Renewable Energy and Energy Efficiency for Tribal Community and Project Development

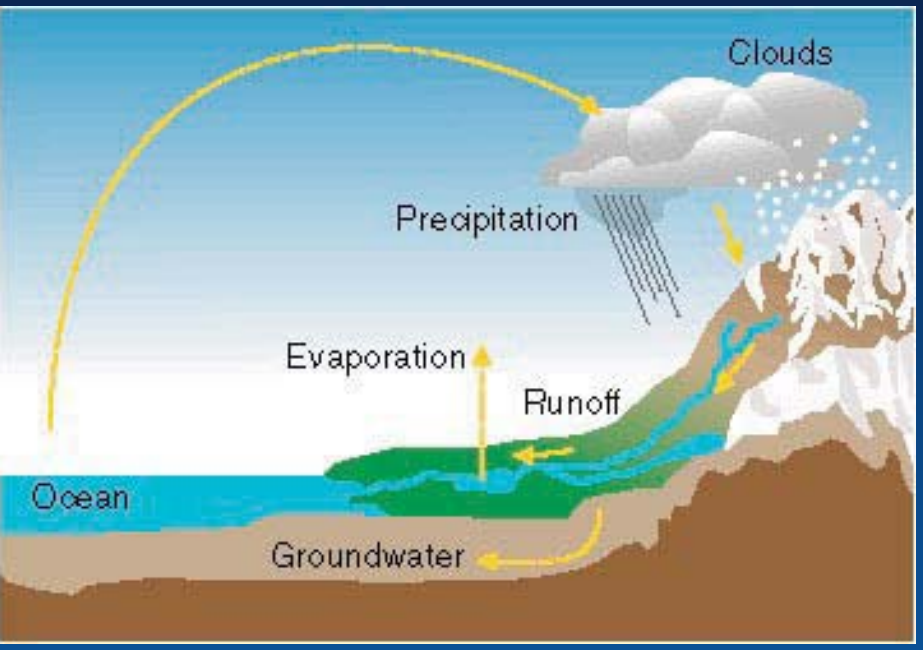
Overview of Hydroelectricity
and
Case Study

Faline Haven

National Renewable Energy Laboratory

January 21-24, 2008
Sacramento, CA

Hydroelectricity



The hydrologic cycle
http://hydropower.inel.gov/hydrofacts/how_hydro_works.shtml

- **Hydropower** or **hydraulic power** is the force or energy of moving water. It may be captured for some useful purpose.

Types of Water Power

Undershot water wheels on the Orontes River in Hama, Syria

Waterwheels, used for hundreds of years to power mills and machinery

Hydroelectricity, usually referring to hydroelectric dams or run-of-the-river setups.

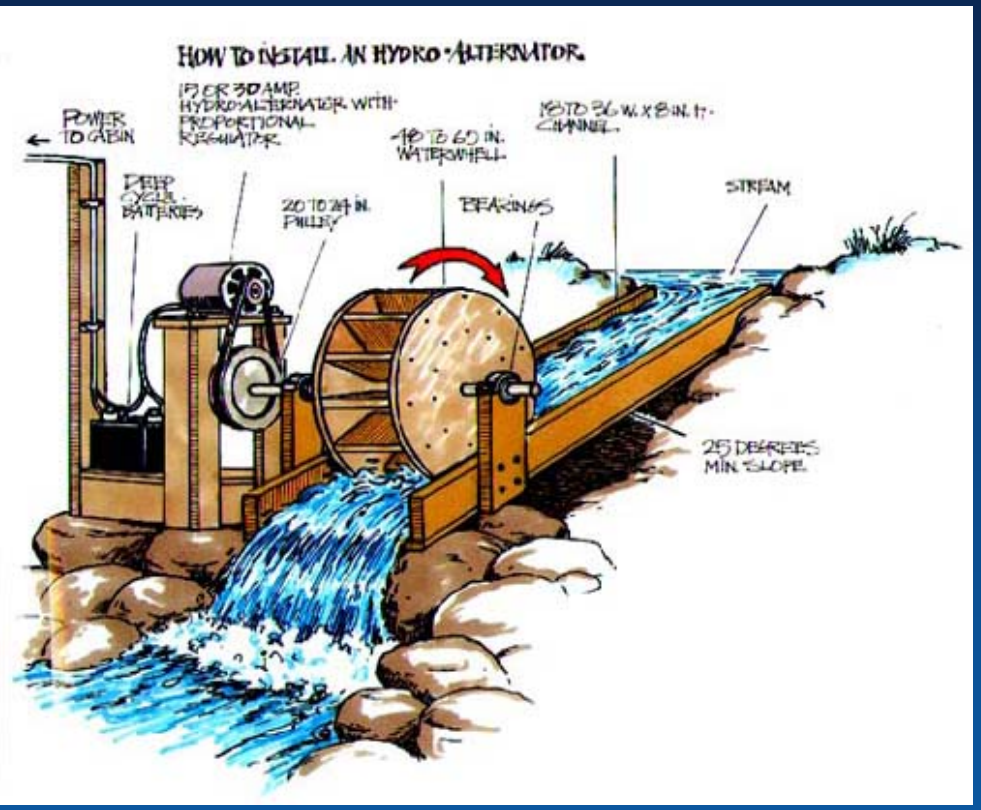
Damless hydro, which captures the kinetic energy in rivers, streams and oceans.

Tidal power, which captures energy from the tides in horizontal direction.

Tidal stream power, which does the same vertically

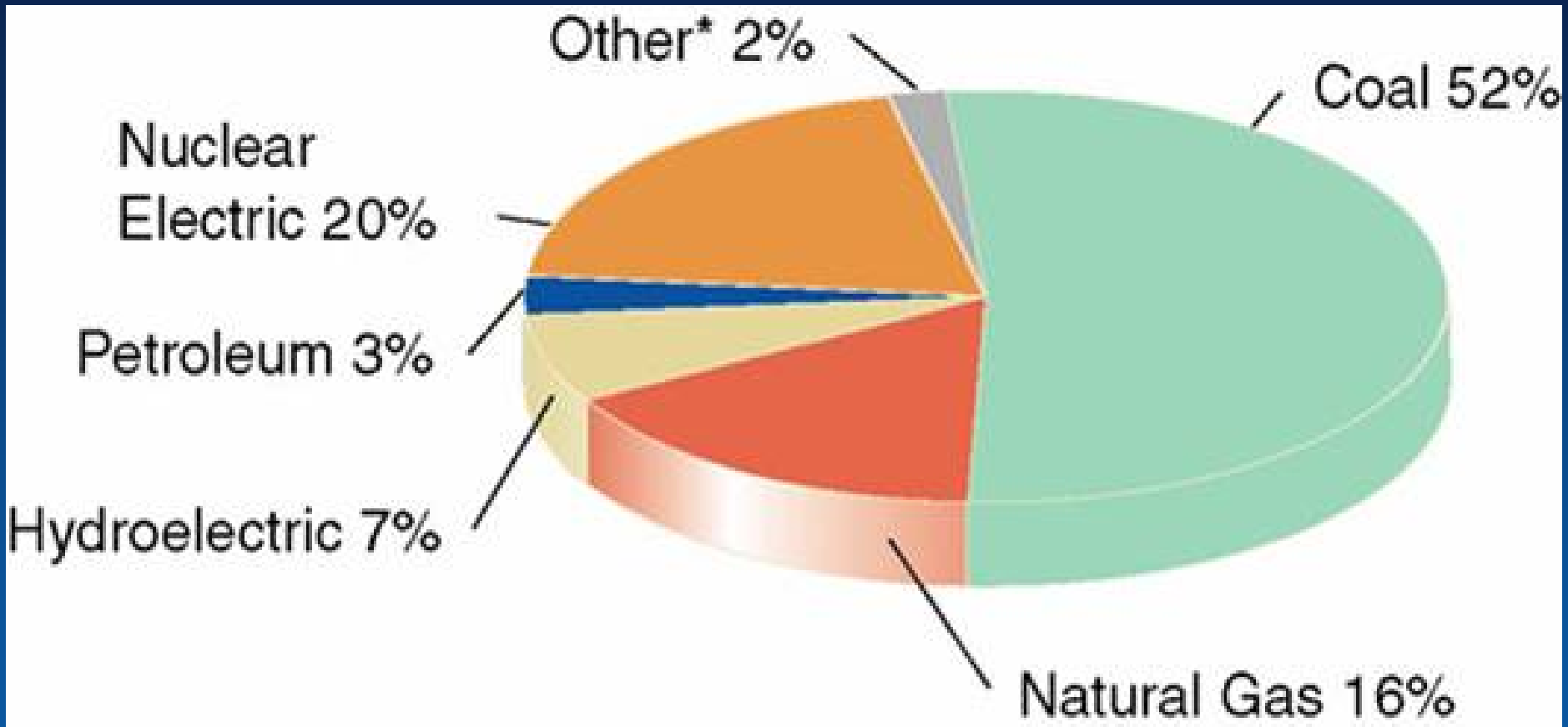
Wave power, Wave energy conversion devices capture mechanical power from the waves and use it to directly or indirectly power a turbine and a generator.

Hydroelectricity Facts



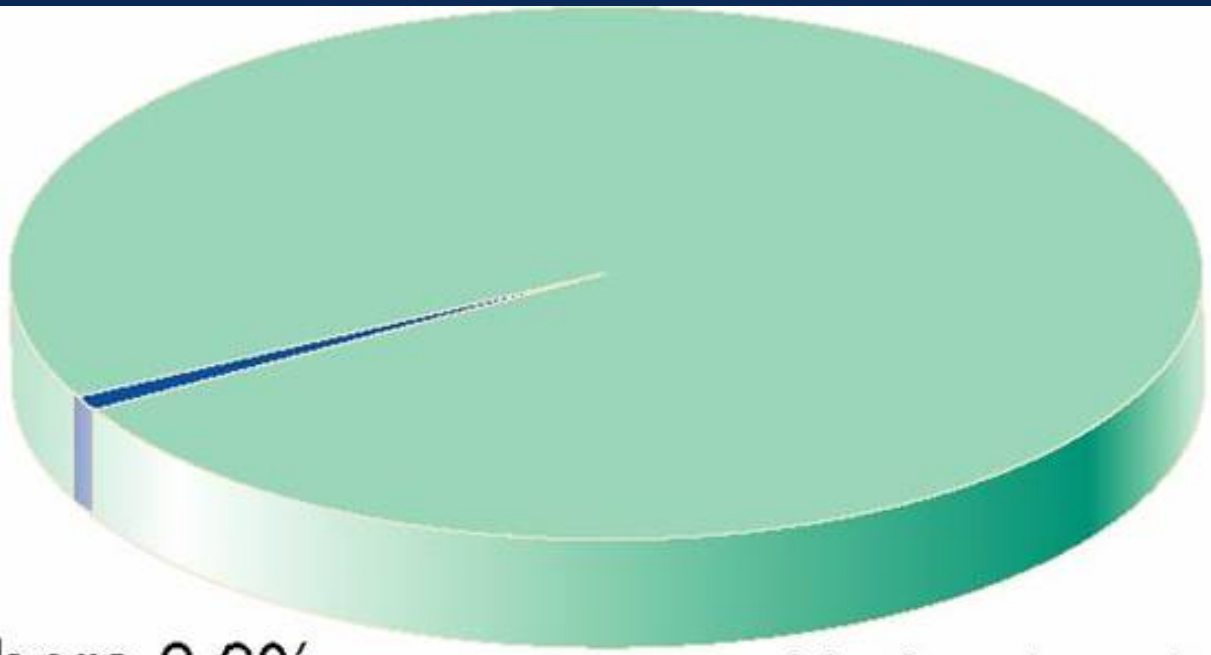
- Hydroelectric power now supplies about 715,000 MWe or 19% of world electricity
- hydro power is normally applied to peak load demand because it is readily stopped and started
- Hydropower supplies 9 percent of the country's electricity and accounts for 49 percent of all renewable energy used in the U.S

USA Energy Consumption, 2001



Source: EIA, Electric Power Monthly, March 2001. Tables 3 & 58.
* Other includes geothermal, biomass, wind, photovoltaic, and solar thermal. Includes utility and nonutility generation.

Percentage of Renewable Energy Production in the USA

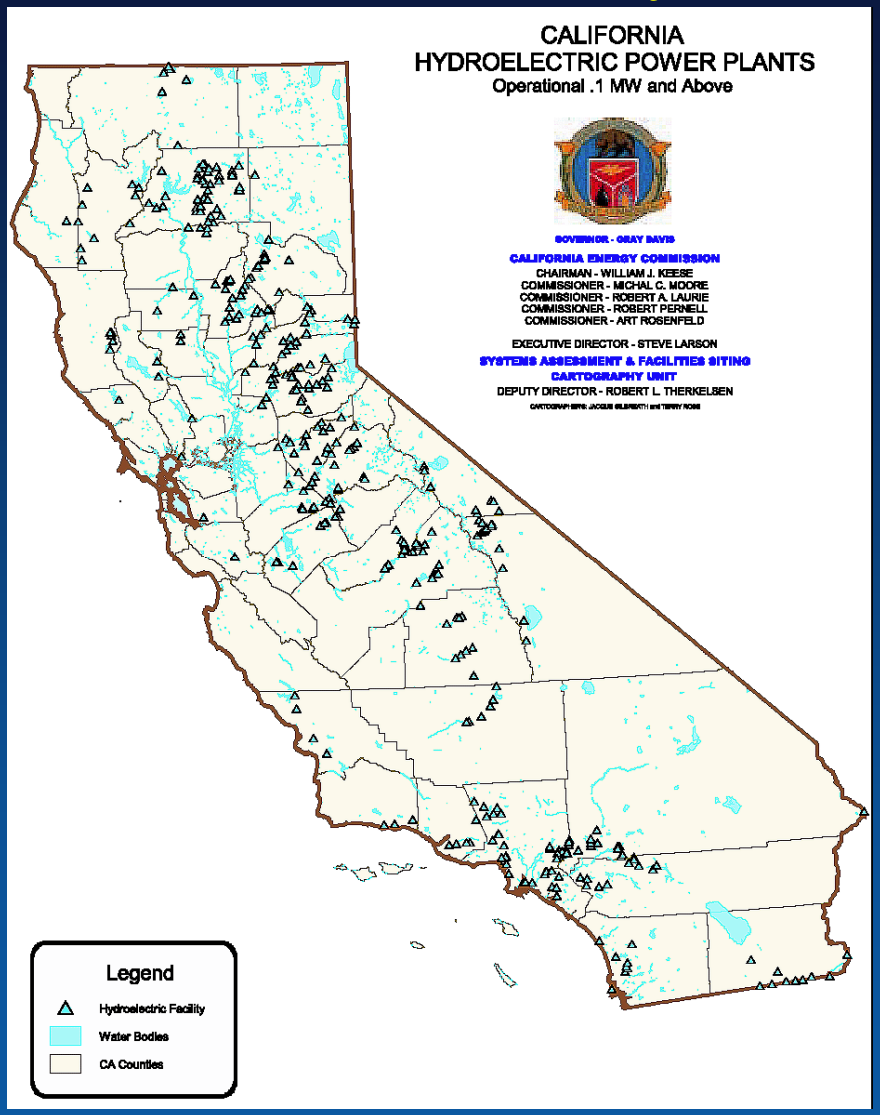


Total others 0.9%
(Geothermal 0.6%)
(Biomass 0.8%)
(Wind 0.01%)
(Photovoltaic 0.001%)

Hydroelectric 99.1%

Source: EIA, Electric Power Monthly, March 2001, Tables 5 & 60.

California Hydroelectric Power Plants



http://www.energy.ca.gov/electricity/hydro_power_plants.html

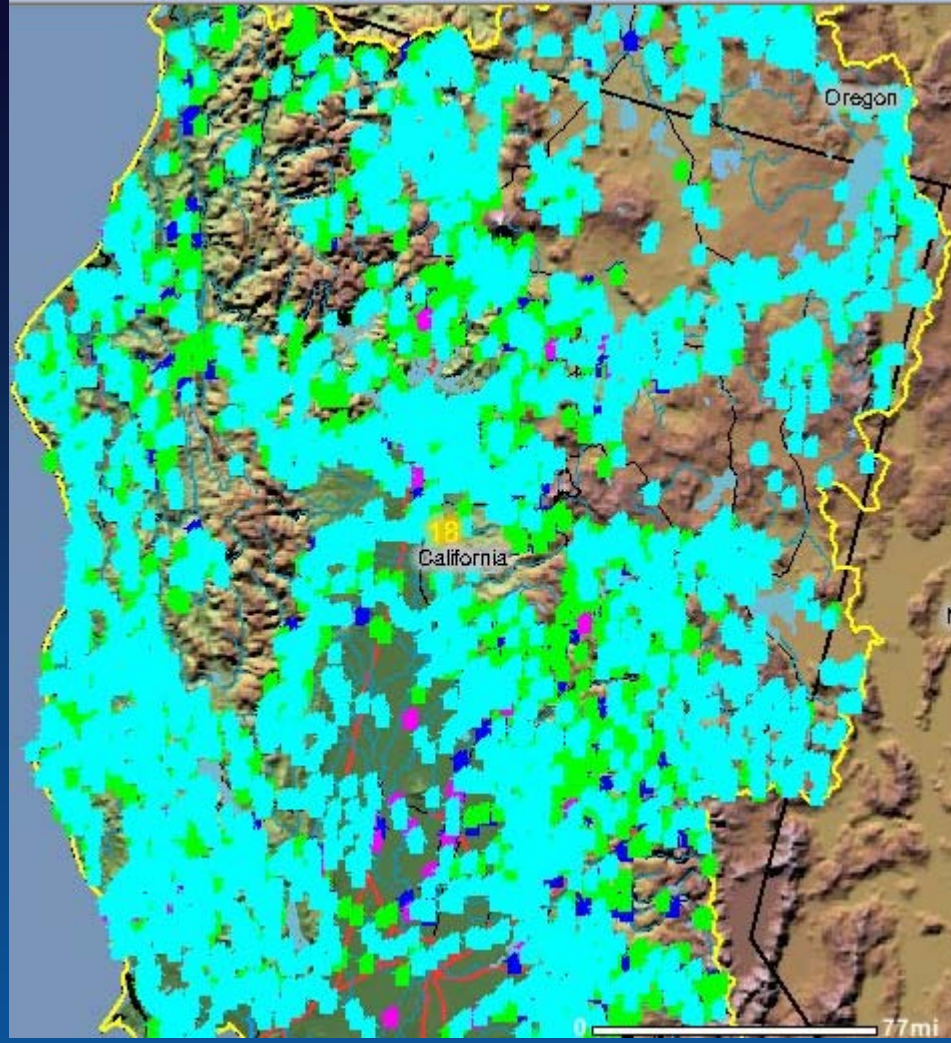
- Over one-half of the total U.S. hydroelectric capacity for electricity generation is concentrated in three States (Washington, California and Oregon) with approximately 27 percent in Washington, the location of the Nation's largest hydroelectric facility – the Grand Coulee Dam.
- CA is ranked second in generation

Potential Resources

Virtual Hydropower Prospector
Region Selector
http://hydropower.id.doe.gov/prospector/r_selector.shtml

- Conventional hydro (low power to large hydro = 62,300 MW):
- –Capacity gains at large & small hydro = 4,300 MW
- –New small (<30 MW) and low (<1 MW) hydro = 58,000 MW
- –New hydro at existing dams = (16,700 MW included above)
- –[Efficiency gains (4%) = 3,100 MW]
- •Hydrokinetic = 12,800 MW (tidal only assessed for 5 states, ocean current not assessed)
- •Wave Energy = 10,000 to 20,000 MW
- •Pump storage not assessed
- **•TOTAL = 85,100 -95,100 MW**

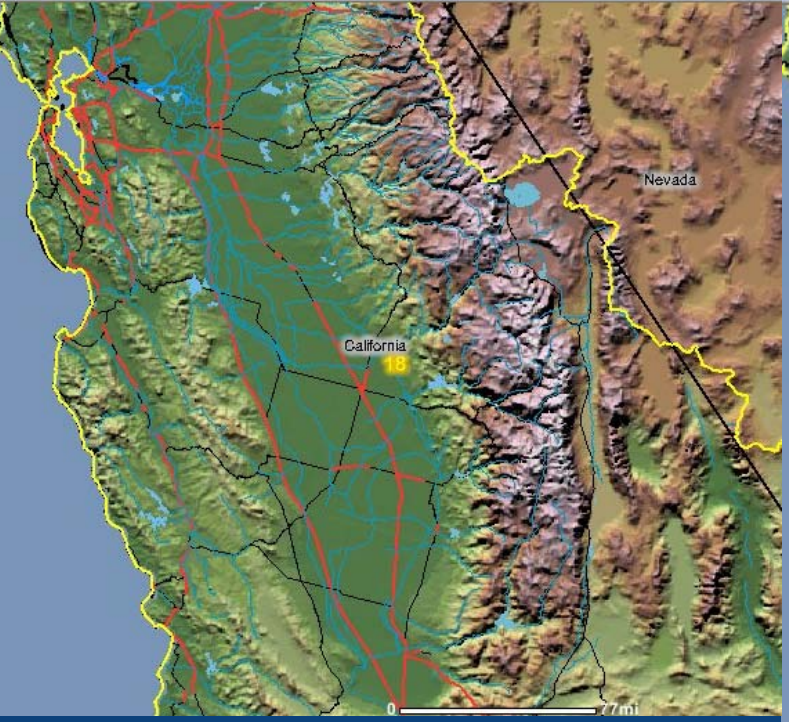
Small Hydropower Opportunities in California

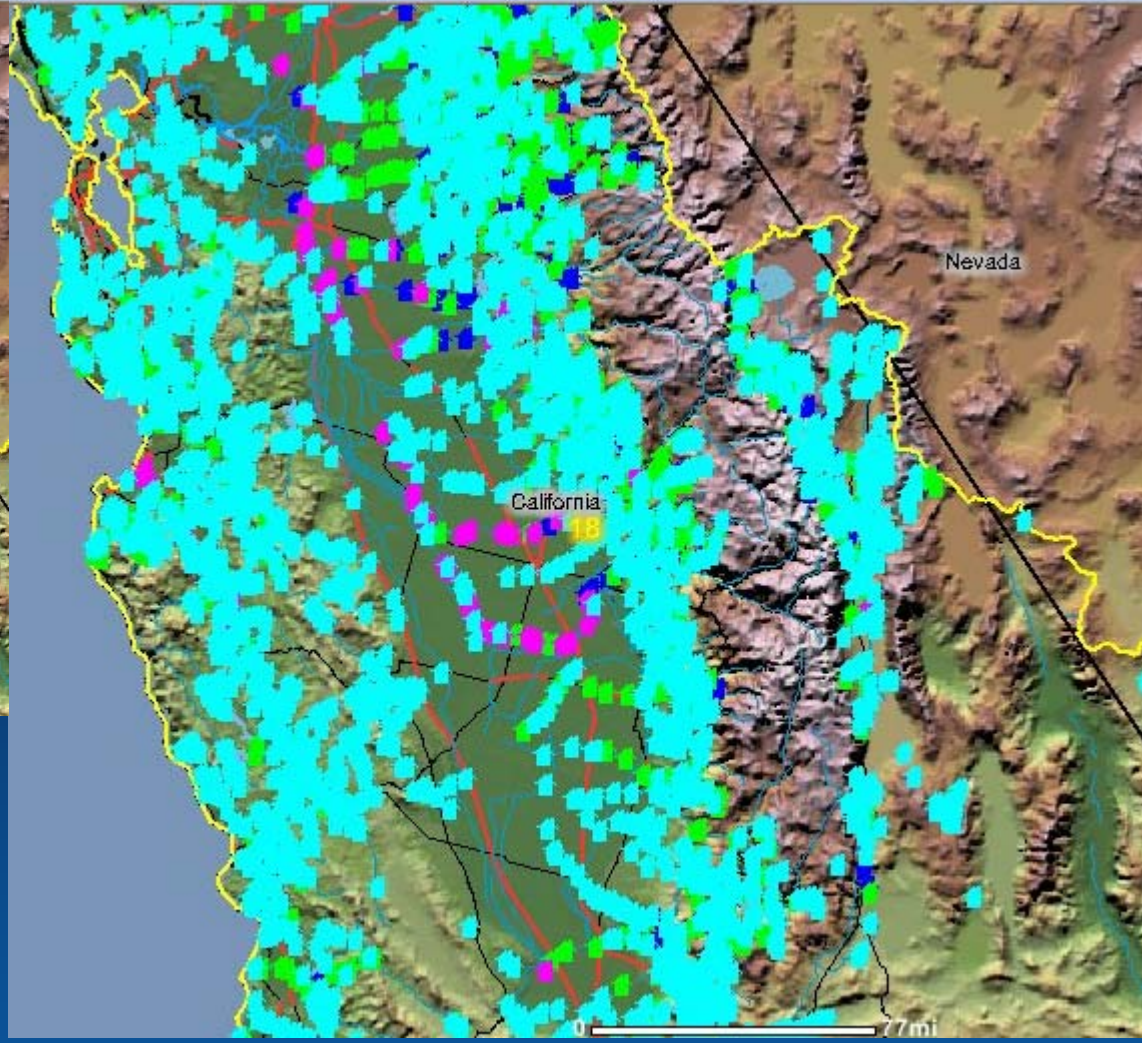


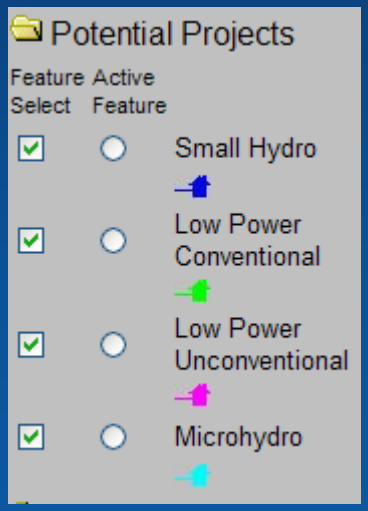
Potential Projects

Feature Select	Active Feature	
☑	○	Small Hydro
☑	○	Low Power Conventional
☑	○	Low Power Unconventional
☑	○	Microhydro

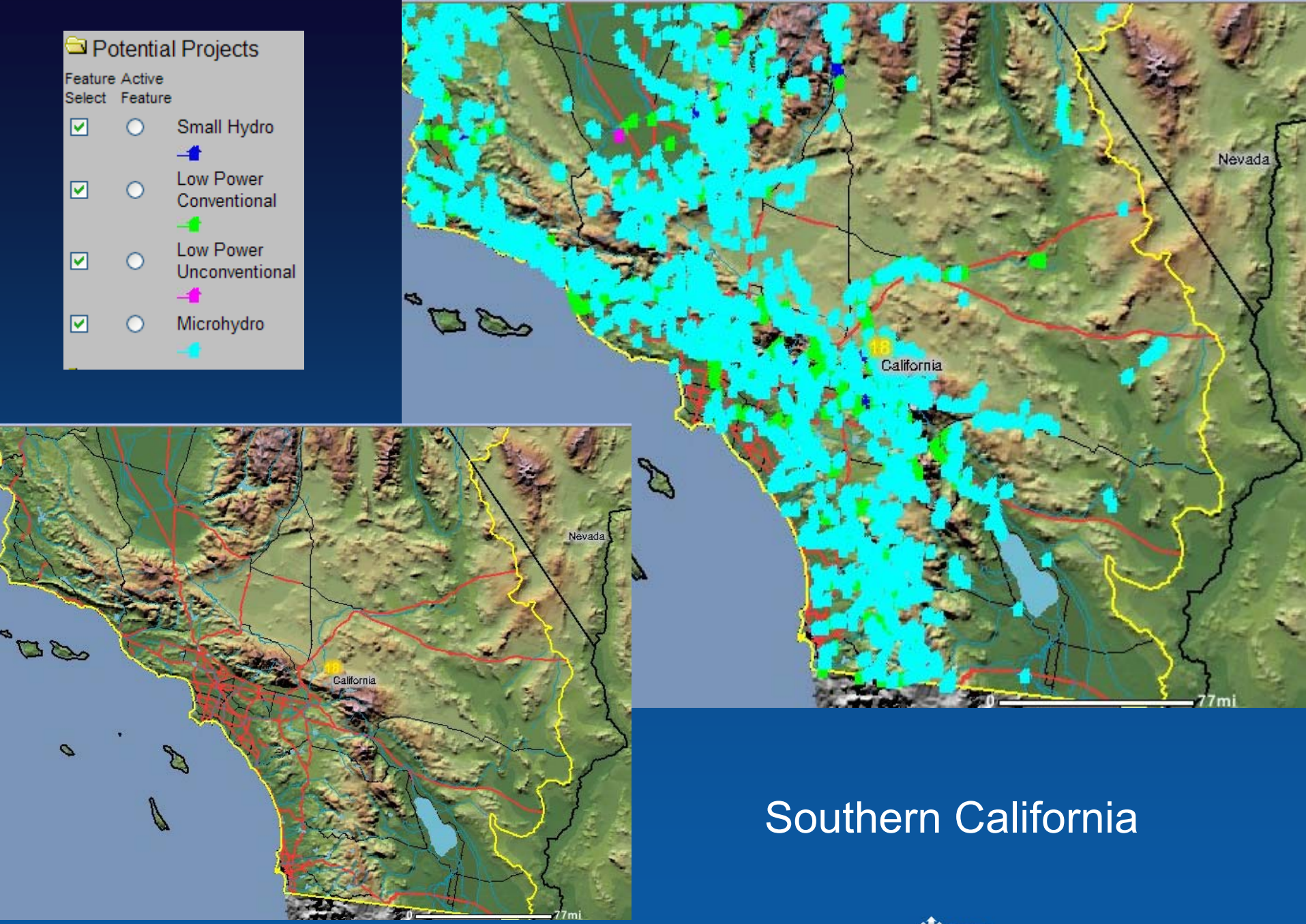
Northern California





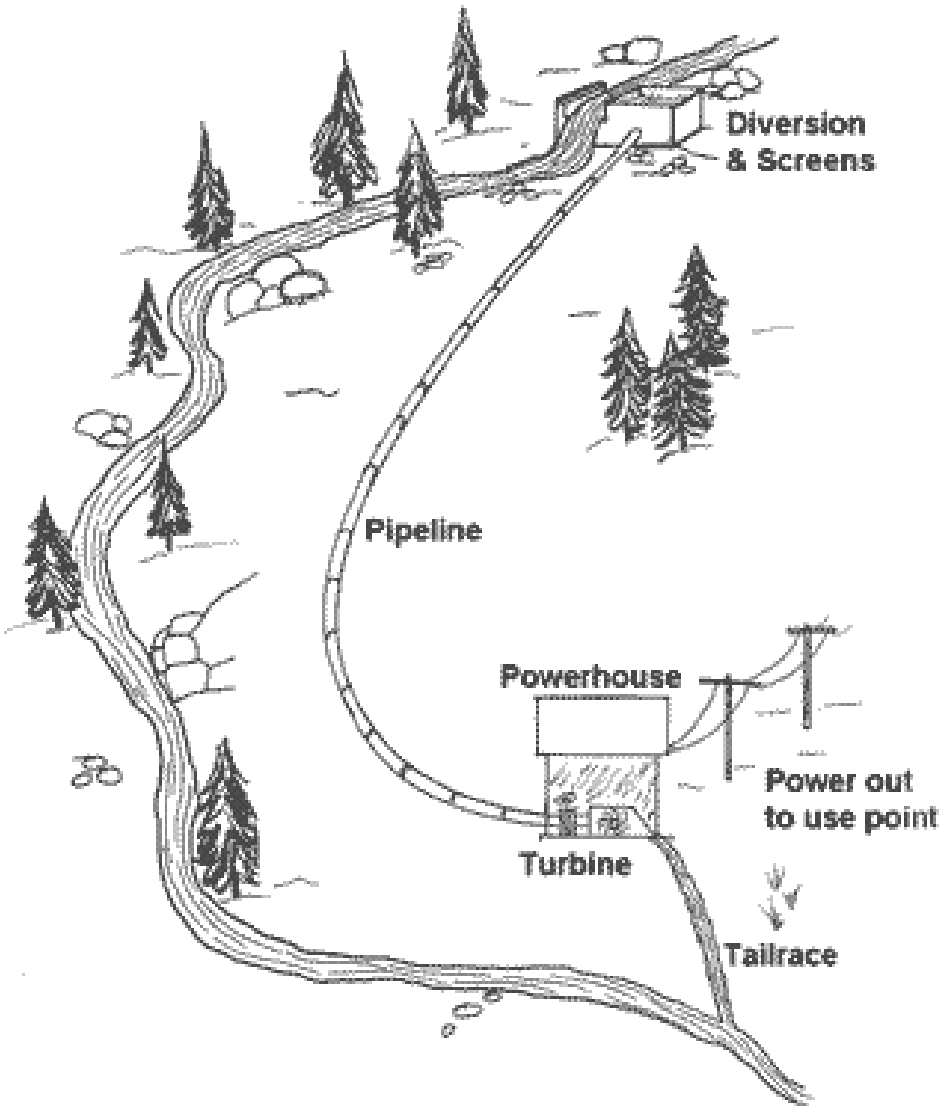


Central California



Southern California

Hydroelectricity Components



Hydro power plants are composed of three basic components:

1. A water diversion or intake system
2. a pipeline to move the water, and
3. a powerhouse.

- A key element in the selection of a site, is the height elevation of the pipeline from the water intake to the powerhouse. This height elevation creates the water pressure needed at the bottom of the pipeline as it enters the powerhouse to drive the turbine and in-turn the generator.

- Two terms used to describe the amount of water pressure created as the water flows downhill, and the volume of water at the end of the pipeline are "Head and Flow" respectively.

- The Head and Flow determines everything from the size of the turbine and generator to the diameter of the pipeline. For the most efficient hydro-power plant, the turbulence caused by surface friction, and the vibration of the individual components must be kept to a minimum. This means all surfaces must be smooth and polished for the highest efficiency.

Hydroelectricity Physics

$$\text{Power (kW)} = 10 \times \text{Flow } (m^3/s) \times \text{Head (m)} \times \eta$$

- Hydropower converts the energy in flowing water into electricity. The quantity of electricity generated is determined by the volume of water flow and the amount of "head" (the height from turbines in the power plant to the water surface) created by the dam. The greater the flow and head, the more electricity produced.
- **Simple Hydro Power model:**
- *(Head (ft) x Flow in Cubic Feet per Second) / 11.8 = P = KW output. or*
  (Head (ft) x Flow in Cubic Feet per Second) / 8.8 = HP output.

  Then take KW output x Hrs producing x Generating Rate ($/KWH) = $

How Much Electricity Can a Hydroelectric Plant Make?

The amount of electricity a hydropower plant produces depends on two factors:

- **How Far the Water Falls.** The farther the water falls, the more power it has. Generally, the distance that the water falls depends on the size of the dam. The higher the dam, the farther the water falls and the more power it has. Scientists would say that the power of falling water is "directly proportional" to the distance it falls. In other words, water falling twice as far has twice as much energy.

- **Amount of Water Falling.** More water falling through the turbine will produce more power. The amount of water available depends on the amount of water flowing down the river. Bigger rivers have more flowing water and can produce more energy. Power is also "directly proportional" to river flow. A river with twice the amount of flowing water as another river can produce twice as much energy.

Can I Figure Out How Much Energy a Dam in My Area Can Make?

- Let's say that there is a small dam in your area that is not used to produce electricity. Maybe the dam is used to provide water to irrigate farmlands or maybe it was built to make a lake for recreation. As we explained above, you need to know two things:
- **How far the water falls.** From talking to the person who operates the dam, we learn that the dam is 10 feet high, so the water falls 10 feet.
- **Amount of water flowing in the river.** We contact the United States Geological Survey, the agency in the U.S. that measures river flow, and learn that the average amount of water flowing in our river is 500 cubic feet per second.

Can I Figure Out How Much Energy a Dam in My Area Can Make?

Now all we need to do is a little mathematics. Engineers have found that we can calculate the power of a dam using the following formula:

Power = (Height of Dam) x (River Flow) x (Efficiency) / 11.8

- **Power -** The electric power in kilowatts (one kilowatt equals 1,000 watts).
- **Height of Dam-** The distance the water falls measured in feet.
- **River Flow-** The amount of water flowing in the river measured in cubic feet per second.
- **Efficiency -** How well the turbine and generator convert the power of falling water into electric power. For older, poorly maintained hydroplants this might be 60% (0.60) while for newer, well operated plants this might be as high as 90% (0.90).
- **11.8-** Converts units of feet and seconds into kilowatts. For the dam in our area, lets say we buy a turbine and generator with an efficiency of 80%.

Can I Figure Out How Much Energy a Dam in My Area Can Make?

Then the power for our dam will be:

Power = (10 feet) x (500 cubic feet per second) x (0.80) / 11.8 = **339 kilowatts**

- To get an idea what 339 kilowatts means, let's see how much electric energy we can make in a year.

- Since electric energy is normally measured in kilowatt-hours, we multiply the power from our dam by the number of hours in a year.
- **Electric Energy** = (339 kilowatts) x (24 hours per day) x (365 days per year) = **2,969,000 kilowatt hours.**

- The average annual residential energy use in the U.S. is about 3,000 kilowatt-hours for each person. So we can figure out how many people our dam could serve by dividing the annual energy production by 3,000.

- **People Served** = 2,969,000 kilowatts-hours / 3,000 kilowatt-hours per person) = **990 people.**
- So our local irrigation or recreation dam could provide enough renewable energy to meet the residential needs of 990 people if we added a turbine and generator.

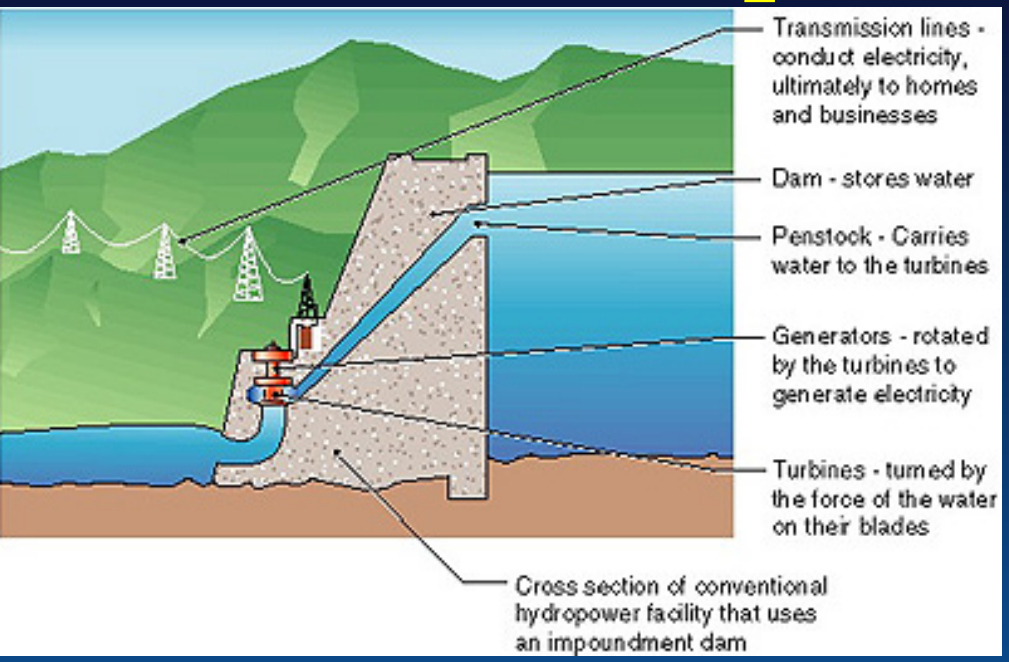
Hydroelectricity
Power Plant Overview

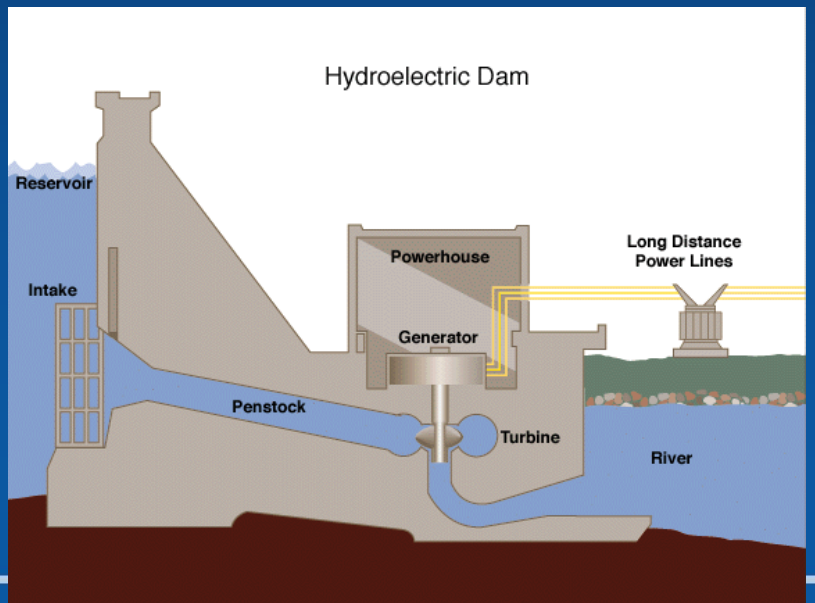
Overlooking Snoqualmie Falls is the historic Salish Lodge & Spa, WA

There are three types of hydropower facilities:

- impoundment,
- diversion, and
- pumped storage

Impoundment





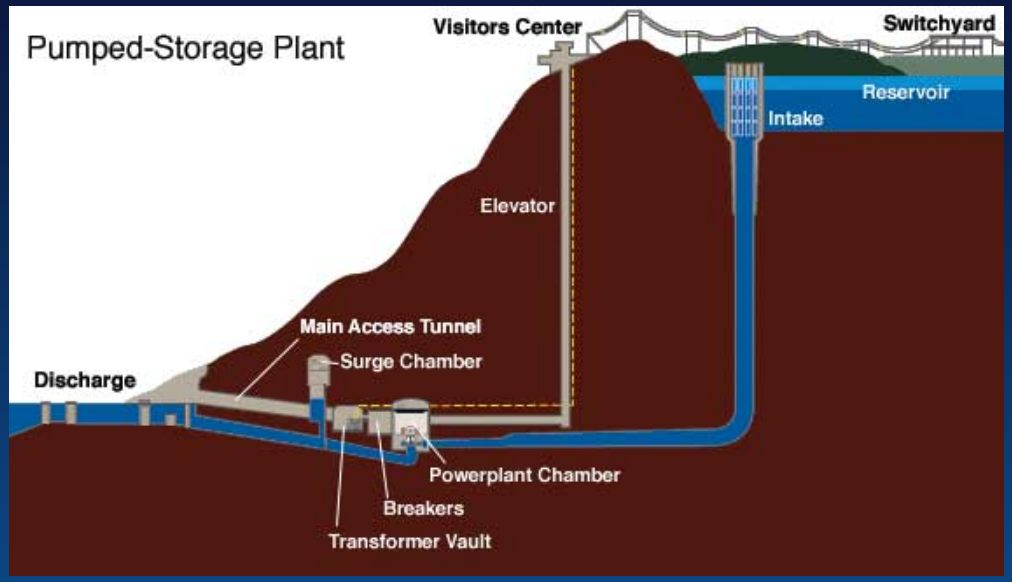
- The most common type of hydroelectric power plant
- typically a large hydropower system
- uses a dam to store river water in a reservoir
- Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity
- The water may be released either to meet changing electricity needs or to maintain a constant reservoir level

Diversion

- A diversion, sometimes called run-of-river, facility channels a portion of a river through a canal or penstock.
- It may not require the use of a dam.

Chief Joseph Dam, WA

Pumped Storage

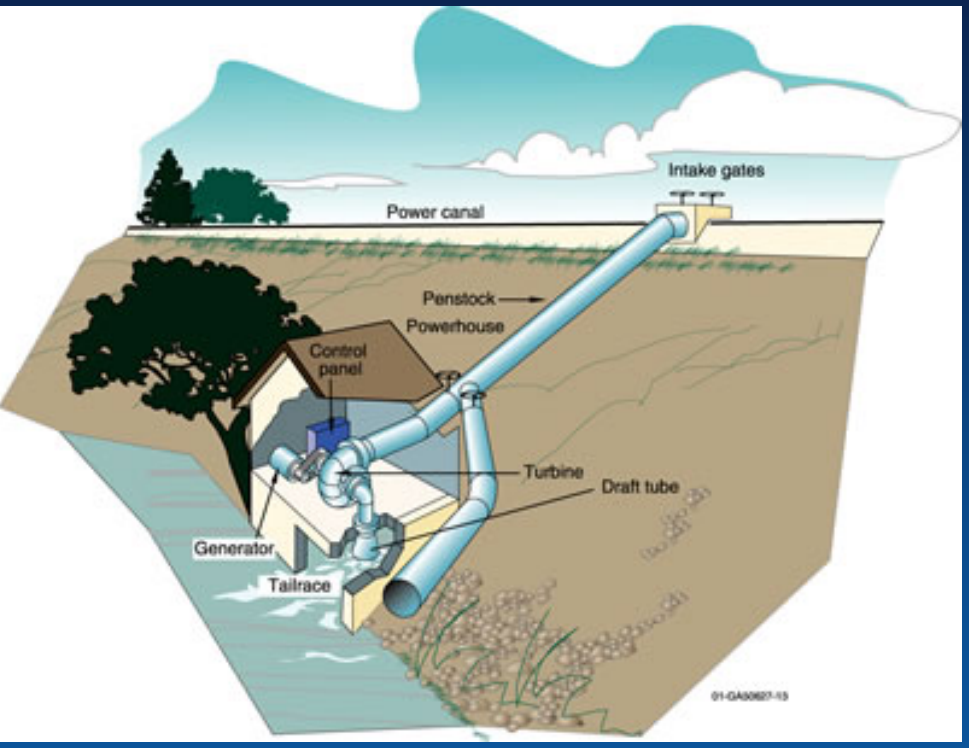


When the demand for electricity is low, a pumped storage facility stores energy by pumping water from a lower reservoir to an upper reservoir.

- During periods of high electrical demand, the water is released back to the lower reservoir to generate electricity.

Castaic Dam is a dam near the city of Castaic, California

Sizes of Hydroelectric Power Plants



Microhydro Power Plant

Large Hydropower

- Although definitions vary, DOE defines large hydropower as facilities that have a capacity of more than 30 megawatts.

Small Hydropower

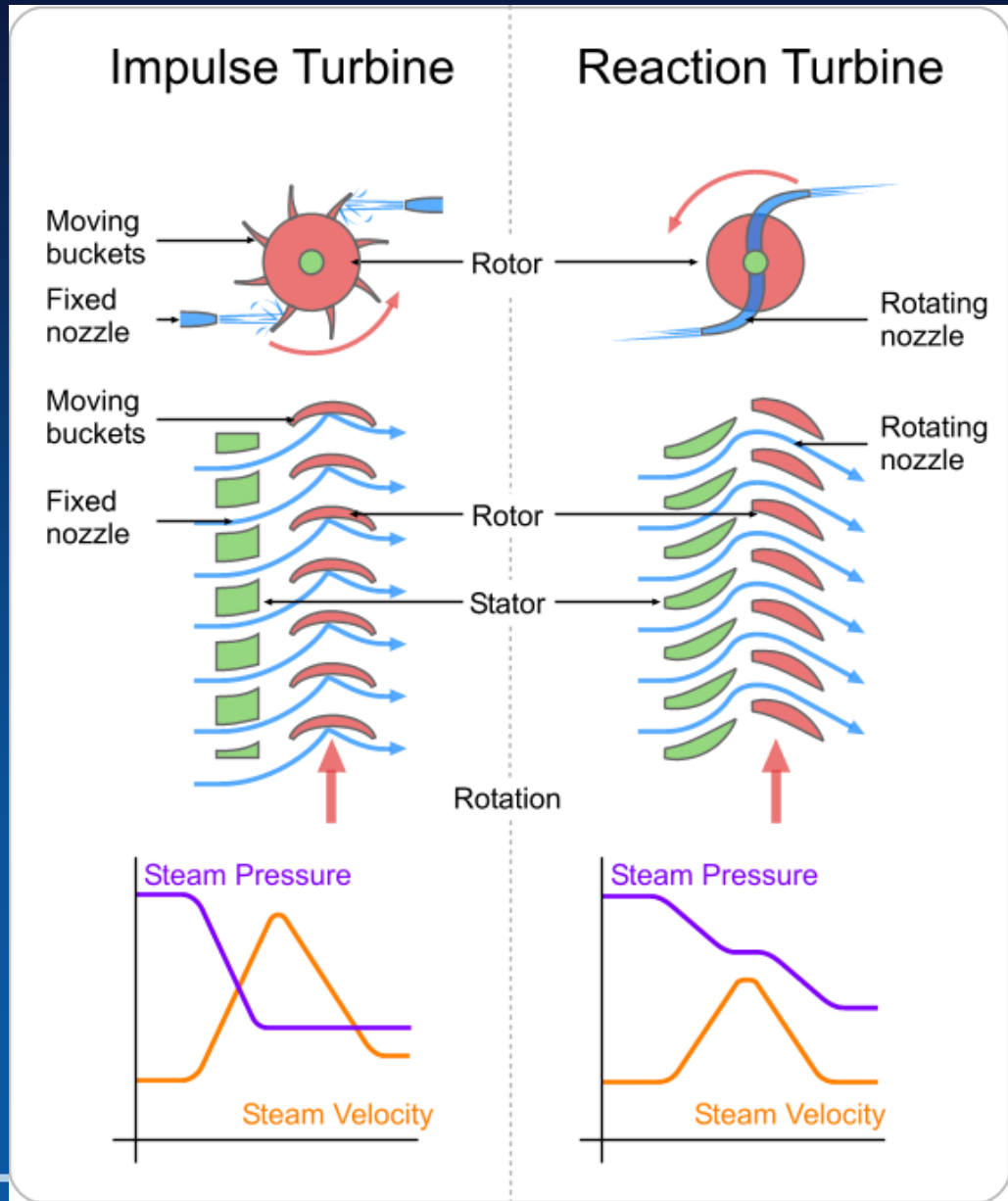
- Although definitions vary, DOE defines small hydropower as facilities that have a capacity of 100 kilowatts to 30 megawatts.

Micro Hydropower

- A micro hydropower plant has a capacity of up to 100 kilowatts. A small or micro-hydroelectric power system can produce enough electricity for a home, farm, ranch, or village.

Types of Hydropower Turbines

- There are two main types of hydro turbines: impulse and reaction.
- The type of hydropower turbine selected for a project is based on the height of standing water—referred to as "head"—and the flow, or volume of water, at the site.
- Other deciding factors include how deep the turbine must be set, efficiency, and cost.



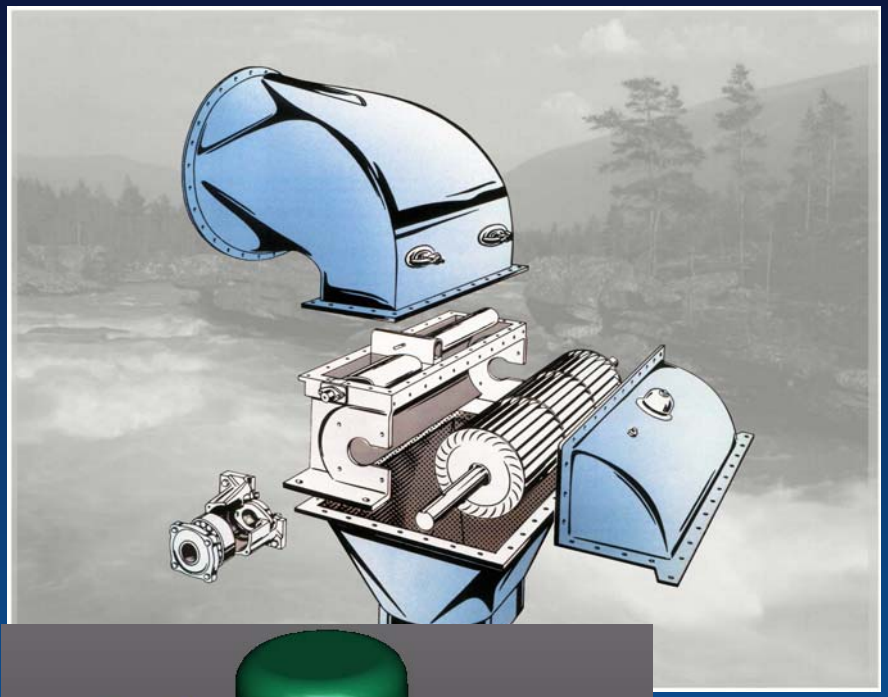
Impulse Turbine

The impulse turbine generally uses the velocity of the water to move the runner and discharges to atmospheric pressure. The water stream hits each bucket on the runner. There is no suction on the down side of the turbine, and the water flows out the bottom of the turbine housing after hitting the runner. An impulse turbine is generally suitable for high head, low flow applications.

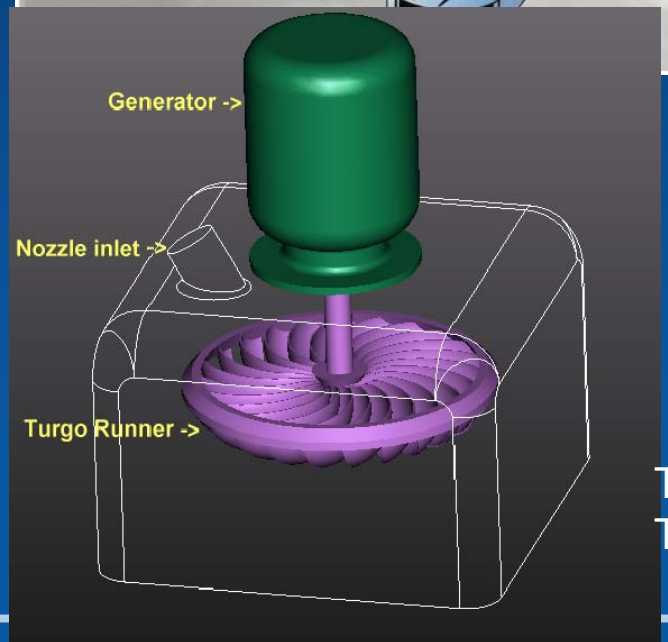
Impulse Turbine - Pelton

- A pelton wheel has one or more free jets discharging water into an aerated space and impinging on the buckets of a runner.
- A Turgo Wheel is a variation on the Pelton and is made exclusively by Gilkes in England. The Turgo runner is a cast wheel whose shape generally resembles a fan blade that is closed on the outer edges.

Impulse Turbine- Cross Flow



Cross-Flow Turbine



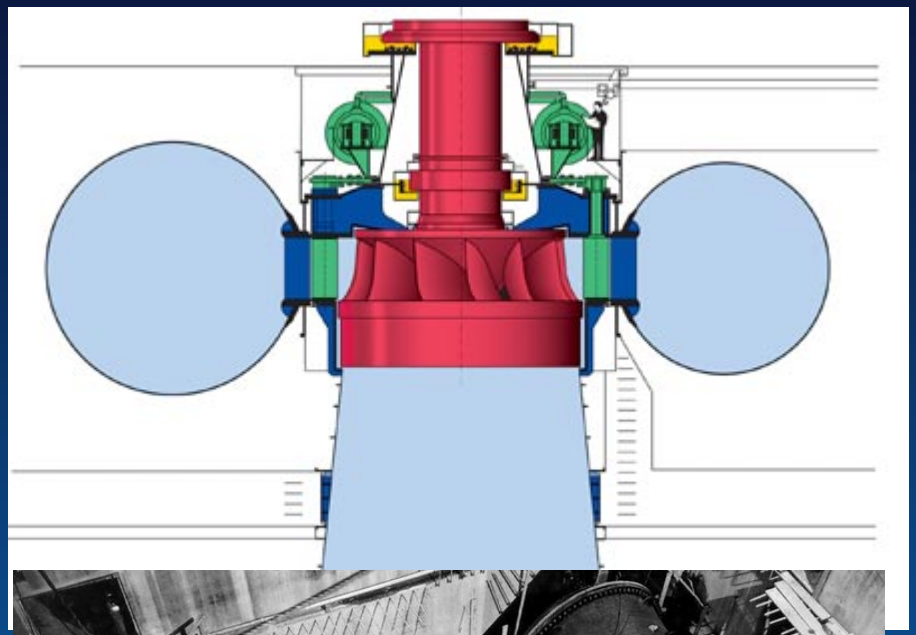
Turgo Turbine

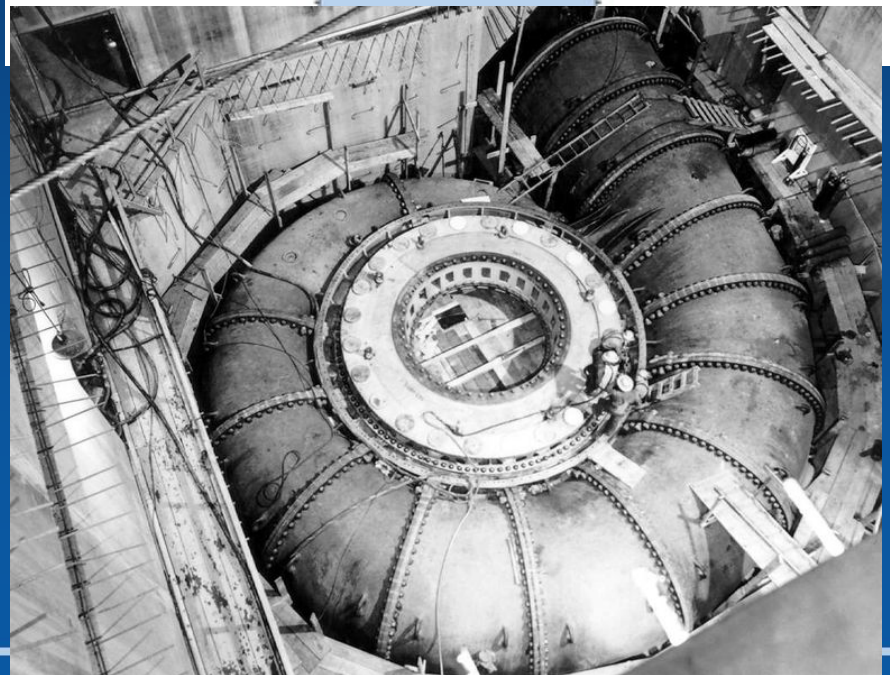
- A cross-flow turbine is drum-shaped and uses an elongated, rectangular-section nozzle directed against curved vanes on a cylindrically shaped runner.
- The cross-flow turbine allows the water to flow through the blades twice.
- The first pass is when the water flows from the outside of the blades to the inside; the second pass is from the inside back out.

Reaction Turbine

A reaction turbine develops power from the combined action of pressure and moving water. The runner is placed directly in the water stream flowing over the blades rather than striking each individually. Reaction turbines are generally used for sites with lower head and higher flows than compared with the impulse turbines

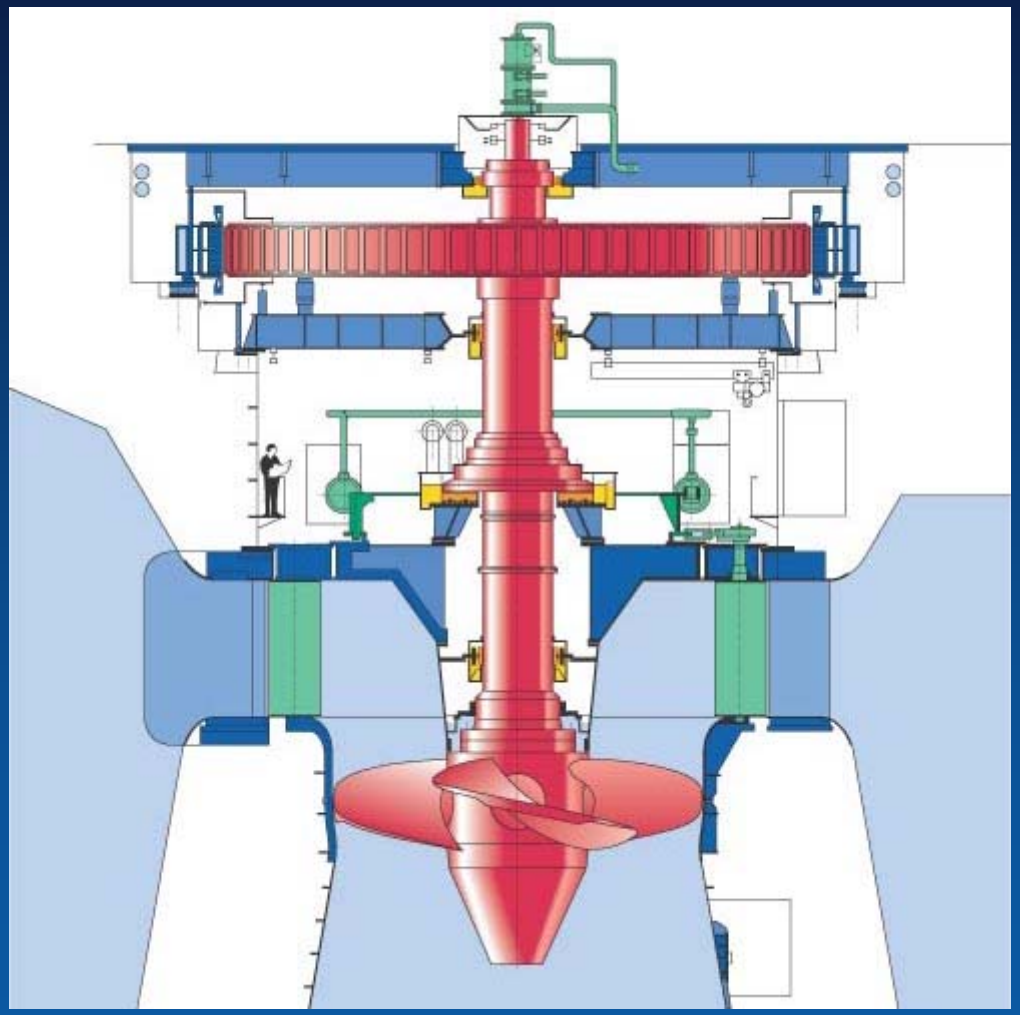
Reaction Turbine - Francis





- A Francis turbine has a runner with fixed buckets (vanes), usually nine or more.
- Water is introduced just above the runner and all around it and then falls through, causing it to spin.
- Besides the runner, the other major components are the scroll case, wicket gates, and draft tube.

Reaction Turbine - Propeller



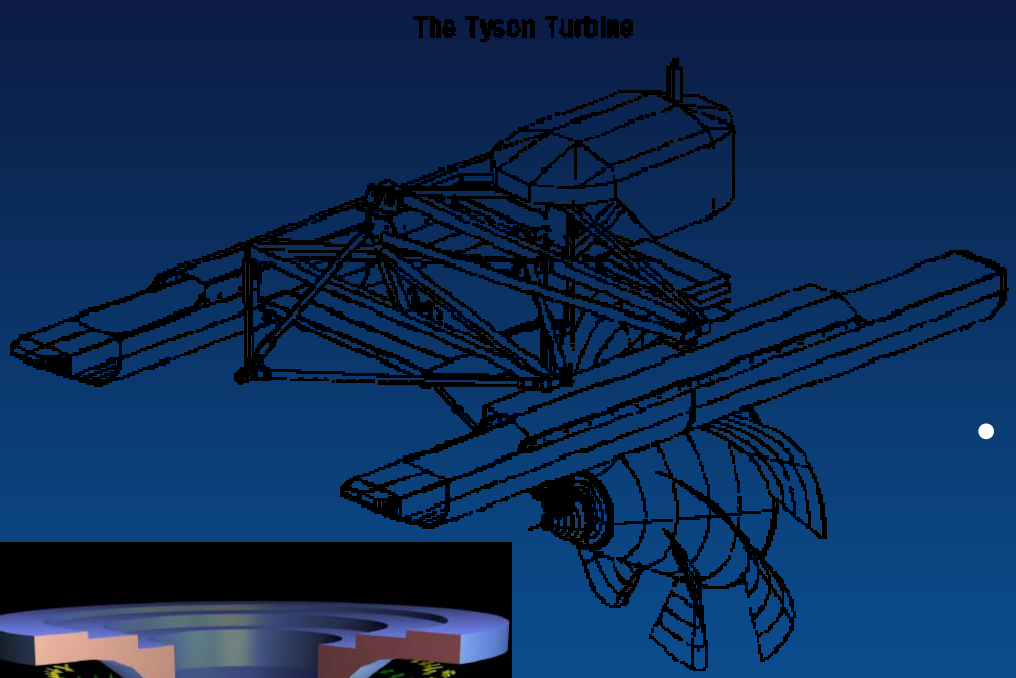
A propeller turbine generally has a runner with three to six blades in which the water contacts all of the blades constantly.

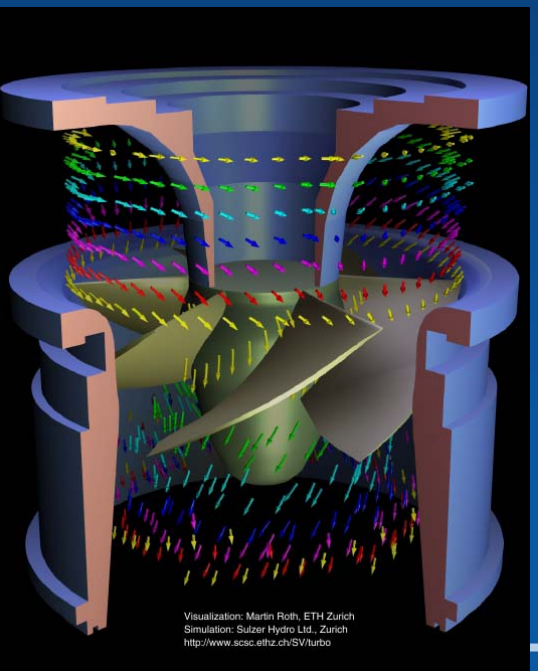
Picture a boat propeller running in a pipe. Through the pipe, the pressure is constant; if it isn't, the runner would be out of balance.

The pitch of the blades may be fixed or adjustable.

The major components besides the runner are a scroll case, wicket gates, and a draft tube.

Reaction Turbine - Kinetic



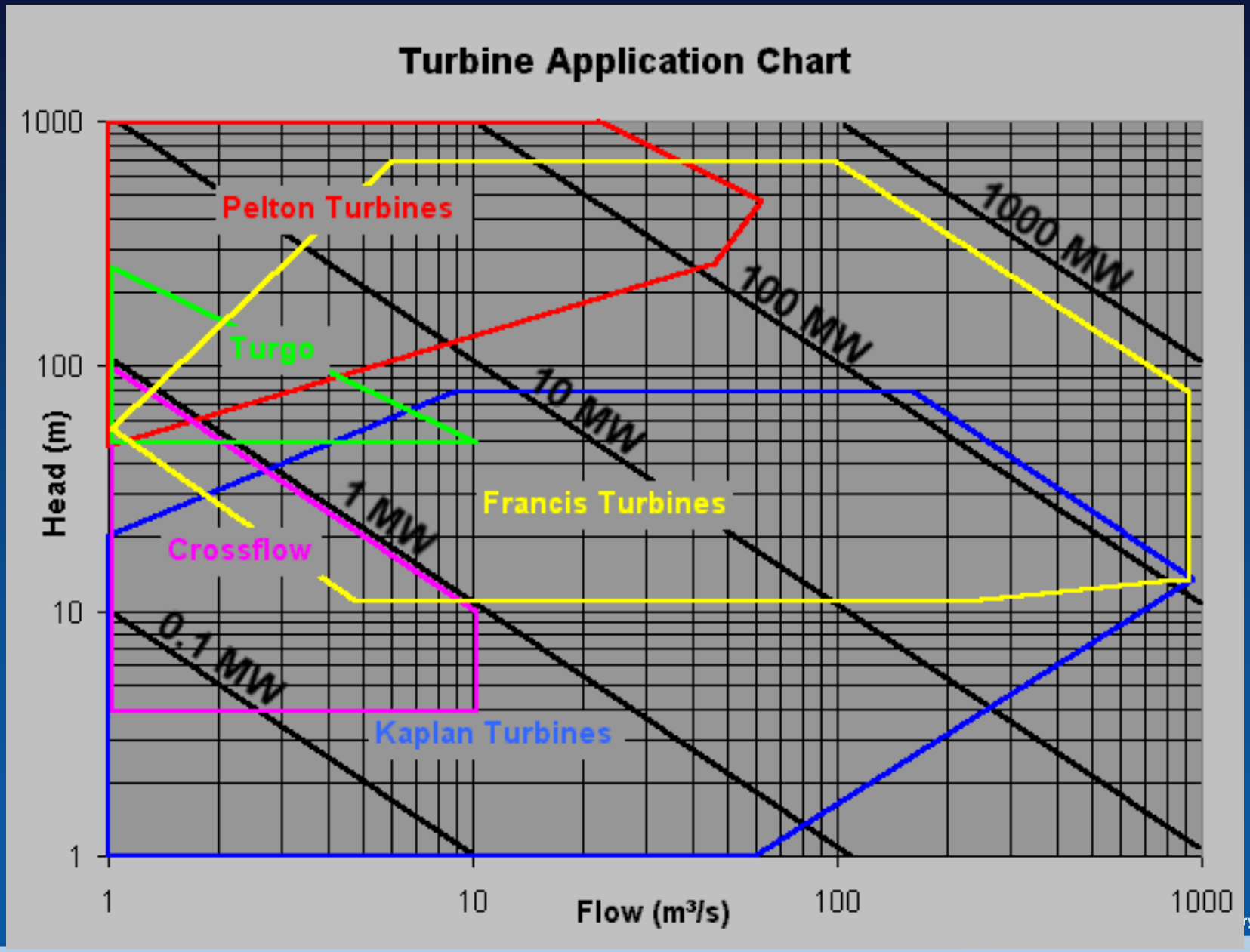


- Kinetic energy turbines, also called free-flow turbines, generate electricity from the kinetic energy present in flowing water rather than the potential energy from the head.
- The systems may operate in rivers, man-made channels, tidal waters, or ocean currents.
- do not require large civil works; however, they can use existing structures such as bridges, tailraces and channels.

Turbine Application

Turbine	Head (pressure)		
	High (30m +)	Medium	Low (<10 m)
Impulse	Pelton Turgo	Crossflow Pelton Turgo	Crossflow
Reaction	-	Francis Pump	Propeller Darius

Turbine Application



Economic Analysis

- Flow
  - The **design flow** will be a percentage of the measured stream flow.
  - Design flow determines penstock size
  - Design flow determines nozzle size
- Head
  - Elevation difference between the penstock intake and the turbine
- Penstock length.
  - Often the major cost.

Hydropower Evaluation Software

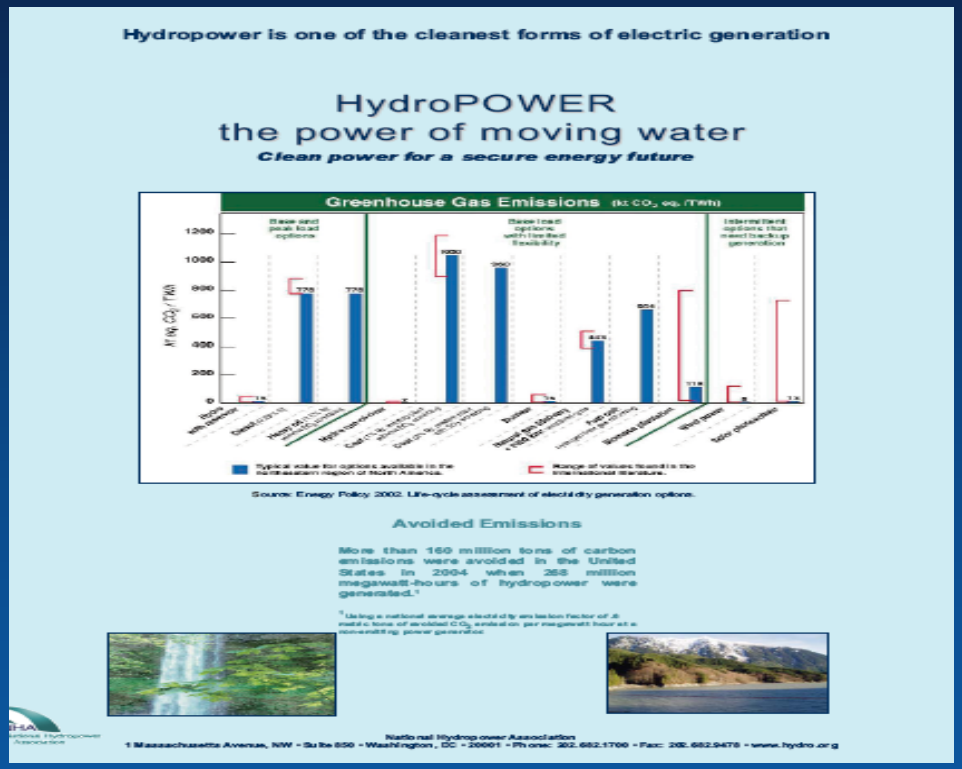
http://hydro2.inel.gov/resourceassessment/software/

- To assess the hydropower potential in any area of the United States from a national perspective, a uniform set of criteria was developed and a probability factor computer model, called Hydropower Evaluation Software (HES), was designed to standardize the assessment.
- HES offers the PC user the ability to factor in environmental attributes of a hydropower site to calculate a relative development suitability factor for a project.

Economic Advantages

- The major advantage of hydroelectricity is elimination of the cost of fuel.
- The cost of operating a hydroelectric plant is nearly immune to increases in the cost of fossil fuel.
- Fuel is not required and so it need not be imported.
- Hydroelectric plants tend to have longer economic lives than fuel-fired generation.
- Operating labor cost is usually low since plants are automated and have few personnel on site during normal operation.

Evironmental Impacts Advantages

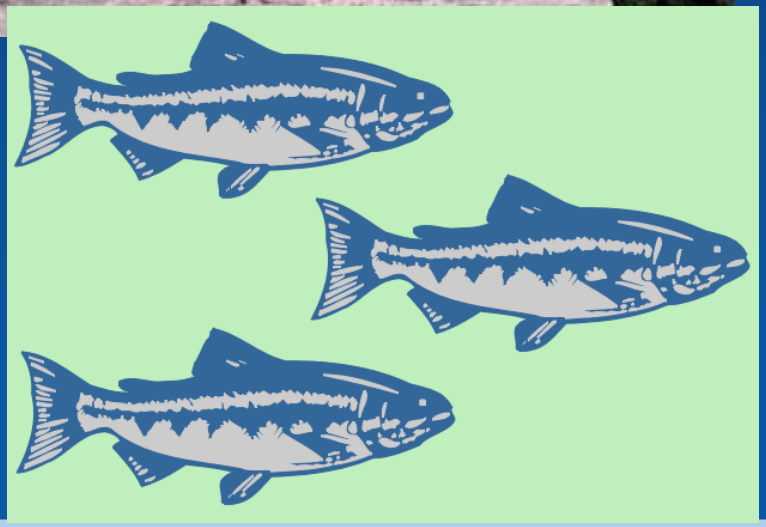


Greenhouse gas emissions

- Since hydroelectric dams do not burn fossil fuels, they do not directly produce carbon dioxide (a greenhouse gas).

Source: Energy Policy. 2002. Life-cycle assessment of electricity generation options.

Environmental Impacts Disadvantages



- Reduced salmon populations by preventing access to spawning grounds upstream
- Water exiting a turbine usually contains very little suspended sediment, which can lead to scouring of river beds and loss of riverbanks.
- Can impact water quality and flow.
- The entire river may be diverted leaving a dry riverbed.
- Dam Failures
- Hydropower plants can be impacted by drought

Federal Incentives

Energy Policy Act of 2005 (EPAct 2005)

- *Hydropower –The Secretary shall conduct a program of research, development, demonstration, and commercial application for cost competitive technologies that enable the development of new and incremental hydropower capacity, adding to the diversity of energy supply of the United States, including (i) fish friendly large turbines and (ii) advanced technologies to enhance environmental performance and yield greater energy efficiency*

Federal Incentives

Energy Policy Act of 2005 (EPAct 2005): the challenging licensing process and the lack of significant growth during the last decade.

Hydropower Licensing Reform
While the law brings important new reforms to the Federal Energy Regulatory Commission's (FERC) hydropower licensing process, it also ensures environmental standards for rivers in the country are maintained.

Alternative Conditions
Any party in a licensing proceeding can offer a cost or power-saving alternative to a mandatory condition (Section 4(e) or Section 18) proposed by a federal resource agency. If the agency determines the proposed alternative meets statutory requirements for environmental and resource protection, and the agency finds that the alternative will – compared to the original condition or prescription – provide significant cost or power savings, the agency must accept the alternative.
For Section 18 alternative prescriptions, the alternative must be "no less protective than the fishway initially prescribed," and for 4(e) alternatives, the alternative must "provide for the adequate protection and utilization of the reservation."

Equal Consideration
Federal agencies must document that they gave equal consideration to the effects of a mandatory condition on the many benefits of hydropower, such as energy supply, distribution, cost, flood control, navigation, water supply, and air quality. Equal consideration is also required when an agency rejects an alternative condition. The goal of this provision is to ensure that during the licensing process, a hydropower project's many positive attributes are preserved as fully as possible, while at the same time, provide for the appropriate and necessary levels of environmental impact mitigation.

Federal / State Tax Credits and Incentives

- **Tax Credit Bonds**
  A new category of tax credit bonds is now available for non-tax paying hydropower generators. The goal is to create financial incentives for public power and electric cooperatives to build qualified renewable energy projects. Qualified projects mirror those under the Section 45 PTC.
- **Incentive Payments**
  Two incentive programs were created to help increase hydropower generation in the country. One is for developing new hydropower projects, and the other is for increasing efficiency at existing projects. Both programs need appropriations for funding.
- **Federal Purchase Program**
  Incremental hydropower is now included in the federal power purchase program for renewable energy. The program requires the federal government to purchase a certain percentage of its electricity from renewable energy sources. The percentages are as follows:
- **Commitment to research and development (R&D)**
  The Department of Energy must conduct a program of "research, development, demonstration, and commercial application for cost competitive technologies to enable the development of new and incremental hydropower, including fish-friendly turbines and advanced technologies to enhance environmental performance and yield greater efficiencies."
- **Production Tax Credit**

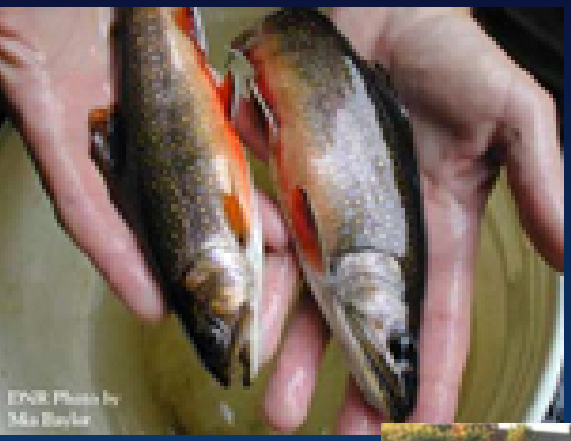
  Incremental hydropower (new energy at existing facilities through additions of capacity and efficiency improvements) and "qualified" (run-of-river hydropower at existing FERC-licensed non-hydropower dams) are now eligible for a production tax credit (PTC) for renewable energy outlined in Section 45 of the IRS code.

  A ten-year tax credit of 0.9 cents per KwH is available for hydropower placed in service by Jan. 1, 2008.

Federal / State Tax Credits and Incentives

- Production tax credit (PTC)
- Local property tax credits
- Accelerated depreciation (MACRS)
- Loan guarantees (DOE, USDA, BIA)
- Renewable portfolio standards
- Renewable energy certificates
- Carbon credits (mostly signatories to Kyoto)
- New Market Tax Credits
- CREBS (Clean Renewable Energy bonds)

Federal Energy Regulatory Commission (FERC)



Brook trout

Water spills over dam

Construction at hydroelectric project

The Commission's responsibilities include:

- Issuance of licenses for the construction of a new project;
- Issuance of licenses for the continuance of an existing project (relicensing); and
- Oversight of all ongoing project operations, including dam safety inspections and environmental monitoring.

http://ferc.gov/industries/hydropower.asp

Hydropower is a domestic source of renewable, reliable, and affordable electricity. No other energy source offers so many advantages.

Domestic and Secure

Water from our rivers is a domestic resource that is not subject to disruptions from foreign suppliers, cost fluctuations, and transportation issues.

Renewable

Like wind, solar, and geothermal, hydropower's "fuel" is essentially infinite and is not depleted during the production of electricity. Hydropower facilities simply harness the natural energy of flowing and falling water to generate electricity.

Popular

Nationally, 93% of individuals believe hydropower is important or very important for meeting future electricity needs.

Source: 2002 public opinion poll by Biscont Research Inc.

Efficient

Today's hydropower turbines are capable of converting more than 90% of available energy into electricity, which is more efficient than any other form of generation (the best fossil fuel power plant is only about 50% efficient).

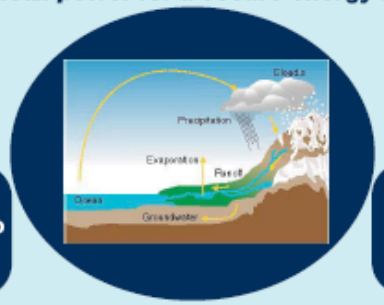
Clean

Hydropower uses water to generate electricity. It is climate-friendly and does not produce air pollution or create any toxic by-products.

HydroPOWER
the power of moving water

Clean power for a secure energy future

Any moving water has the potential to make power



Water used for power is returned to the water cycle

The hydrologic cycle

source: http://hydropower.inel.gov/hydrofacts/how_hydro_works.html

Reliable

Hydropower can go from zero power to maximum output rapidly and predictably. This makes hydropower exceptionally good at meeting changing demands for electricity and providing ancillary electrical services that maintain the balance between supply and demand.

Flexible

Hydropower has the unique ability to change output quickly. Its unique voltage control, load-following, and peaking capabilities are critical for electric grid stability. This ability also provides an efficient and cost-effective way to support the use of intermittent renewable sources of power such as wind and solar energy.

Non-power benefits

Hydropower projects do more than just produce electricity; they create wildlife conservation lands, provide stable habitat for many kinds of wildlife, support healthy fisheries, provide water supply, control floods, irrigate land for food production, and create recreational opportunities for millions of Americans.

National Hydropower Association
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Resources

- US Federal Energy Regulatory Commission
  - http://ferc.gov/industries/hydropower.asp
- National Hydropower Association
  - http://www.hydro.org/
- **The hydrologic cycle**
  - http://hydropower.inel.gov/hydrofacts/how_hydro_works.shtml
- Source: *"Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants"* U.S. Department of
  - Energy, Energy Efficiency and Renewable Energy Wind and Hydropower Technologies, http://hydropower.inl.gov/resourceassessment/pdfs/main_report_appendix_a_final.pdf