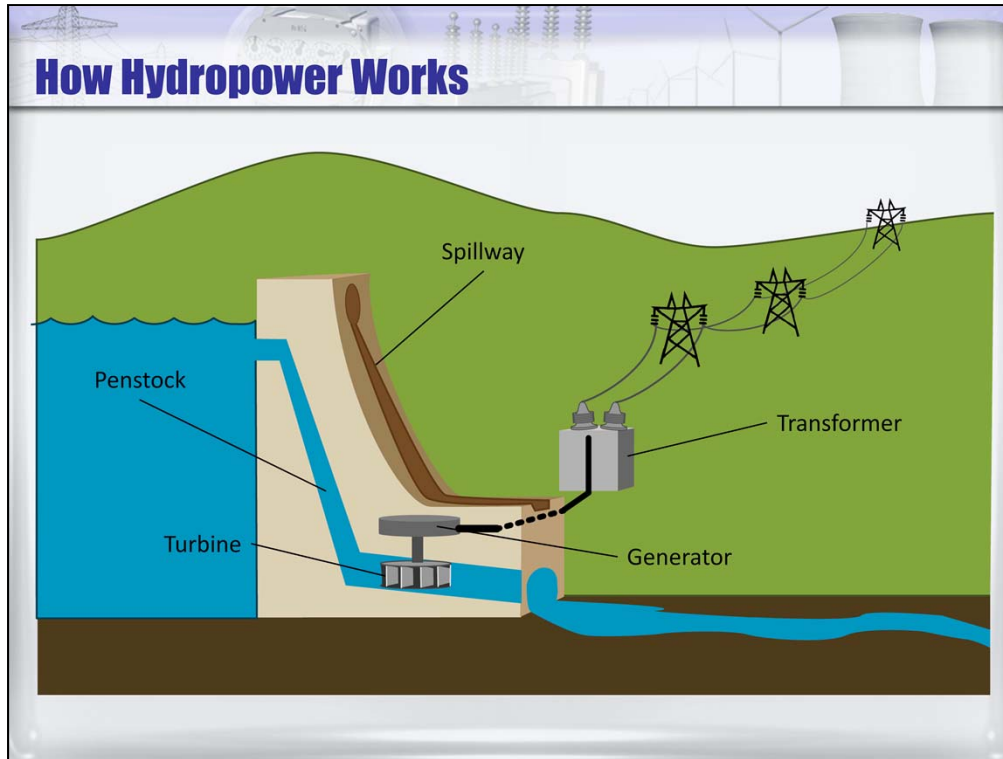
In essence, pumped storage facilities are a means of storing electricity. When demand is high the unit is used to generate electricity, and when demand is low electricity is used to pump water back uphill. Over time, pumped storage facilities are net consumers of power since it takes electricity to pump the water uphill, but on any given hour they can be an important and valuable source of generation when the water flows downhill.

Types of Hydro Power – Tidal Power



Rance Tidal Power Station, Brittany France

Finally, a few plants characterized as tidal hydro exist in the world. The plants, also called tidal barrage plants, depend on dams across an estuary or tidal channel that trap incoming tidal flows and then release the water through turbines as the tides flow back out. Because tidal hydro currently makes up a very small portion of hydro capacity in the U.S. we will not discuss this technology further.



To generate power in a hydro facility, flowing water is directed through an intake into a penstock or canal that carries the water to the turbines. The force of the water spins the turbines, which in turn spin the generator that creates electricity.

Transformers then increase the voltage to the required voltage for the transmission line connecting the facility to the electric grid. After exiting the turbine, the water is returned to the river downstream.

Many dams also include a spillway that allows excess water to be channeled to the downstream river directly so that during flood conditions water does not spill over the face of the dam.

In a run-of-the-river system the force of the water is created mostly by the flow of the river while in an impoundment system most of the force is created by the drop of water through the penstock as water is released from the reservoir.

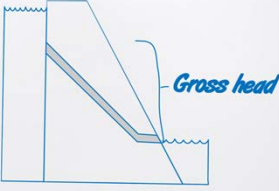
How Hydropower Works

Output Factors:

Discharge flow
Gallons per minute
Cubic feet per second
Tons per second

Net head
Gross head
minus friction

Efficiency/Capacity



Three key factors determine the amount of electric output from a hydro plant.

First is the discharge flow, which is the amount of water flowing through the turbine measured in gallons per minute, cubic feet per second, or tons per second.

Second is the site net head, which is a measure of the pressure of the falling water. Gross head is determined by the vertical distance from the water source to the spot where the water discharges from the turbine. Net head is a lower value that adjusts the gross head for the friction caused by the channel or penstock directing the water. Head is measured in feet.

Third is the efficiency and capacity of the turbine/generator set.

How Hydropower Works

Calculate Capacity:

$$MW = \text{Net Head} \times \text{Flow} \\ \times \text{Efficiency} \times \text{Constant}$$

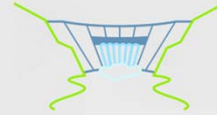
Flow *100 cfs*

Net Head *500ft*

Efficiency *70%*

Constant *X .00085*

2.98 MW

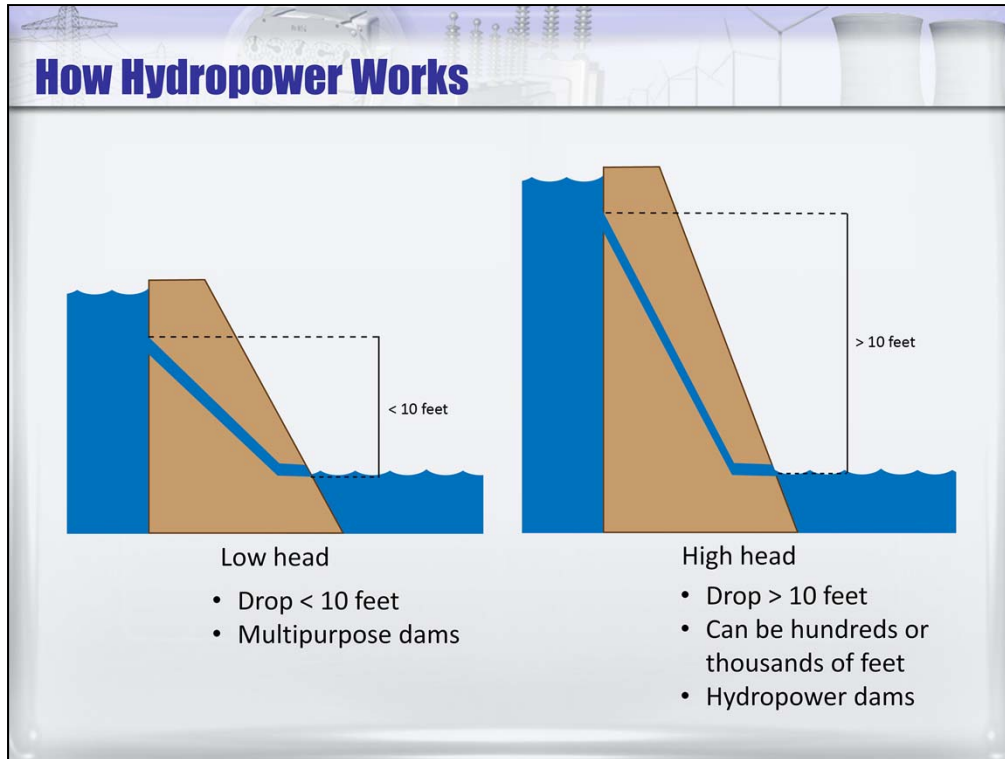


Using these three factors, along with a constant that converts units, the capacity of a hydro facility can be calculated.

For example, a facility with a flow of 100 cubic feet per second, a net head of 500 feet, and an efficiency of 70% can be calculated using the constant value of .00085 which results in a power availability of 2.98 MW.



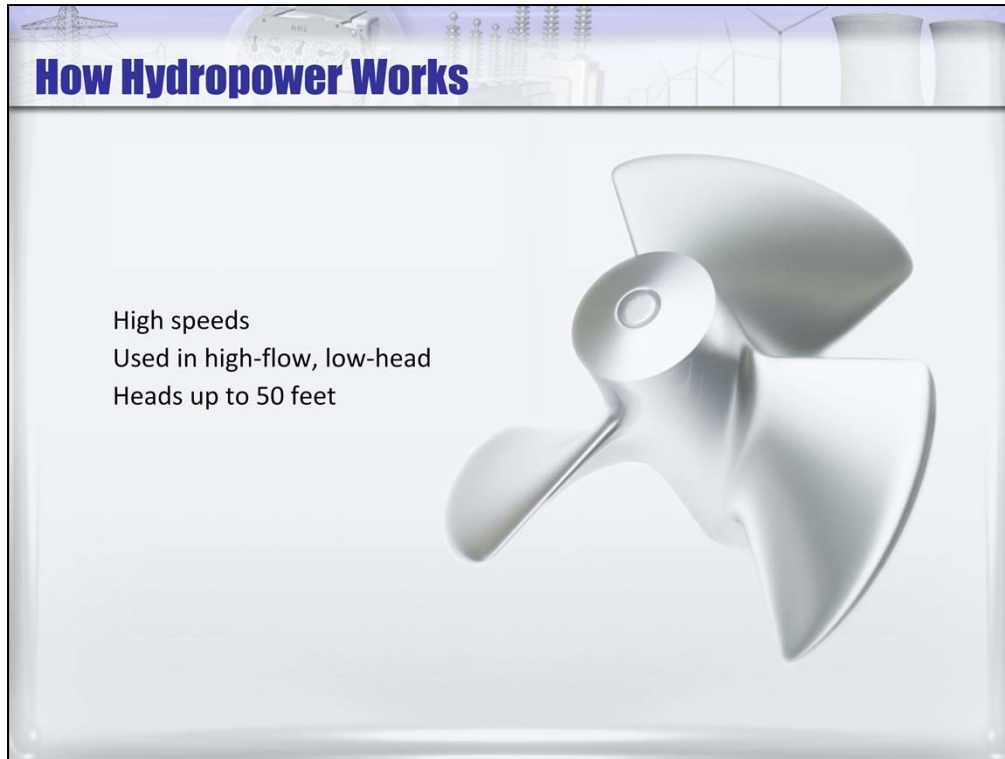
Larger hydro facilities are often designed to allow operators to vary power output based on system needs by controlling the flow of water into the penstock.



Hydropower sites are frequently categorized as low-head or high-head.

Low-head sites typically refer to an elevation drop of less than 10 feet and are frequently located behind multipurpose dams built for flood control or water supply projects.

High-head sites have greater than 10 feet elevation drop, often hundreds or even thousands of feet, and are usually located behind dams with reservoirs designed specifically for hydro power.



Different types of turbines are used depending on the site characteristics. Propeller turbines are the most simple, and spin by the force of the water striking the propeller. Propeller turbines can reach high speeds and are thus useful for high-flow but low-head applications. They are commonly used for head up to 50 feet.

How Hydropower Works



Retired turbine at Bonneville Dam

Adjustable blades
Used in run-of-the-river
Heads up to 100 feet

The Kaplan turbine is similar to a propeller turbine except that the blades are adjustable to match different flows. Thus Kaplan turbines are useful for run-of-the-river where flow varies. Kaplan turbines are used for head up to 100 feet.

How Hydropower Works

Low flow, high head
Heads 1,000 feet or more



For sites with lower flow but high head, Pelton turbines are used. Pelton turbines use spoon-shaped buckets to capture the power of falling water. Pelton turbines are used for sites with heads of 1,000 feet and higher.

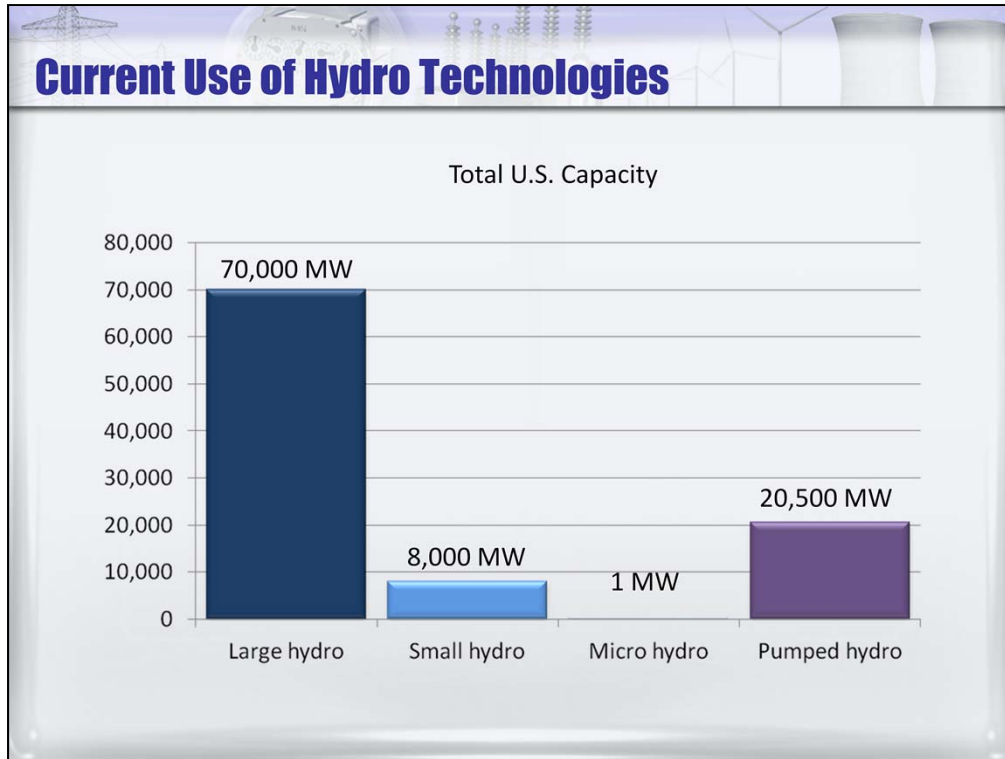
How Hydropower Works



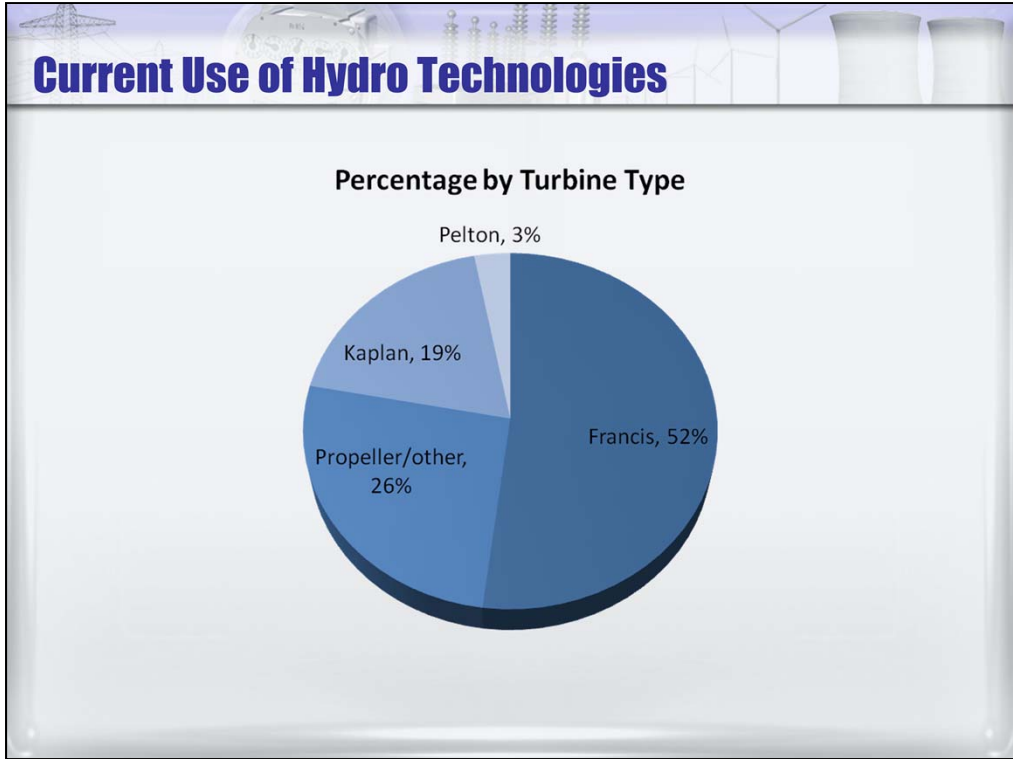
Retired turbine from Hoover Dam

Used in impoundments
Head from 30 – 1,000 feet

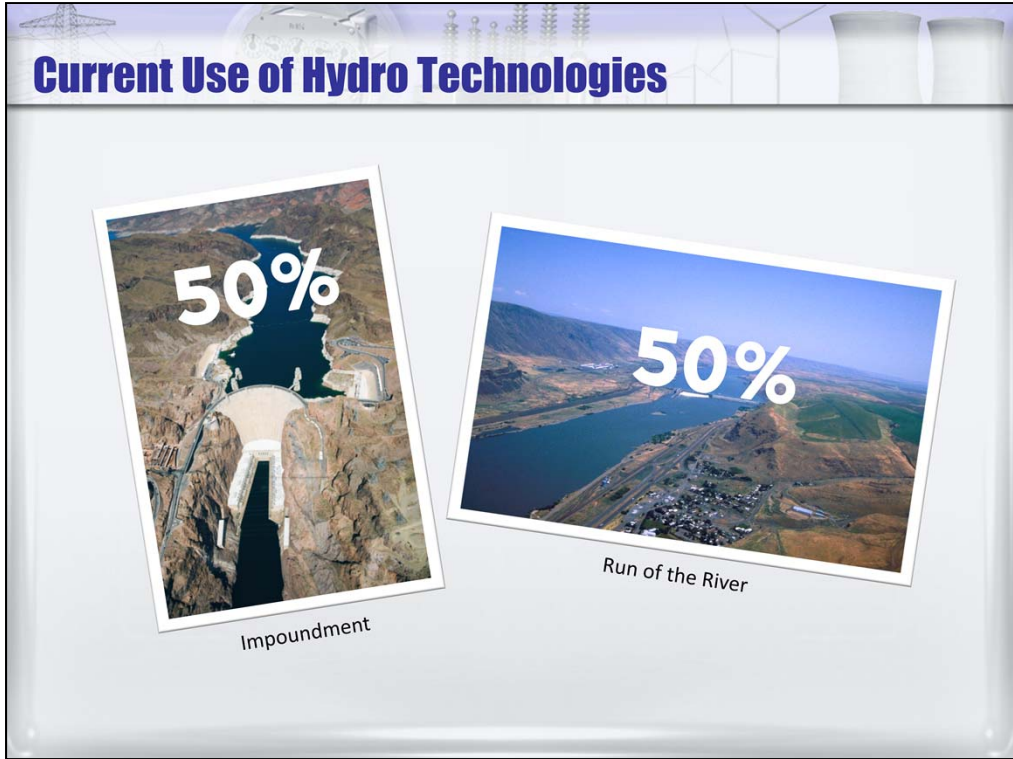
For impoundment facilities, the most common turbine is the Francis turbine. The blades in the Francis turbine are curved so that water strikes the outside of the blade and is directed toward the center of the blade, causing the turbine to spin. Francis turbines are commonly used with heads ranging from 30 to 1,000 feet.



Hydro power capacity in the U.S. is dominated by large hydro projects. As of 2010, about 70,000 MW out of a total of 78,000 MW was large hydro. Just under 8,000 MW was small hydro and about 1 MW was micro hydro. There was an additional 20,500 MW of pumped hydro capacity.



According to a study done in 2011, 52% of hydro capacity in the U.S. used Francis turbines, 26% used propeller or other types of turbines, 19% used Kaplan turbines, and 3% used Pelton turbines.



It is estimated that about 50% of U.S. hydro capacity is impoundment type and 50% run-of-the-river.



Technologies used to generate hydrokinetic power are varied. This is because hydrokinetic power includes power generated by varying resources including tidal currents, river currents and ocean waves and because the technology is in the research and development phase meaning many different ideas are being tried.

Types of Hydrokinetic Power

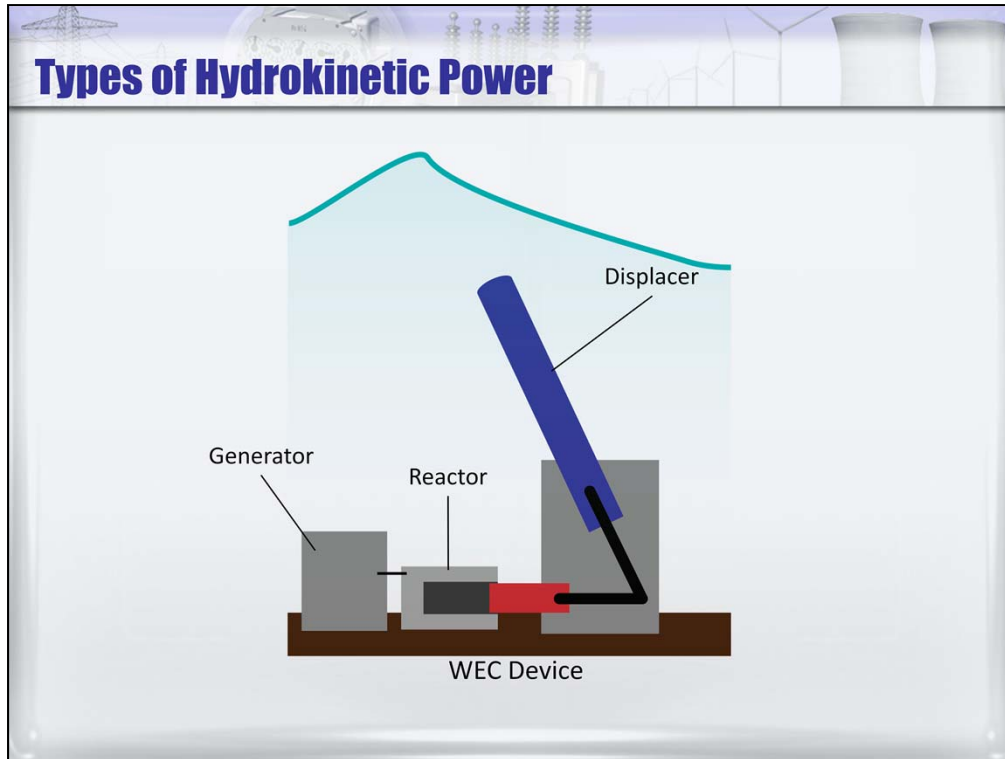


Galway Bay Wave Device

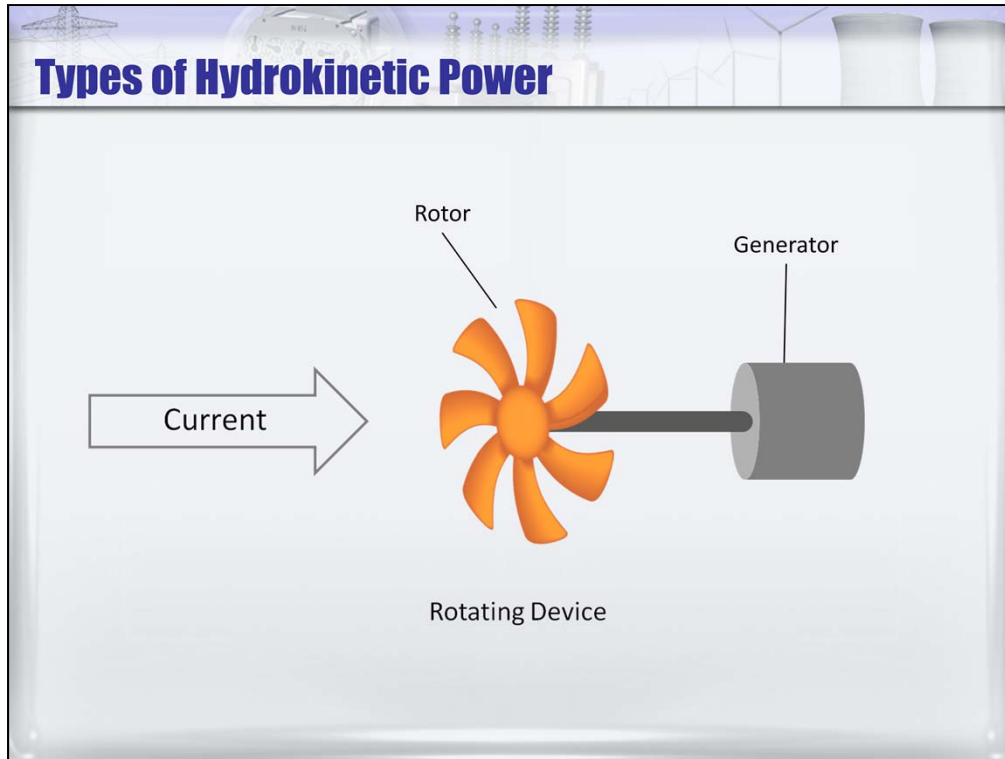


Seaflow Tidal Stream Generator

Hydrokinetic technologies are classified as either Wave Energy Conversion devices (WECs) or rotating devices.



WECs use the motion of two or more devices relative to each other. One of these bodies, called the displacer, is acted on by the waves. The second body, the reactor, moves in response to the displacer and drives a generator to create electricity.

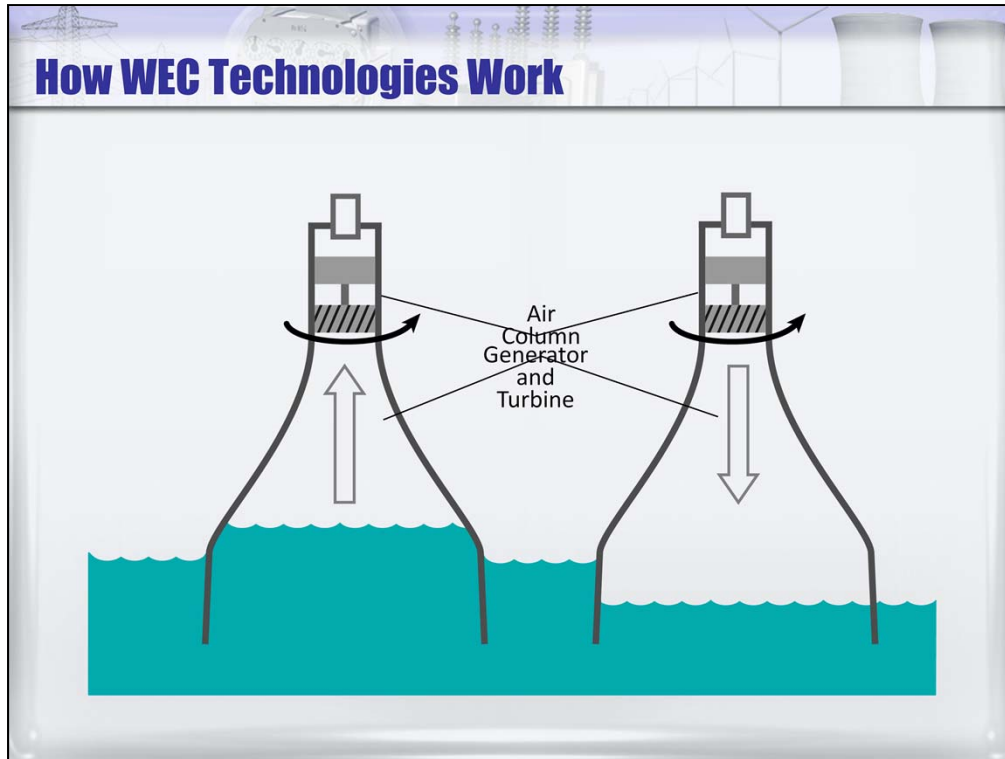


Rotating devices are spun by the kinetic energy of moving water as tidal streams, ocean currents or river currents strike a rotor. The spinning rotor drives a generator to create electricity.

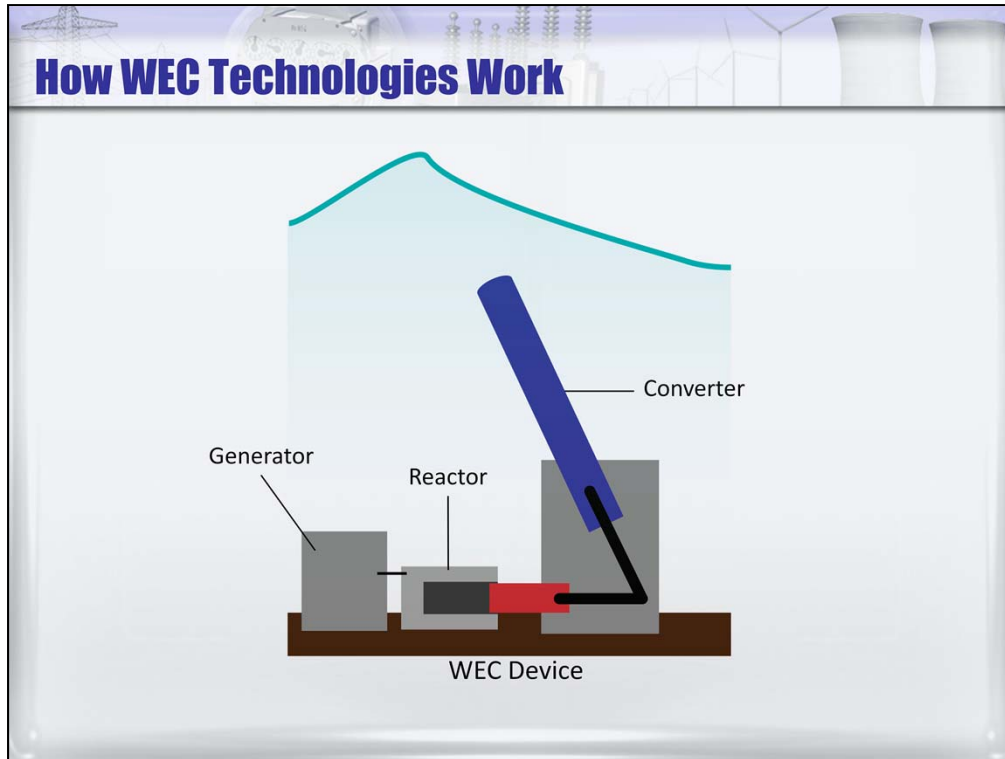


There are many types of WECs under development in research projects. We will consider five key types of WEC technologies.

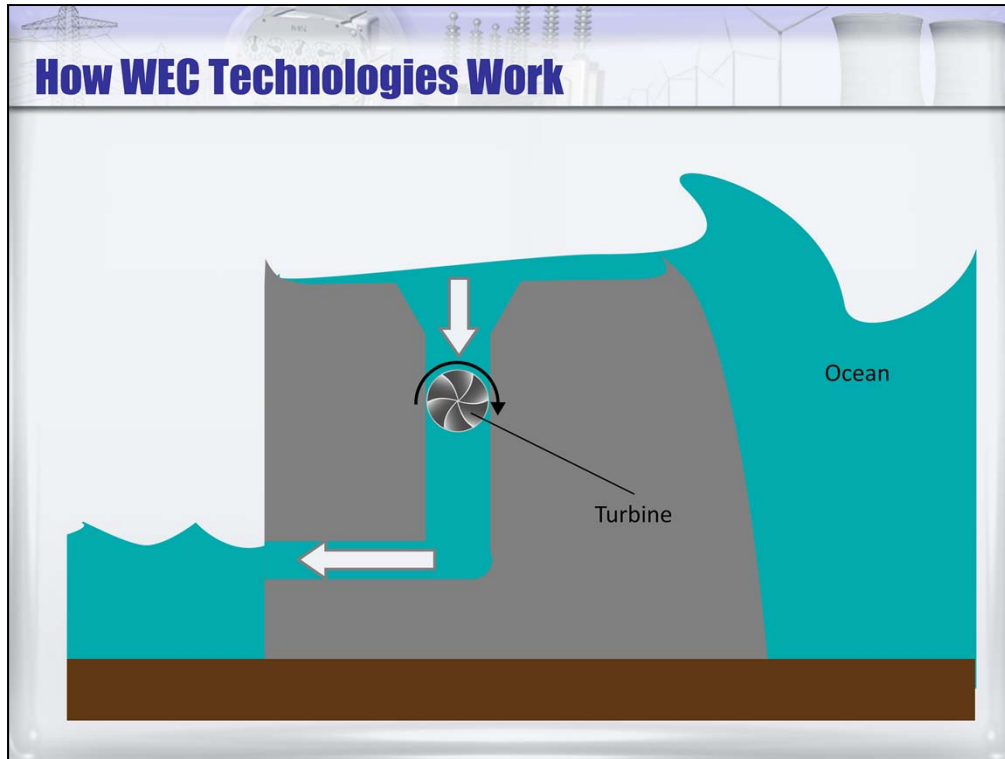
The attenuator is a long, jointed floating device oriented parallel to wave motion and anchored at the end. As the wave passes, each section is set in motion relative to the next section. This motion is used to pressure a hydraulic piston that drives fluid through a motor that drives a generator. Attenuators are also sometimes called heave-surge devices.



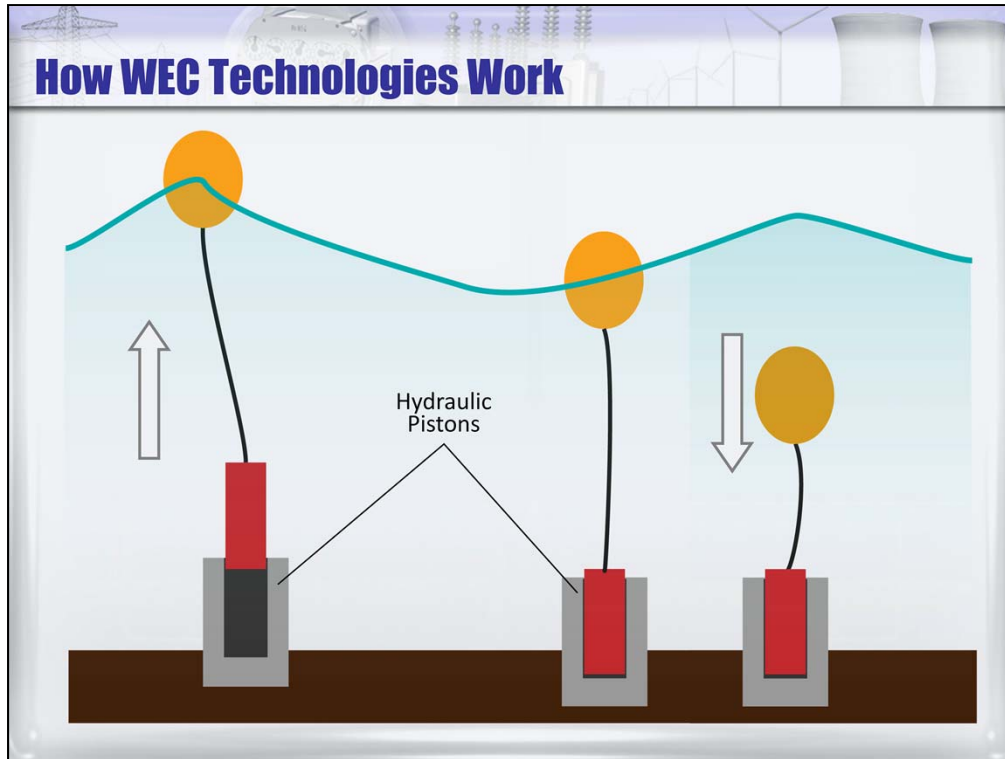
The oscillating water column is a partially submerged collector that encloses a column of air above a column of water. As the waves funnel into the device the water column rises and falls. The movement of the water column alternately pressurizes or depressurizes the air column. When the air is pressurized it is driven through a turbine causing the turbine to spin and turn a generator.



The oscillating wave surge converter uses a blade, float, flap, or membrane as a converter to capture wave energy without a collector. The energy of the wave moves the converter back and forth. The converter's movement drives a hydraulic system that moves fluid through a motor that drives a generator.



The overtopping device combines hydropower technology with ongoing wave action. A partially submerged structure funnels waves into a small reservoir. The reservoir directs the flow through low-head turbines and then back out to sea. Power is generated as the turbines spin a generator. The system is continuously renewed as waves splash over the edge of the structure.



A point absorber uses the vertical motion of waves to capture kinetic energy. The up-and-down motion of a buoy drives a hydraulic piston, which, like in other technologies previously described, can then be used to drive a generator.

Point absorbers may utilize a surface-floating buoy or may be submerged.

How Rotating Devices Work



SeaFlow Tidal Turbine, Lynmouth UK



ORPC Beta Turbine Generator Unit, Eastport ME

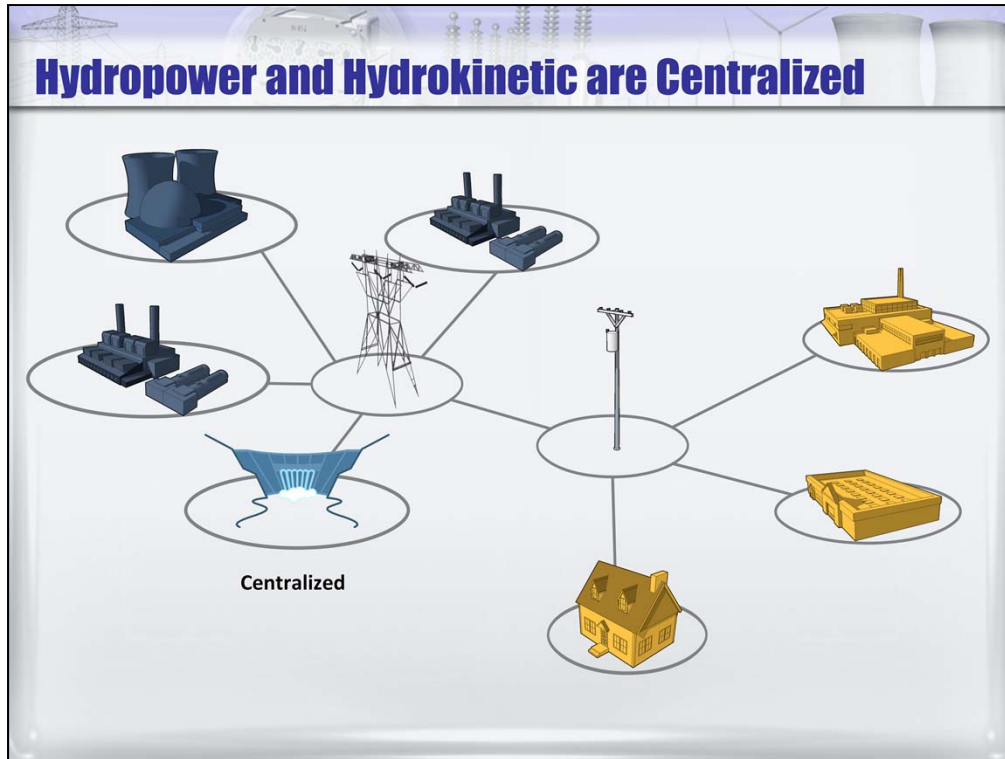
There are two principal types of rotating devices used for hydrokinetic power. These are axial flow turbines and cross flow turbines.

An axial flow turbine is also known as a horizontal axis turbine. These look similar to wind turbines called propeller types. Blades are mounted on a horizontal rotor and spun by the current. The spinning rotor drives a generator that creates electricity.

A cross flow turbine is also known as a vertical axis turbine. These look similar to the wind turbines sometimes called egg-beaters. Curved blades are mounted on a vertical rotor which in turn drives a generator.



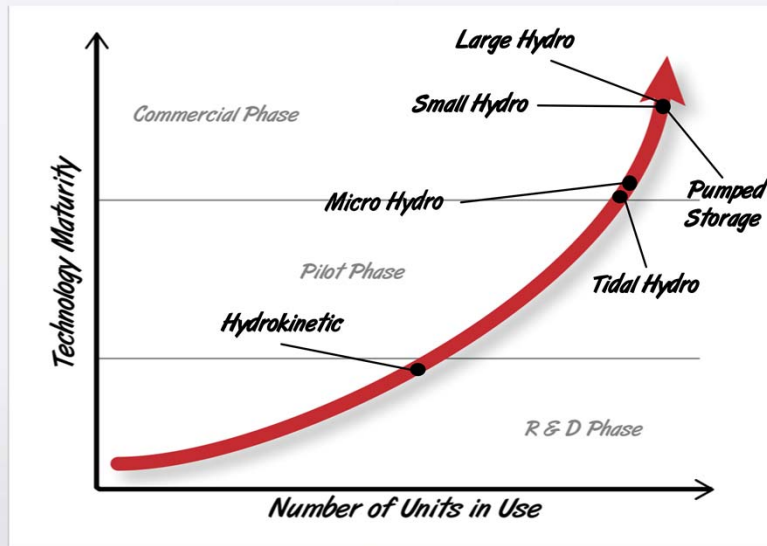
Numerous demonstration projects are under development for the various hydrokinetic technologies. As of September 2011, the U.S. Department of Energy listed seven companies actively developing projects that have at least reached the siting/planning stage. Of these companies, three use axial flow turbines, two use floating point absorbers, one uses oscillating water columns, and one uses cross flow turbines.



Most hydro projects are centralized and connected to the transmission system of a regional grid. The exceptions are some small hydro and micro hydro projects which may be connected to distribution grids or used internally by a single consumer.

Since hydrokinetic power is usually located remotely from load centers it is assumed that most projects will also be centralized and connected to the transmission grid.

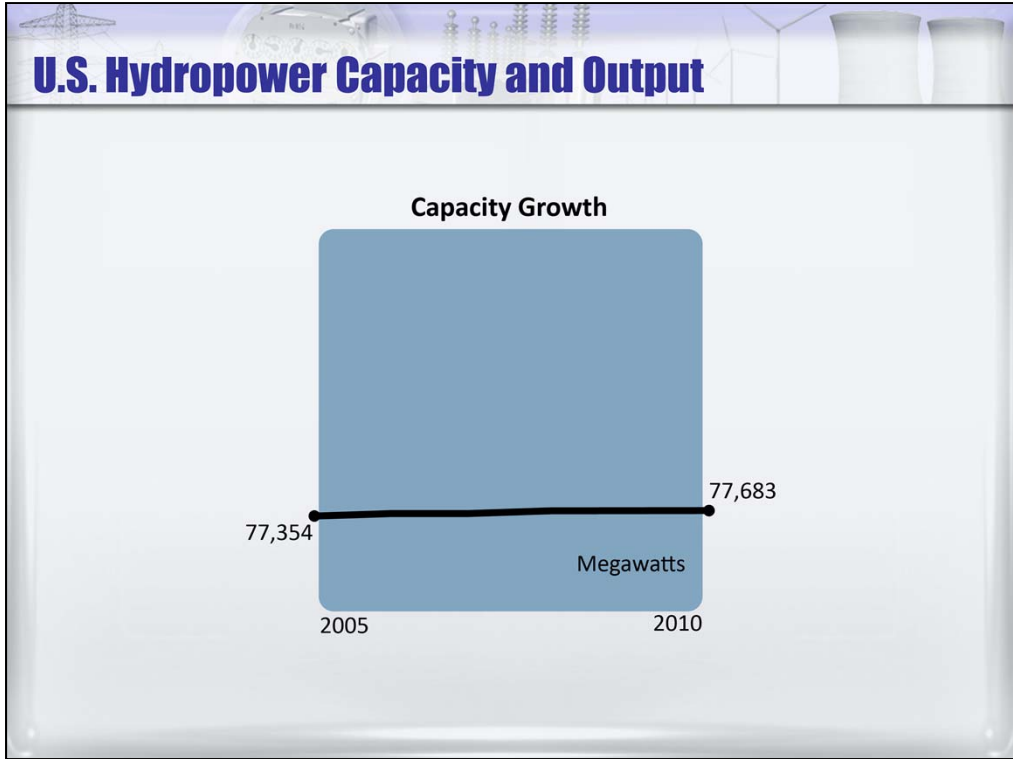
Hydropower and Hydrokinetic Power Maturity



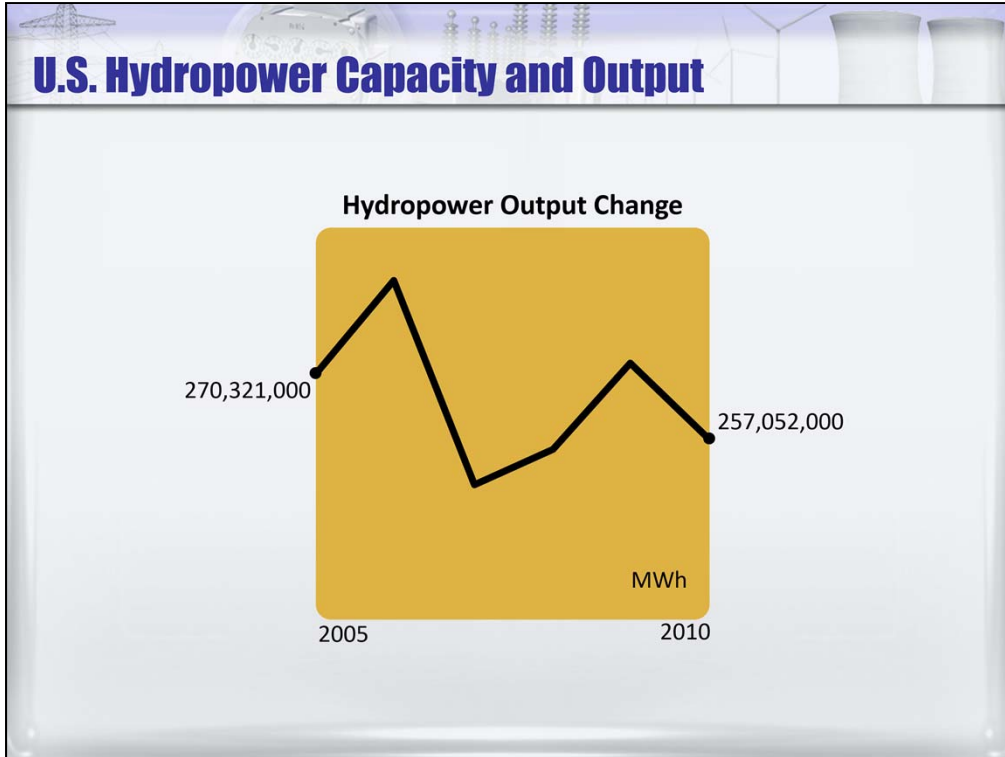
Large hydro, small hydro, and pumped storage power are all mature technologies with some units having been in commercial operation for over 100 years.

Current micro hydro and tidal hydro technologies are newer but have passed from the pilot to commercial phase of development.

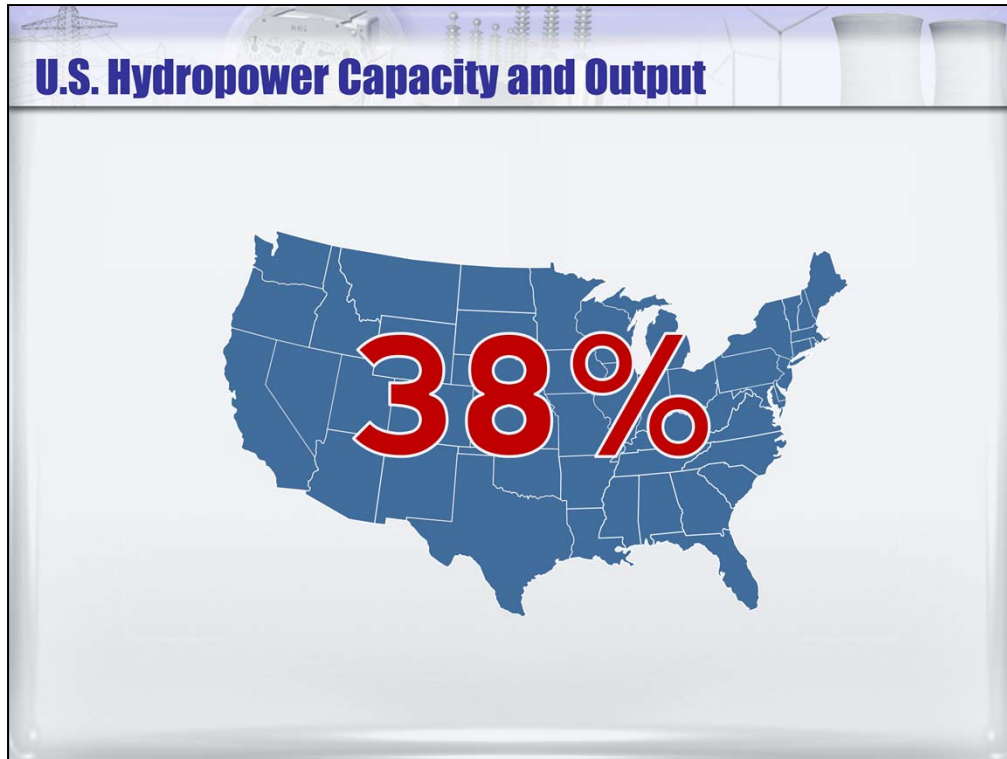
Hydrokinetic power technology is mostly in the R&D phase with a few pilot projects being implemented.



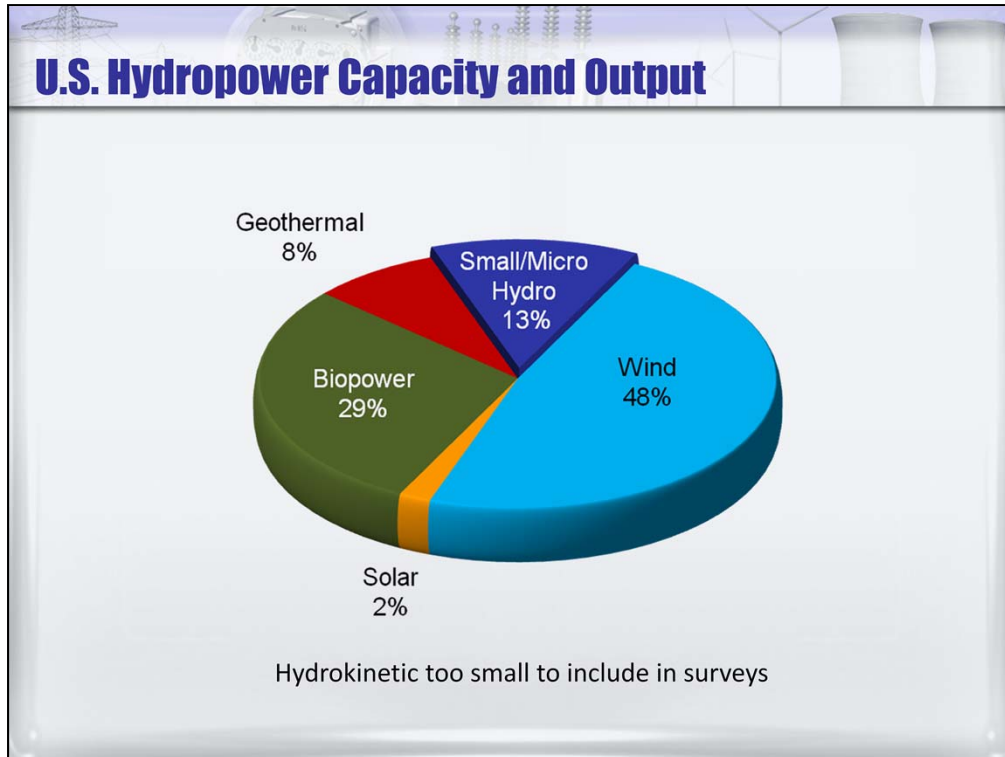
The total nameplate rating for hydropower in the U.S. as of the end of 2010 was 77,683 MW, which made up about 7% of total electric generation capacity in the U.S. The nameplate rating for pumped storage was 20,538 MW which is about 2% of total U.S. capacity. Capacity for these sources has remained level over the five years from 2005 to 2010.



In the same five-year period, hydropower output fluctuated up and down based on weather conditions. Output in 2010 was 257 million MWh, which is about 6% of all electric generation output in the U.S. Output of hydrokinetic power is currently too small to be included in statistical surveys.



The average capacity factor for hydropower in the U.S. in 2010 was 38%.

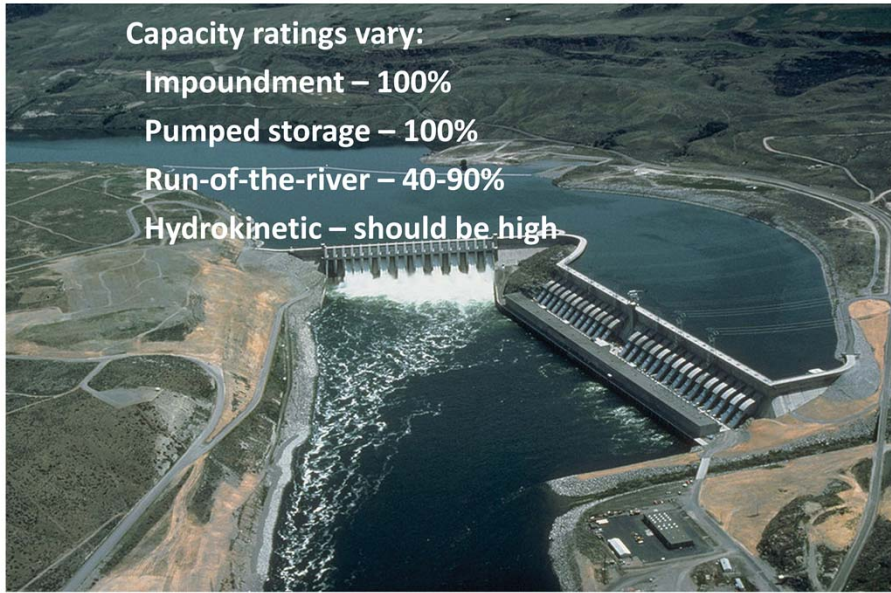


If all hydro power is counted, hydro power would be the largest of the renewable generating sources. However, as previously discussed, most jurisdictions exclude large hydro from definitions of renewable energy. If only small and micro hydro are included in the numbers, hydro power is the third largest renewable technology after wind and biopower.

Hydrokinetic output is smaller than all other renewable technologies and currently makes up a very small part of renewable output.

Capacity for Reliability Purposes

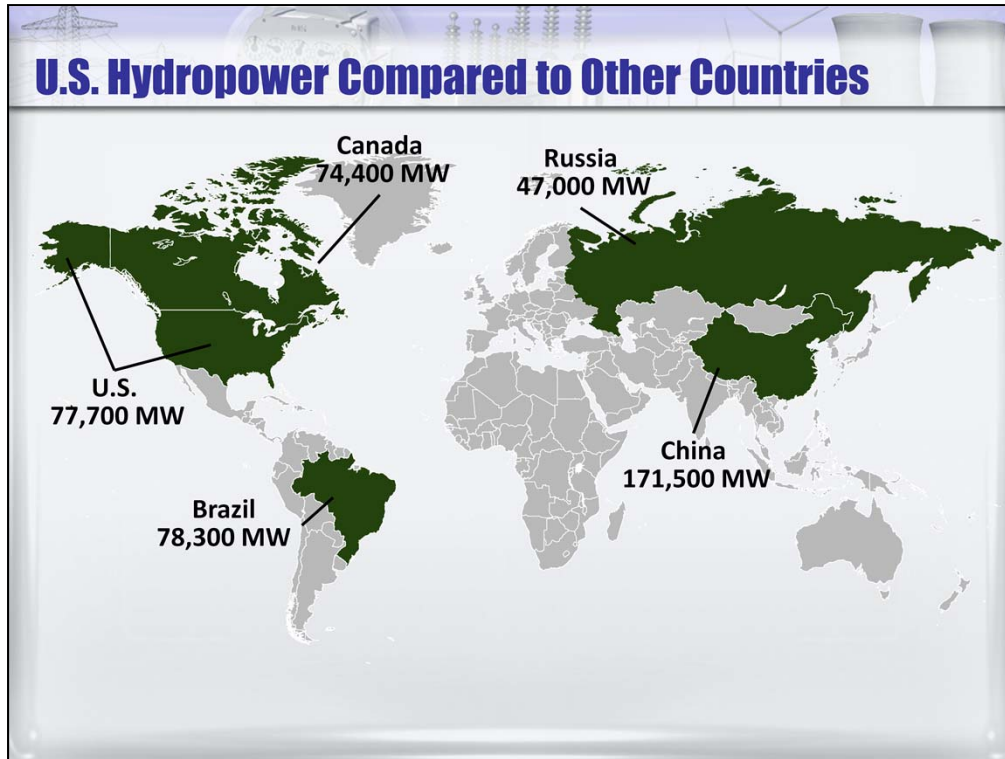
Capacity ratings vary:
Impoundment – 100%
Pumped storage – 100%
Run-of-the-river – 40-90%
Hydrokinetic – should be high



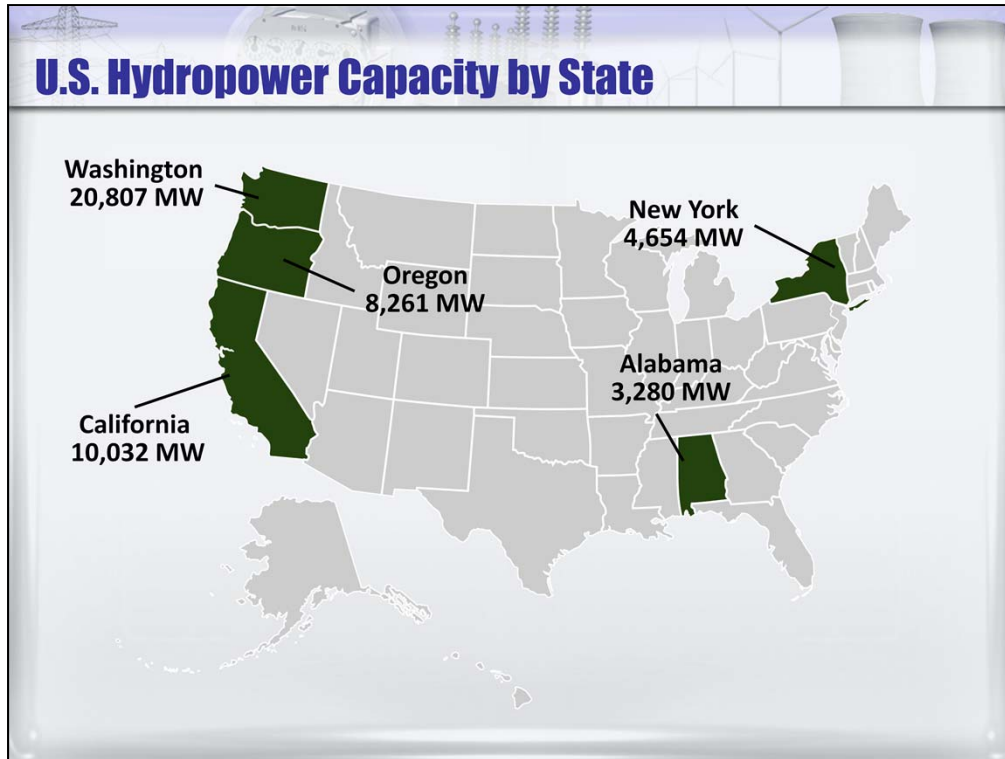
Capacity ratings for reliability purposes for hydro power vary depending on the characteristics of a specific facility. Impoundment plants with plentiful storage often have capacity ratings near 100% of nameplate, although they may be rated lower than 100% if water resource availability varies from year to year. Pumped storage plants are also typically rated at close to 100%.

Run-of-the-river plant capacity ratings vary from 40 to 90% depending on the expected variability of the river flow.

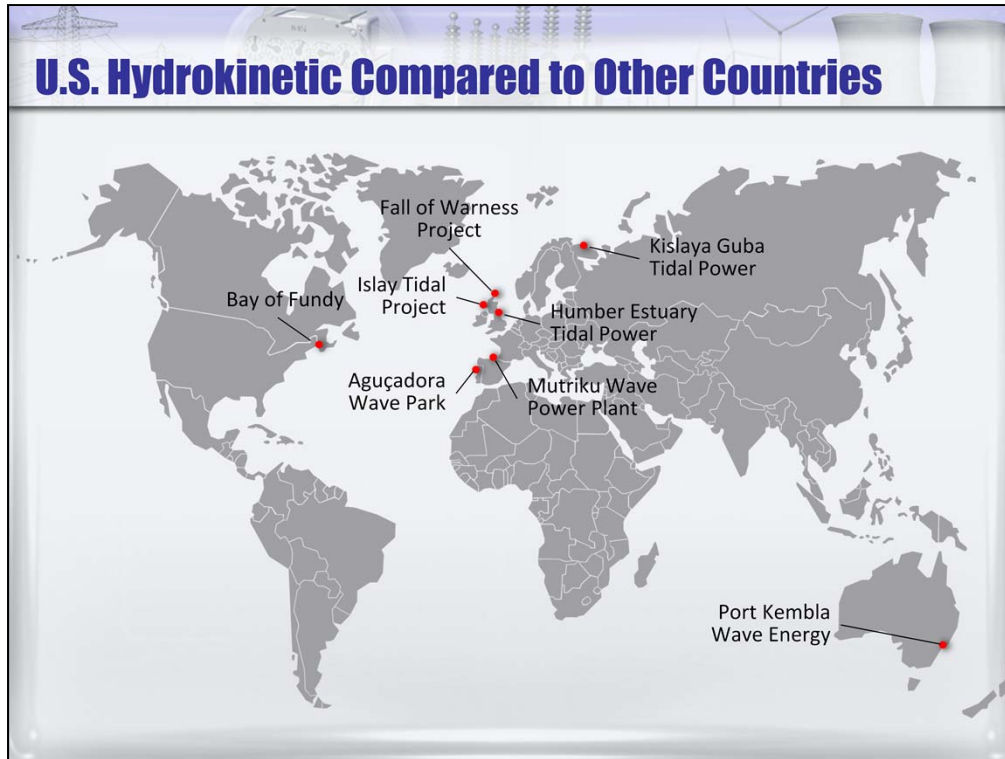
Not enough is known about hydrokinetic technology to specify capacity ratings for reliability purposes. It is hoped that as the technology is developed it will prove to have high capacity ratings since the motion of currents or waves in good locations is expected to be constant.



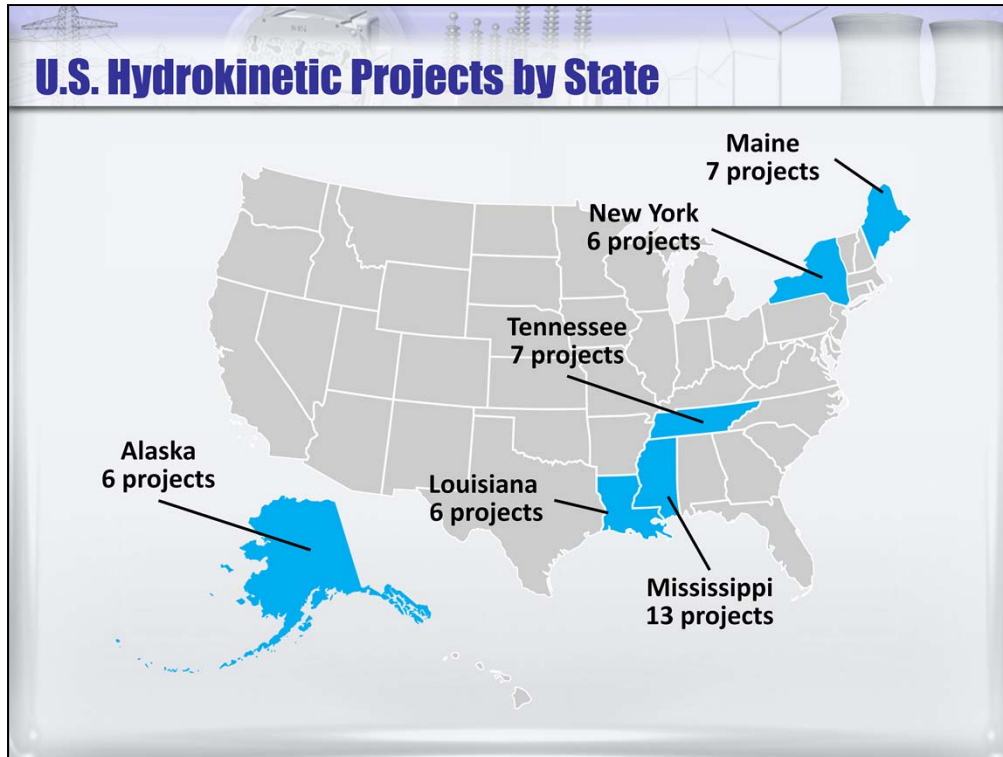
As of 2009, China had the largest amount of hydropower in the world followed by Brazil, the U.S., Canada, and Russia.



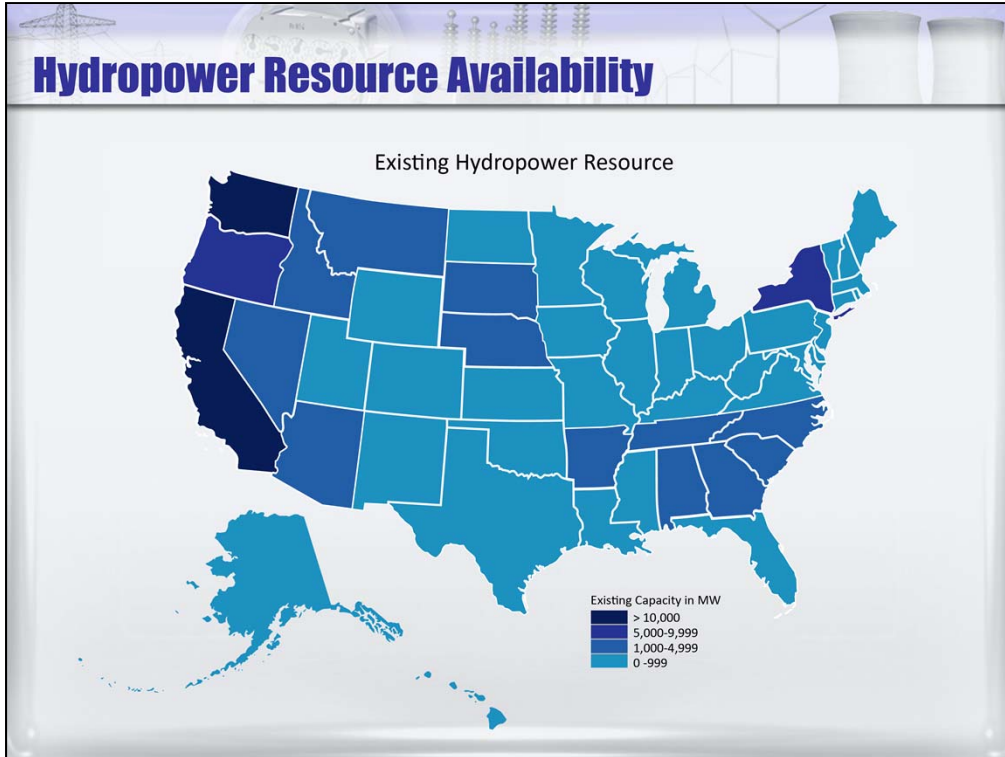
Among the U.S. states, hydropower capacity is greatest in Washington, California, Oregon, New York, and Alabama.



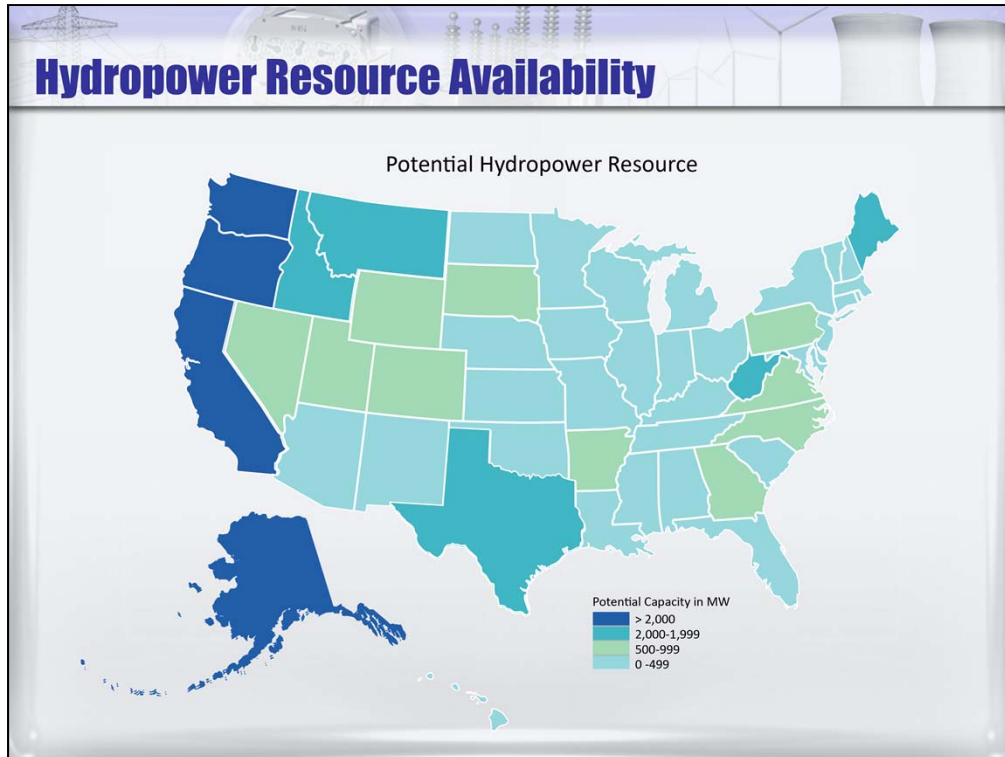
In addition to the U.S. projects that we will discuss next, a handful of countries in the world have operating pilot hydrokinetic plants. These countries include Portugal, Canada, the U.K., Russia, Spain, and Australia.



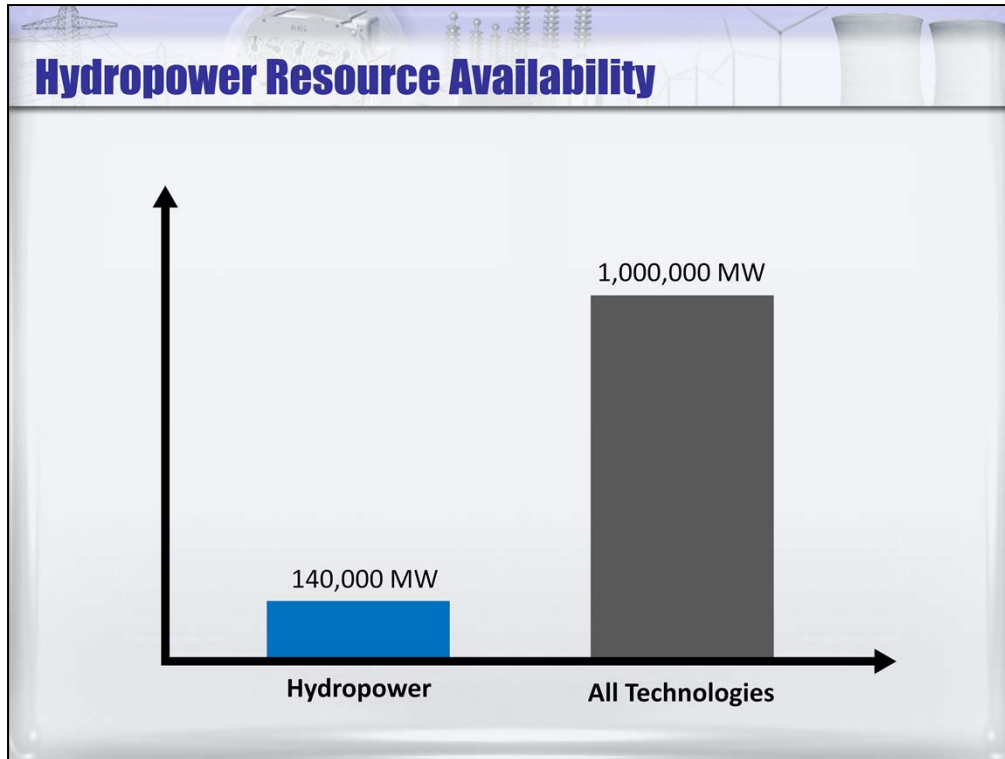
A handful of small hydrokinetic plants have been installed in the U.S. Based on preliminary and commercial licenses issued by the Federal Energy Regulatory Commission (FERC) as of 2011, key states working to develop hydrokinetic capacity include Mississippi with 13 projects, Tennessee and Maine with seven projects each, and Alaska, New York, and Louisiana with six projects each. It should be noted that most of these projects are in the development phase and have yet to be completed.



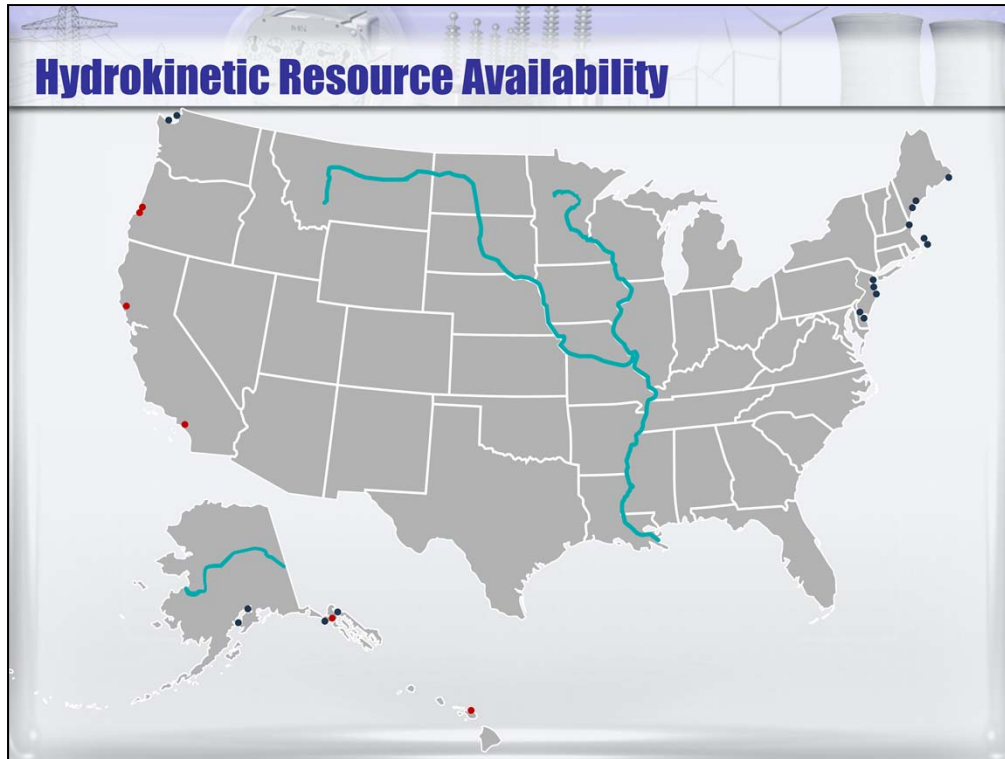
As you can see on this map of existing hydro resources, the largest resources are along the West Coast with significant resources also in the West, the Great Plains, New York, and parts of the Southeast.



It is assumed that all potential large hydro sites have already been developed. Potential additional resources for hydro power include repowering existing plants with larger capacity turbines, adding power generation capabilities to currently unpowered dams, and adding small and micro hydro facilities in new locations. This map shows an estimate of additional potential hydro resources by state. As you can see the largest potential is in the West Coast and Alaska with additional significant potential in the Rocky Mountains, Texas, and Maine.



The ultimate developable hydropower resource in the U.S. is estimated to be 140,000 MW. By way of comparison, total generating capacity for all technologies in the U.S. as of 2010 was about 1 million MW. Thus hydropower could be an important contributor to overall electric generation capacity, but it will not be a primary source of electricity for the U.S.



Potential sites for hydrokinetic power development include wave potential along the West Coast and in Alaska and Hawaii; tidal potential in Washington State, California, the East Coast, and Alaska; and river potential in large inland rivers such as the Mississippi, Missouri, and the Yukon.

Given the current immaturity of this technology it is premature to say what the ultimate potential is for hydrokinetic power.

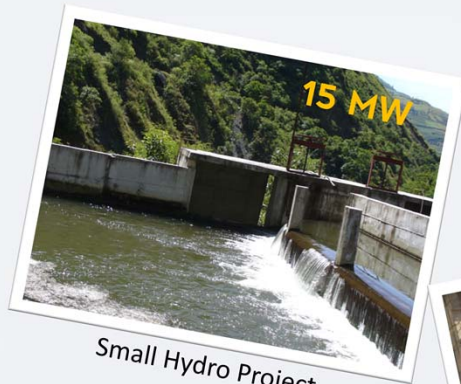
Hydropower and Hydrokinetic Power Costs

Costs depend on project size and site conditions
Operating costs often less than \$20/MWh

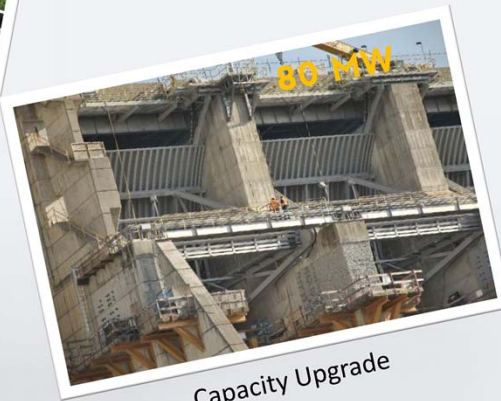


The cost of hydro power depends on the size of the project and site-specific conditions. Operating costs for existing hydro projects are very low, often less than \$20/MWh.

Hydropower and Hydrokinetic Power Costs

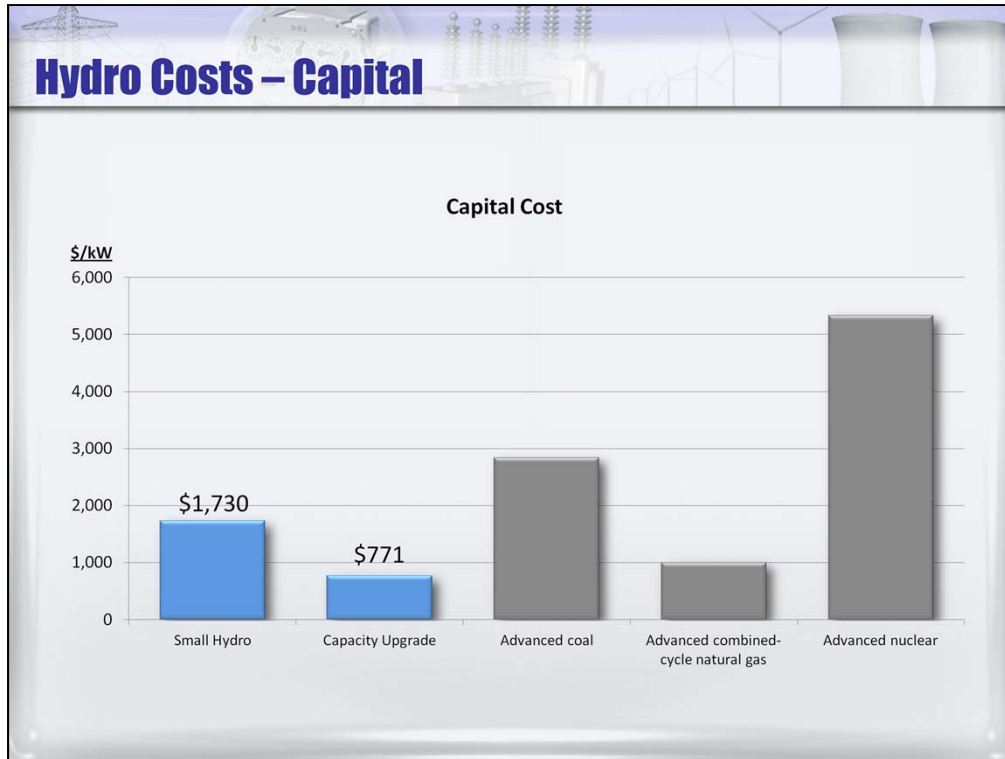


Small Hydro Project

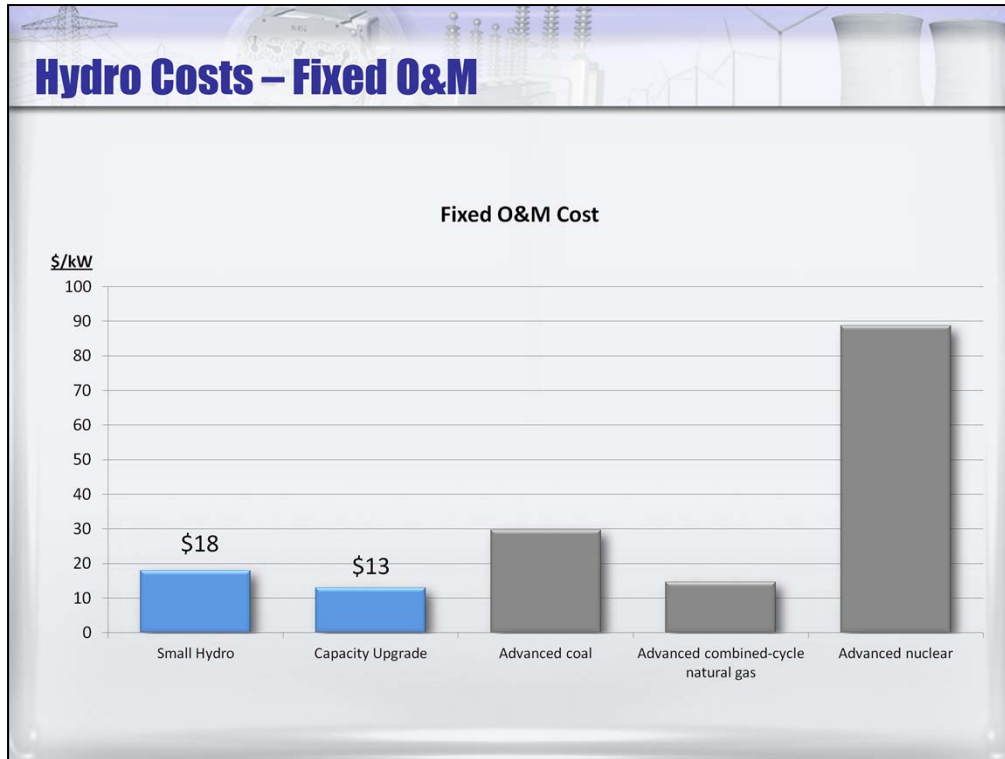


Capacity Upgrade

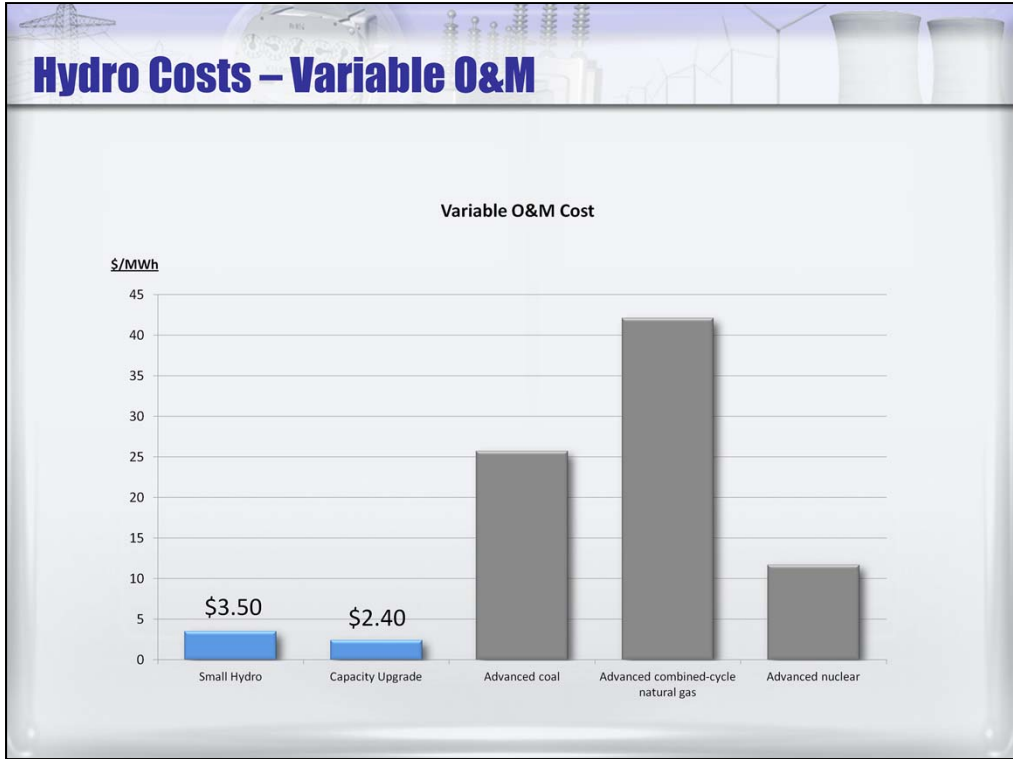
As an example let's consider costs for two new hydro projects. One is a small hydro project with a capacity of 15 MW, and the second is a capacity upgrade of 80 MW at an existing site.



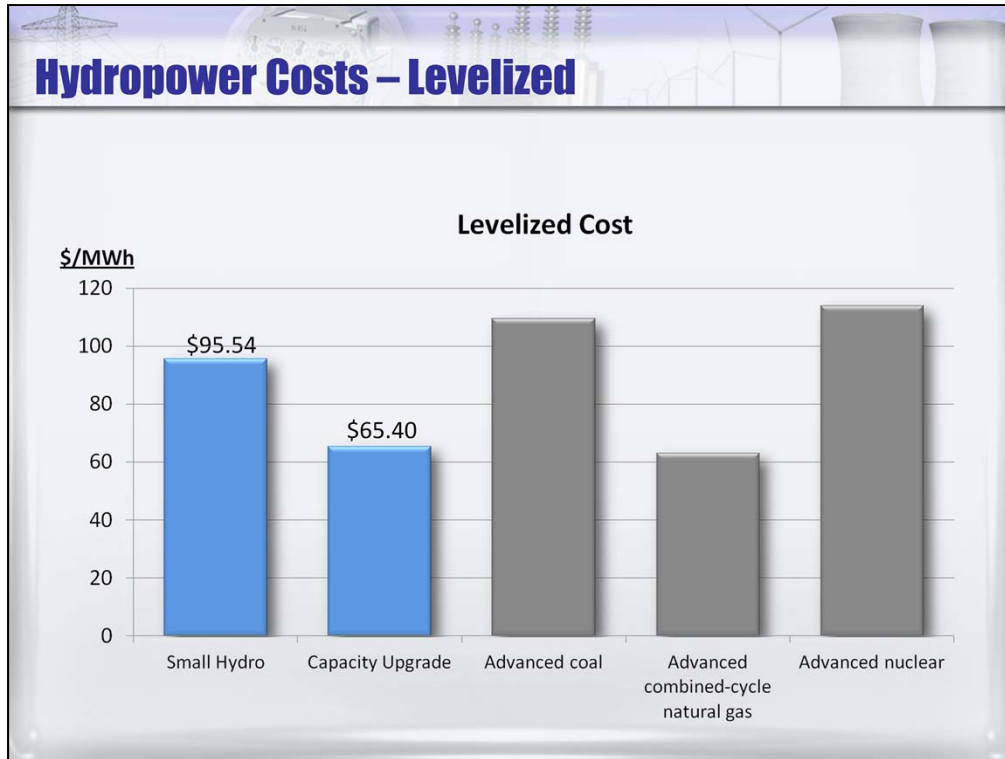
Estimated upfront capital costs for a small hydro plant are \$1,730/kW and for the upgrade are \$771/kW.



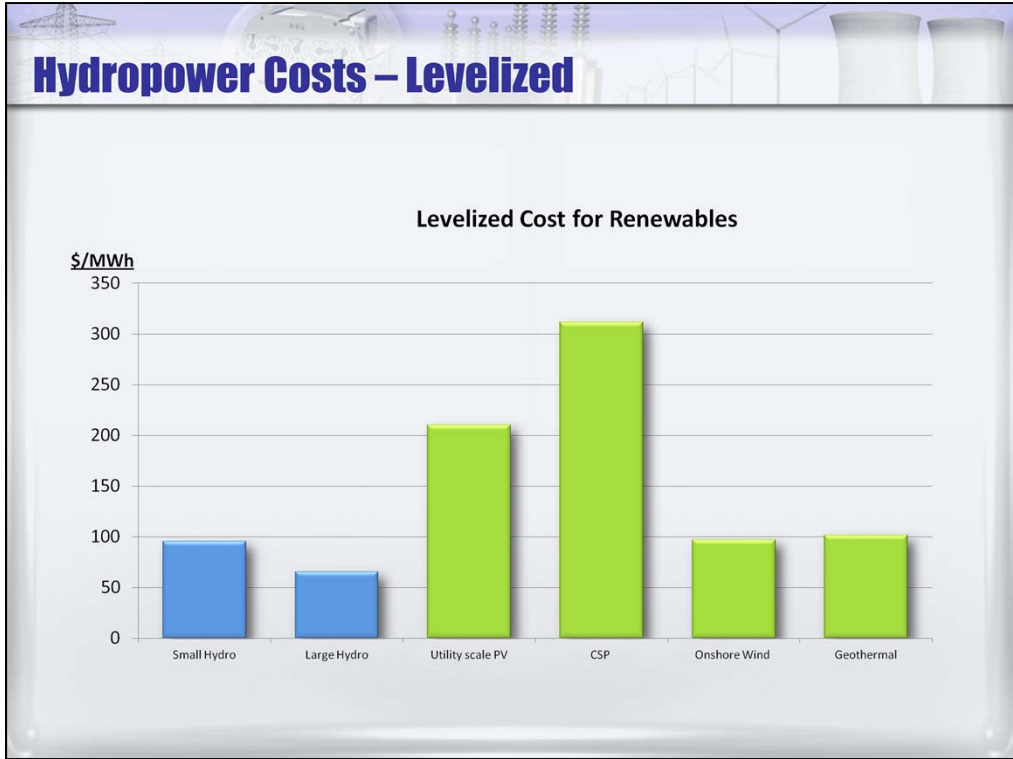
Estimated fixed operations and maintenance costs for the small hydro plant are \$18/kW-year and for the upgrade are \$13/kW-year.



Estimated variable operations and maintenance costs for the small hydro plant are \$3.50/MWh and for the upgrade are \$2.40/MWh.



Estimated levelized costs for the small hydro plant are \$95.54/MWh and for the capacity upgrade are \$65.40.

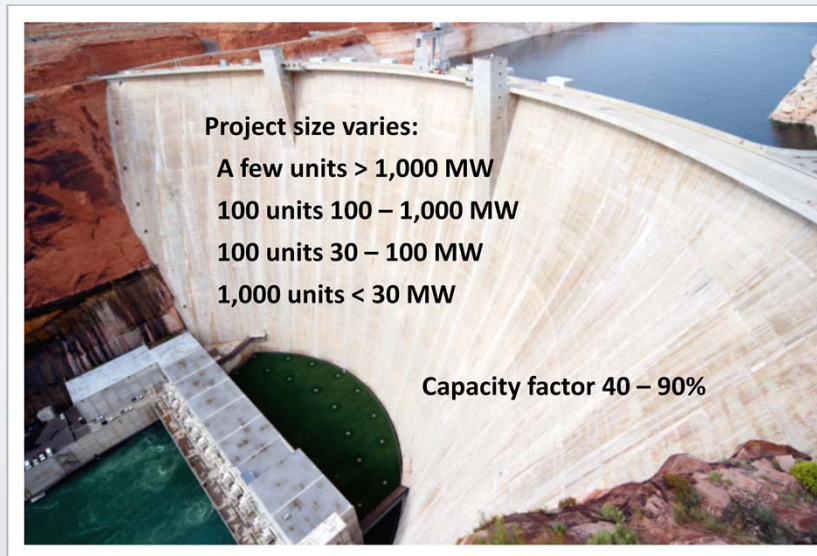


Hydropower is among the cheapest of renewable technologies.



Not enough is yet known to estimate costs for hydrokinetic power.

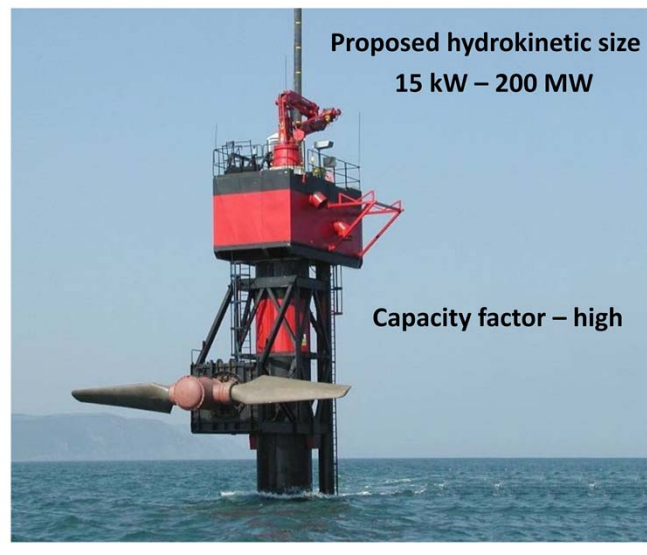
Typical Project Size and Capacity Factor



The typical size of a hydropower plant varies depending on the available resource. In the U.S. a few hydro facilities are larger than 1,000 MW, close to 100 facilities are between 100 MW and 1,000 MW with a similar number between 30 MW and 100 MW. There are close to 1,000 facilities below 30 MW.

Capacity factors for new hydropower projects are expected to range from 40 to 90% depending on the nature of the specific facility.

Typical Project Size and Capacity Factor



It is premature to determine expected sizes for any future commercial hydrokinetic facilities, but current proposals range from projects as small as 15 kW to projects in the 200 MW range. It is expected that capacity factors should be high since the intent is to locate hydrokinetic facilities in locations with steady resources.

Variability/Dispatchability/Predictability

Run-of-the-river:

- Variable
- Dispatchable
- High predictability

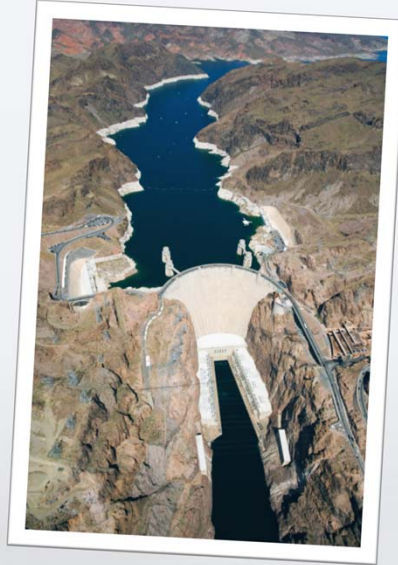


The operating characteristics of hydropower differ depending on the type of facility. Run-of-the-river units are variable depending on river flows. These units may have some dispatchability if there is pondage for water storage; if not, they are not dispatchable. In most cases predictability of river flows is high, meaning that power output can be predicted in advance for scheduling purposes.

Variability/Dispatchability/Predictability

Impoundment:

- Less variable
- Dispatchable
- High predictability



Impoundment units are much less variable since large amounts of water can be stored and are dispatchable since flows through the turbine can be controlled. Thus they are also highly predictable.

Variability/Dispatchability/Predictability

Both types affected by drought



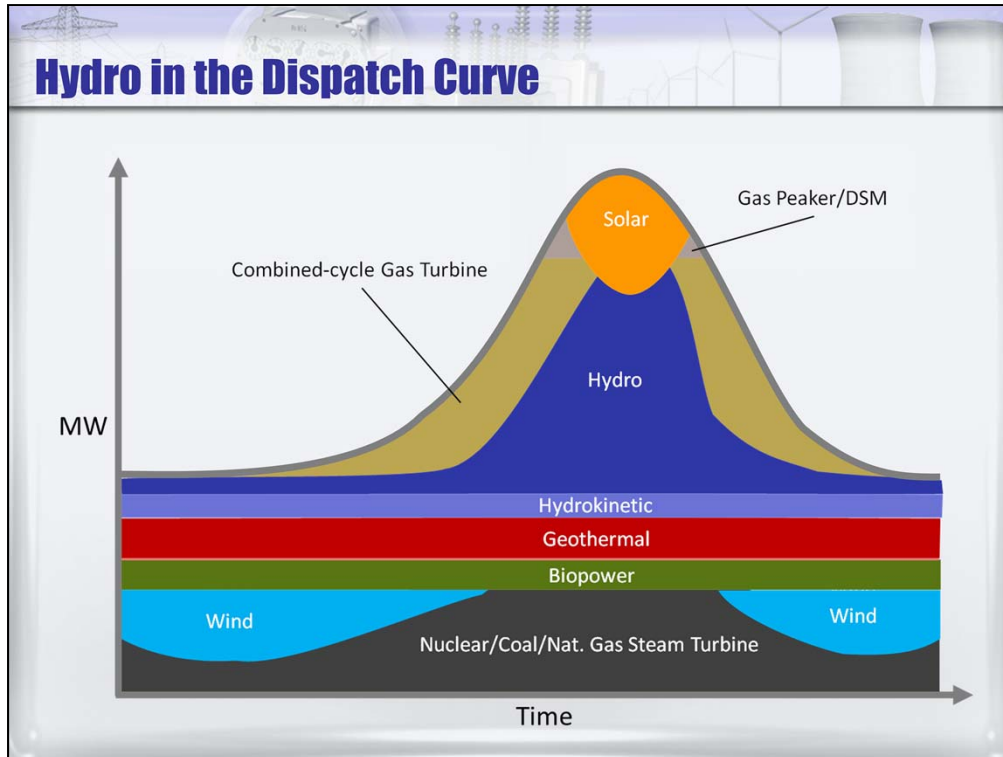
An issue for both run-of-the-river and impoundment units can be year-to-year variability. During times of drought output from hydro units can decline well below their nameplate capacity. This can put severe stress on electrical grids dependent on hydropower.

Variability/Dispatchability/Predictability

Hydrokinetic characteristics unknown



We do not have sufficient actual operating experience with hydrokinetic power to state its operating characteristics.



Since hydropower is usually cheap, and in the case of run-of-the-river not dispatchable, hydropower is often used for baseload needs. But with impoundment facilities, if there is a limited amount of water it is more economic to utilize the water during high-priced intermediate or peak times, so with these facilities hydro is sometimes used as an intermediate or peaking resource. Pumped hydro is almost always used as a peaking resource.

The intent with hydrokinetic power is to place facilities in locations with constant flows, resulting in baseload power. But we do not have sufficient operating experience to state for certain that this will occur.

Integration

Backup resources not needed

- Impoundment dispatchable
- Run-of-the-river predictable



Since impoundment facilities are dispatchable, and since run-of-the-river units are highly predictable and variability tends to be over longer periods of time, new flexible backup resources are not required to integrate hydropower onto the grid.

Integration

Backup generation may be required for low hydro years



In cases where water availability varies from year to year, backup generation may be required to cover power needs during low-hydro conditions.



Not enough is yet known about hydrokinetic to determine its integration characteristics.

Transmission Requirements

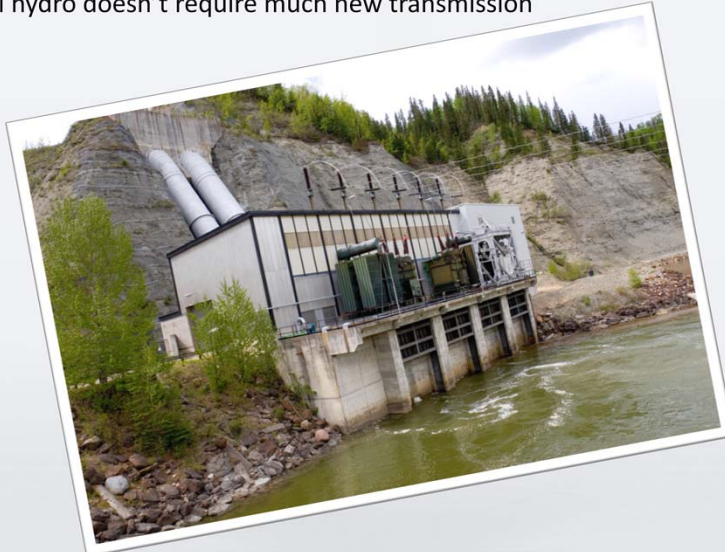
Large hydro requires new transmission



New large hydropower projects usually require new transmission since they are located in areas without existing transmission. Increasing the capacity of existing plants or adding capacity to new dams also is likely to require new or upgraded transmission since existing transmission lines at hydro projects are usually sized for the original capacity.

Transmission Requirements

Small hydro doesn't require much new transmission



Small hydro projects do not usually require much in the way of transmission construction due to their size and often the ability of nearby local loads to consume their output.

Transmission Requirements

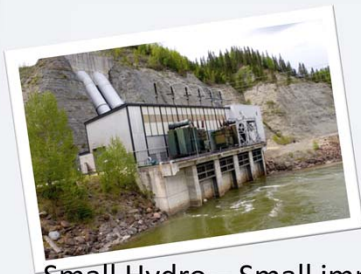
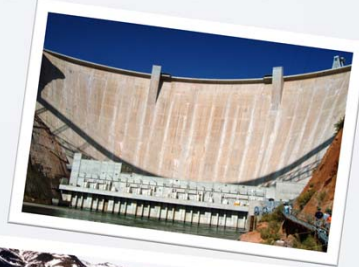
Hydrokinetic will require new transmission



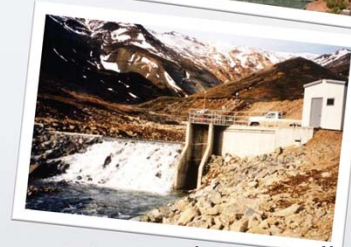
Hydrokinetic projects are expected to require new transmission construction since they will likely be located in offshore areas without access to existing transmission.

Hydro and the Environment

Large Hydro – High impacts



Small Hydro – Small impact



Micro Hydro – Small impact



Hydrokinetic – small impact expected

Environmental impacts for hydropower vary significantly depending on the size of the project. New large hydro projects have significant environmental impacts on local ecosystems and downstream habitats. Small and micro hydro projects usually have limited environmental impacts.

Hydrokinetic power is expected to have limited environmental impacts, but research needs to be done as pilot projects are implemented to determine whether this is indeed true.

Hydro and the Environment

Issue	Level of Impact		
	Large	Small	Micro
New transmission	High	Low	Low
Land use	High	Low	Low
Aesthetics	High	Low	Low
Wildlife	High	Low	Low
Manufacturing byproducts	Low	Low	Low
Air emissions	Low	Low	Low
Water Impacts	High	Low	Low
Extraction impacts	Low	Low	Low

As discussed earlier, new transmission requirements are significant with large hydro, so environmental impacts of transmission upgrades are potentially significant. For small and micro hydro transmission such impacts are usually small.

Land-use impacts are significant for large hydro but minimal for small and micro hydro.

Aesthetic issues may be significant for large hydro and may be considered negative or positive since reservoirs can be used for recreation. Aesthetic issues for small and micro hydro should be minimal.

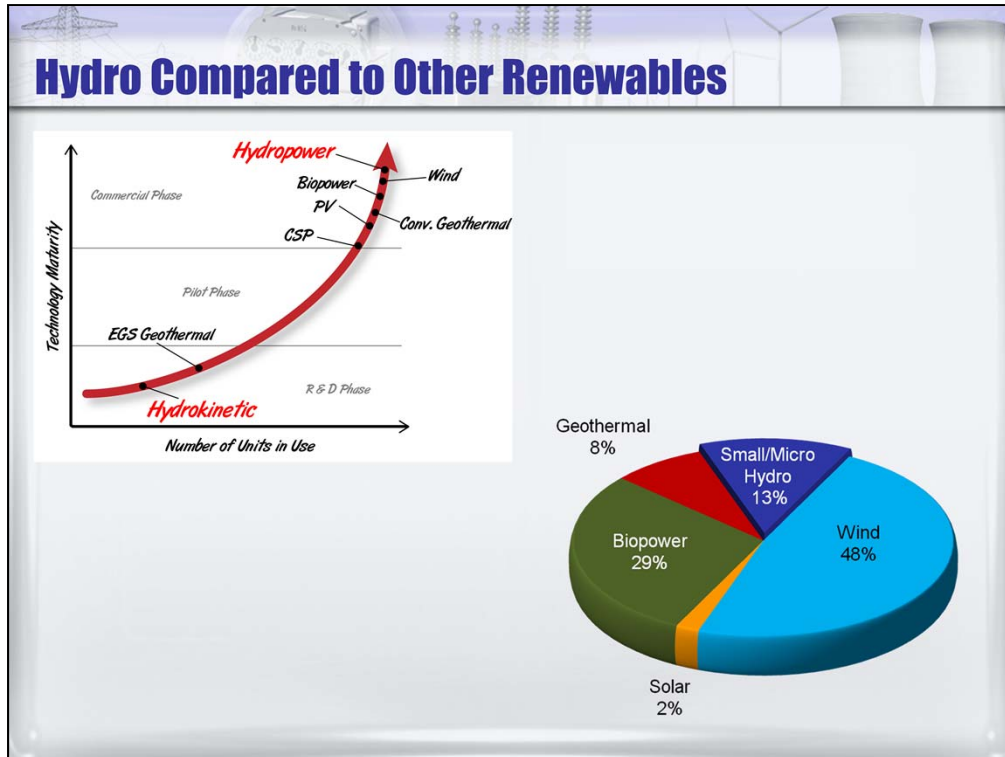
Impacts on wildlife are high for large hydro since downstream flows and fish migrations are interrupted. Small and micro hydro usually have minimal impacts on wildlife, but impacts on fisheries must be considered.

Manufacturing by-products are not an issue for hydro.

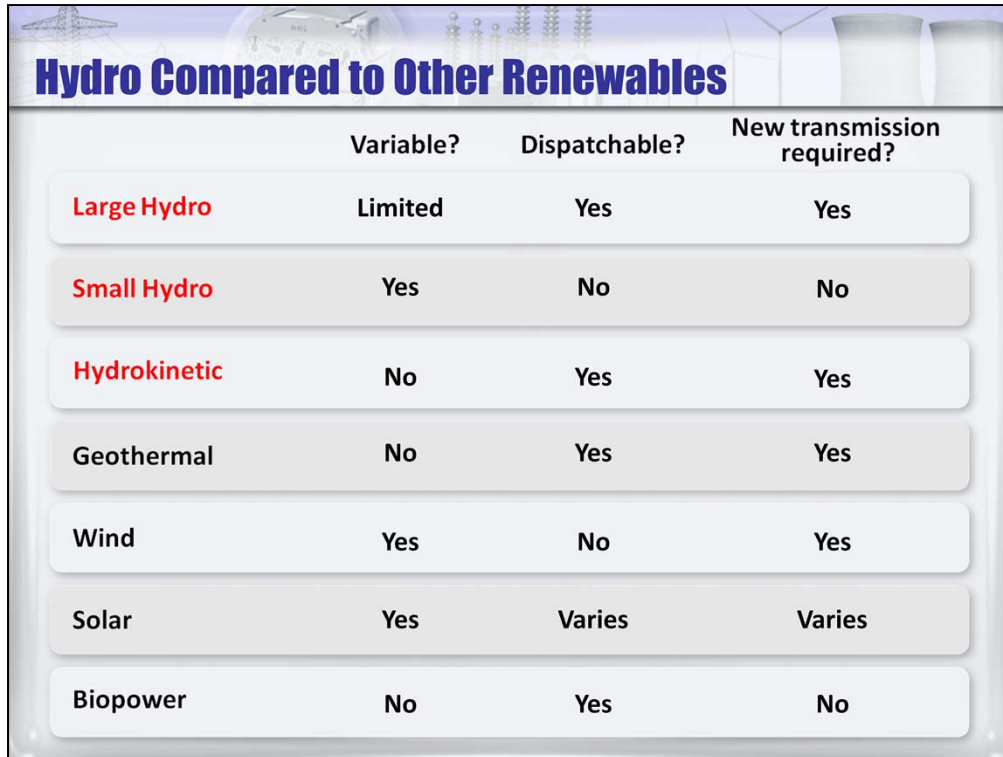
In most cases air emissions are not an issue for hydro, but there is a concern that large hydro projects may lead to increased greenhouse gas emissions due to releases of carbon dioxide from plants decaying on the bottom of the reservoir.

Water impacts can be significant for large hydro since water quality is impacted by reservoirs and evaporation leads to water loss. But the ability of reservoirs to store water can be a benefit both for agriculture and for municipal water systems. Water impacts are low for small and micro hydro.

Extraction impacts are minimal for hydro.



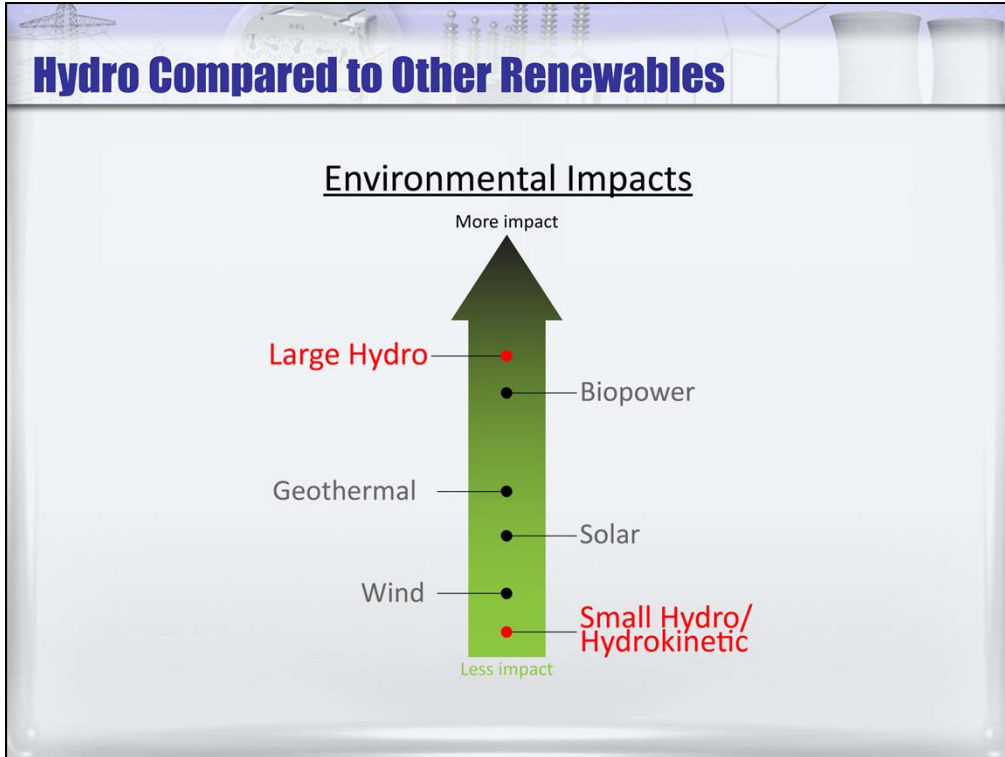
Compared to other renewable technologies, hydropower is commercially mature. Hydropower's current output in the U.S. is about double the output of all other renewable technologies combined. If just small and micro hydro plus hydrokinetic power are counted, then the current output is less than wind output but more than biopower.



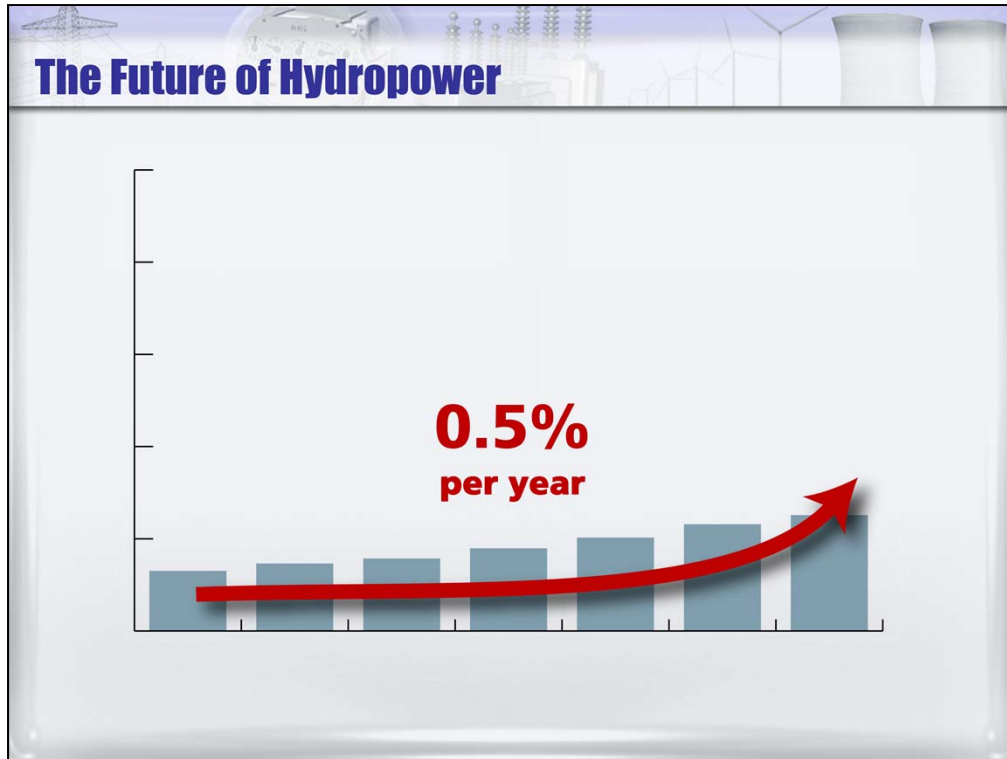
The image shows a table titled "Hydro Compared to Other Renewables" with a decorative header featuring a power line tower, a hydroelectric dam, and wind turbines. The table compares various renewable energy sources based on three criteria: Variable?, Dispatchable?, and New transmission required?.

	Variable?	Dispatchable?	New transmission required?
Large Hydro	Limited	Yes	Yes
Small Hydro	Yes	No	No
Hydrokinetic	No	Yes	Yes
Geothermal	No	Yes	Yes
Wind	Yes	No	Yes
Solar	Yes	Varies	Varies
Biopower	No	Yes	No

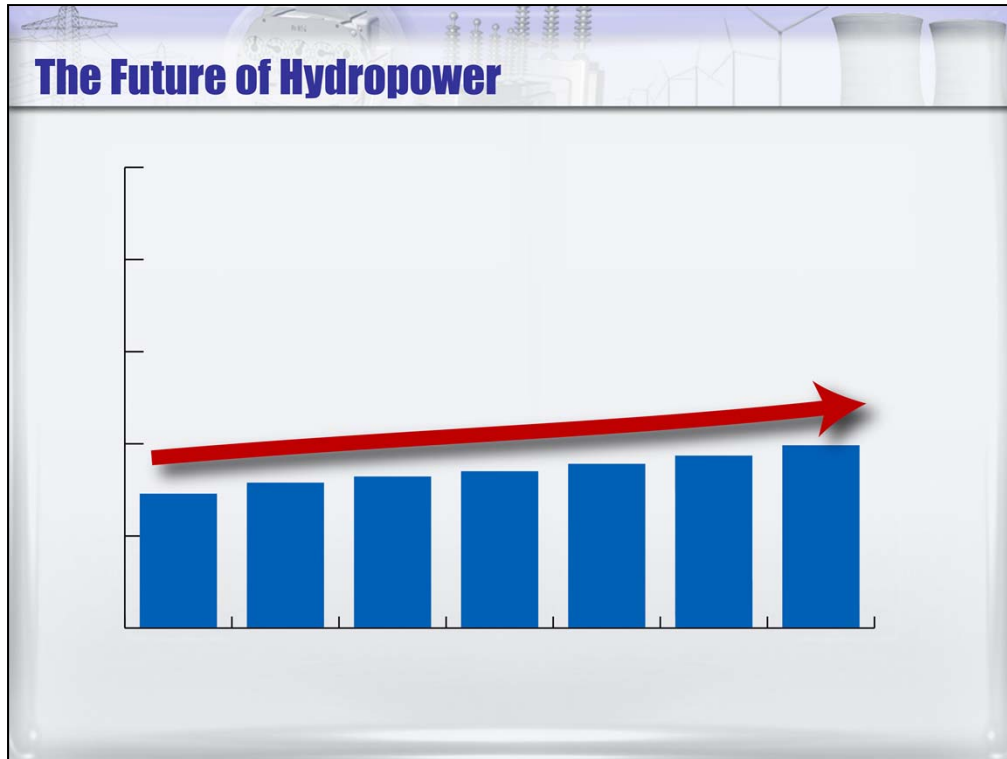
Unlike wind and solar, impoundment hydro power has the advantage of having limited variability and being dispatchable while run-of-the-river is highly predictable and is dispatchable in some cases. It is assumed that hydrokinetic power will be generally non-variable and dispatchable. Unlike wind and solar, transmission requirements are low in most cases for small and micro hydro. Transmission needs are greater for large hydro and are expected to be greater for hydrokinetic.



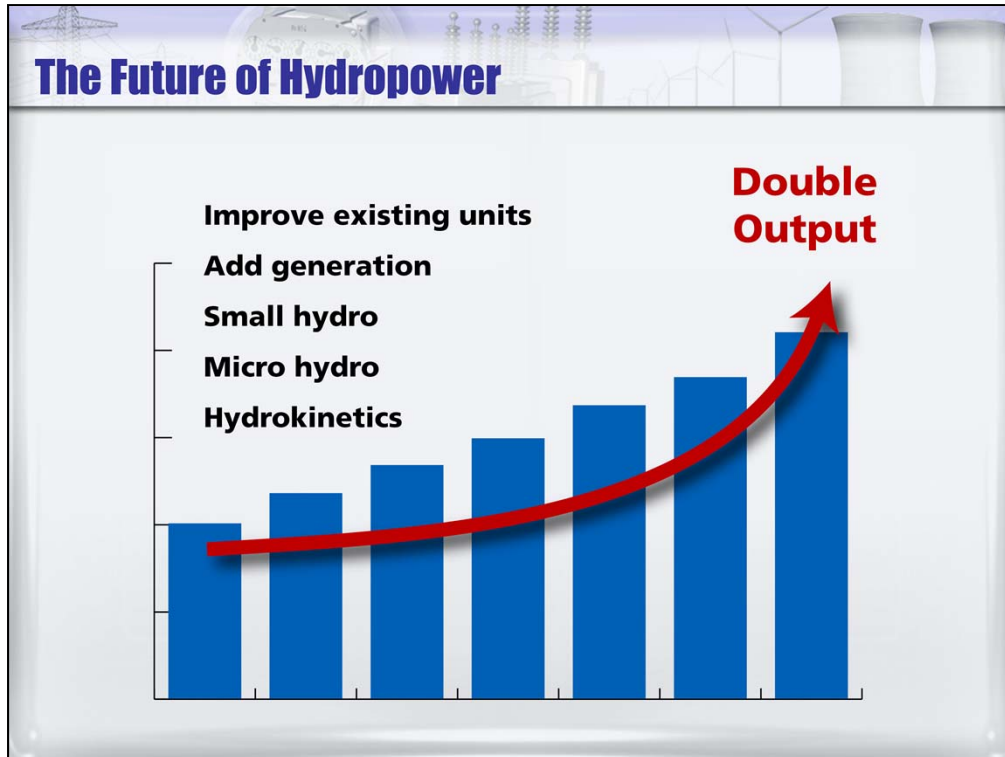
Like wind and solar, environmental impacts are low for small or micro hydro, but they can be significant for large hydro. It is expected environmental impacts will be low for hydrokinetic, but additional research needs to be done.



Hydropower capacity and output is expected to remain relatively flat. The U.S. Energy Information Administration (EIA) projects that hydropower capacity will grow by about 0.1% per year over the next 25 years with output growing by about 0.5% per year.



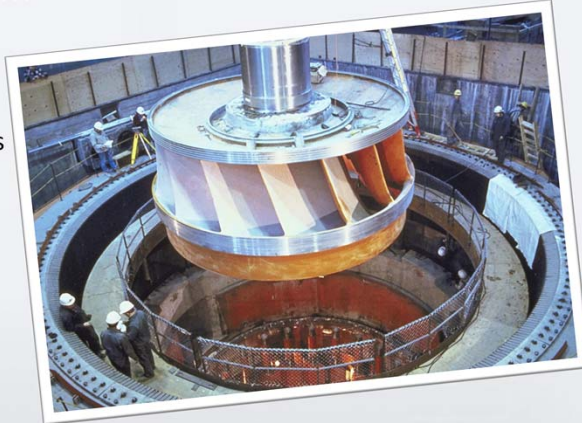
According to the EIA's 2011 projections, hydropower will be only slightly higher than non-hydro renewable power by 2035.



However, other groups within the Department of Energy have suggested that a concentrated effort to repower existing units with larger and more efficient turbines, add generating capabilities to dams that are currently not powered, and add small, micro hydro and hydrokinetics could result in a doubling of hydro capacity and output during that timeframe.

Future Areas for Research

- Improve efficiency
- Identify small/micro resources
- Efficient turbines
- Low head/flow turbines
- Variable flow turbines
- Water/wastewater turbines
- Dam safety
- Reduce fish impacts



Research and development of hydro power and hydrokinetic power are at two very different stages.

For hydro power, research centers around making existing technologies more efficient and identifying resources for construction of small and micro hydro projects that will have minimal impact on the environment. Some areas of current research include developing more efficient turbines, developing low head and low flow turbines, developing variable flow turbines, developing turbines for use in water and waste water pipes, improving dam safety, and developing new ways to minimize impacts on fish populations.

Future Areas for Research

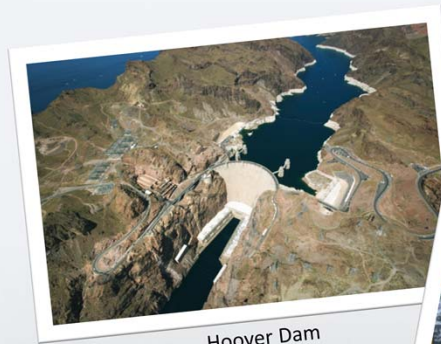
- Move from pilot to commercial
- Prove technology
- Durability testing
- Standardize technology



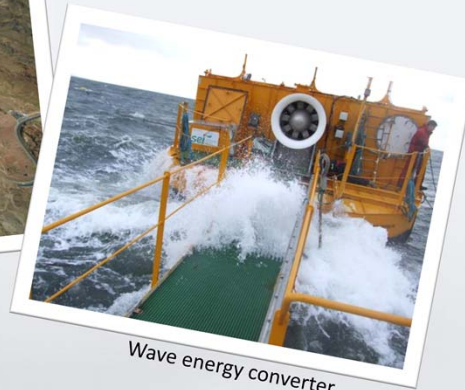
For hydrokinetic power, research is focused on moving technologies from the lab and from pilot projects into commercial projects. Current research includes proving that concepts actually work when applied in the field, component testing to determine durability under marine conditions, and technology standardization.

Summary

Both hydropower and hydrokinetic power describe electricity derived by converting the kinetic or potential energy of water into electricity. The two differ by the method that is used to capture the energy of water.



Hoover Dam



Wave energy converter

Now let's quickly review some of the important points you've learned in this module.

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Summary

Hydropower uses either impoundment of a river behind a dam or diversion of a river flow through a penstock or canal to direct moving water over a turbine.



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Summary

Hydrokinetic power uses natural flows in ocean currents, tides and inland waterways or the motion of waves without impoundment or diversion.



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Hydro facilities are divided into large hydro, small hydro and micro hydro.



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Facilities with significant water storage in a reservoir are called impoundment facilities while facilities without are called run-of-the-river.



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Summary

A related facility to an impoundment facility is pumped hydro which has reservoirs both upstream and downstream with the capability to pump water back up hill.



Seneca Pumped Storage Station and Kinzua Dam

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Summary

Hydrokinetic technologies are classified as either Wave Energy Conversion devices (WECs) or rotating devices.



Galway Bay Wave Device

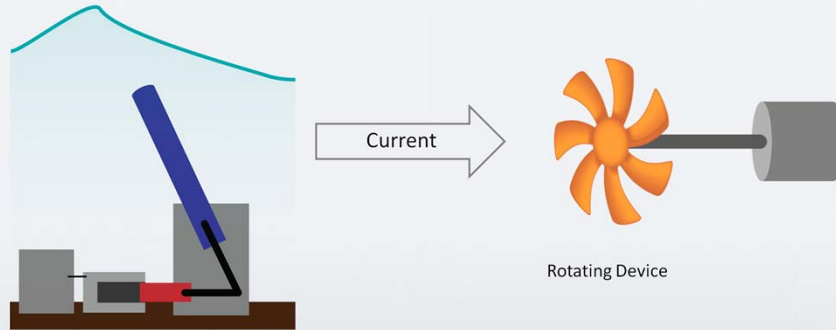


Seaflow Tidal Stream Generator

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Summary

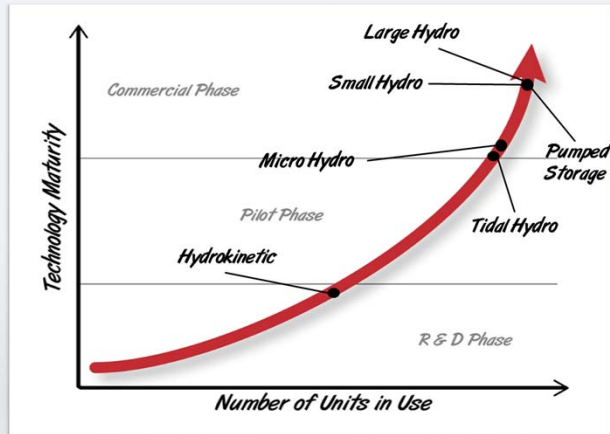
WECs use the motion of two or more devices relative to each other. Rotating devices are spun by the kinetic energy of moving water as tidal streams, ocean currents, or river currents strike a rotor.



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Summary

Hydro power is a mature, commercial technology while hydrokinetic power is in the research and development phase.



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Summary

The total nameplate rating for hydropower in the U.S. as of the end of 2010 was about 78,000 MW, which made up about 7% of total electric generation capacity in the U.S. The nameplate rating for pumped storage was 20,500 MW, which is about 2% of total U.S. capacity.

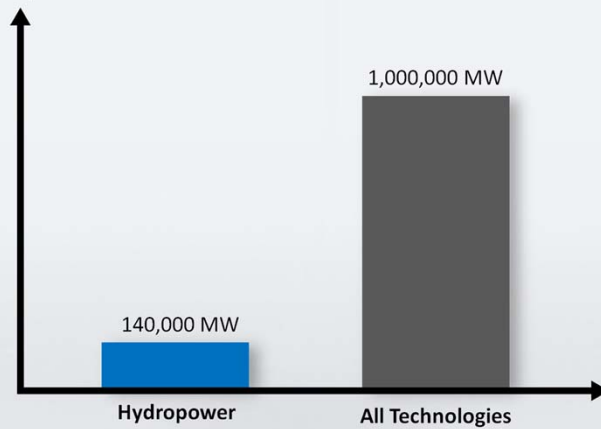


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The nameplate rating for pumped storage was 20,500 MW, which is about 2% of total U.S. capacity. Of the 78,000 MW, about 8,000 MW was small hydro and about 1 MW was micro hydro.

Summary

Hydropower is currently and is expected to continue to be an important contributor to overall electric generation capacity, but it will not be a primary source of electricity for the U.S. The potential for hydrokinetic energy is not yet known.



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Summary

Capacity factors for new hydropower projects are expected to range from 40 to 90% depending on the nature of the specific facility. Not enough is yet known to determine expected capacity factors for hydrokinetic projects, but they are expected to be high.

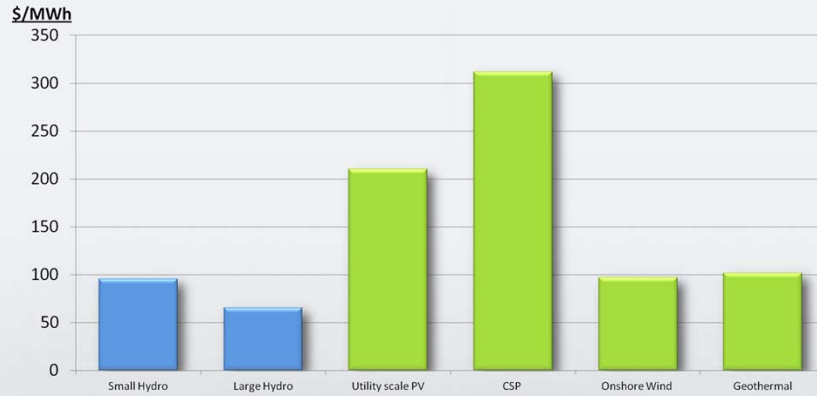


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Summary

In general, hydro power costs are at the low end of renewable power costs. Not enough is yet known to state hydrokinetic costs.

Levelized Cost for Renewables



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Summary

Impoundment and pumped storage hydro units are non-variable and dispatchable in the short term although hydro output may vary from year to year based on water conditions. Run-of-the-river units are variable but highly predictable and generally non-dispatchable except for units with pondage.



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