NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Tribal Energy Program Webinar
Hydropower 101

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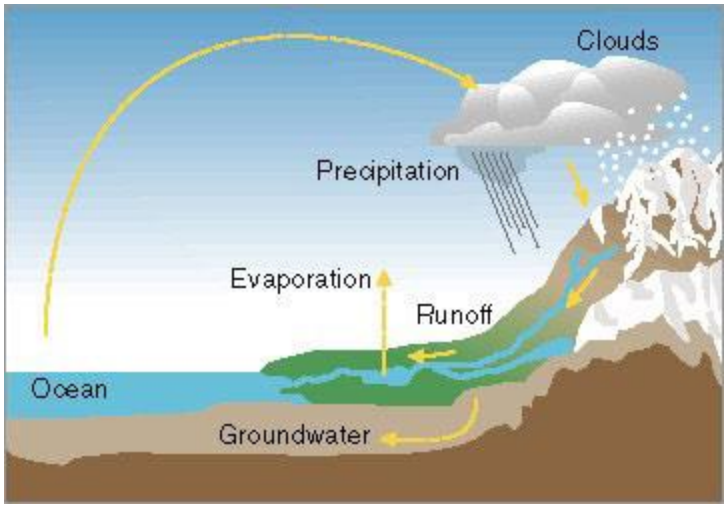
9/17/10

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Hydroelectric Power: Where It Comes From

- Flowing water has energy that can be captured for some useful purpose
- When this energy is captured and used to generate electricity, it is called hydroelectric power or hydropower
- Hydropower plants use the energy of flowing water to turn a turbine that rotates a generator to produce electricity
- Hydrologic cycle: sun causes evaporation from lakes and oceans, forms clouds, falls as rain or snow, then flows back down to the ocean, and the cycle repeats
- Hydropower is renewable because the water cycle is an endless, constantly recharging system
- Hydropower uses a fuel (water) that is not consumed in the process of generating electricity



The water (hydrologic) cycle

Water Power Technologies

Land-based water power

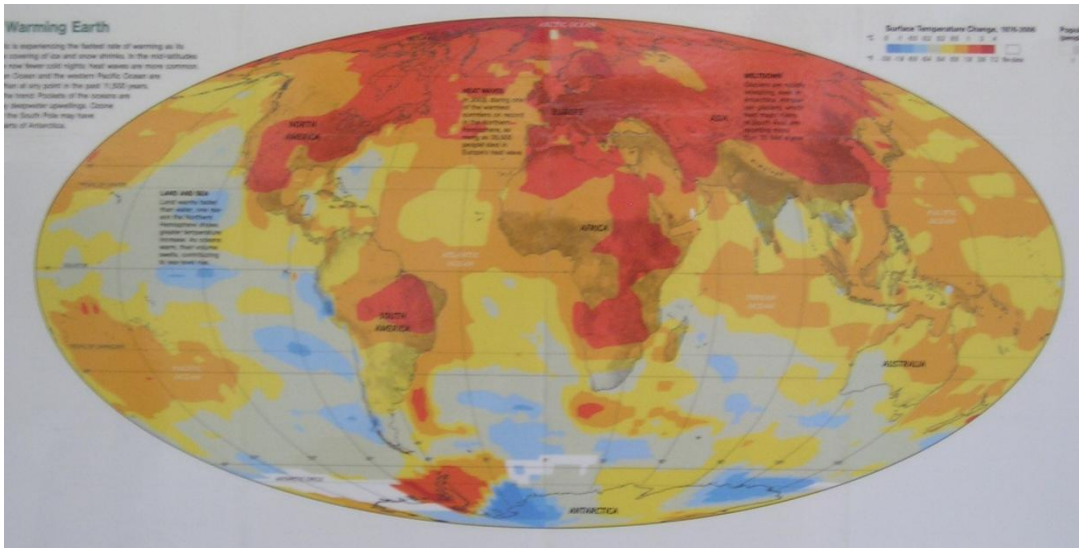
- Waterwheels
- Dams
- Diversion
- Hydrokinetic

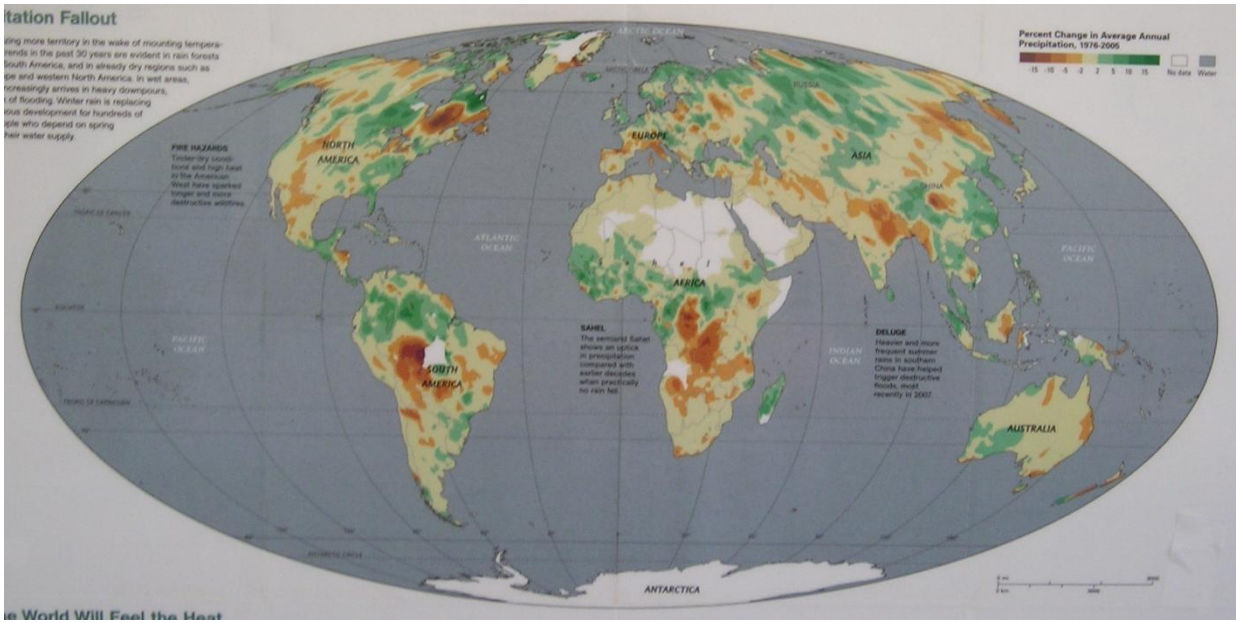
Ocean-based water power

- Wave power
- Tidal power
- Ocean thermal energy conversion
- Osmotic power

Undershot water wheels on the Orontes River in Syria

Climate Change





National Geographic

Hydropower Currently Provides ~ 6% of U.S. Electricity Generation

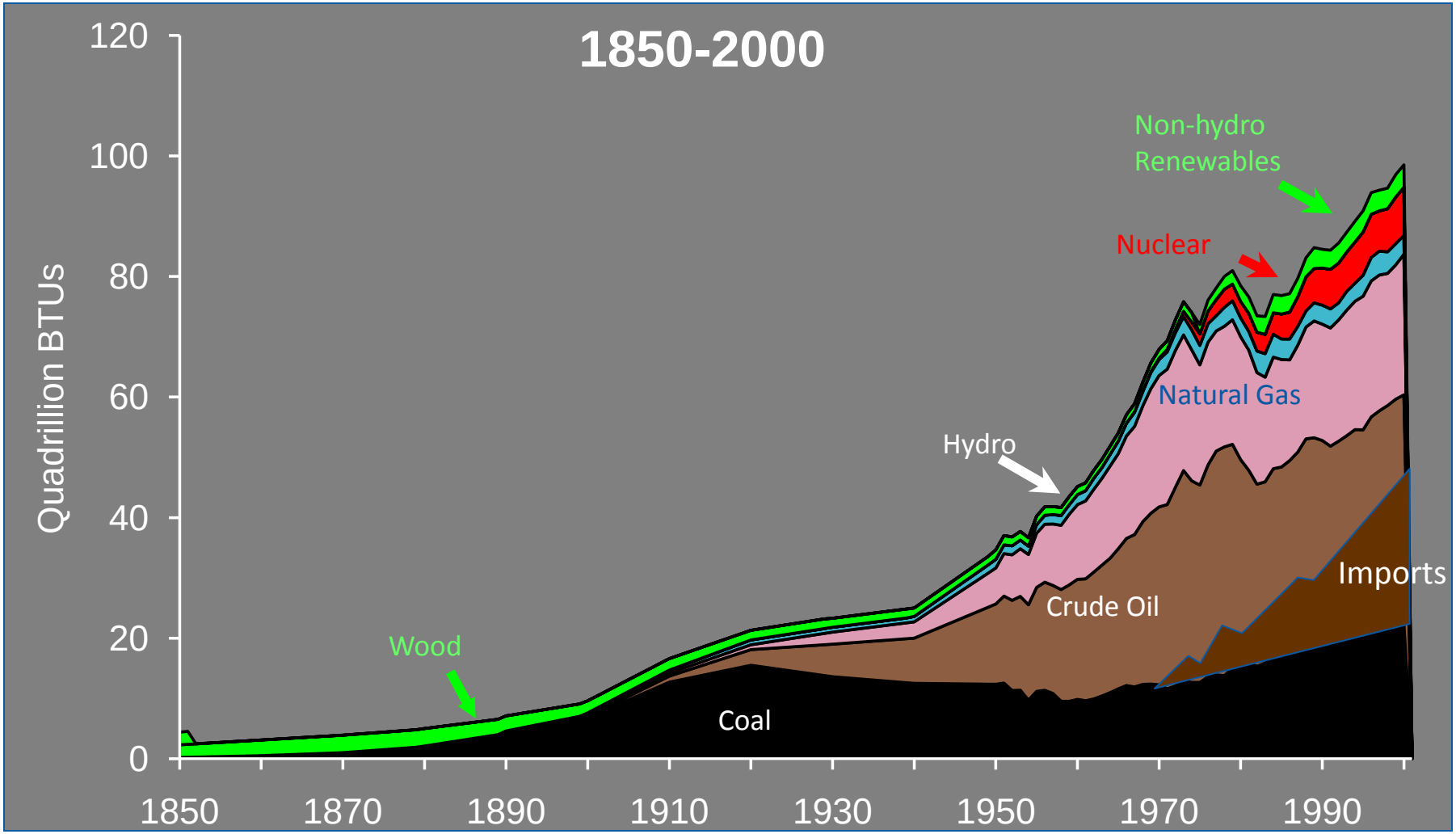
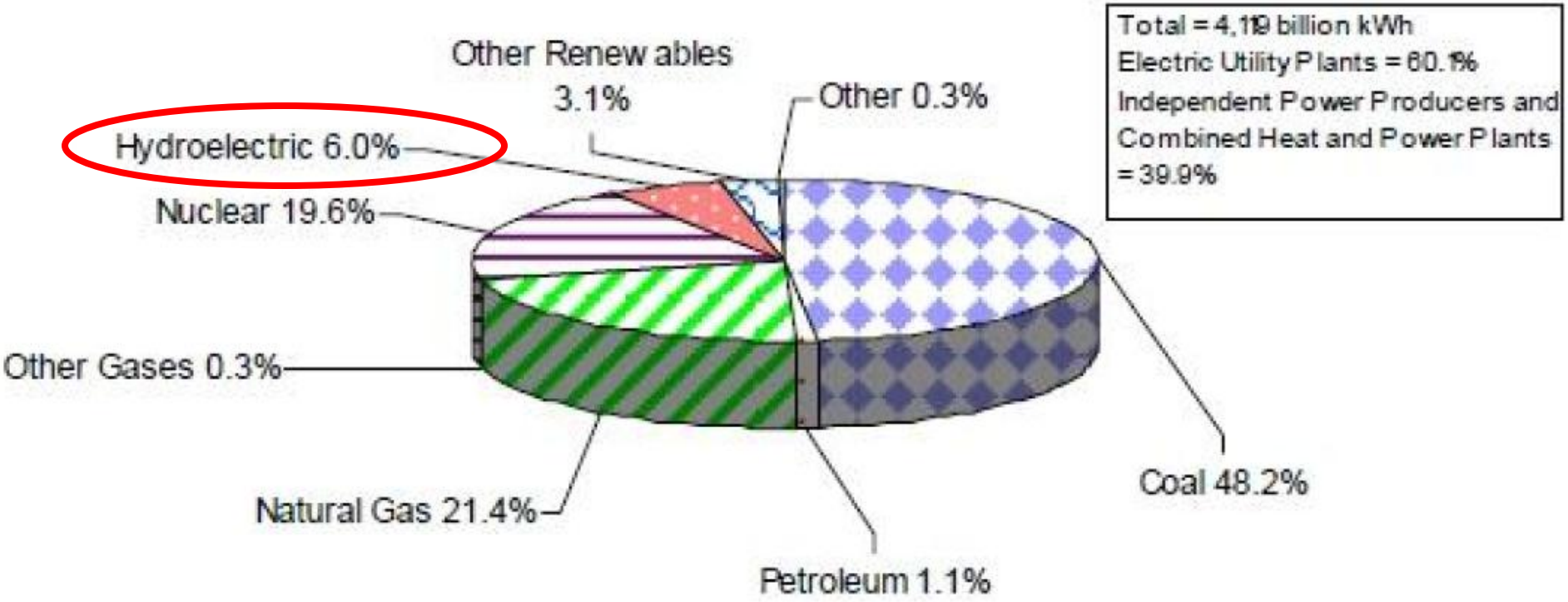
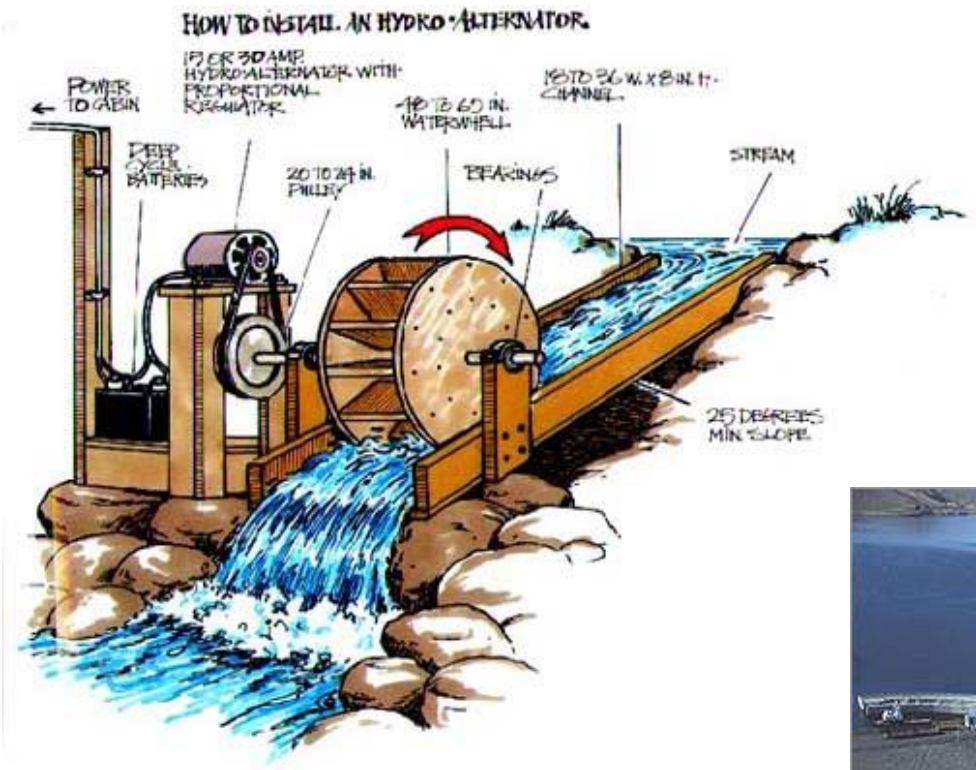


Figure ES 1. US Electric Power Industry Net Generation, 2008

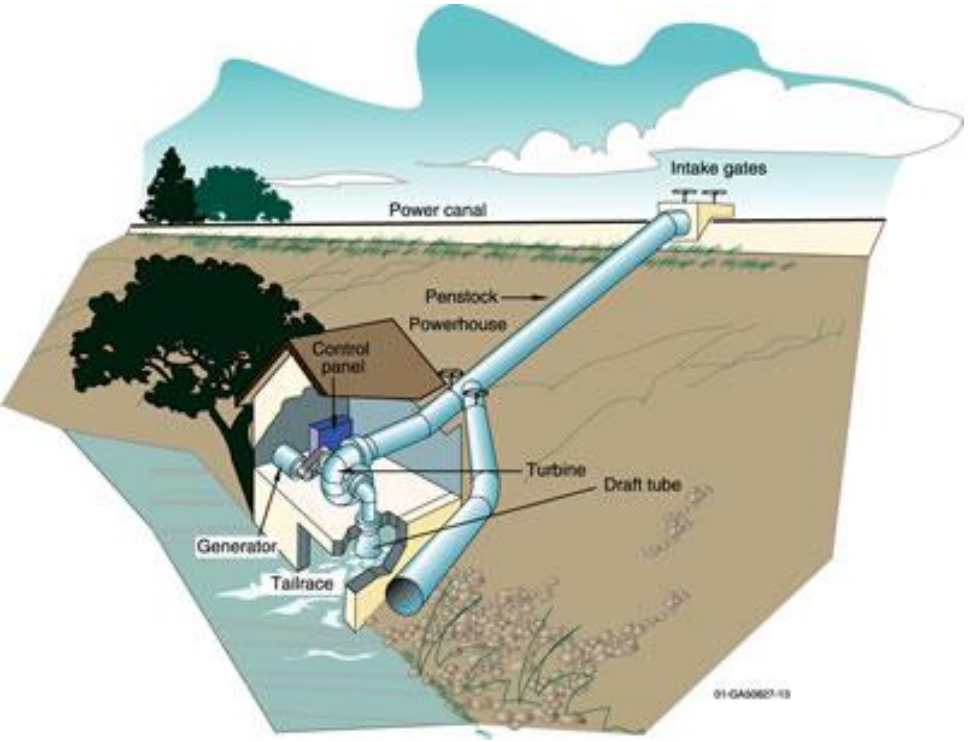


Sources: U.S. Energy Information Administration, Form EIA-923, "Power Plant Operations Report."

Hydropower Is Scalable



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

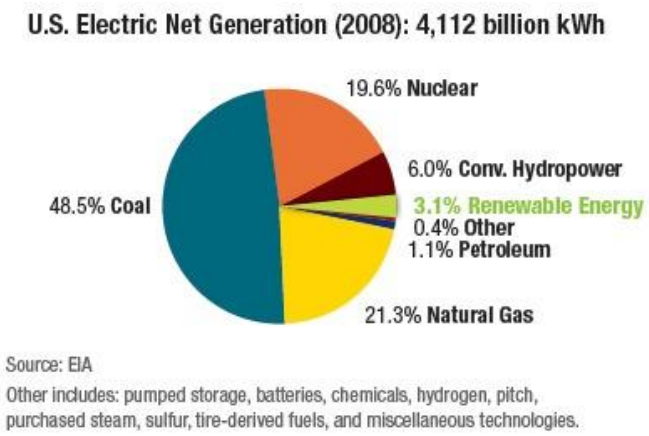
Although definitions vary, DOE defines small hydropower as facilities that have a capacity of 100 kilowatts to 30 megawatts.

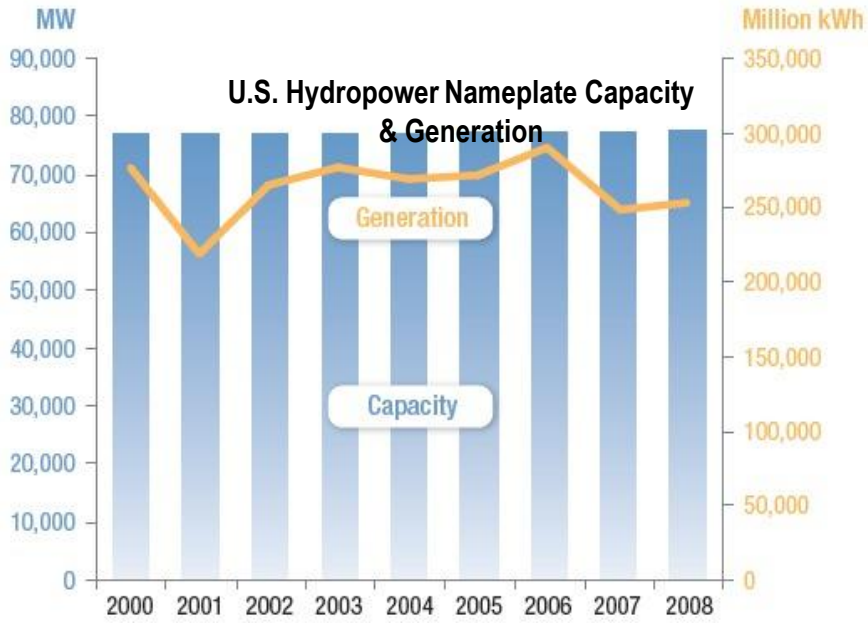
Micro Hydropower

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.

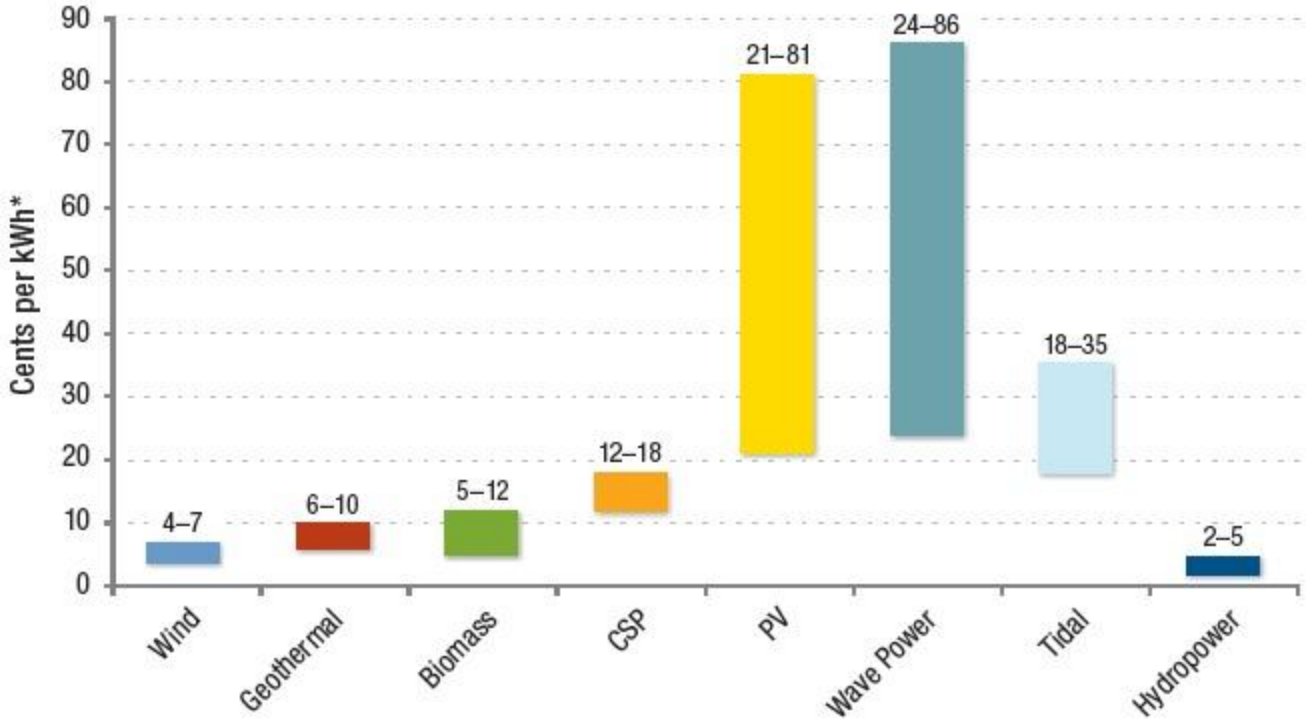
U.S. Hydropower Capacity & Generation

- 1940s: 40% of the country's electricity came from hydroelectric plants
- Today: 6% of our electricity comes from hydropower (until recently, 2/3 of renewable generation)
- 2000-2008: Hydro generating *capacity* has remained constant; *actual* generation fluctuates with the water supply





Price of Electricity from Hydropower



(2008 data)

* Average cost varies according to the financing method used and the quality of the renewable resource available

Key Advantages & Disadvantages

Advantages

- No greenhouse gas emissions from operation
- Grid support: large hydro plants can produce electricity on demand, responding in seconds to large and rapidly varying loads
- The fuel (water) is free
- Require no fuel & little maintenance, so running costs are lower than fossil-fueled power systems
- Long-lasting and robust technology; systems can last for 50 years or more without major new investments

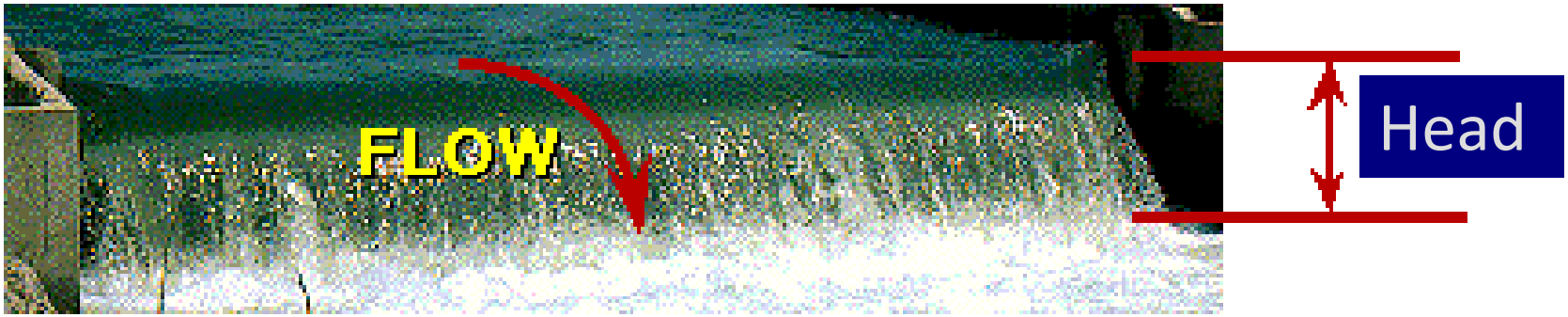
Disadvantages

- Damming a river can change the local or regional ecology, for example:
- Reservoir floods existing wildlife habitat
- Fish populations can decline because they can’t swim past the dam to spawning grounds upstream or because they are killed by passing through the turbine on their way downstream
- The water below the dam is often colder than natural river water; can kill fish
- All hydro plants: output can be affected by drought
- Diversion/hydrokinetic plants: river flow rates can vary a lot with the seasons, limiting the reliable power output

Economic Advantages

- The major advantages of hydroelectricity are 1) elimination of the cost of fuel, and 2) high capacity factors.
- 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.

Hydroelectricity Physics



Power (kW) = 10 x Flow (m^3/s) x Head (m) x η

Power (kW) = Head (ft) x Flow (cfs) x η /11.8

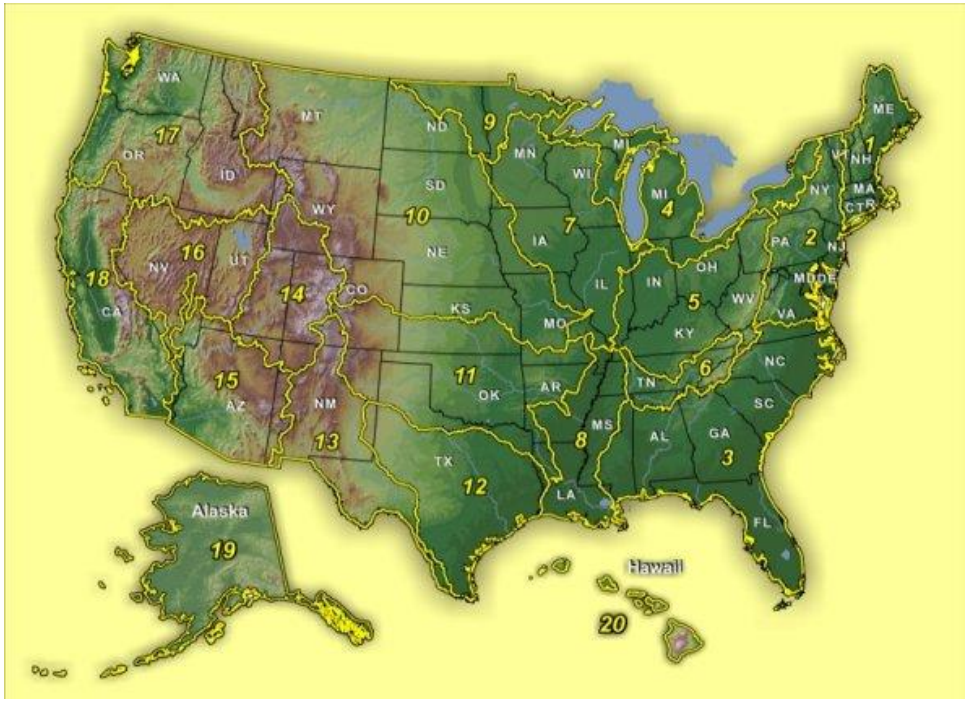
η= turbine-generator efficiency ~80%

Potential Resources

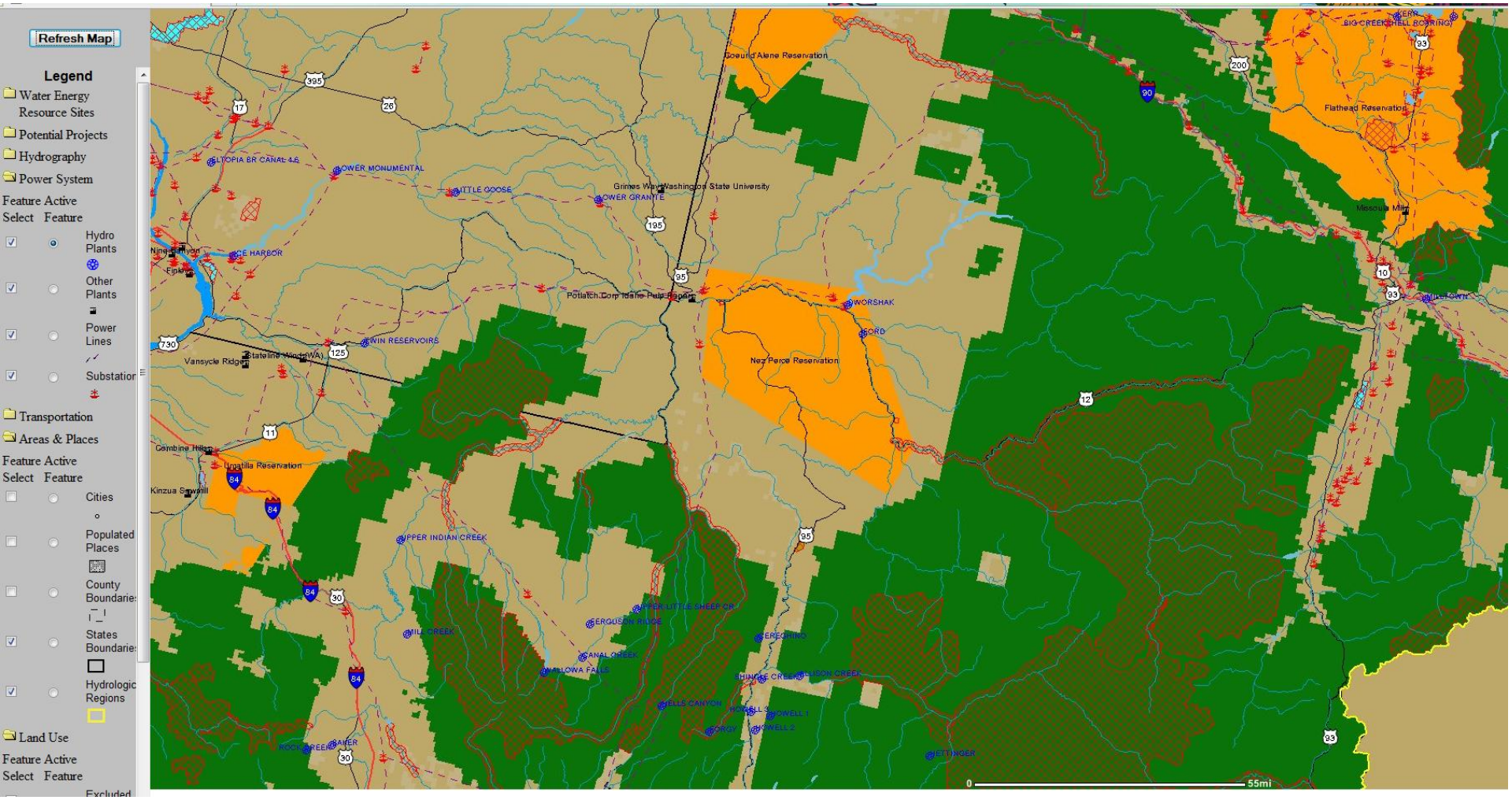
Virtual Hydropower Prospector
Region Selector
http://hydropower.id.doe.gov/prospector/r_selector.shtml

New Conventional Hydro (low power to large hydro) = 62,300 MW
•Hydrokinetic = 12,800 MW (tidal only assessed for 5 states, ocean current not assessed)
•Wave Energy = 10,000 to 20,000 MW

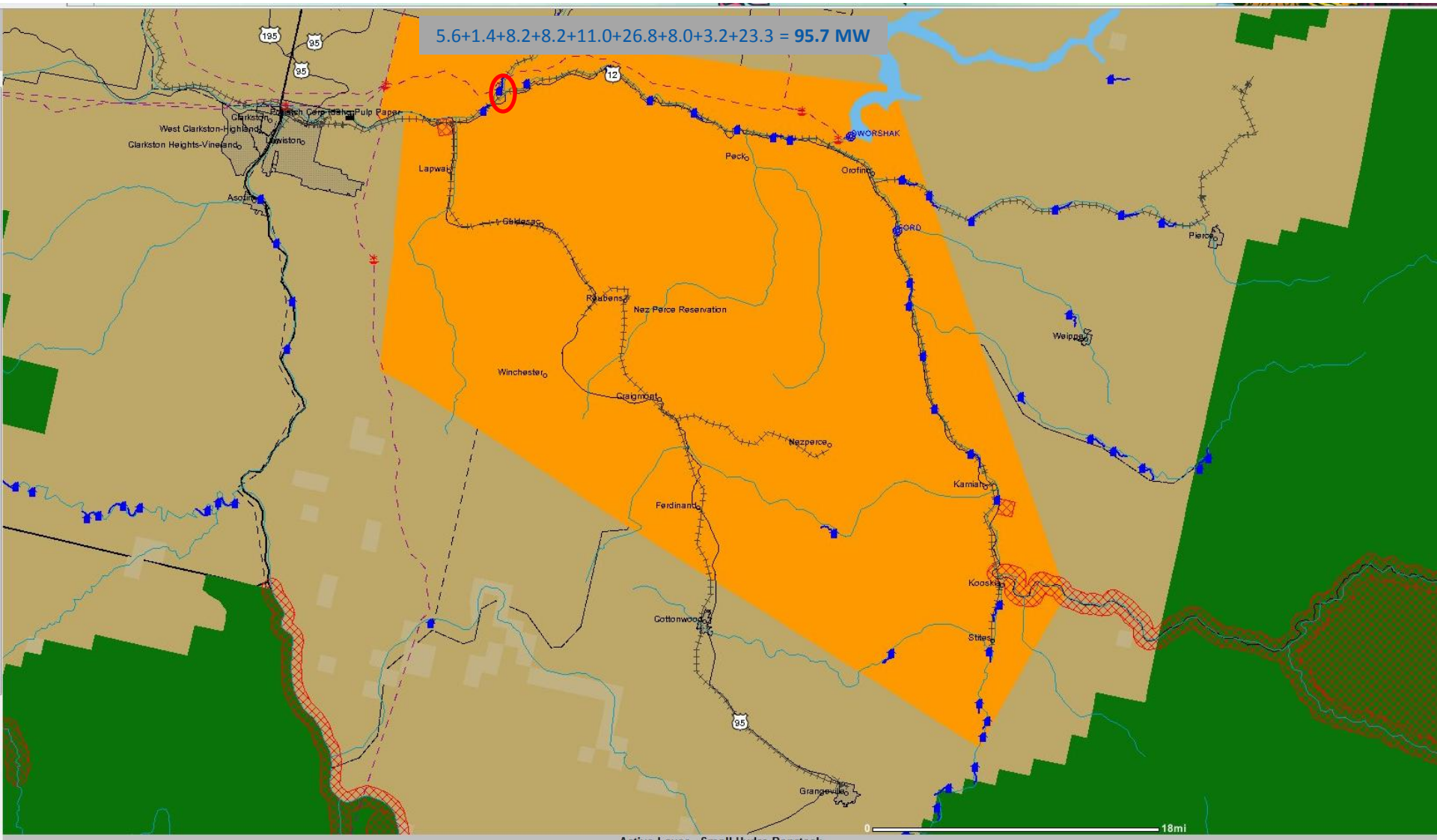
TOTAL = 85-95 GW



Existing Hydro, Transmission, Land Ownership



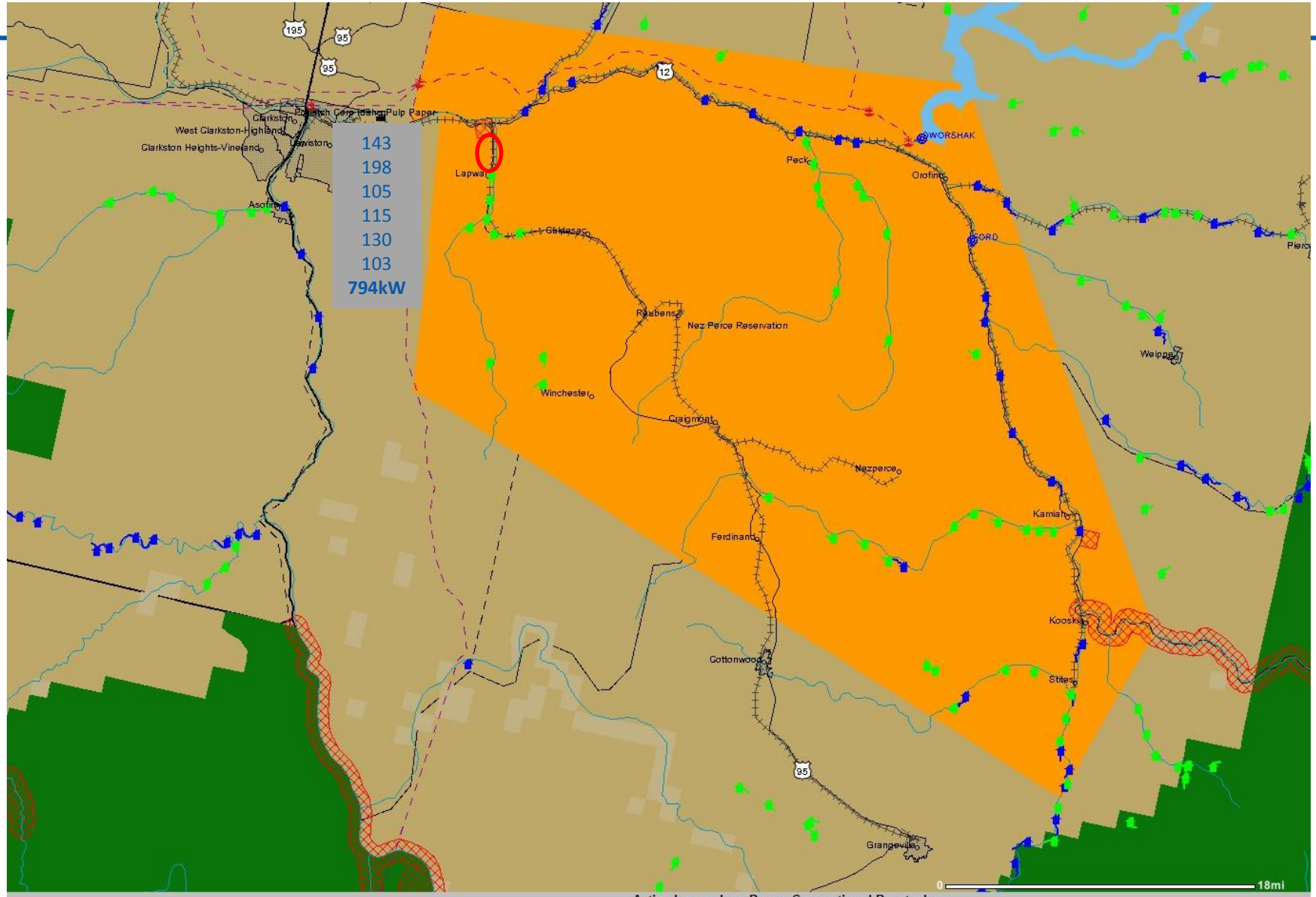
Small Hydro Penstock



Active Layer - Small Hydro Penstock

Rec	Power Class	Prime Candidate	Power (mW)	Working Flow Rate (cfs)	Working Head (ft)	Penstock Length (ft)	Federally Exluded	EnvironmentallyExcluded	State	County	Reach Length (ft)	Reach Power Potential (MW)	Reach Head (ft)	Reach Flow Rate (cfs)	Nearest Road (mi)	Nearest Railroad (mi)	Nearest Population (mi)	Nearest Powerline(mi)	Nearest Substation (mi)	Nearest Plant (mi)	Start Elevation (ft)	End Elevation (ft)	Reach Grade (%)
1	Small Hydro	Y	1.374	232.988	69.587	6786.498	N	N	Idaho	Nez Perce	25625.029	5.588	141.5	465.975	0.117	0.06	1.364	0.233	7.769	10.31	944.423	802.92	0.552

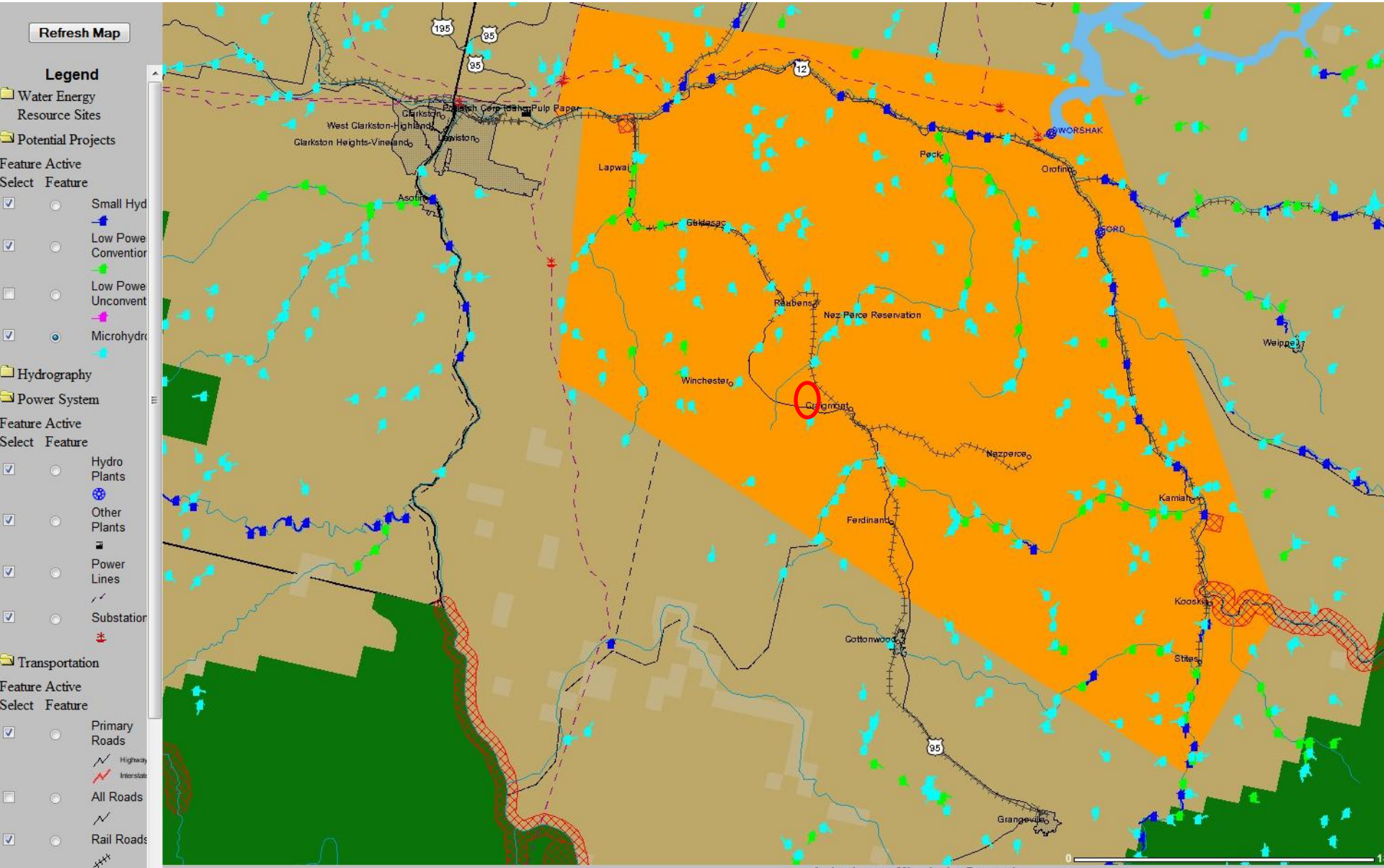
Low Power Conventional Penstock



Active Layer - Low Power Conventional Penstock

Rec	Power Class	Prime Candidate	Power (mW)	Working Flow Rate (cfs)	Working Head (ft)	Penstock Length (ft)	Federally Exluded	EnvironmentallyExcluded	State	County	Reach Length (ft)	Reach Power Potential (MW)	Reach Head (ft)	Reach Flow Rate (cfs)	Nearest Road (mi)	Nearest Railroad (mi)	Nearest Population (mi)	Nearest Powerline(mi)	Nearest Substation (mi)
1	Low Power, Conventional	Y	0.143	46.26	36.352	3591.291	N	N	Idaho	Nez Perce	6116.352	0.469	59.78	92.52	0.074	0.017	0.071	5.027	6.945

Micro-Hydro Penstock



Rec	Power (mW)	Power Class	Prime Candidate	State	County
1	0.061	Microhydro	Y	Idaho	Idaho

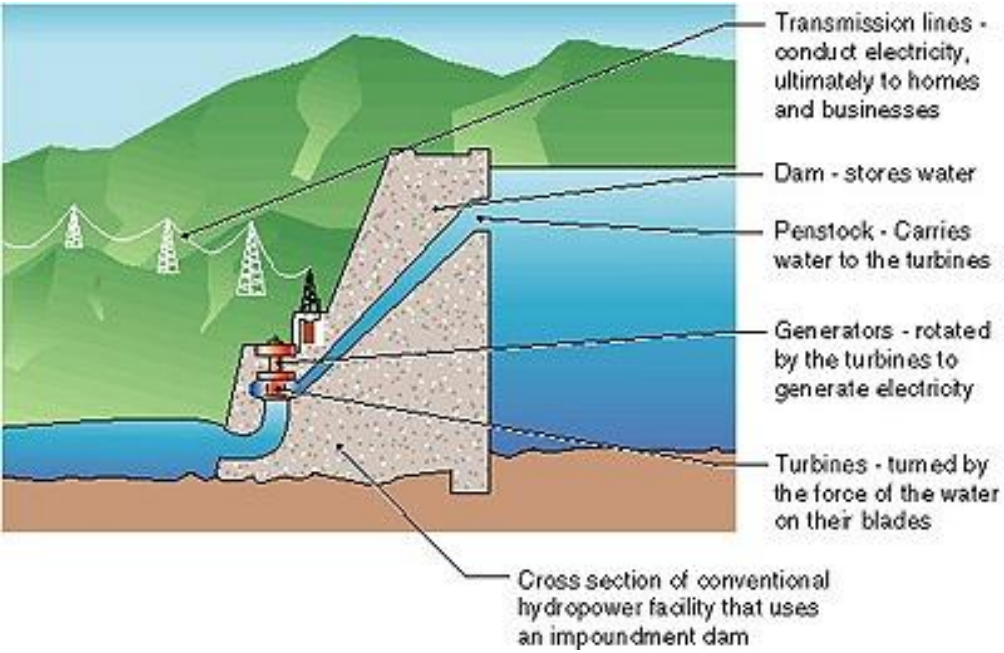
Hydroelectricity—Power Plant Overview

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 that uses a dam to store river water in a reservoir

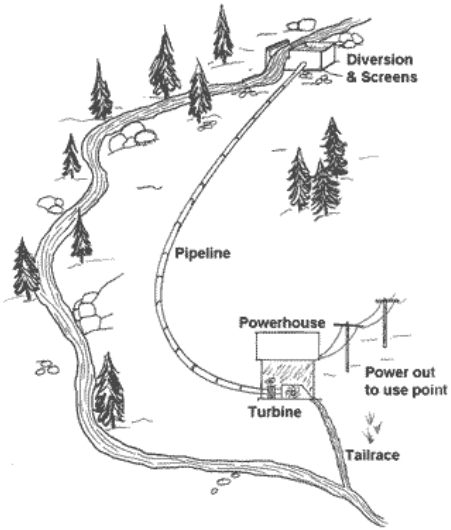
Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity

The water may be released either to meet changing electricity needs or to maintain a constant reservoir level

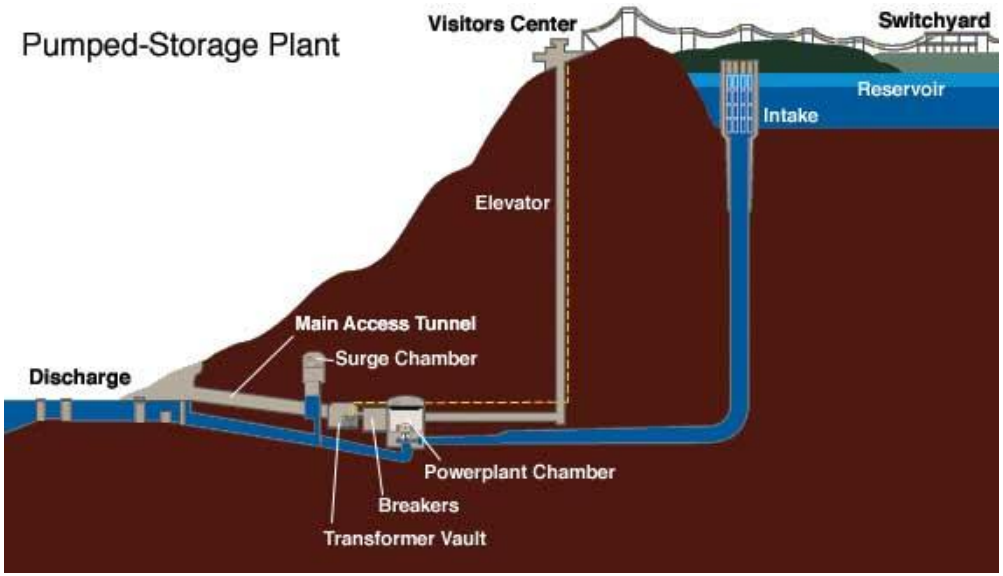
Diversion

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.



Pumped Storage

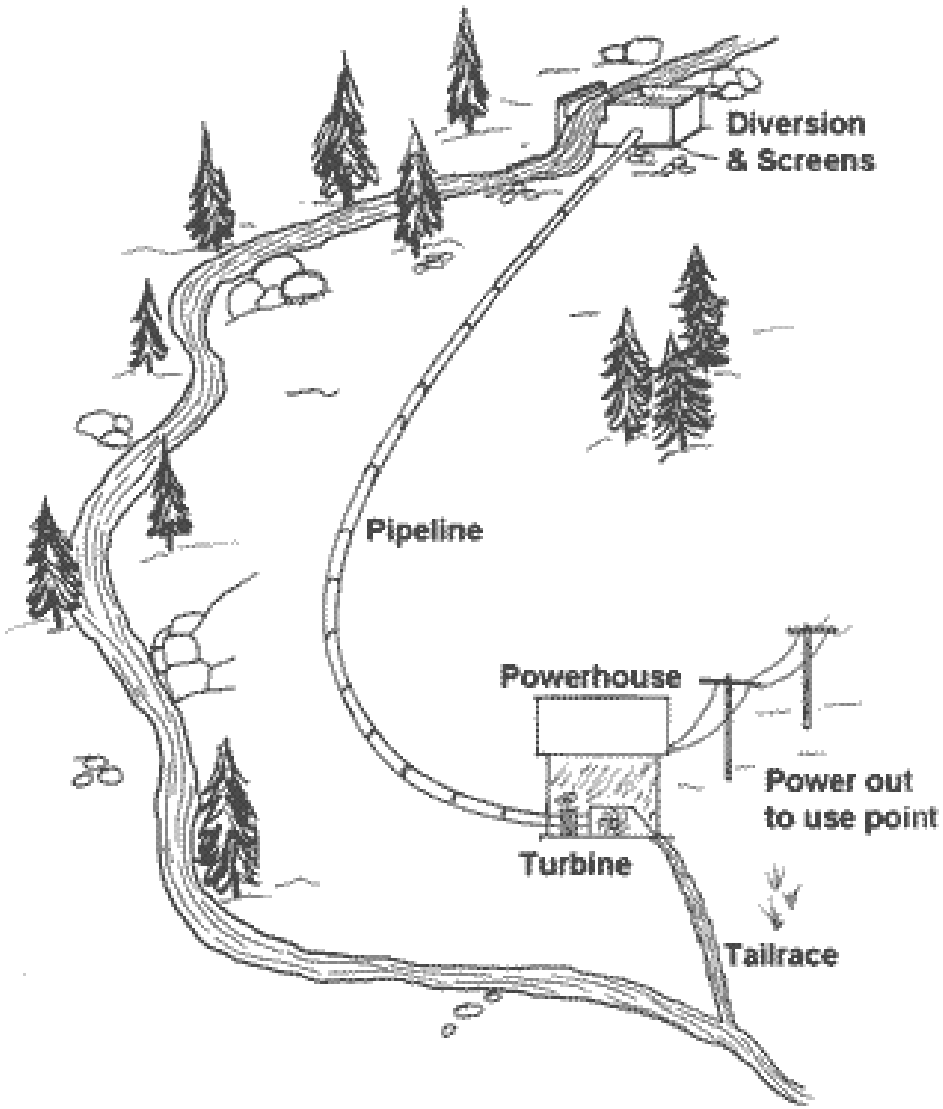


When the demand for electricity is low, a pumped storage facility stores energy by pumping water from a lower reservoir to an upper reservoir.

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

Castaic Dam near the city of Castaic, California

Hydroelectricity Components



Hydropower 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.

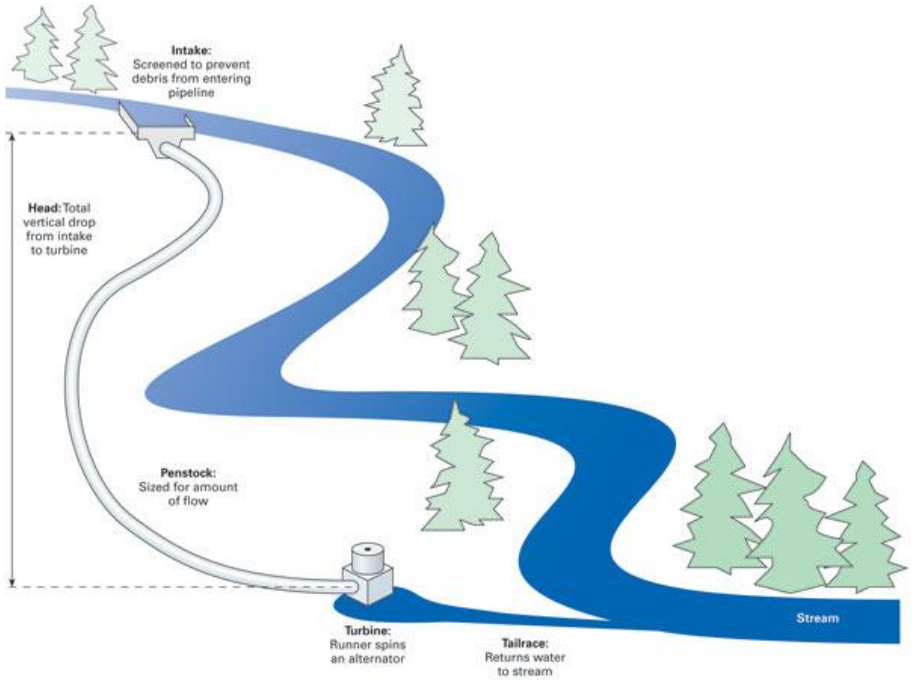
Resource Evaluation at Your Site

Two measurements you must make before designing your hydro system or estimating how much electricity it can produce:

- **Head** – The vertical distance the water falls from the intake to the turbine
- **Flow** – The volume of water falling from a potential hydro site

These measurements determine everything about your hydro system: pipeline size, turbine type, and generator size.

Even rough cost estimates are impossible until you have measured head and flow.



Typical microhydro installation showing the site's "head"

Hydroelectricity Physics

Power (kW) = 10 x Flow (m^3/s) x Head (m) x η

Power (kW) = Head (ft) x Flow (cfs) x η /11.8

η= turbine-generator efficiency ~80%

Determining a Microhydro Site's Head

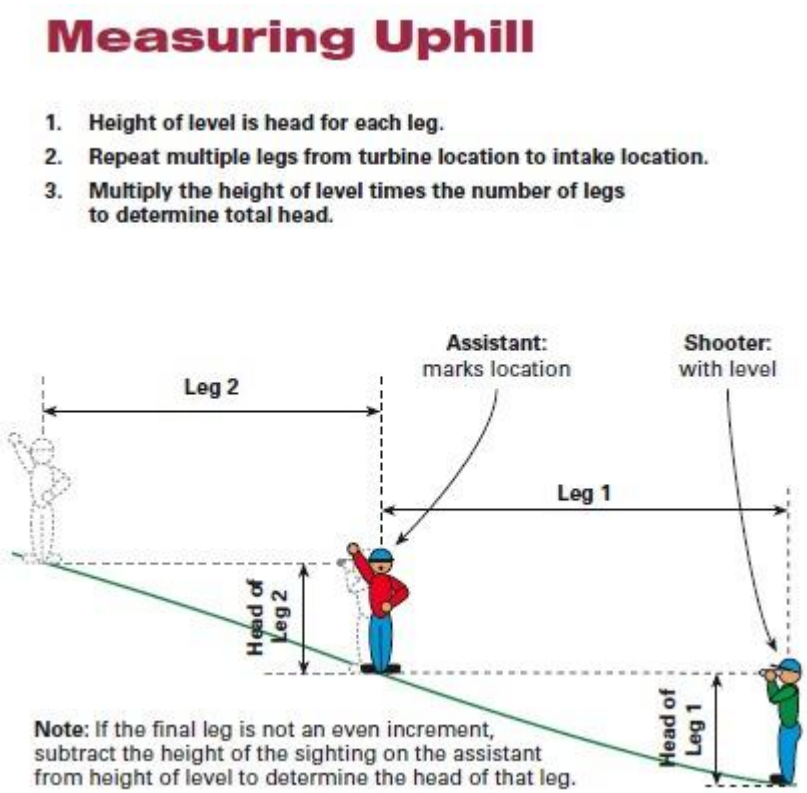
The easy way (for a rough measurement):

- If fairly open terrain, use a handheld GPS system to measure elevation at the intake and at the turbine
- If the elevation drop is several hundred feet, rent or borrow an aircraft altimeter from a small airport
- Topographical maps

Hiring a professional surveyor will provide the most accurate results.

If you want to conduct your own measurements, you can use a handheld sight level ("peashooter") and a measuring stick to measure the head in stages with the help of an assistant.

Additional methods are described in the *Guide on How to Develop a Small Hydropower Plant.*



Direct height measurement of head requires two people

Determining a Microhydro Site's Flow

The easy way – obtain data from:

- U.S. Geological Survey
- U.S. Army Corps of Engineers
- U.S. Department of Agriculture
- Local water supply or flood control authorities

If data is unavailable, you'll have to conduct your own flow measurements.

One method involves damming the stream with boards to divert its flow into a bucket or other container and timing how long it takes to fill - e.g., if a 5-gallon bucket takes 1 minute to fill, your stream's flow rate is 5 gallons per minute.

Additional methods are described in the *Guide on How to Develop a Small Hydropower Plant.*

The bucket method of measuring flow means getting in the stream and timing how long it takes to fill a container of known volume.

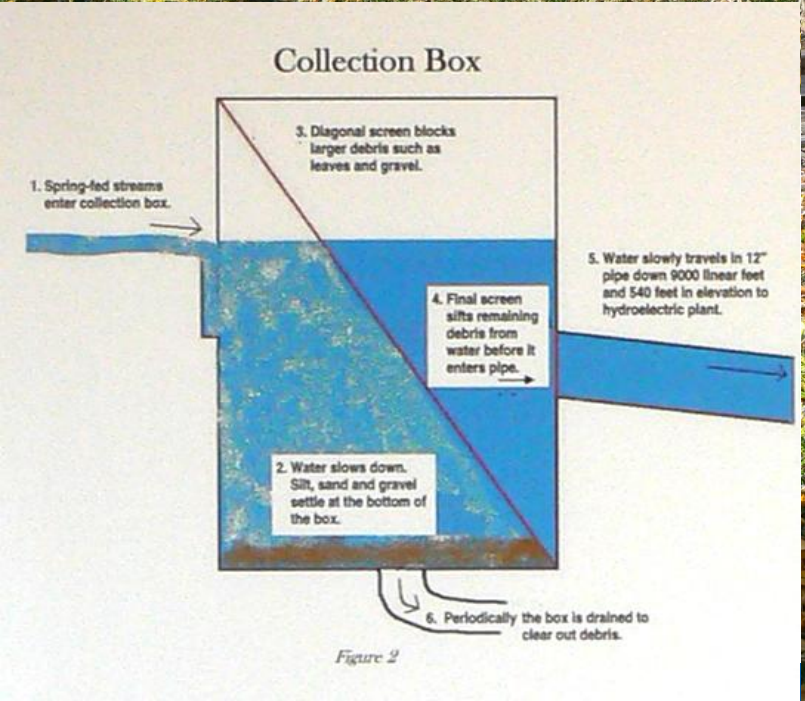
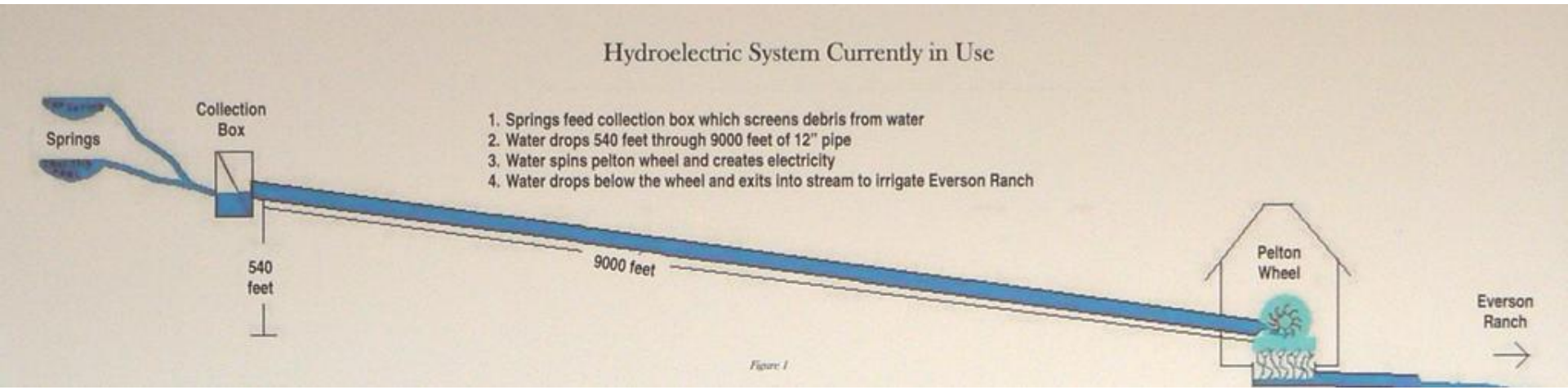
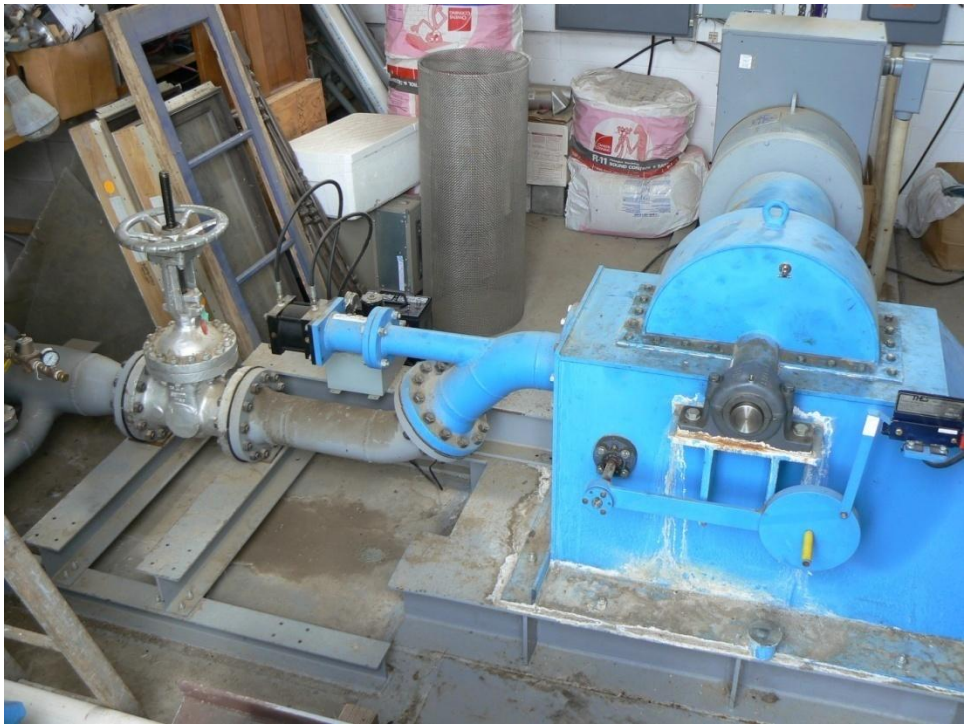

Collection Box
1. Spring-fed streams enter collection box.
2. Water slows down. Silt, sand and gravel settle at the bottom of the box.
3. Diagonal screen blocks larger debris such as leaves and gravel.
4. Final screen sifts remaining debris from water before it enters pipe.
5. Water slowly travels in 12" pipe down 9000 linear feet and 540 feet in elevation to hydroelectric plant.
6. Periodically the box is drained to clear out debris.

Figure 2


Hydroelectric System Currently in Use
Springs
Collection Box
1. Springs feed collection box which screens debris from water
2. Water drops 540 feet through 9000 feet of 12" pipe
3. Water spins pelton wheel and creates electricity
4. Water drops below the wheel and exits into stream to irrigate Everson Ranch
540 feet
9000 feet
Pelton Wheel
Everson Ranch
Figure 1



Microhydropower System Components

- Battery bank – To store surplus energy
- Monitoring meter – Tracks battery bank's level of charge, turbine output, your electricity consumption, etc.
- Regulator (charge controller) – Protects the batteries from being overcharged, sending excess energy to a dump load
- Dump load (diversion/shunt load) – An electrical resistance heater
- DC disconnect (battery-inverter disconnect) – Isolates the inverter from the batteries
- Inverter (DC-AC converter) – Transforms DC electricity from batteries to run AC appliances
- AC breaker panel (breaker box) – Isolates all of a building's electrical circuitry from energy sources, whether hydro or grid
- Kilowatt-hour meter – Monitors electricity consumption in grid-tied applications

Battery and system monitoring meter

Charge controller

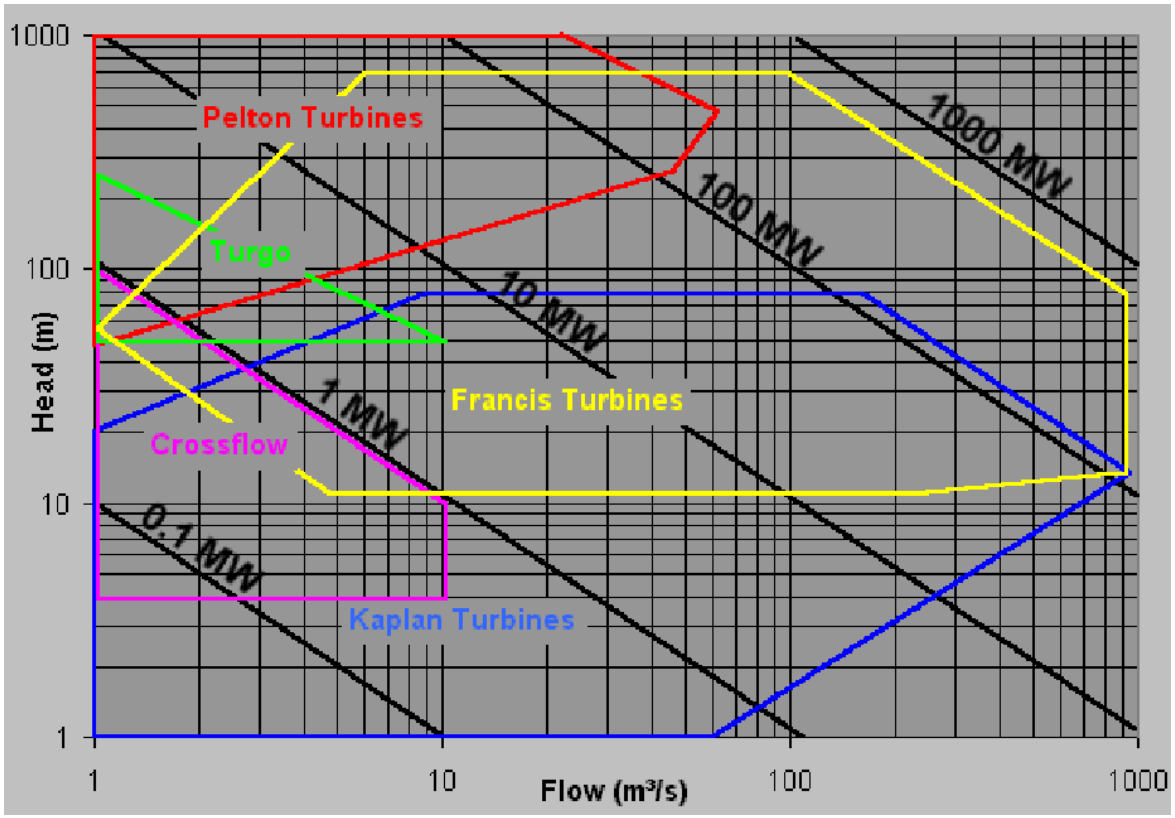
Dump load (in this case, an air heater)

Battery-inverter disconnect

Inverter

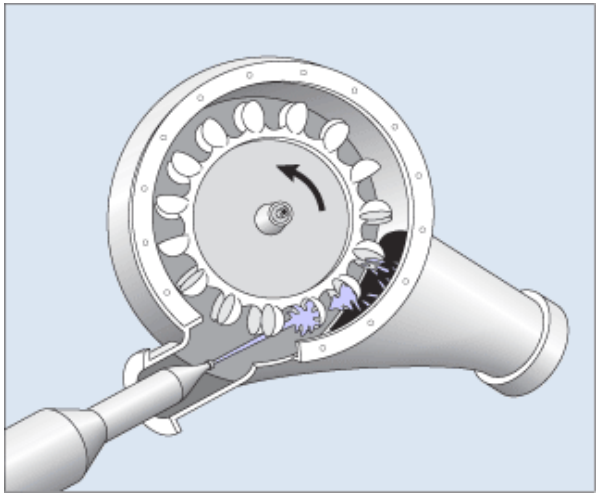
Turbine Applications

Turbine	Head		
	High (>30 m)	Medium	Low (<10 m)
Impulse	Pelton, Turgo	Crossflow Pelton, Turgo	Crossflow
Reaction	X	Francis, Pump	Propeller

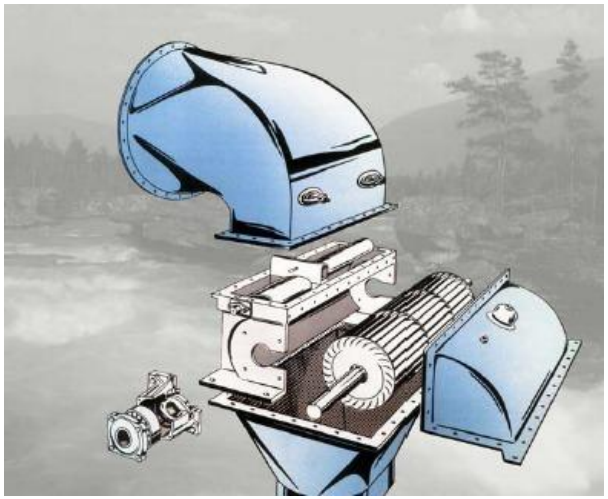


Types of Hydropower Turbines: Impulse

- High head, low flow applications
- The *velocity* of water turns the turbine
- Water jet is directed at buckets or vanes attached to the turbine wheel ("runner"), which spins freely in the air
- Types of impulse turbine
  - **Pelton wheel** – Directs water at buckets. The **Turgo** wheel is a more efficient type of Pelton wheel that directs the water jet at 2-3 buckets simultaneously.
  - **Cross-flow turbine** – Drum-shaped; uses an elongated, rectangular-section nozzle directed against curved vanes on a cylindrical runner. Design allows 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. Works with lower head and higher flow than Pelton wheel.



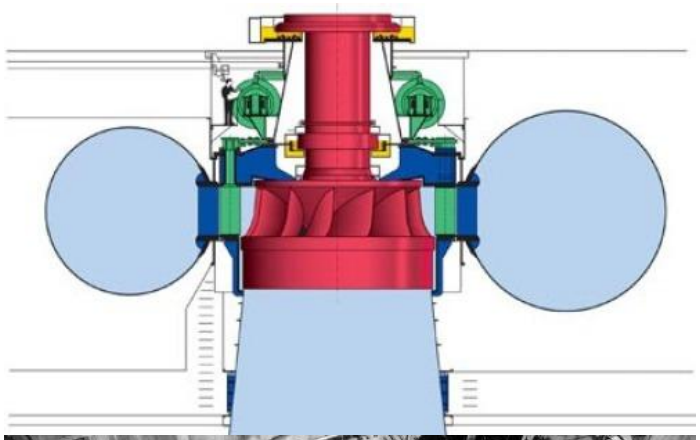
A Pelton wheel. Multinozzle systems allow a greater amount of water to impact the runner, which can increase turbine output.

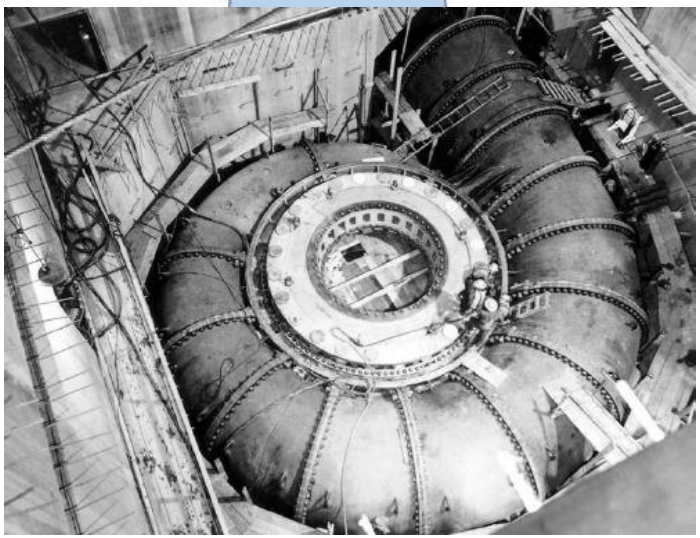


Cross-flow turbine

Types of Hydropower Turbines: Reaction

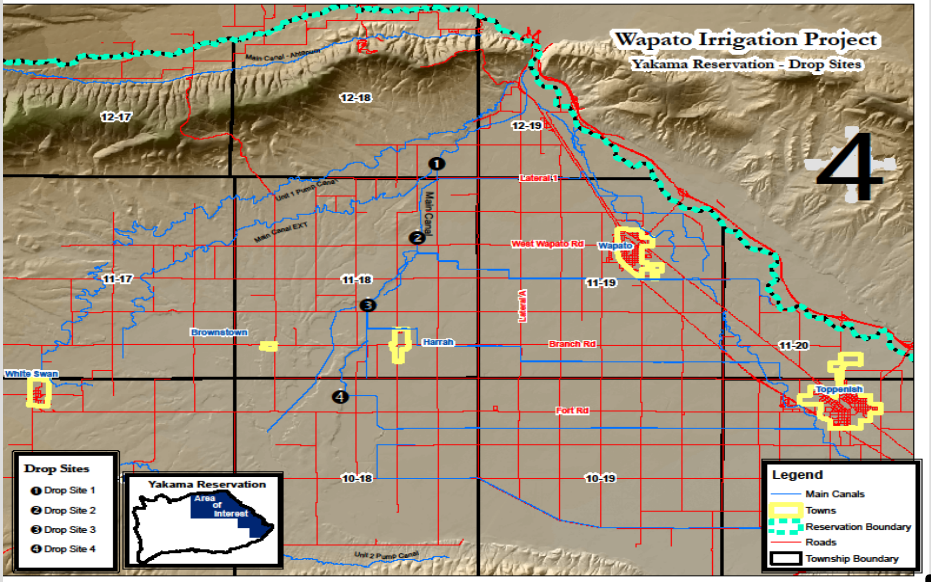
- Low head, high flow applications
- The *pressure* of water turns the turbine
- Turbine runner is immersed in the water stream, instead of water being directed at buckets/vanes
- Typically used at large-scale hydro plants
- Types of reaction turbine
  - **Francis turbine** – Has a runner with 9+ fixed vanes. Water is introduced just above the runner and all around it and then falls through, causing it to spin.
  - **Propeller turbine** – Has a runner with 3-6 blades. Picture a boat propeller running in a pipe. **Kaplan** turbines have adjustable blades.
  - **Kinetic ("free flow") turbine** – Does not require piping to direct the water. Instead, it is immersed directly into a river, man-made channel, tidal waters, or ocean currents. Picture a boat propeller with water flowing all around it. Can be attached to existing structures such as bridges.





A Francis turbine. Photo shows intake piping with the turbine removed. Diagram is a cross-section through the entire assembly showing the turbine.

Yakama Wapato Irrigation Project



Hydro Power Feasibility Study

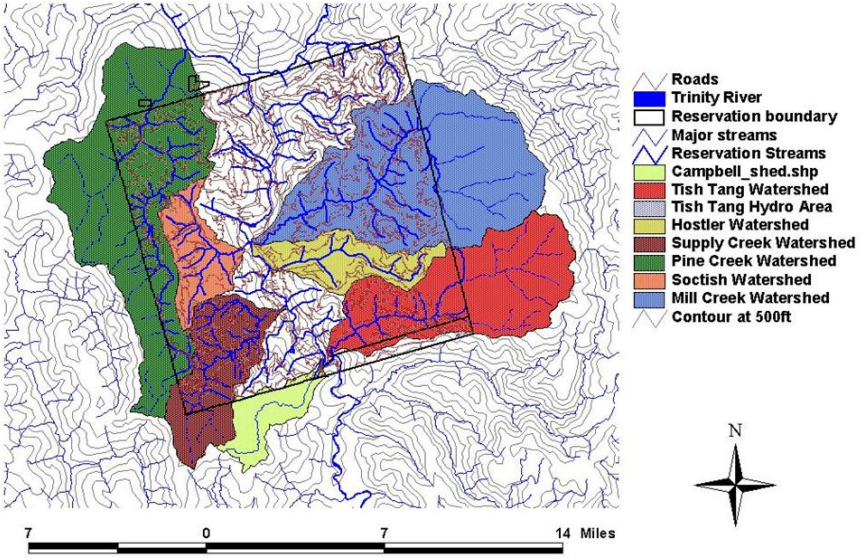
Hoopa Valley Tribe

Curtis Miller

cmiller@hoopa-nsn.gov

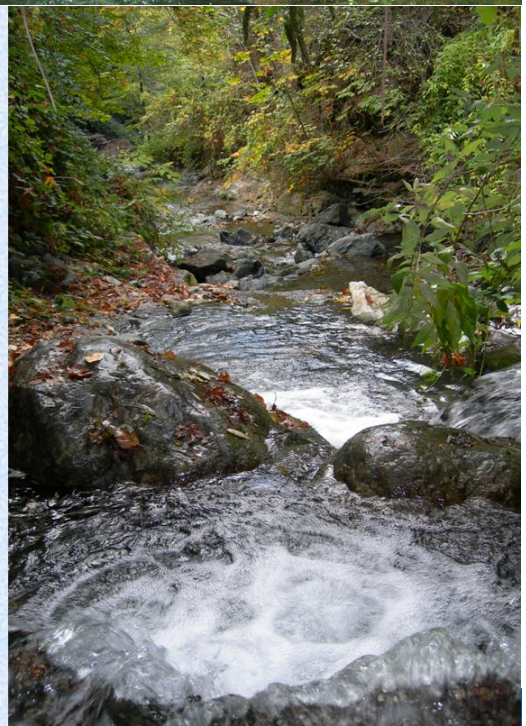
(530)-625-5515

Hoopa Valley Hydrosheds



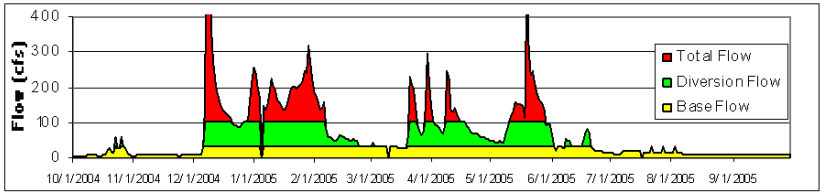
Hostler Creek

- Gross head, 39 feet
- Length of pipe, 375 feet
- Design flow, 10 cfs
- Flow duration 217 days
- Recommended pipe diameter, 16"
- Calculated net head, 35 feet
- Expected power, 19KW
- Revenue ~$6,000 annually

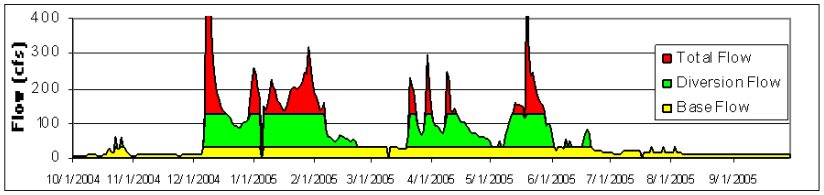


Supply Creek

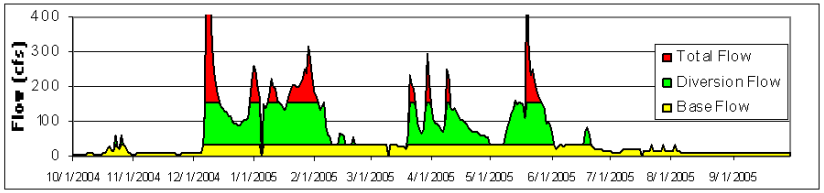
36”



42”



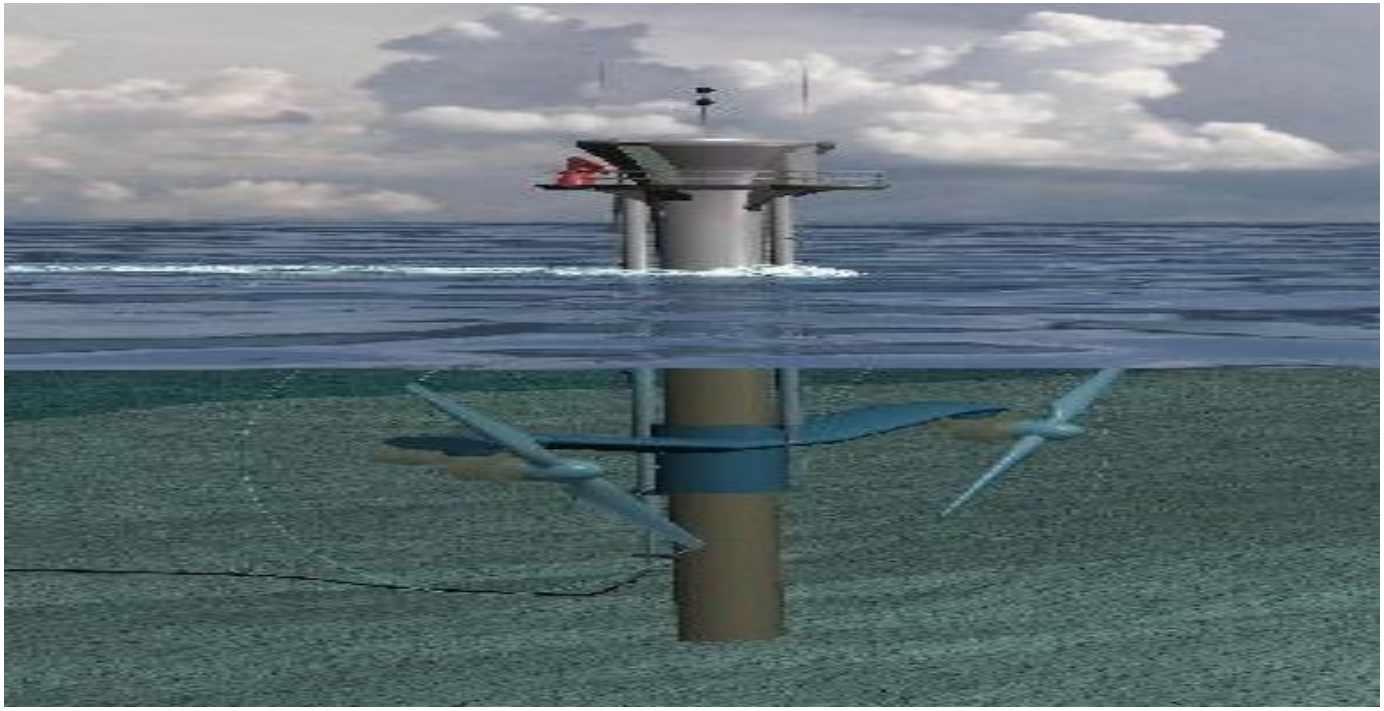
48”



Definitions

Hydrokinetic: “Moving Water” (no dams!)

- Currents: Ocean & River
- Waves



EPRI TP-008-NA

North America Tidal In-Stream Energy Conversion Technology Feasibility Study

Roger Bedard, Ocean Energy Leader, EPRI;
Mirko Previsic; Brian Polagye, Univ. of Wash; George Hagerman, Virginia Tech;
Andre Casavant, Devine Tarbell and Associates
June 11, 2006

GCK	Lunar	MCT	Open Hydro	Sea power	SMD Hydro	UEK	Ver-dant
V axis Lift	H axis Duct	H axis Dual	H Axis Rim Gen	V axis Drag	H axis Dual	H Axis Dual	H axis
1 m dia	21m dia	18 m dia	15 m dia	1 m dia	8 m dia	3 m dia	5 m dia
7 kW	2 MW	1.5 MW	1.5 MW	44 kW	1 MW	400 kW	34 kW

1) Axis type; 2) Diameter of the rotor and 3) Rated power

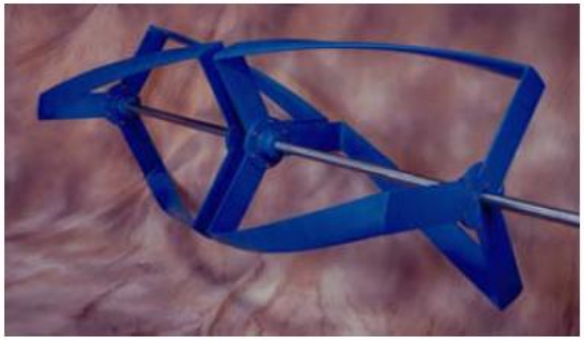


Figure 4. Gorlov Helical Turbine

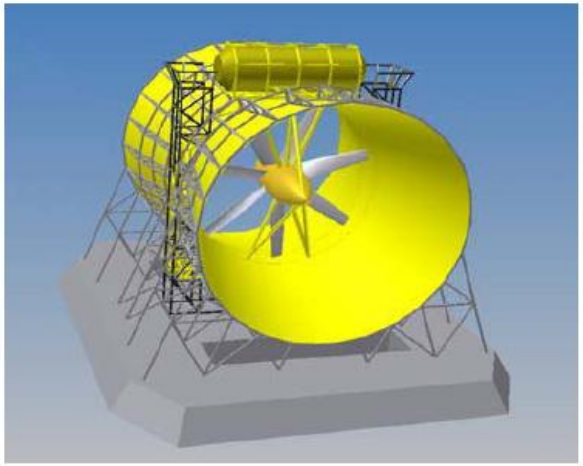


Figure 5. Lunar Energy RTT Turbine

Figure 6. MCT Experimental SeaFlow

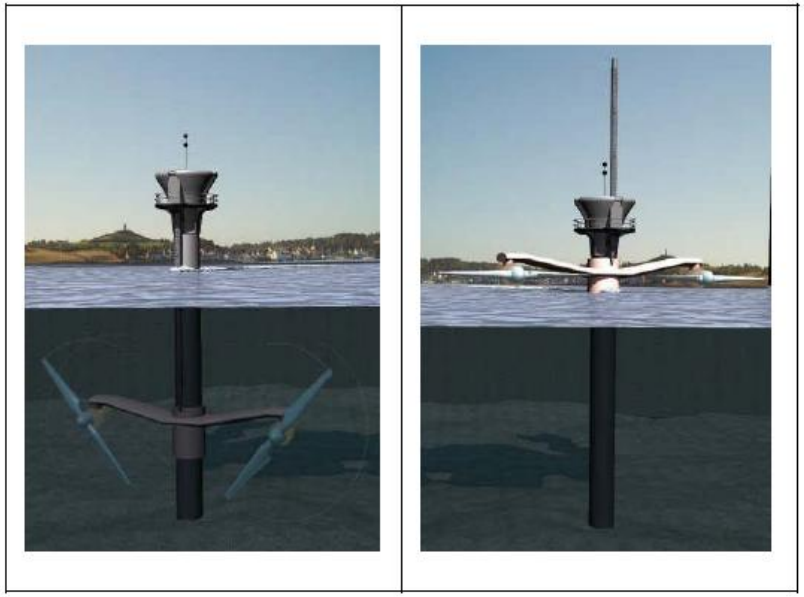


Figure 7. MCT SeaGen Prototype

Figure 8. Open Hydo Rim Drive Turbine

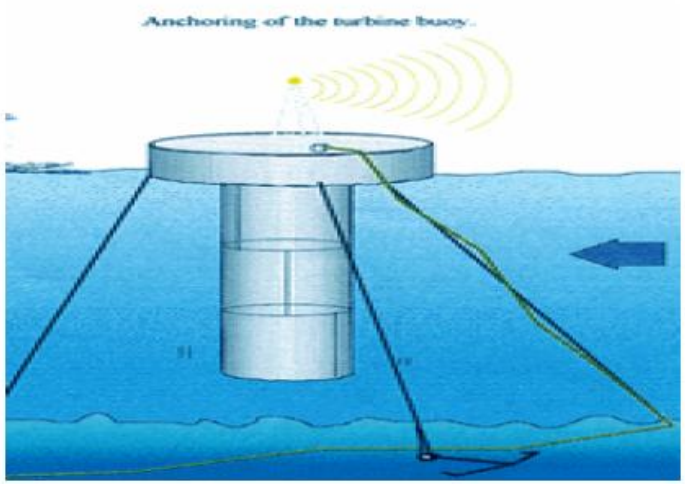


Figure 9. Seapower Vertival Axis Turbine

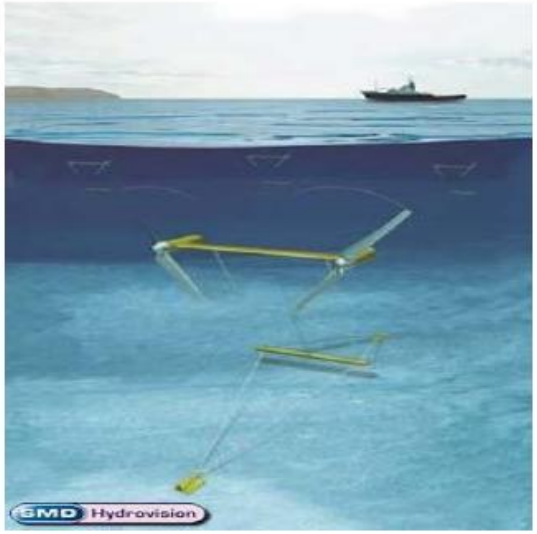


Figure 10. SMD Hydrovision

Figure 110. UEK Shrouded Turbine

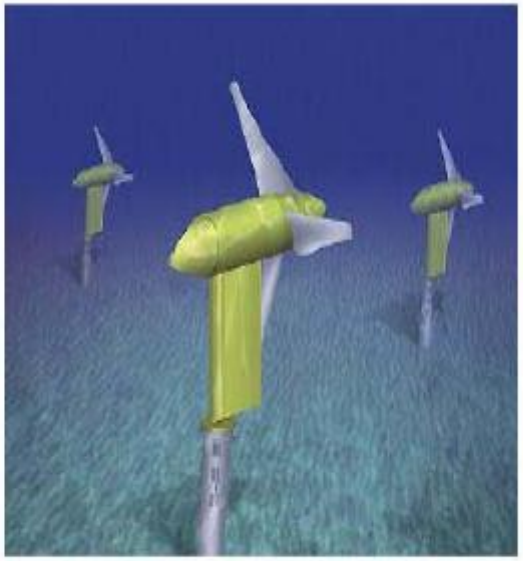


Figure 121. Verdant Power RITE Turbines

Verdant Power

Roosevelt Island Tidal Energy (RITE) Project

Phase 2 Demonstration Completed

Verdant Power recently achieved a major milestone by successfully completing the RITE Project's Phase 2 Demonstration, which began in 2006 with the installation of the company's first full-scale (5m diameter rotor) Free Flow System turbine into the East River.

Over this two-year period, Verdant Power operated six full-scale turbines in array at the RITE Project, successfully demonstrating the Free Flow System as an efficient source of renewable energy with the following outcomes:

Excellent hydrodynamic, mechanical and electrical performance;

Grid-connected power with no power quality problems;

Fully bidirectional operation – passive yawing with high efficiency on both ebb and flood tides;

Automatic control and continuous, unattended operation;

No fouling or damage from debris;

70 megawatt hours of energy delivered to two end users;

9,000 turbine-hours of operation.

Ocean Renewable Power Corp. Maine

River/Tidal:
Cross-Flow Vertical Axis

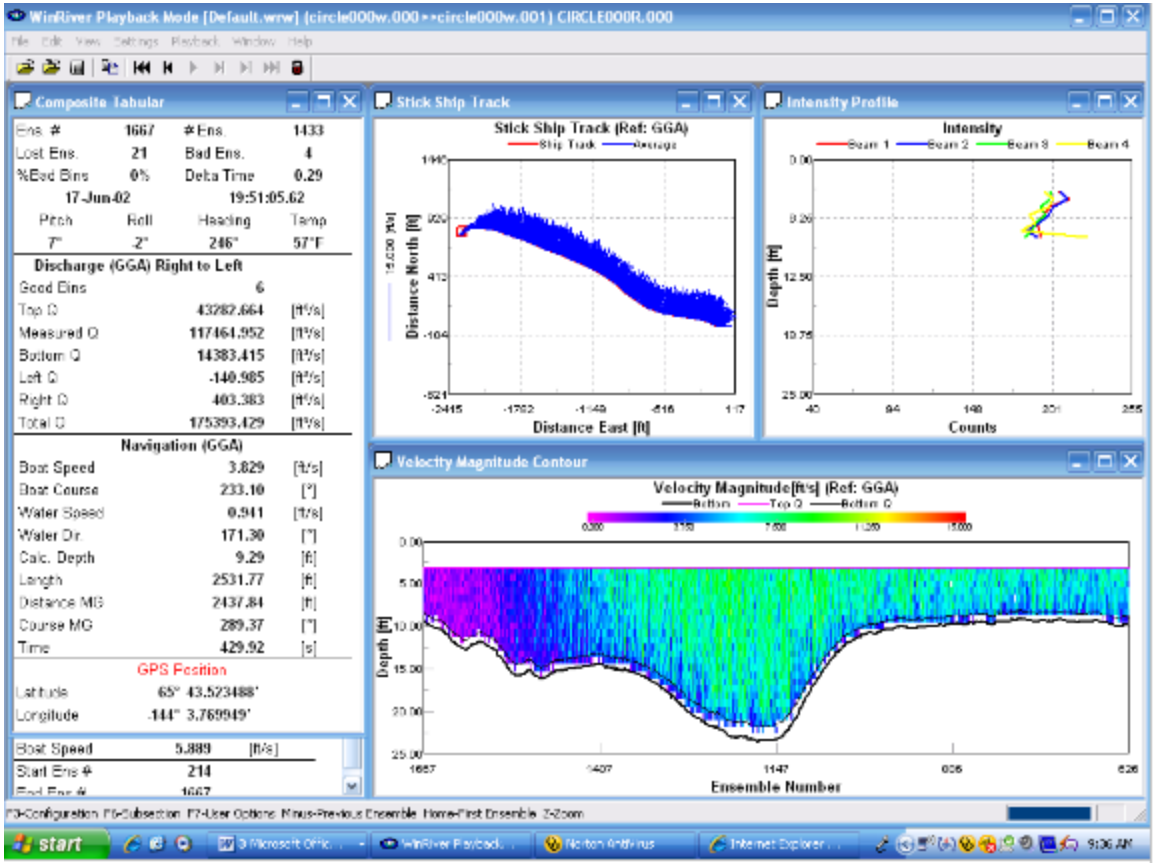
New Energy's 5 kW Encurrent Turbine at Ruby, AK

New Energy's 5 kW Encurrent Turbine

25 kW Turbine

Resource Assessment

Water Speed Profile of Yukon River at Circle



Hydro Green Energy delivered the first of two hydrokinetic turbines to Hastings, Minnesota, in early December. The barge-mounted power plant will be parked in the output of Mississippi Lock and Dam No. 2, which is visible in the background. (12/15/08)

http://www.eere.energy.gov/news/images/08_12_17_hydrokinetic_turbine.jpg

HYDRO GREEN ENERGY'S 1ST PROJECT

The Hastings hydrokinetic project is the first commercially-operational, FERC-licensed hydrokinetic power facility in the history of the United States.

Challenges/Considerations

- » River “Trash” (Debris)
- » Ice & break-up
- » Silt
- » Water Speed
- » Anchoring
- » Power Delivery to Shore
- » Navigable Waters
- » Fish
- » Permitting

Wave Power: Attenuator

Photo Credit: Pelamis Wave power

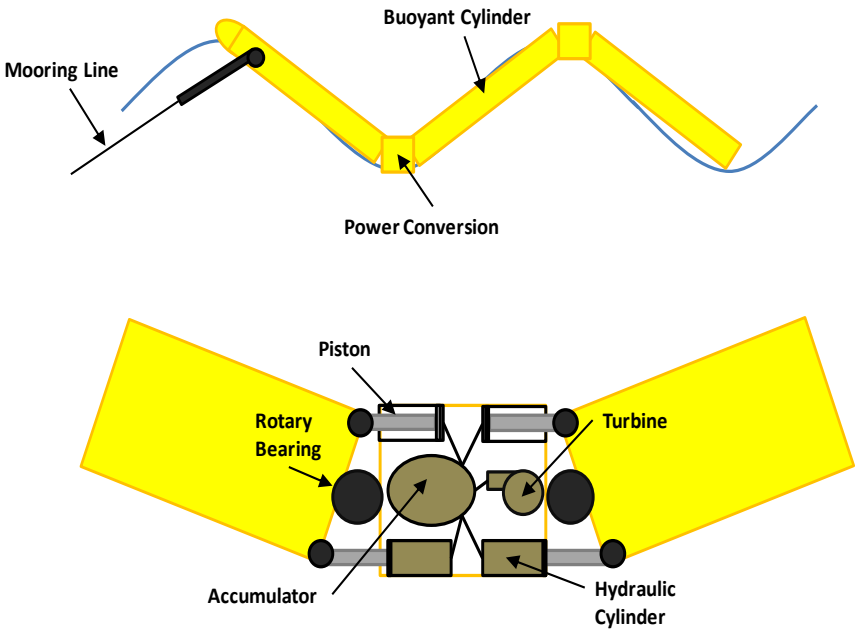
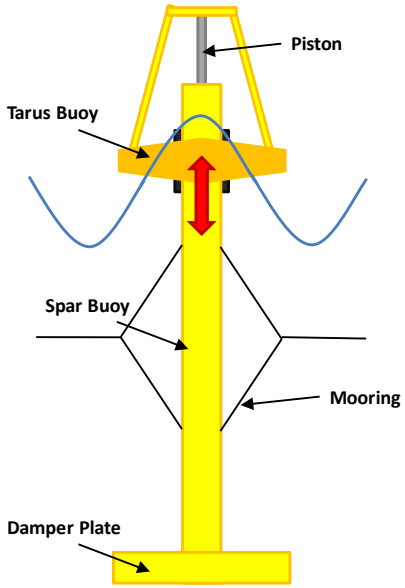
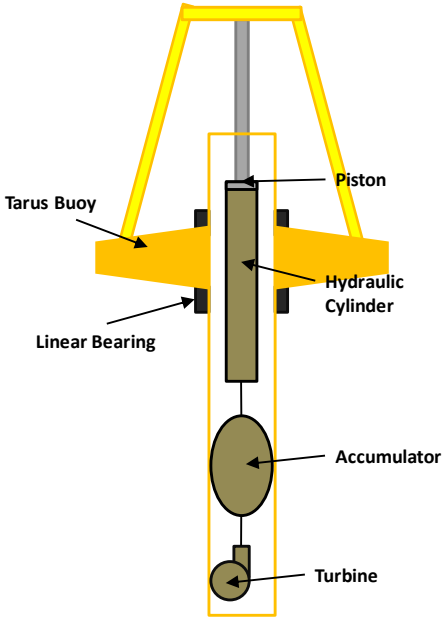


Figure Credit: David Elwood

Pelamis 2.25 MW Pilot Project Installed 2008 Portugal

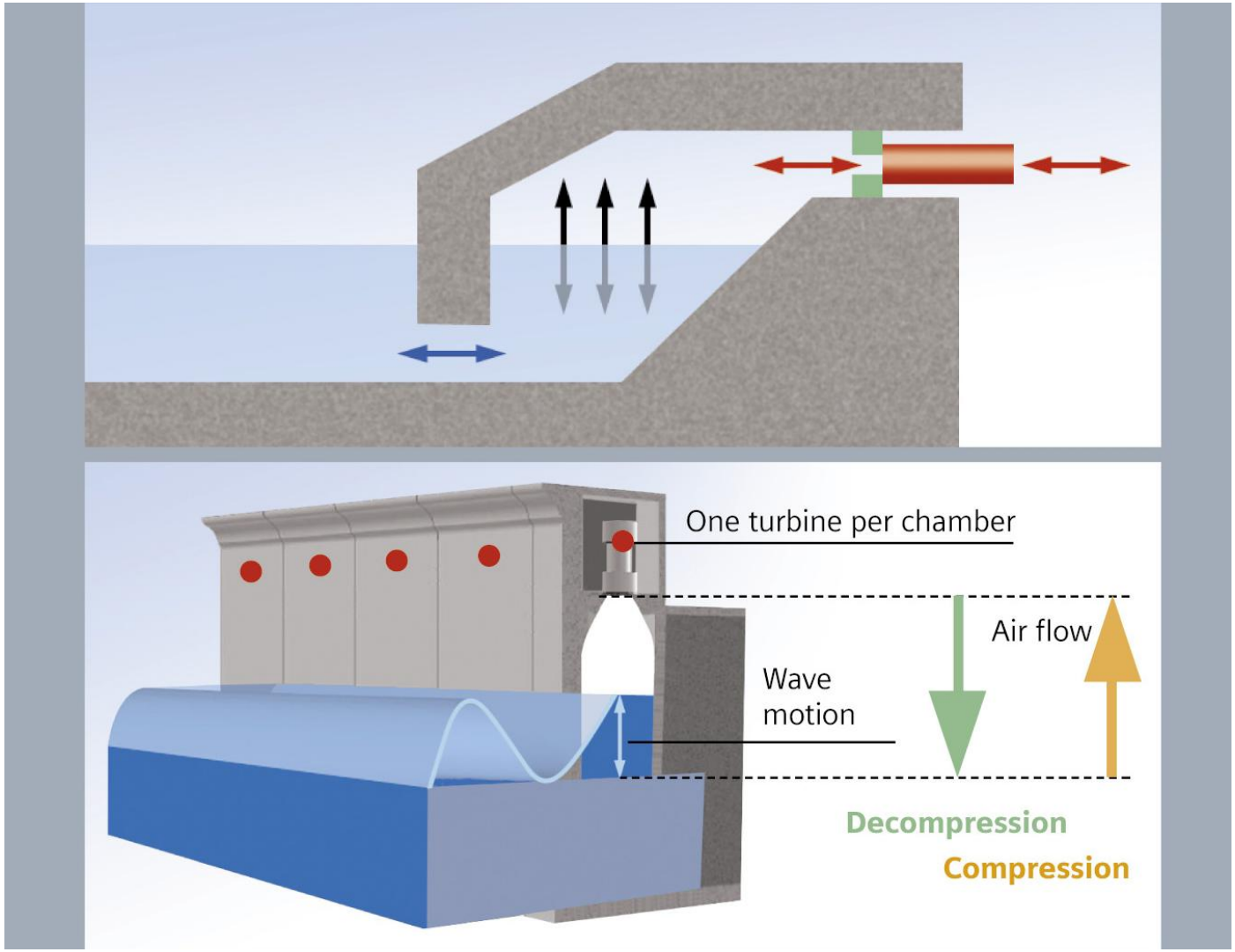
Wave Power: Point Absorber





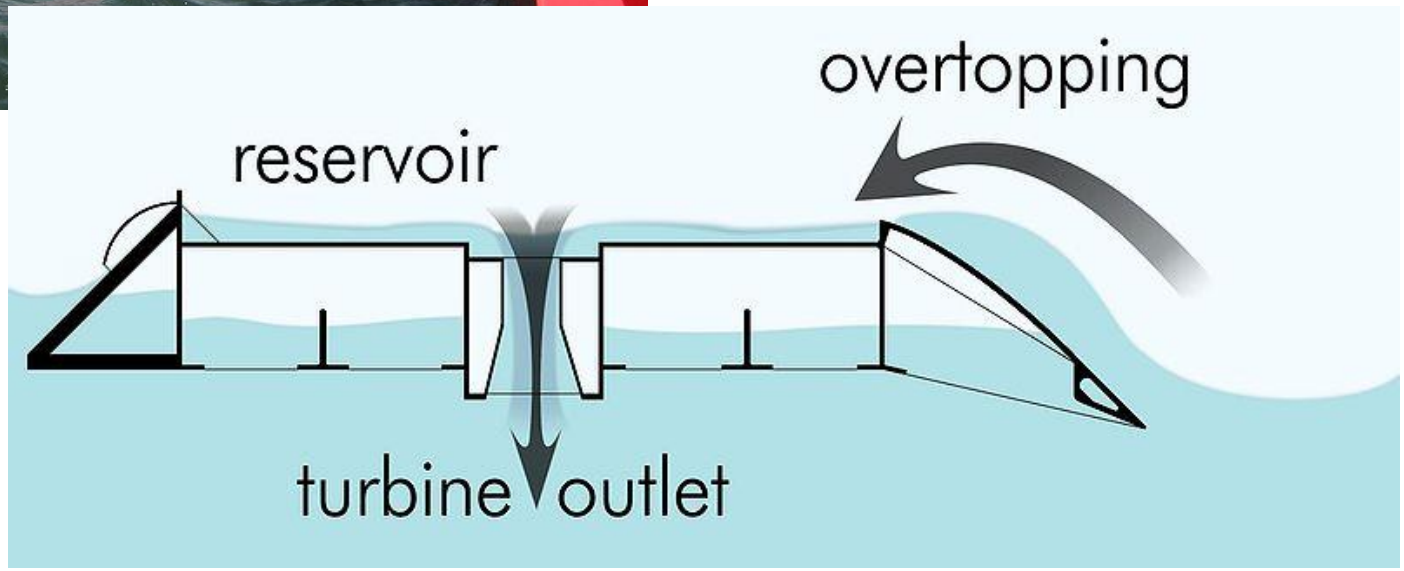
Photos: Ocean Power Technologies
Diagram Courtesy of David Elwood

Wave Power: Oscillating Water Column



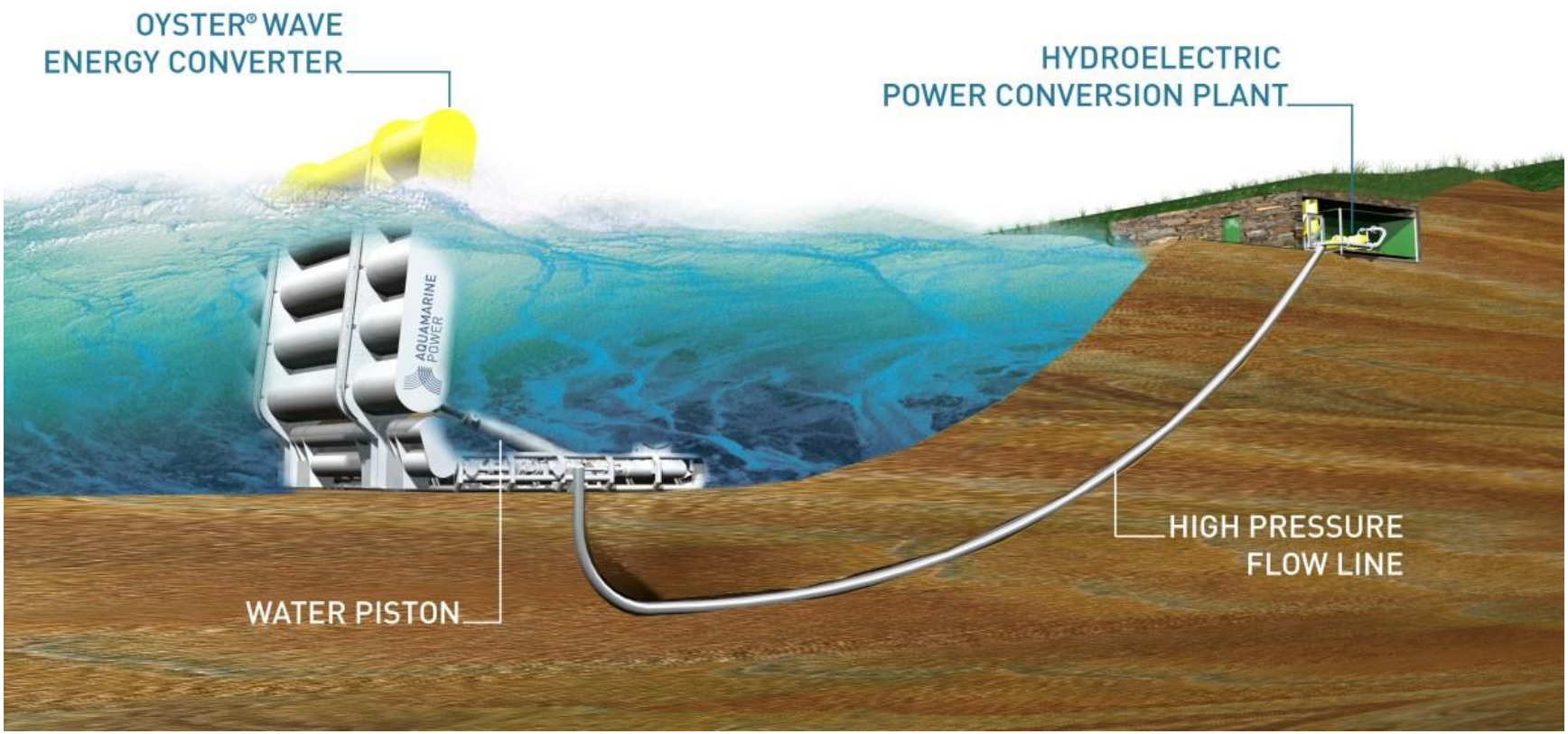
From: Voith Hydro Wavegen

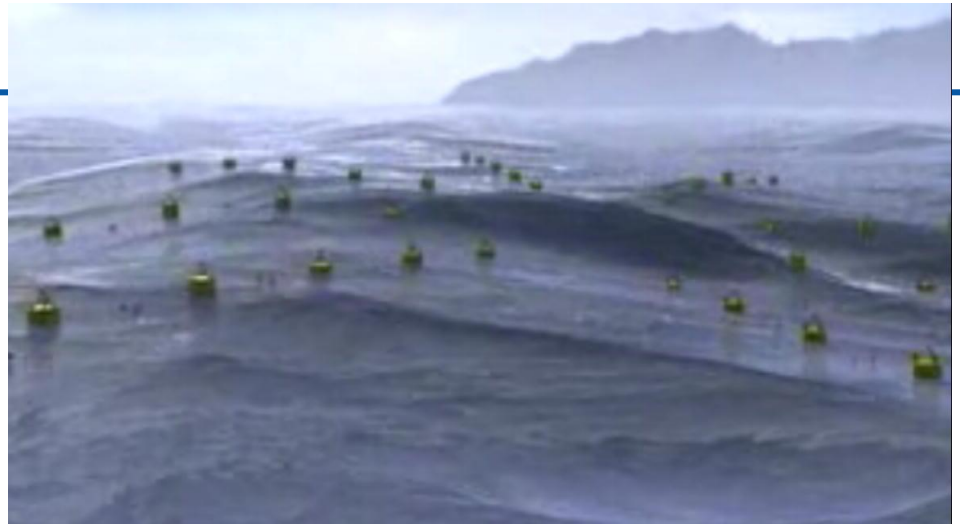
Wave Power: Over-topping Device



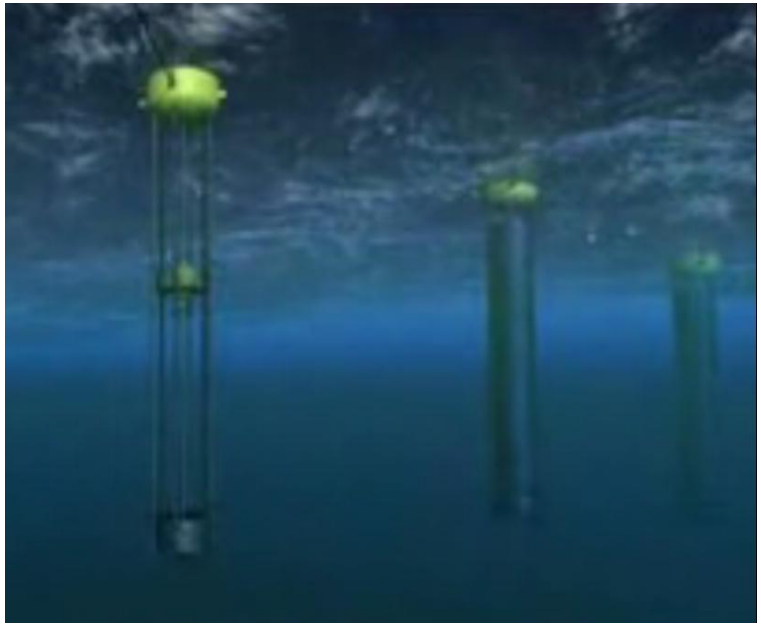
Wave Dragon
Denmark

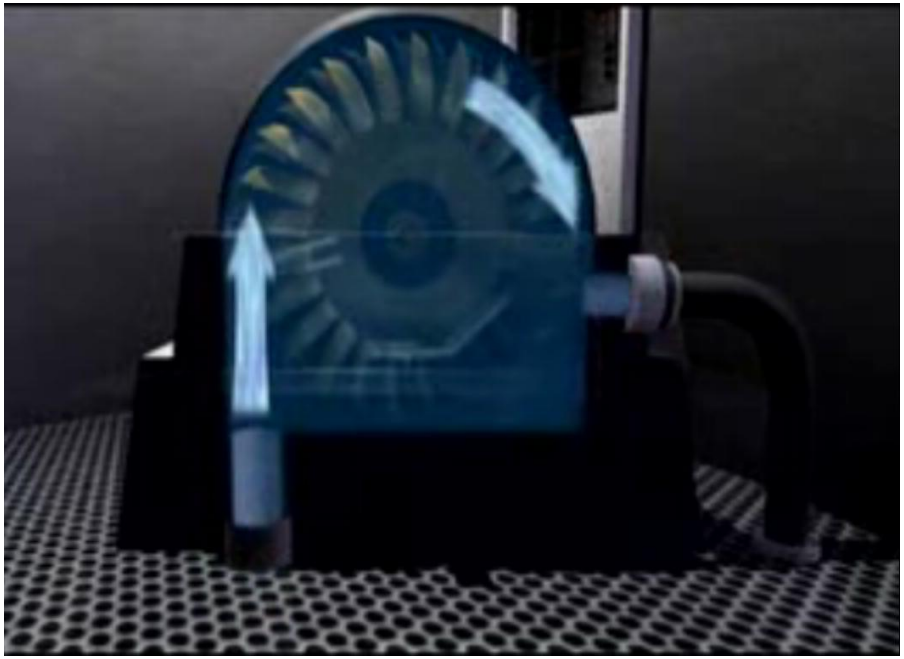
Wave Technology: Aquamarine Oyster



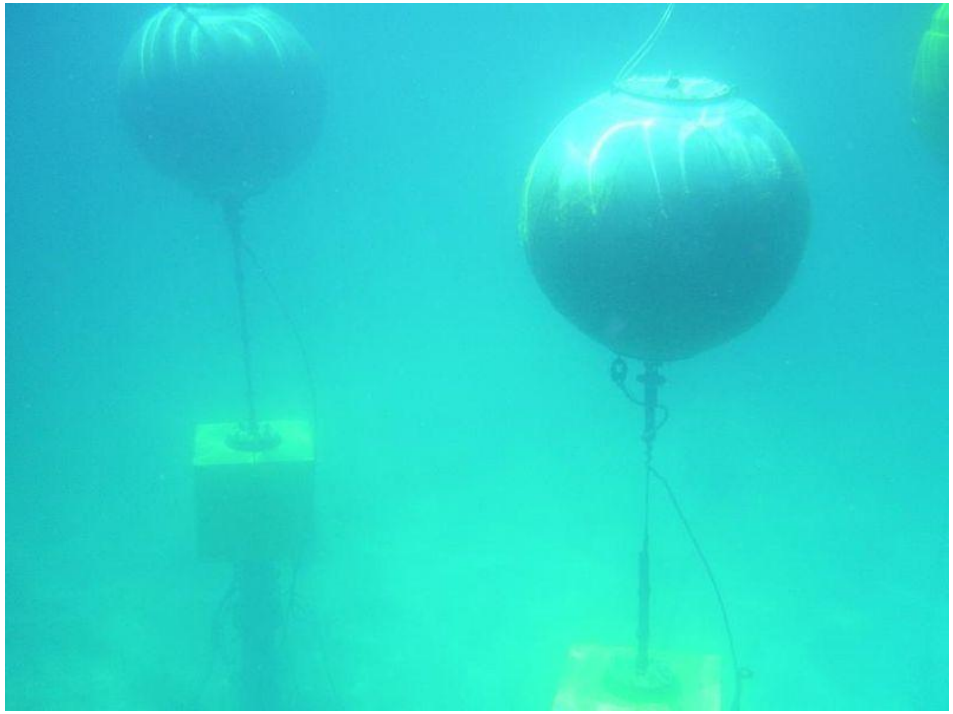


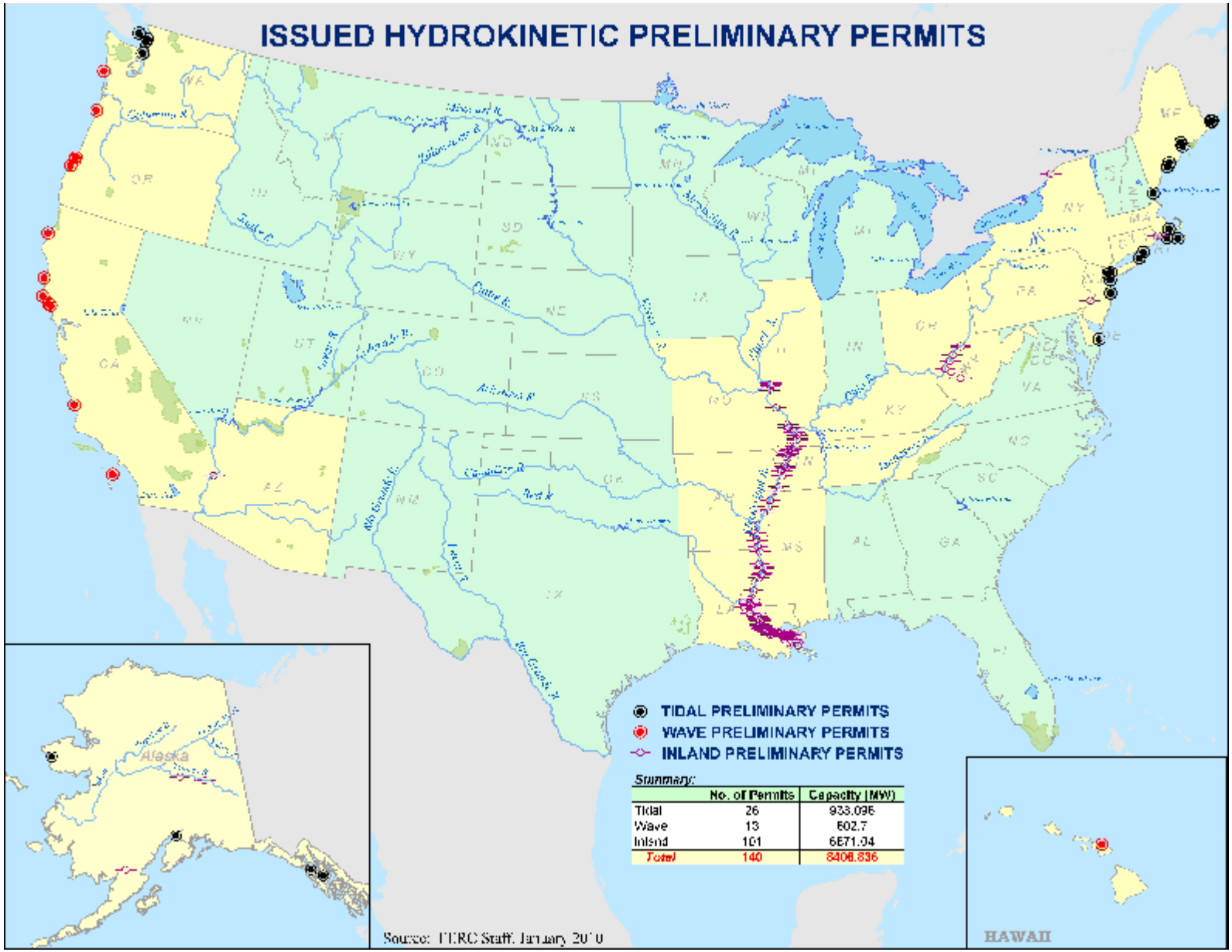
Finavera Renewables Aqua Buoy





CETO - Australia





From: http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics/issued-hydrokinetic-permits-map.pdf

Potential in Alaska

Permitting & Related Issues

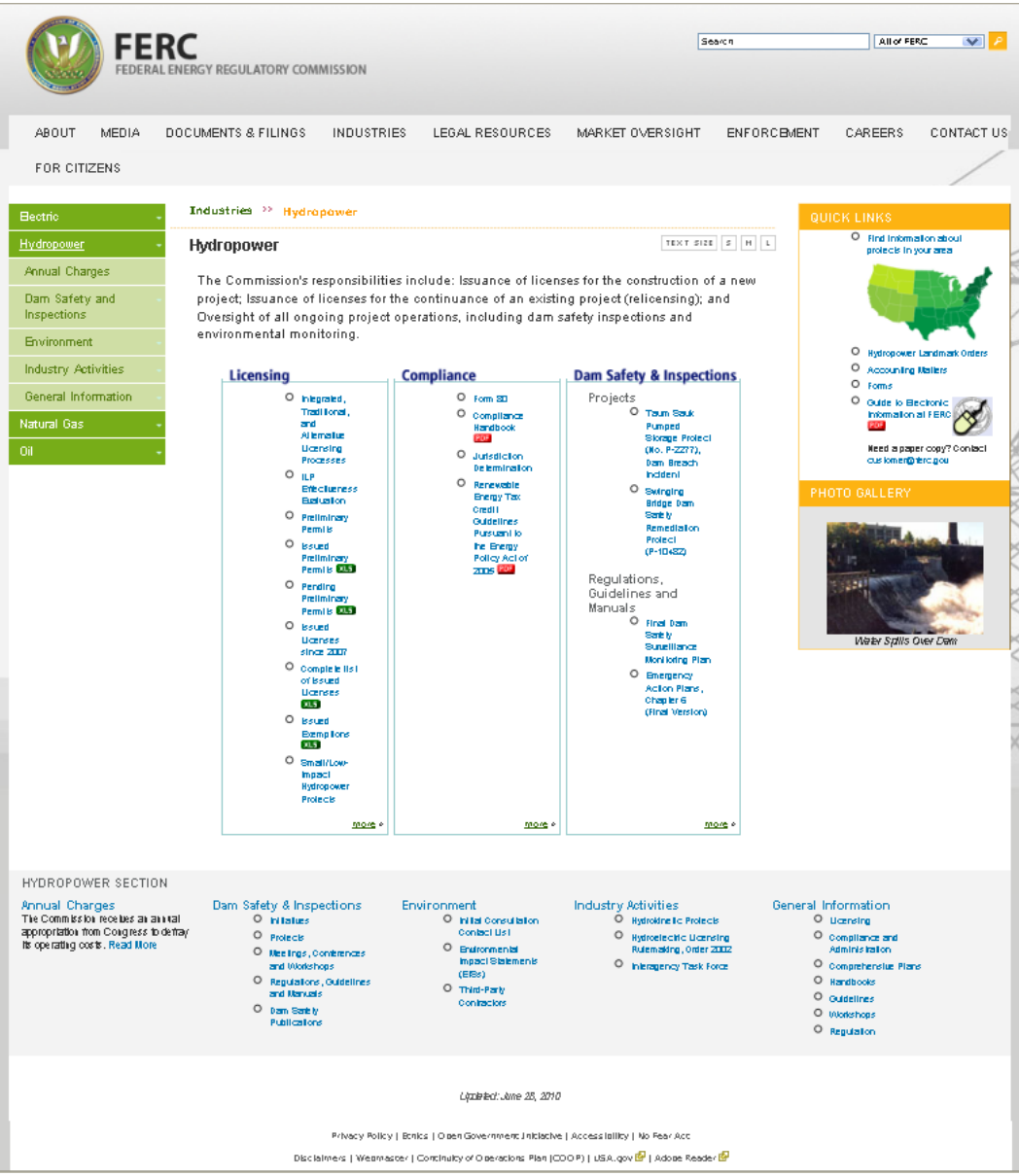
- Water Rights & Land Use - DNR
- Fish Habitat and Fish Collection (impact study) – ADF&G

- Coastal Zone Management
- US Army Corps Permit (Section 10): Multi-agency

- FERC Preliminary Permit: Up to 3 years to show progress; "exclusive right" to develop and apply for Pilot Project & Full license
- FERC Pilot Project License: Up to 5 years to prove out technology
- FERC Full Permit: 30-50 years

- Coast Guard notification

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



DOE Awards Millions for Marine and Hydrokinetic Energy Technology

WASHINGTON, D.C., U.S. 9/10/10 (PennWell) -- Energy Secretary Steven Chu has announced selections for more than $37 million in funding to accelerate the technological and commercial readiness of emerging marine and hydrokinetic (MHK) technologies, which seek to generate renewable electricity from the nation's oceans and free-flowing rivers and streams.

The 27 projects range from concept studies and component design research to prototype development and in-water device testing. This unprecedented level of funding will advance the ability of marine and hydrokinetic energy technologies to contribute to the nation's electricity supply, DOE reported.

"This funding represents the largest single investment of federal funding to date in the development of marine and hydrokinetic energy technologies," said Secretary Chu. "These innovative projects will help grow water power's contribution to America's clean energy economy."

The nation's ocean waves, tides, currents, thermal gradients and free-flowing rivers represent a promising energy source located close to centers of electricity demand. The Department of Energy is working with industry, universities, national laboratories and other groups to develop technologies capable of harnessing these resources to generate environmentally sustainable, cost-competitive power. The Department of Energy will leverage private sector investments in marine and hydrokinetic energy technologies by providing cost-shared funding to industry and industry-led partnerships.

On the FERC Front

FERC licenses small Kansas project in six months (Sep 9, 2010)
The Federal Energy Regulatory Commission has licensed a small hydro project on the Kansas River in only six months, one of several recent expedited licensings of small projects having few environmental issues.
FERC launches small/low impact hydro Internet site (Sep 2, 2010)
The Federal Energy Regulatory Commission has unveiled its Small/Low Impact Hydropower Program Internet site, explaining how developers can quickly and efficiently win FERC approval to build and operate small hydro projects.
FERC, Colorado plan pilot program for small hydro exemptions (Aug 25, 2010)
The Federal Energy Regulatory Commission and the state of Colorado have signed a memorandum of understanding under which Colorado is to develop a pilot program to advance FERC hydropower licensing exemptions for small hydro projects in the state.

HYDROWORLD.com

Federal Financial Incentives

Tax credits - Only useful if you are working with a developer who has a tax appetite:

- Production Tax Credit (PTC) of 2.1 cents/kWh for 10 years
- Investment Tax Credit (ITC) for 30% of capital costs of project (depreciable items)
- Section 1603 lump-sum payment in lieu of tax credit

Clean Renewable Energy Bonds (CREBs) - Designed for non-taxable entities that cannot receive the PTC or ITC.

Loan guarantees - Including the Innovative Loan Guarantee Program created to support the deployment of energy technologies that "reduce, avoid or sequester carbon dioxide and other air emissions."

Tribal Economic Development Bonds & Additional Recovery Act Incentives - The Recovery Act temporarily allows tribal governments to issue $2 billion of tax-exempt bonds for economic development projects on tribal. Overall, the Act expands the ability of tribes to borrow on a lower-cost tax-exempt basis, permits tribes to issue a new type of tax credit bond, provides tax credit subsidies of up to $400 million for tribal school construction, and adds further tax incentives to make tribal bonds more appealing to investors and lenders.

DOE Tribal Energy Program grants - The program provides financial assistance, technical assistance, education, and training to tribes for the evaluation and development of renewable energy resources.

Information Resources

General

Hydropower facts and figures: *2008 Renewable Energy Data Book*
www.eere.energy.gov/maps_data/pdfs/eere_databook.pdf

Glossary of hydropower terms
www.eere.energy.gov/windandhydro/hydro_glossary.html

Hydropower Resource Assessments

Web site: http://hydropower.id.doe.gov/resourceassessment/index.shtml
- *State Resource Assessment Reports*
- *Water Energy Resources of the U.S. with Emphasis on Low Head/Low Power Resources*
- Virtual Hydropower Prospector
- Hydropower Evaluation Software

Federal Financial Incentives for Hydropower

Wind & Hydropower Program: Overview of Related Incentives & Funding Opportunities
www.eere.energy.gov/windandhydro/pdfs/wind-water_incentives_funding.pdf

Tribal Energy Program grants and other assistance
www.eere.energy.gov/tribalenergy/government_grants.cfm#Tribal

Information Resources

Legal Considerations & Development Options

Federal Energy Regulatory Commission (FERC)
www.ferc.gov/industries/hydropower.asp

Indian tribes must comply with federal requirements. Start by contacting FERC. FERC is responsible for issuing licenses, dam safety inspections, and environmental monitoring.

U.S. Army Corps of Engineers: Wetlands and Waterways Regulation and Permitting
www.usace.army.mil/CECW/Pages/ww_reg_permit.aspx

National Hydropower Association
www.hydro.org
Contact them if you are interested in developing/improving a large hydropower facility.

Tribal Case Studies

Tribal Energy Program: Projects on Tribal Lands
www.eere.energy.gov/tribalenergy/projects_technology.cfm

Information Resources

How-To Guides & Training

Guide to Tribal Energy Development: Hydroelectric Power
www.eere.energy.gov/tribalenergy/guide/hydroelectric_power.html

European Small Hydropower Association
www.esha.be/index.php?id=39
- *Guide on How to Develop a Small Hydropower Plant*
- *Checklist on Small Hydropower*

Home Power Magazine
www.homepower.com
Events page lists renewable energy workshops and trainings held around the country.