Lecture 14 – Hydropower

Dr. Yu Zhang

ECE, UCSC

ECE180J

Outline

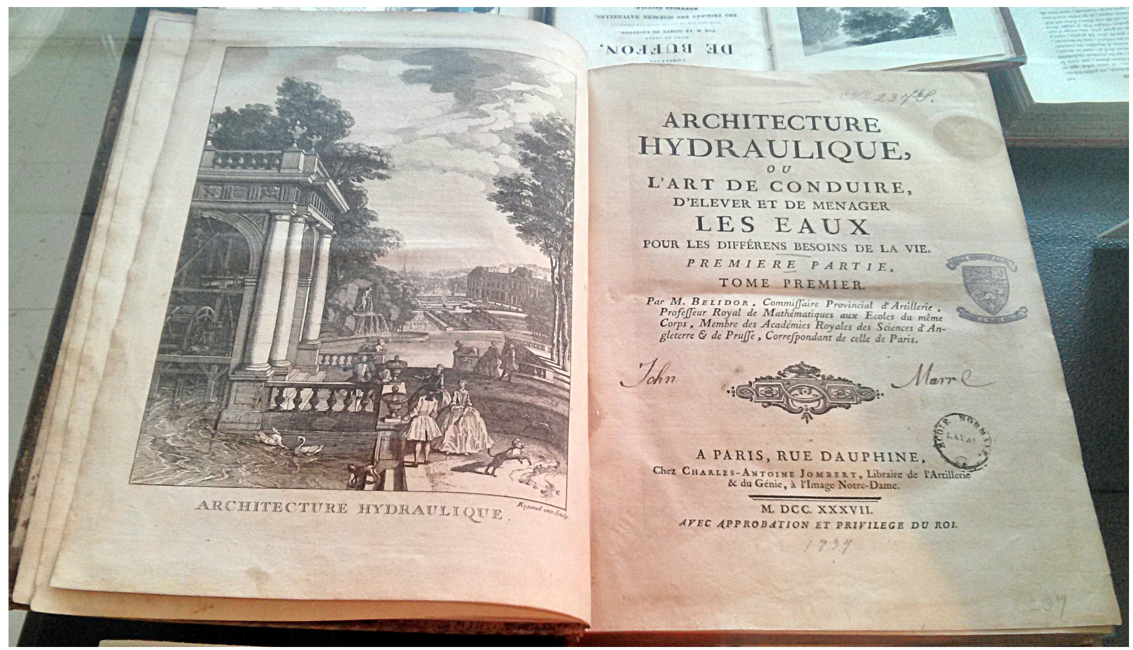
- Hydropower History and Resources
- Types of Hydro Plants
- Potential Energy, Flow Rate and Net Head
- Types of Hydropower Turbines
- Hydropower Economics
- Environmental and Social Impacts

- B3: Chap 6
- B1: Sec 8.5-8.6

Long History of Water Power

- We have been harnessing water to perform work for thousands of years: the Greeks used water wheels for grinding wheat into flour more than 2,000 years ago.
- The evolution of the modern hydropower turbine began in the mid-1700s.

Bernard Forest de Bélidor
(1698–1761, French engineer)

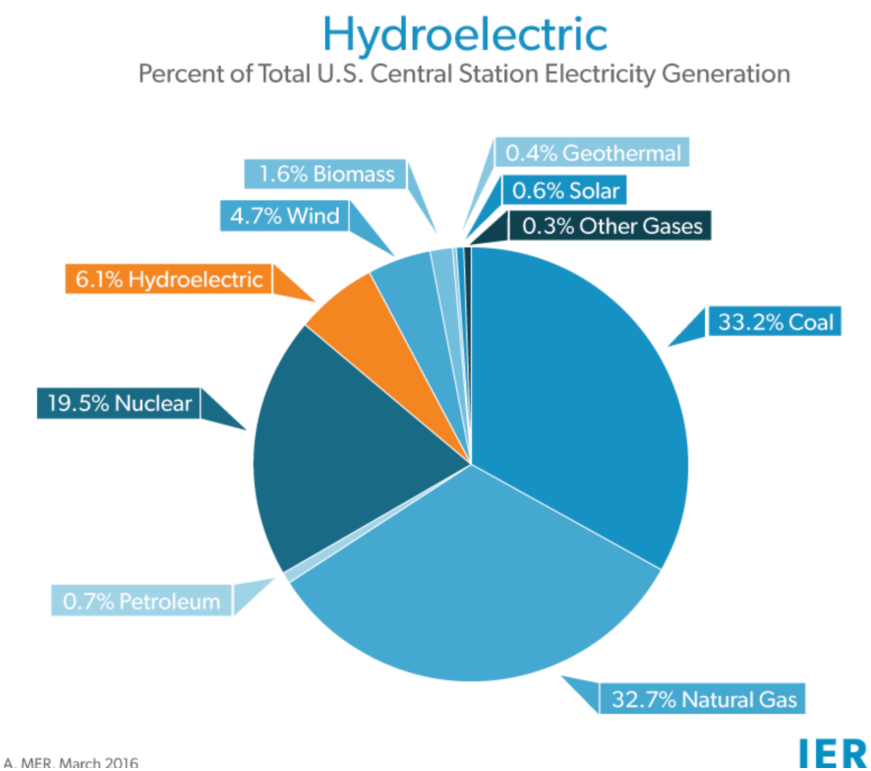


Architecture Hydraulique

Development of Water Power

- 1880: A dynamo driven by a water turbine was used to provide arc lighting (DC) in Grand Rapids, MI.
- 1893: First U.S. commercial installation of AC hydropower plant at the Redlands Power Plant in CA.

[Modern history of hydropower]()



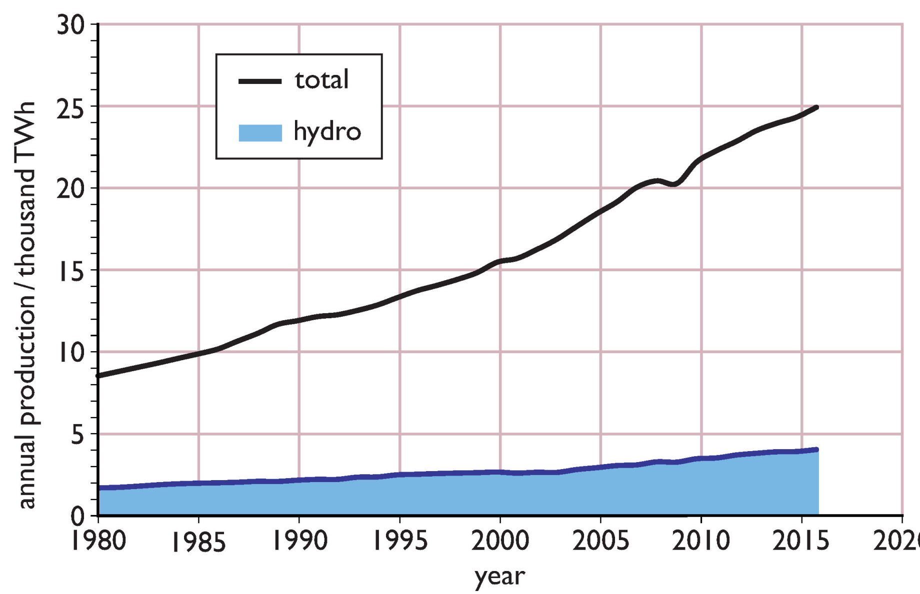
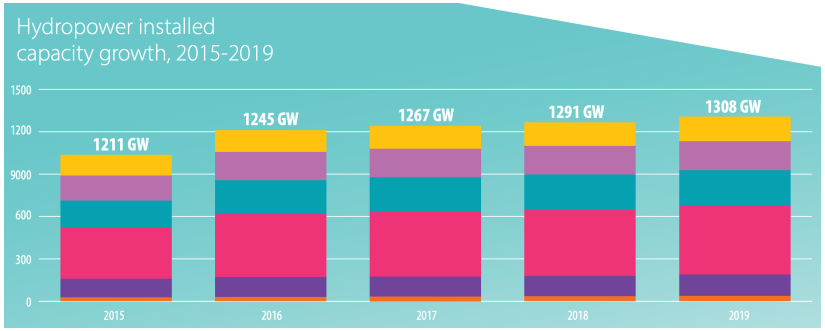
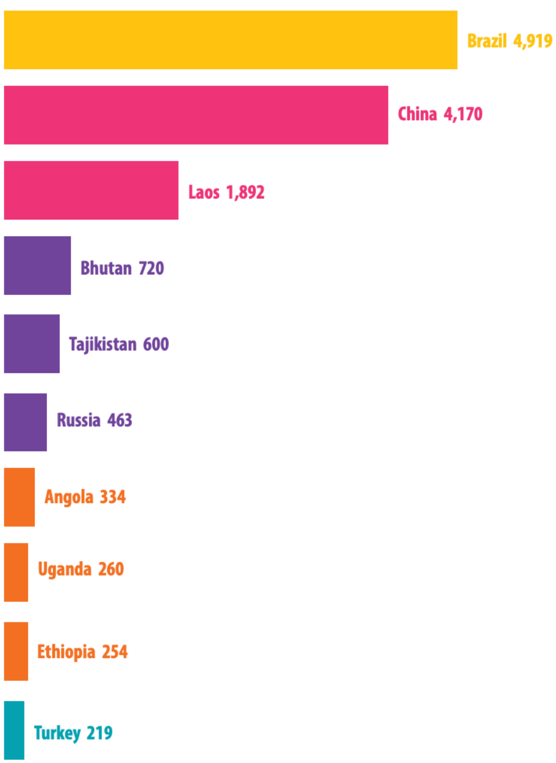


Fig: World total electricity production and hydro contribution

Key Stats



Top 10 countries by new installed capacity (MW)



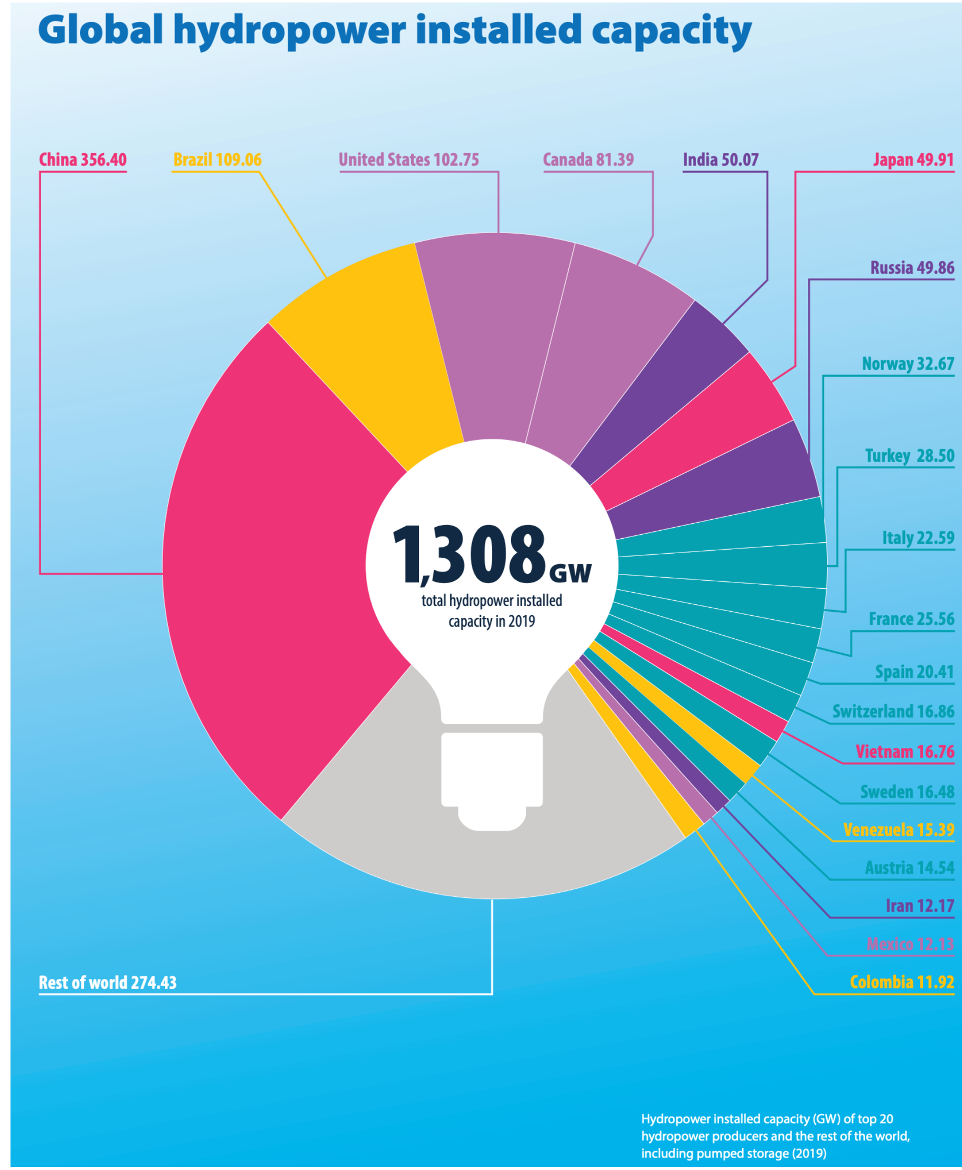


Figure source: IHA 2020 hydropower status report

Key Stats (Cont'd)

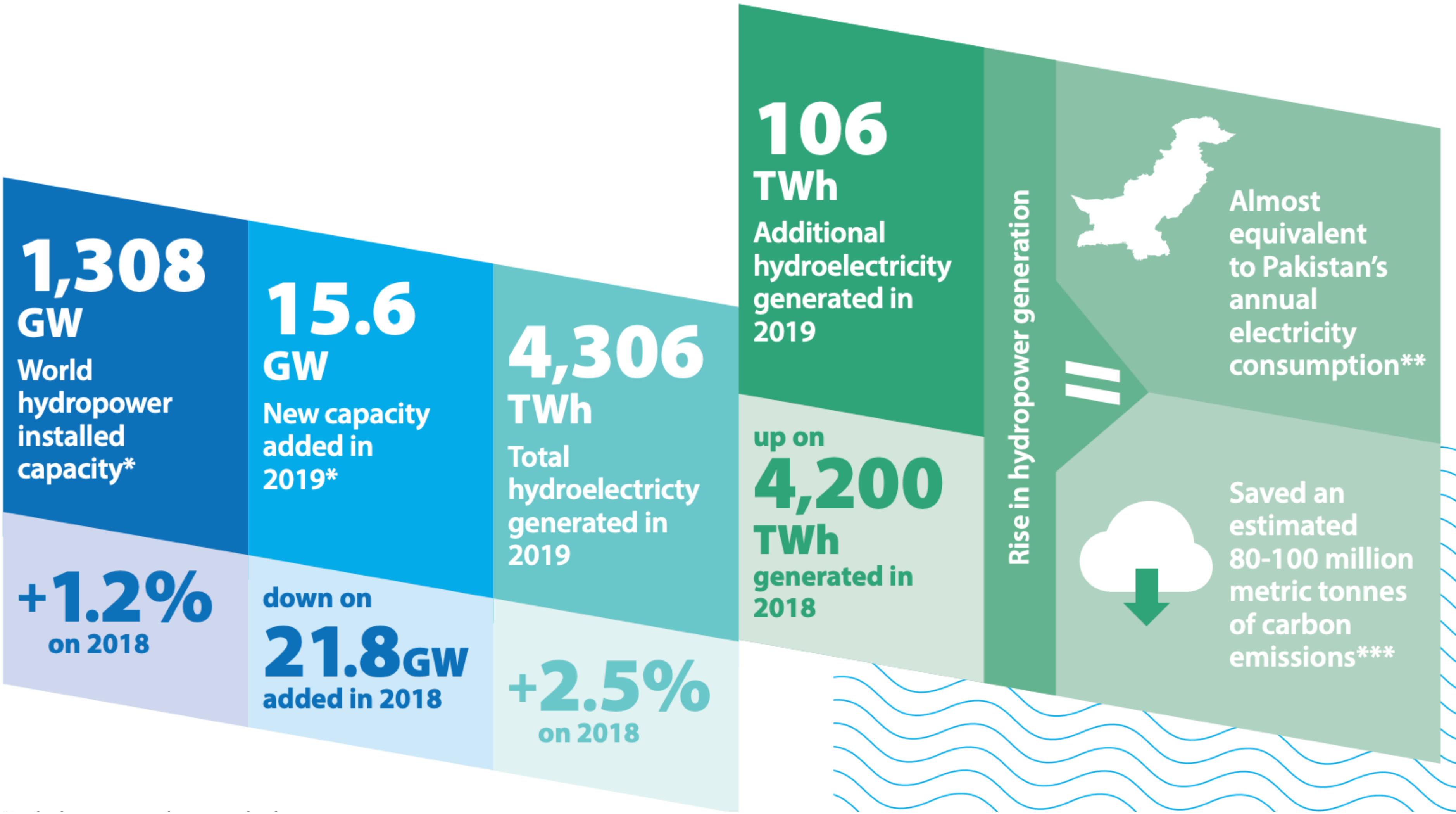
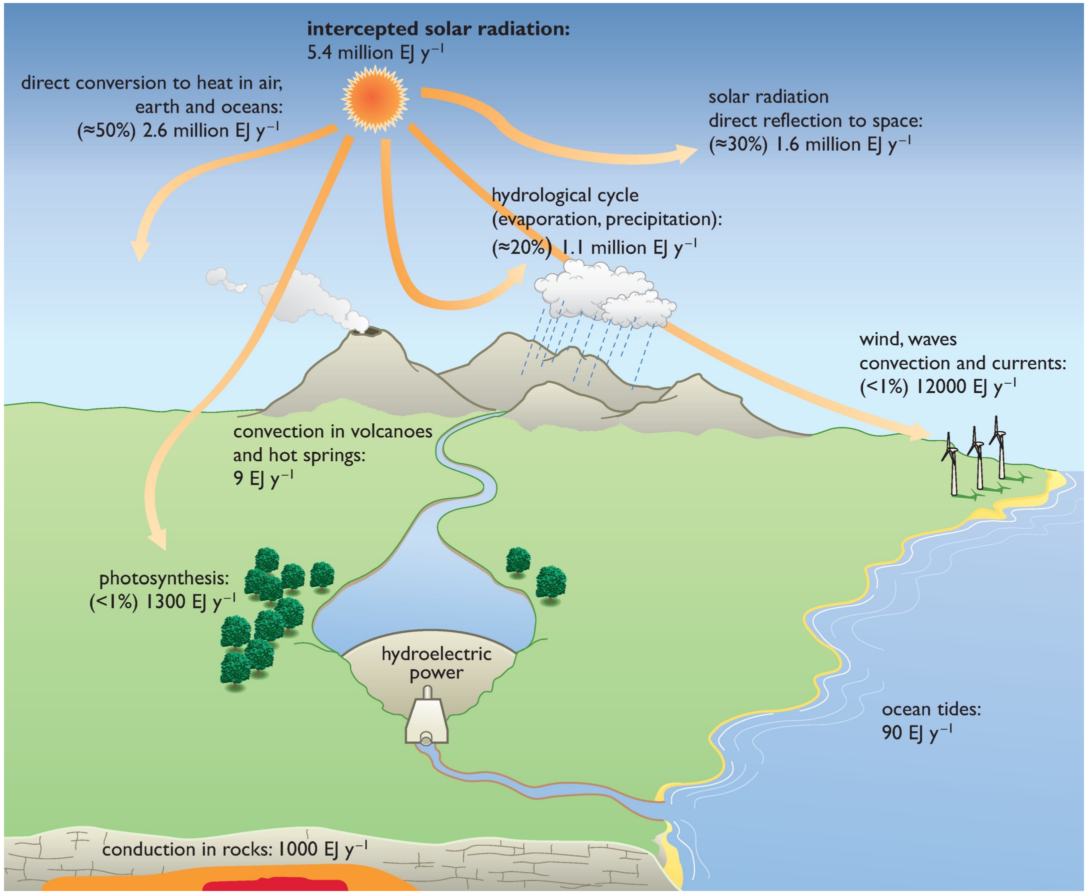
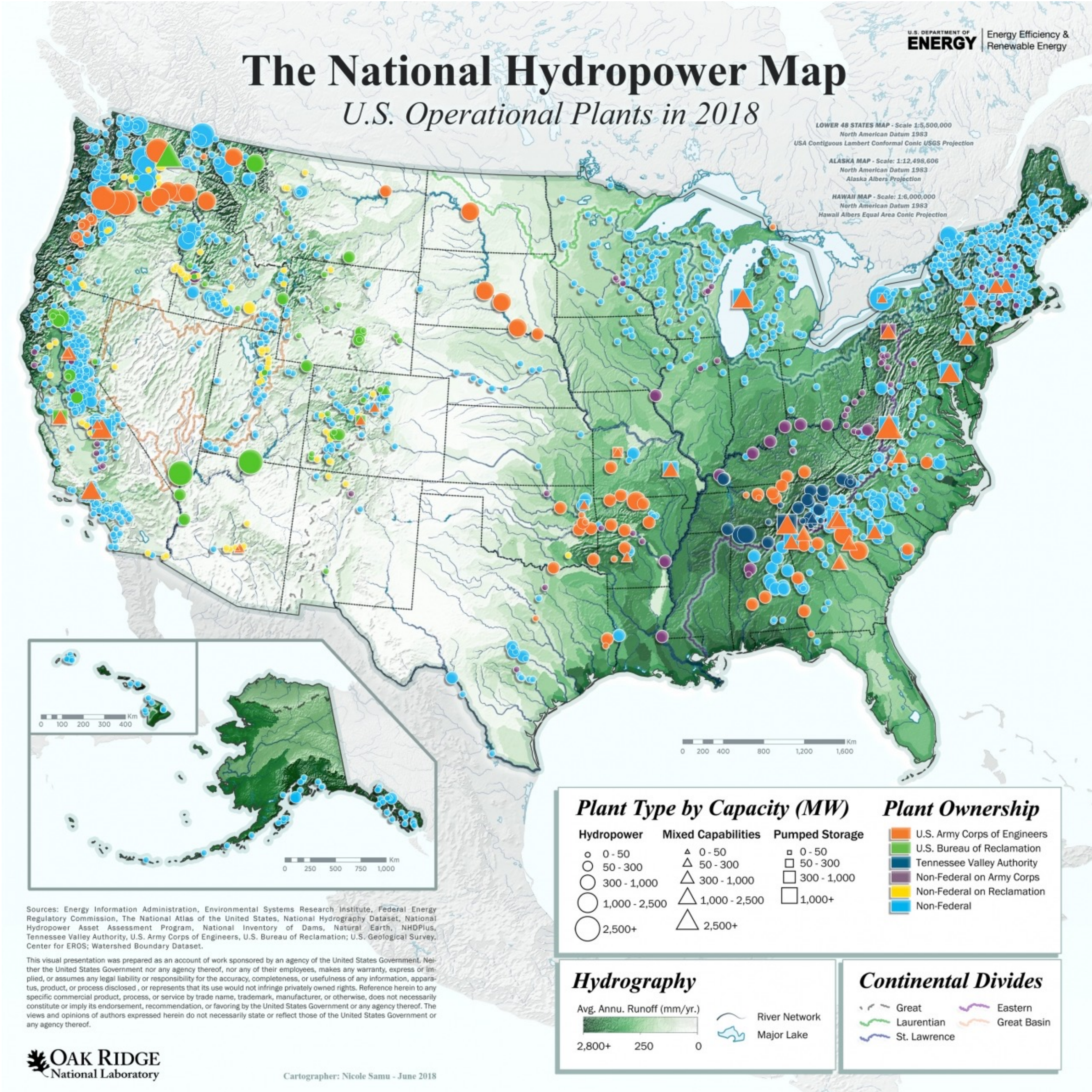


Figure source: IHA 2020 hydropower status report

Hydropower Resources – World

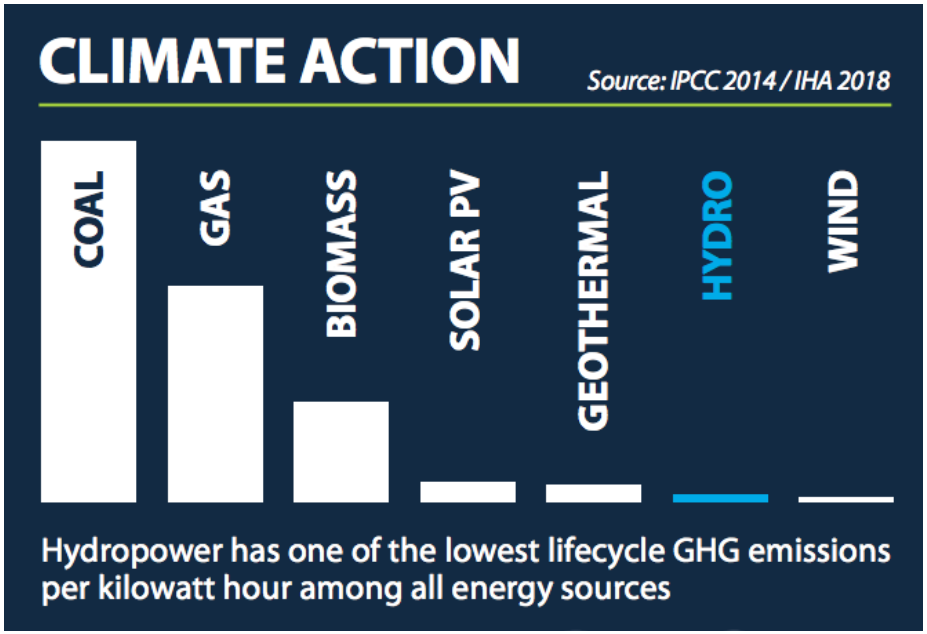


- A tiny fraction (200,000 TWh/y) reaches the Earth as rain or snow.
- 20% (40,000 TWh/y) forms streams/rivers → total hydro resource
- Impossible to build hydro plants everywhere → 40% (16,000 TWh/y) is regarded as the world’s technical hydro potential
- Economic potential: how much is available at a cost that is competitive with other energy sources



The National Hydropower Map
U.S. Operational Plants in 2018
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
LOWER 48 STATES MAP - Scale 1:5,500,000
North American Datum 1983
USA Contiguous Lambert Conformal Conic USGS Projection
ALASKA MAP - Scale: 1:12,498,606
North American Datum 1983
Alaska Albers Projection
HAWAII MAP - Scale: 1:6,000,000
North American Datum 1983
Hawaii Albers Equal Area Conic Projection
0 100 200 300 400 Km
0 250 500 750 1,000 Km
0 200 400 800 1,200 1,600 Km
Plant Type by Capacity (MW)
Hydropower
0 - 50
50 - 300
300 - 1,000
1,000 - 2,500
2,500+
Mixed Capabilities
0 - 50
50 - 300
300 - 1,000
1,000 - 2,500
2,500+
Pumped Storage
0 - 50
50 - 300
300 - 1,000
1,000+
Plant Ownership
U.S. Army Corps of Engineers
U.S. Bureau of Reclamation
Tennessee Valley Authority
Non-Federal on Army Corps
Non-Federal on Reclamation
Non-Federal
Hydrography
Avg. Annu. Runoff (mm/yr.)
2,800+ 250 0
River Network
Major Lake
Continental Divides
Great
Laurentian
St. Lawrence
Eastern
Great Basin
Sources: Energy Information Administration, Environmental Systems Research Institute, Federal Energy Regulatory Commission, The National Atlas of the United States, National Hydrography Dataset, National Hydropower Asset Assessment Program, National Inventory of Dams, Natural Earth, NHDPlus, Tennessee Valley Authority, U.S. Army Corps of Engineers, U.S. Bureau of Reclamation; U.S. Geological Survey, Center for EROS; Watershed Boundary Dataset.
This visual presentation was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed , or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
OAK RIDGE National Laboratory
Cartographer: Nicole Samu - June 2018

Hydropower Benefits



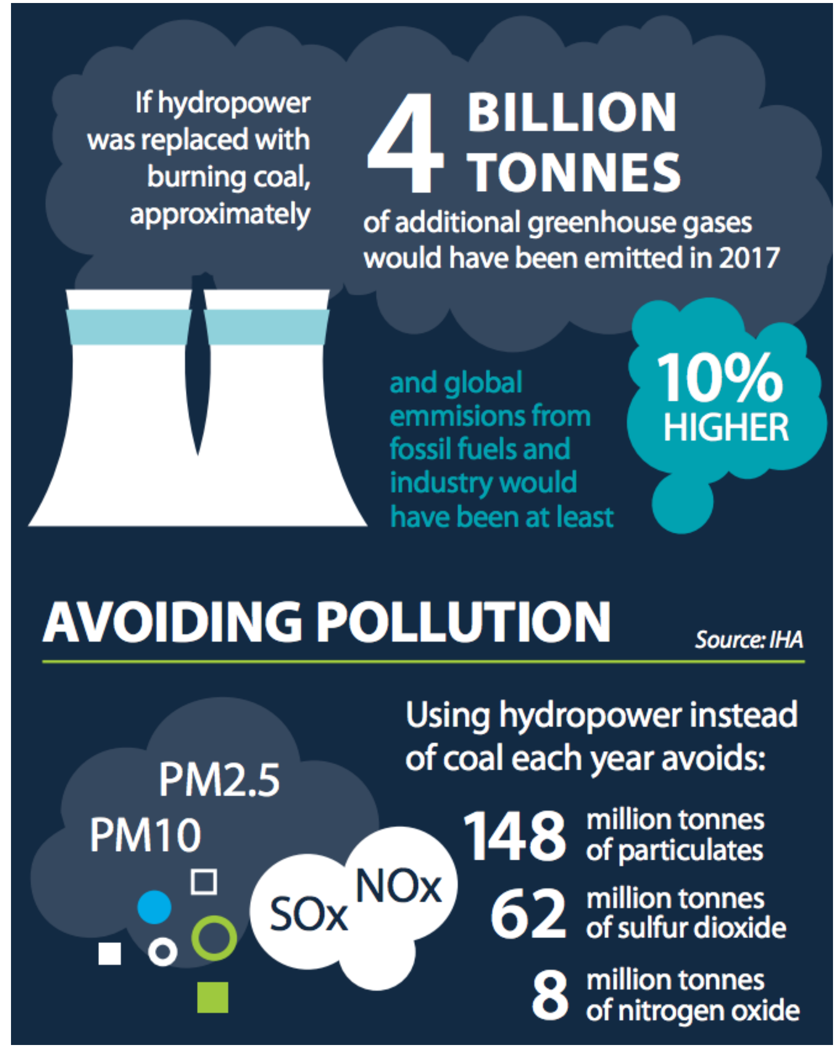
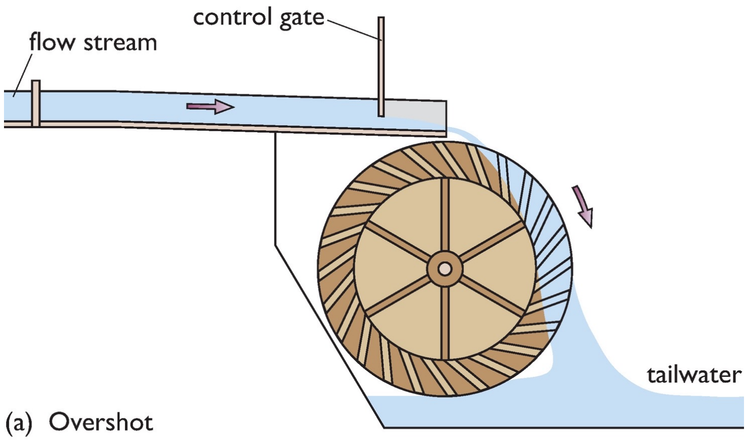


Figure source: IHA 2018 hydropower status report

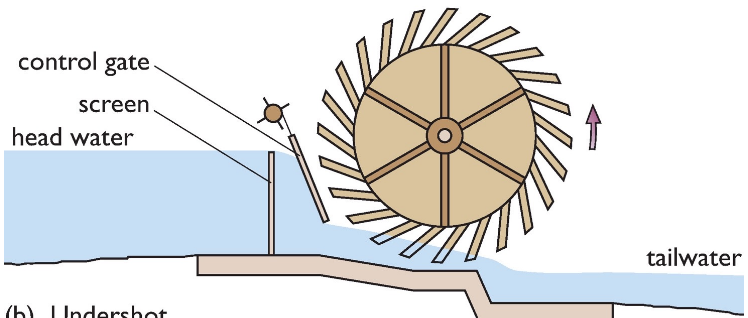
Waterwheel

[Waterwheel video]

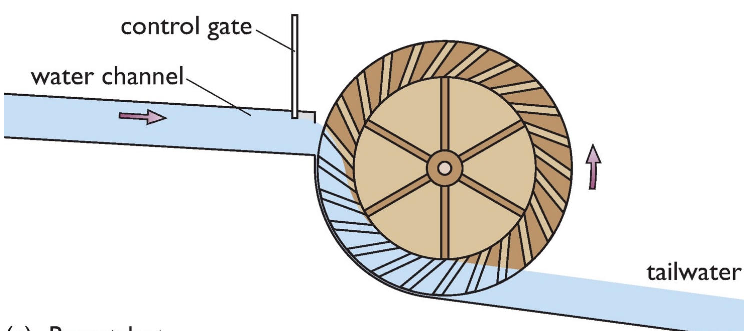
Types of Waterwheel



(a) Overshot



(b) Undershot



(c) Breastshot

- Overshot – water falls onto blades with closed sides
- Undershot – driven by water pressure against lower blades
- Breastshot – water strikes paddles at about the level of the wheel axle

Small-scale Hydro (SSH)

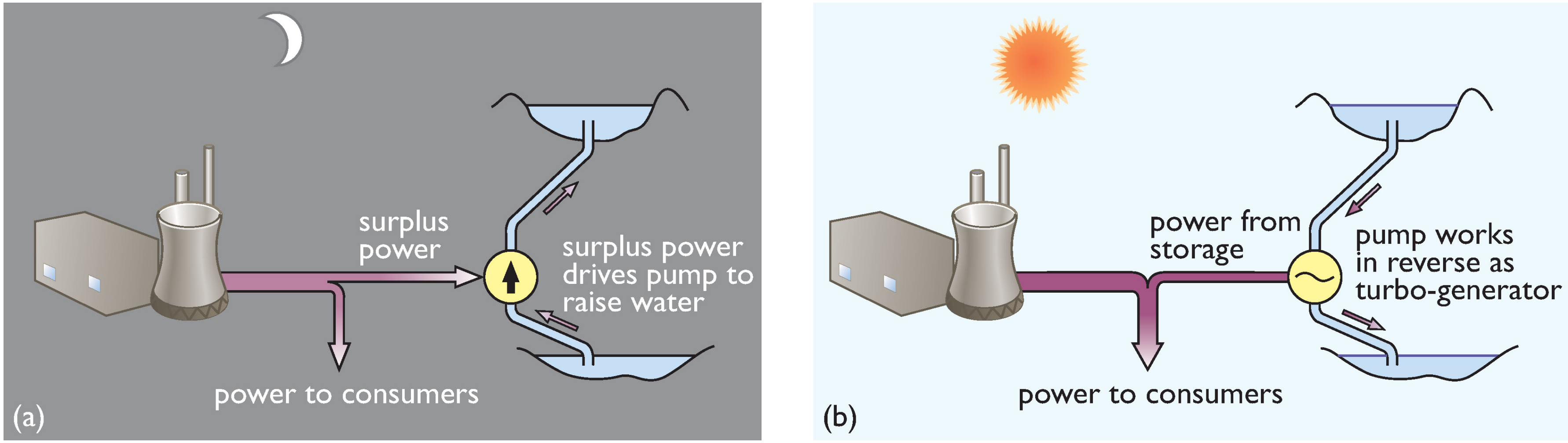
In early days, output ratings between a few kW~MW were installed on streams/rivers, often using dams and sluices of watermills.

Q: What plant output size is now referred to as ‘small-scale’?

Answer:

- Now plant outputs <10 MW are considered as SSH
- Environmental issues have limited the potential for major hydro
- ***micro-hydro*** plants emerging for isolated houses/farms (<100kW)
- A report (WEC, 2010a) suggests that the global total small-scale hydro capacity at the end of 2009 was about 60 GW (6% of the world’s total hydro capacity)

Pumped Storage Hydropower (PSH)



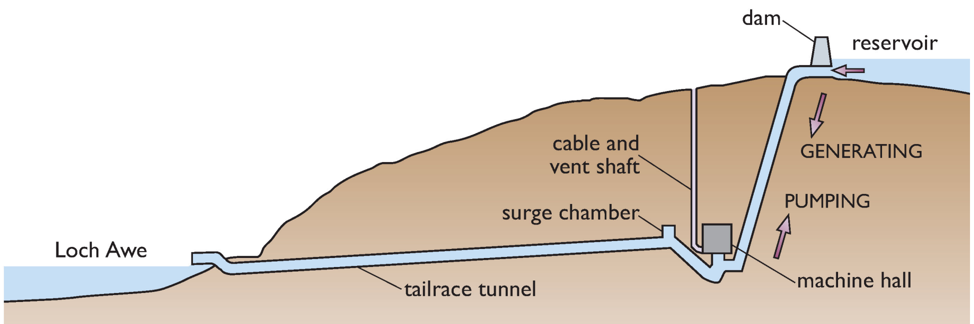
The economic viability of the method depends on:

• The generator can be run 'backwards' as an electric motor.

• The turbine can also run in either direction, either extracting energy from the water as a turbine or delivering energy to the water as a pump.

• PSH (water battery) has become increasingly important, with installed capacity worldwide having grown from 78 GW in 2005 to reach 150 GW in 2016 – nearly one seventh of world total hydro capacity (REN21, 2017).

PSH (cont'd)



(a)

(b)

Fig: Cruachan plant in Scotland:
440MW capacity, 705 GWh annual output

- Turbines/generators: very efficient (80%)
- Value of the system is enhanced by its speed of response: useful as back-up in case of a failure in the grid.
- Low-level reservoir of at least the capacity of the upper one must be available/constructed.
- PSH currently accounts for over 94% of installed global energy storage capacity, and over 96% of energy stored in grid scale applications.

Huge Dams!

Hoover Dam: In the Black Canyon of the Colorado River

Commission date	1936–1960
Hydraulic head	590 ft (180 m) (Max)
Turbines	13× 130 MW 2× 127 MW 1× 68.5 MW 1× 61.5 MW Francis-type 2× 2.4 MW Pelton-type
Installed capacity	2,080 MW
Capacity factor	23%
Annual generation	4.2 TWh (15 PJ)[3]

The Three Gorges Dam in Yichang, Hubei province, China.

Commission date	2003–2012
Type	Conventional
Hydraulic head	Rated: 80.6 m (264 ft) Maximum: 113 m (371 ft)[2]
Turbines	32 × 700 MW 2 × 50 MW Francis-type
Installed capacity	22,500 MW
Capacity factor	45%
Annual generation	87 TWh (310 PJ) (2015)

Types of Hydroelectric Plants

Present-day hydroelectric installations range in capacity from a few hundred watts to more than 10 GW. We can classify installations by:

- **effective head of water**
- **type of turbine used**
- capacity – the rated power output
- location and type of dam, reservoir, etc.

Diagram of measuring head at high head hydropower site

Head: the change in water levels (a vertical height measured in meters) between the hydro intake and the hydro discharge point.
The more head →
1) the higher the water pressure across the hydro turbine and the more generated power;
2) the higher water pressure means we can force a higher flow rate through a smaller turbine;
3) turbine cost is closely related to physical size, higher-head turbines often cost less.

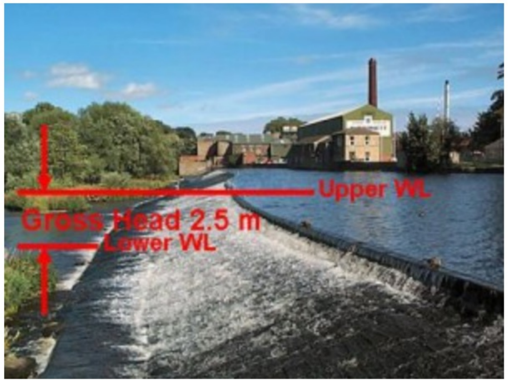


Diagram of measuring head at a low head hydropower site

Fig source: https://www.renewablesfirst.co.uk/

Barrage vs Dam

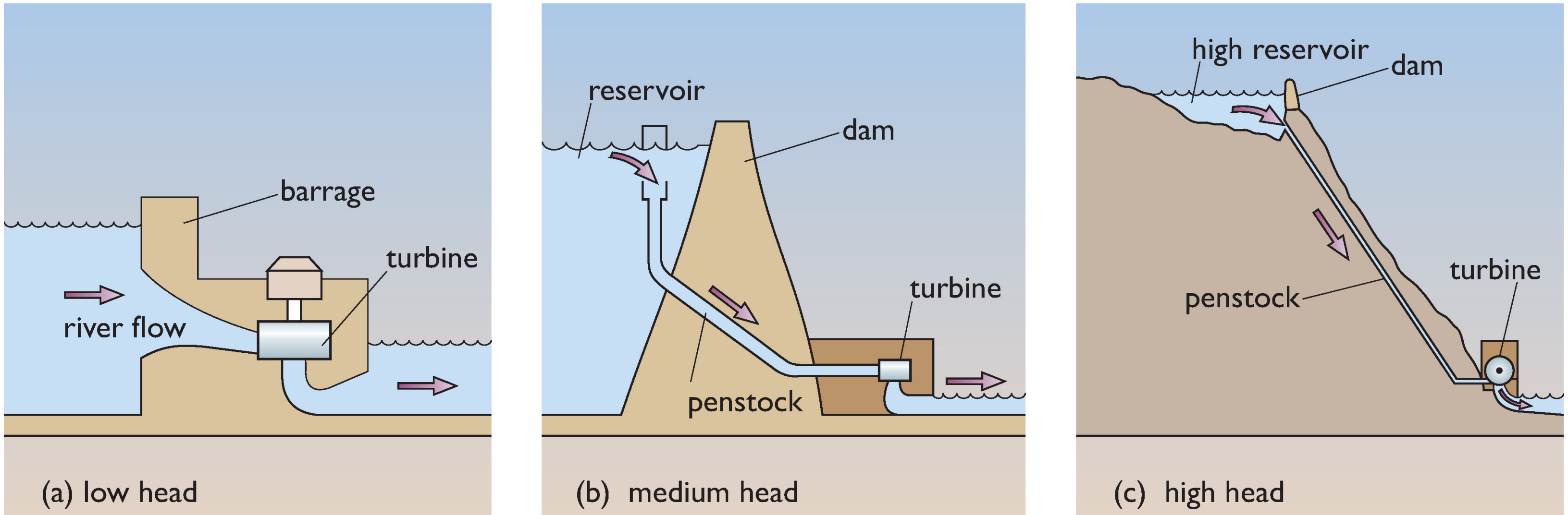
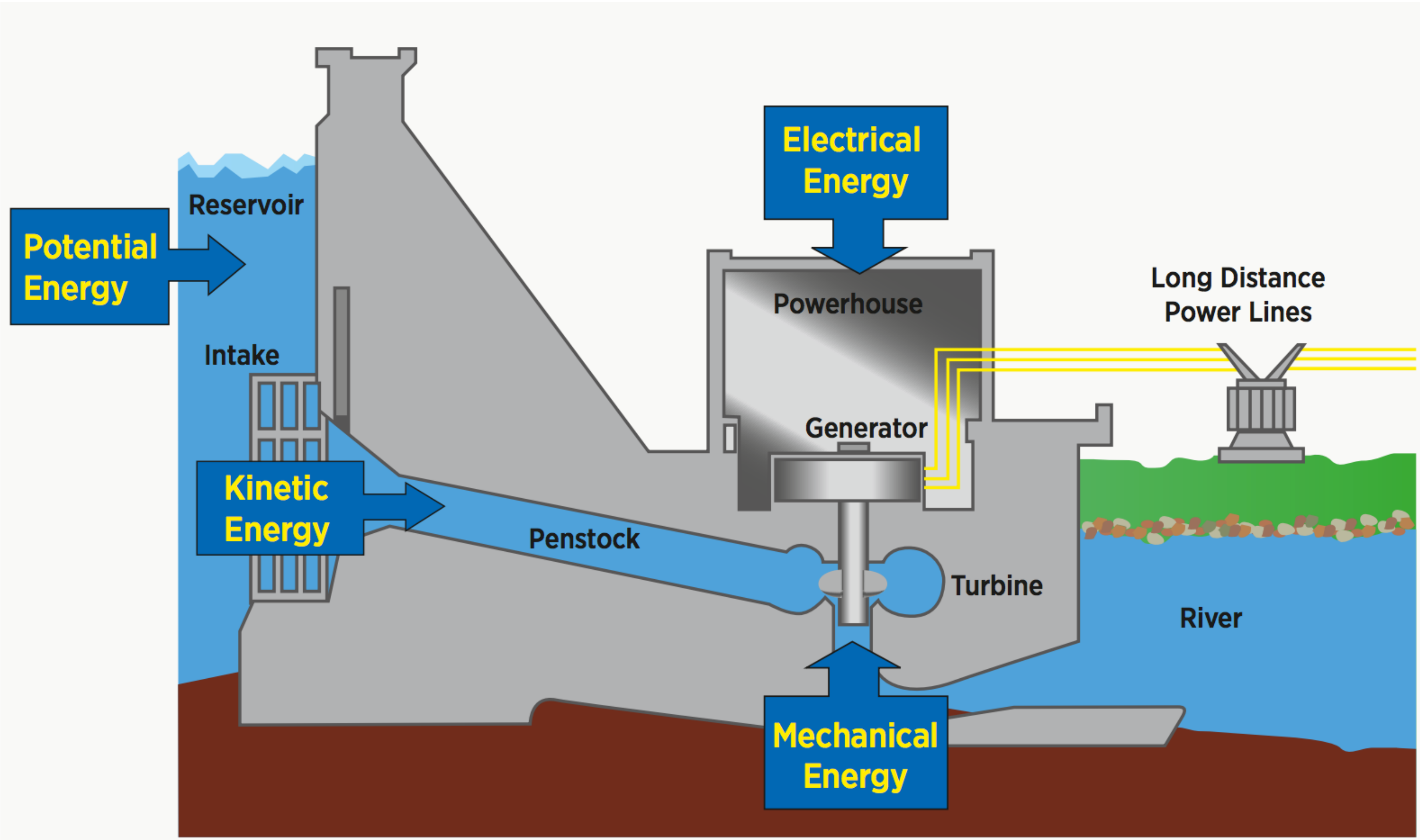


Fig. The boundaries are fuzzy: i) high head usually implies an effective head >100 meters; ii) low head <10 meters.

- A **barrage** is a diversion headwork**:** It's main aim is to divert the flow of river that does not have a storage reservoir on its upstream side. The water is elevated only to few feet.
- A **dam** on the other hand is a storage headwork so the main aim of dam is to create a storage reservoir on the upstream of the dam.
- Headwork is a civil engineering term for any structure at the head or diversion point of a waterway.

Typical “low head” Hydropower Plant



Low, Medium & High Heads

- **Low-head** 'run-of-river' power stations: Relatively little storage capacity. They may have problems of reliability if the flow varies greatly with the time of year or the weather.

- **Medium-head plant:** Typical of the very large hydroelectric installations with a dam at a narrow point in a river valley. The large reservoir behind the dam provides sufficient storage to meet demand in all but exceptionally dry conditions.

- **High-head plant:** Entire reservoir well above the outflow, and the water flows through a long *penstock*. With a high head, smaller flow needed for a given → more compact turbines/generators/housing. Long penstock adds to the cost, and the structure must withstand the extremely high pressures.

Potential & Stored Energy

no of kilograms

no of metres

potential energy = m x g x H

acceleration due to gravity
(around 9.81 m s^{-2} but for rough calculations 10 m s^{-2} used)

1 cubic metre of fresh water has a mass of 998 kg
(very close to 1000)

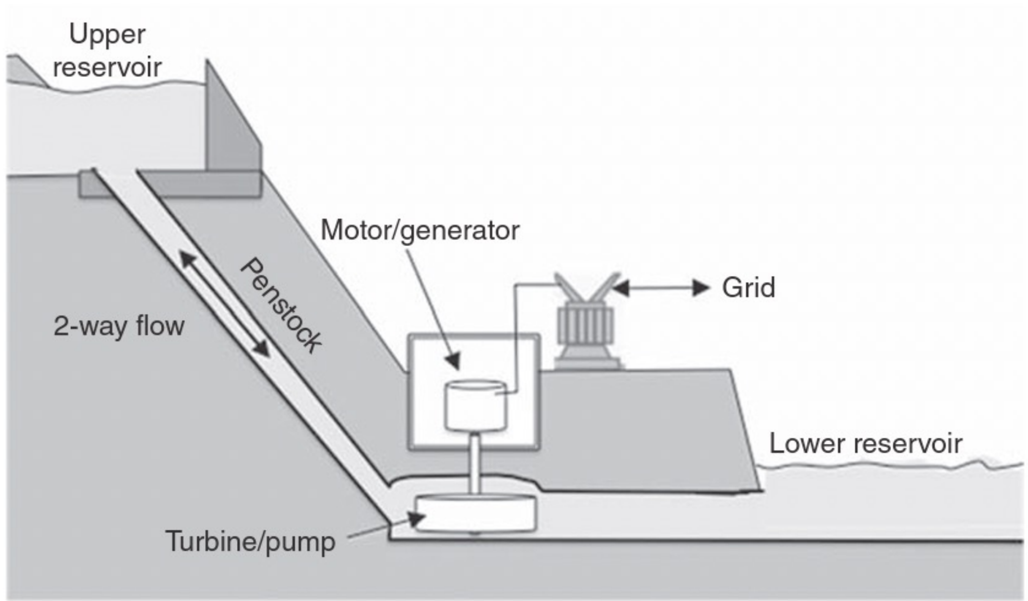
no of metres (height)

stored energy = 1000 x V x g x H

no of cubic metres of water

acceleration due to gravity
(around 9.81 m s^{-2} but for rough calculations 10 m s^{-2} used)

Pumped-Storage Hydro



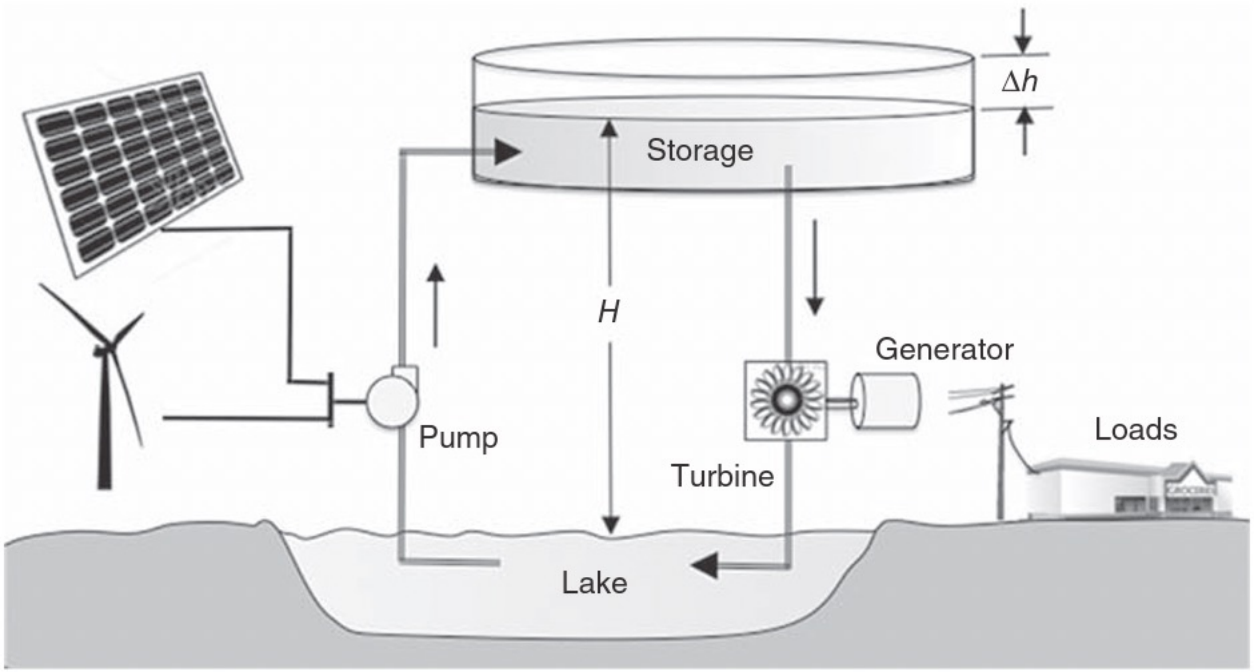
The energy available in the upper reservoir, relative to the lower one is given by

$$E = \frac{\rho A g \Delta h H}{3.6 \times 10^6}$$

where E is the energy (kWh), ρ is the density of water (1000 kg/m^3), A is the surface area of the upper reservoir (m^2), Δh is the allowable change in the surface level (m), g is gravitational acceleration (9.81 m/s^2), H is the average difference in elevation of the two reservoirs (m), and the 3.6 million converts J to kWh.

Example

Example 8.6 A Two-Penstock Pumped Storage System. The system in Figure 8.39 needs to supply a small village that has a 100-kW average load. A storage pond will be built at an elevation of 250 m above an existing lake. The pond will be 3-m deep but only the top 2 m can be used for variable storage. Assuming each penstock has an efficiency of 90% and the pump and turbine each have 85% efficiency, how big should the pond be to provide 2 days of storage during which time the renewables are unable to produce power?



Example Solution

Solution. Energy that needs to be delivered during those two days is

$$E = 100 \text{ kW} \times 24 \text{ h/d} \times 2 \text{ d} = 4800 \text{ kWh to the village}$$

Including inefficiencies, the tank needs to provide

$$E \text{ (from tank)} = \frac{4800 \text{ kWh}}{0.90 \times 0.85} = 6274.5 \text{ kWh}$$

$$E(kWh) = \frac{1000(kg/m^3)A(m^2)9.81(m/s^2)\Delta h(m)H(m)}{3.6 \times 10^6(J/hWh)}$$

$$A = \frac{3.6 \times 10^6 \times 6274.5}{1000 \times 9.81 \times 2 \times 250} = 4605.1m^2$$

Flow Rate & Hydropower

$$\text{Power} = \frac{\text{Energy}}{\text{Time}} = \frac{\text{Weight}}{\text{Volume}} \times \frac{\text{Volume}}{\text{Time}} \times \frac{\text{Energy}}{\text{Weight}} = \gamma Q H$$

turbine efficiency

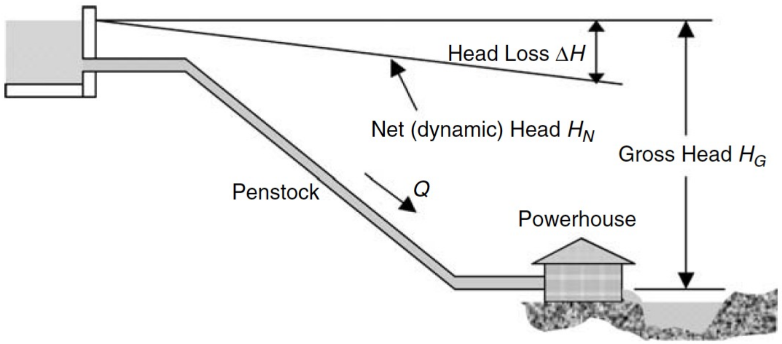
$$\boxed{P_{\text{delivered}}\ (\text{kW}) = \frac{\eta Q\ (\text{gpm}) H_{\text{N}}(\text{ft})}{5300} = 9.81 \eta Q\ (\text{m}^3/\text{s}) H_{\text{N}}(\text{m})}$$

$\gamma = \rho g$: **specific weight** (weight per unit volume of a material)

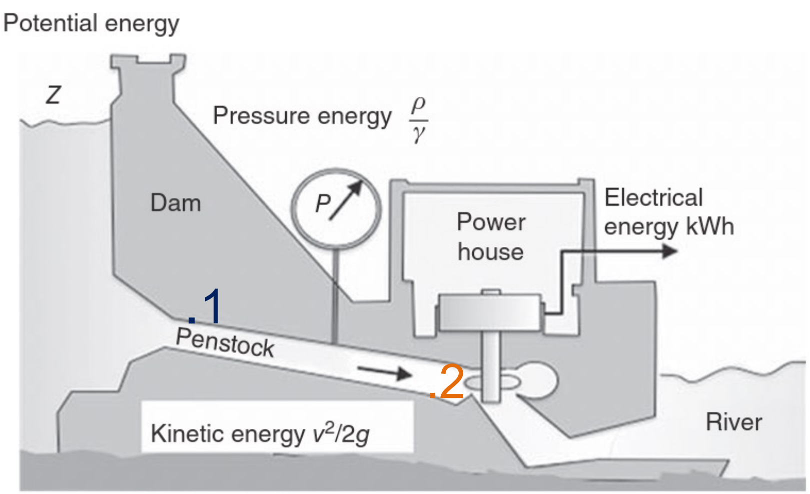
Q: **volume flow rate** of the moving water

H: **net head = gross head – friction head**

- gross head (actual elevation difference).
- friction head (head loss in piping): a function of the pipe diameter, the flow rate, the pipe length, smoothness of the pipe (material), how many bends, valves, and elbow the water has to pass through.



Fluid Dynamics: Bernoulli's Principle



$$\boxed{z + \frac{p}{\gamma} + \frac{v^2}{2g} = \text{constant}}$$

z =elevation above a reference height (m) or (ft)
p =pressure (N/m^2) or (lb/ft^2)
γ =specific weight (N/m^3) or (lb/ft^3)
v =average velocity (m/s) or (ft/s)
g =gravitational acceleration (9.81 m/s^2) or (32.2 ft/s^2)

$$\text{potential head} + \text{pressure head} + \text{kinetic head} = \text{energy head}$$

$$energy\ head_1 = energy\ head_2$$

Head (per-weight energy). The principle asserts that the sum of all forms of energy in a fluid is the same at all points on that streamline.

$$\boxed{z = \frac{mgz}{mg} = \frac{\text{potential energy}}{\text{weight}}} \quad \boxed{\frac{p}{\gamma} = \frac{pV}{\rho V g} = \frac{\text{pressure energy}}{\text{weight}}} \quad \boxed{\frac{v^2}{2g} = \frac{mv^2/2}{mg} = \frac{\text{kinetic energy}}{\text{weight}}}$$

$$\left(p = \frac{F}{A} = \frac{F \times d}{A \times d} = \frac{Energy}{V}\right)$$

Example

TABLE 8.10 Useful Conversions for Water

	American	SI
1 cubic foot =	7.4805 gal	0.02832 m^3
1 foot per second =	0.6818 mph	0.3048 m/s
1 cubic footper second =	448.8 gal/min(gpm)	0.02832 m^3/s
Water density =	62.428 lb/ft^3	1000 kg/m^3
1 pound per square inch =	2.307 ft of water	6896 N/m^2
1 kW =	737.56 ft-lb/s	1000 N-m/s

Example: Suppose a 4-inch-diameter penstock delivers 150gal/min of water through an elevation change of 100 feet. The pressure in the pipe is 27 psi (pounds per square inch) when it reaches the powerhouse. What fraction of the available head is lost in the pipe? How much power is available for the turbine?

Solution. From Equation 8.16:

$$\text{Pressure head} = \frac{p}{\gamma} = \frac{27\ \text{lb/in}^2 \times 144\ \text{in}^2/\text{ft}^2}{62.428\ \text{lb/ft}^3} = 62.28\ \text{ft}$$

To find velocity head, we need to use $Q = vA$, where Q is flow rate, v is velocity, and A is cross-sectional area:

$$v = \frac{Q}{A} = \frac{150\ \text{gpm}}{(\pi/4)\cdot(4/12\ \text{ft})^2 \times 60\ \text{s/min} \times 7.4805\ \text{gal/ft}^3} = 3.83\ \text{ft/s}$$

So, from Equation 8.16, the velocity head is

$$\text{Velocity head} = \frac{v^2}{2g} = \frac{(3.83\ \text{ft/s})^2}{2 \times 32.2\ \text{ft/s}^2} = 0.228\ \text{ft}$$

Example Solution (cont'd)

The total head available for the turbine is the sum of the velocity and pressure head, or 62.28 + 0.228 ft = 62.51 ft. This is called the net head, H_N.

$$H_N = 62.28 + 0.228 \text{ ft} = 62.51 \text{ ft of head}$$

Note that the velocity head is negligible.
Since we started with 100 ft of head, pipe losses are 100 – 62.51 ft = 37.49 ft, or 37.49%.

Using conversions from Table 8.10, while carefully checking to see that units properly cancel, the power delivered to the turbine by a flow of 150 gal/min at a head of 62.51 ft is

$$P = \frac{150 \text{ gpm} \times 62.428 \text{ lb/ft}^3 \times 62.51 \text{ ft}}{60 \text{ s/min} \times 7.4805 \text{ gal/ft}^3} \times \frac{\text{kW}}{737.56 \text{ ft-lb/s}} = 1.77 \text{ kW}$$

Friction Head Loss

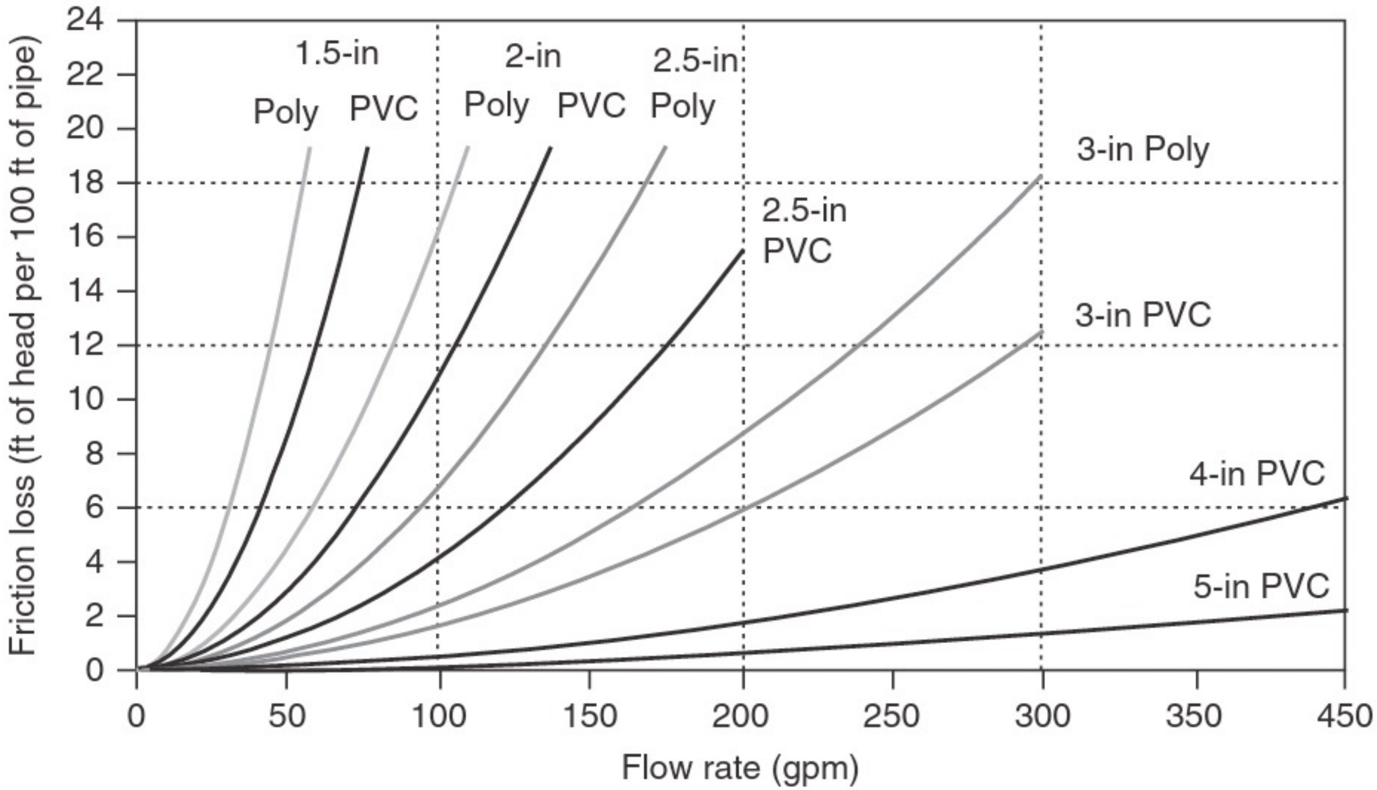


FIGURE 8.35 Friction head loss, in feet of head per 100 ft of pipe, for 160-psi PVC piping and for polyethylene, SDR pressure-rated pipe.

- Poly (polythene): small-diameter ones are easy to install.
- PVC (polyvinyl chloride): has lower friction losses and less expensive.
- Both need to be protected from sunlight that makes them brittle.

Example

Example 8.4 Power from a Micro-Hydro Plant. Suppose 150 gal/min of water is taken from a creek and delivered through 1000 feet of 3-in-diameter polyethylene pipe to a turbine 100 ft lower than the source. Assuming 80% efficiency for the turbine/generator, estimate the energy delivered in a 30-day month.

Solution. From Figure 8.35, at 150 gal/min, 3-in poly loses about 5 ft of head for every 100 ft of length. Since we have 1000 ft of pipe, the friction loss is

$$1000 \text{ ft} \times 5 \text{ ft}/100 \text{ ft} = 50 \text{ ft of head loss}$$

The net head available to the turbine is

$$\text{Net head} = \text{Gross head} - \text{Friction head} = 100 \text{ ft} - 50 \text{ ft} = 50 \text{ ft}$$

Using a 70% turbine/generator efficiency in Equation 8.20 suggests delivered power would be

$$P_{\text{delivered}} \text{ (kW)} = \frac{\eta\, Q \text{ (gpm)} H_{\text{N}}\text{(ft)}}{5300} = \frac{0.80 \times 150 \times 50}{5300} = 1.13 \text{ kW}$$

The monthly electricity supplied would be 24 h × 30 d/mo × 1.13 kW = 815 kWh, which is roughly the average electrical energy used by a typical U.S. household.

Quiz

1) Where does hydropower get its energy from?

- The rays of the Sun
- The internal heat of the Earth
- Moving water sources like rivers
- From the burning of fossil fuels like coal
- All of the above

2) True or False: Hydropower is considered a renewable energy source.

- TRUE
- FALSE

3) In a hydropower plant, water flows through a pipe called a ________.

- Generator
- Turbine
- PVC
- Penstock
- Water main

Quiz (cont'd)

Consider two systems with the same efficiency of 83%, but very different sizes:

1) A mountain stream with an effective head of 25 meters and a modest flow rate of 0.01m^3/s (600 liters/min). The power output:

$$P = 10 \times 83\% \times 0.01 \times 25 = 2.075\,\mathrm{kW}$$

2) A mountain stream with an effective head of 100 meters and a the flow rate is 6000m^3/s – roughly the total flow over Niagara Fall. The power output:

$$P = 10 \times 83\% \times 6000 \times 100 = 4.98 \times 10^6\,\mathrm{kW} \approx 5\,\mathrm{GW}$$

Hydropower Turbines

Turbines vary considerably in size, with ‘runner’ diameters ranging from as little as a 1/3 meters to some 20 times this.

We’ll look at how they work, the factors that determine their efficiency, and the site parameters that determine the most suitable turbine.

Impulse vs Reaction Turbines

Energy in water manifests itself in three forms – potential, pressure, and kinetic head. There are different approaches to transforming that waterpower into the mechanical energy needed to rotate the shaft of an electrical generator.

- Impulse turbines: capture the kinetic energy of high-speed jets of water squirting onto buckets along the circumference of a wheel.

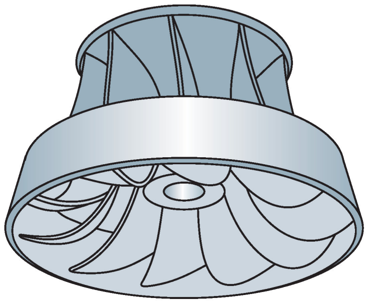
- Reaction turbines: water velocity plays only a modest role, and instead it is mostly the pressure difference across the runners/ blades that creates the desired torque.

- *Impulse turbines are most appropriate in high-head, low-flow circumstances, while the opposite is the case for reaction turbines.*

Types of Turbine

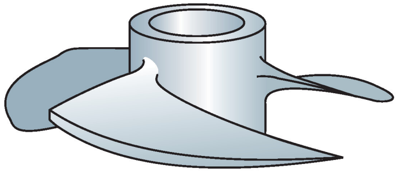
- **Francis turbines** – a combination of both impulse and reaction turbines, where the blades rotate using both reaction and impulse force of water: the most common type in medium/large-scale plants.

  1) they are radial-flow turbines → the water flow is *inwards* towards the center.
  2) maintain exactly the right speed and direction of the incoming water relative to the runner blades is important (95% efficiency).



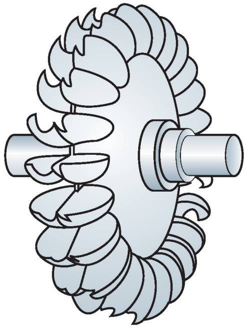
Francis

- **'Propeller' or axial-flow turbines** sweep their blades through the entire area which the water enters → Good for very large volume flows and have become usual where the head is only a few meters.



Fixed pitch propeller

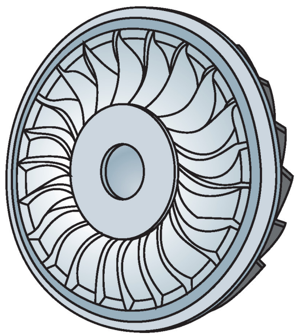
- **Pelton wheels** *[developed and patented by Lester Pelton in 1880]* → Good for very high heads (> 300 meters). It is an *impulse* turbine, operating in air at normal atmospheric pressure, and is a wheel with a set of double cups mounted around the rim.



Pelton

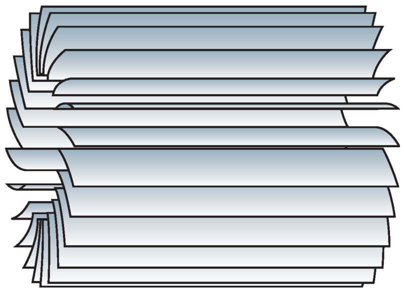
Types of Turbine (Cont'd)

- **Turgo turbines** are a variant on the Pelton wheel, where the double cups are replaced by single, shallower ones. An impulse turbine can handle a larger volume of water than a Pelton wheel of the same diameter; an advantage for power generation at medium heads.



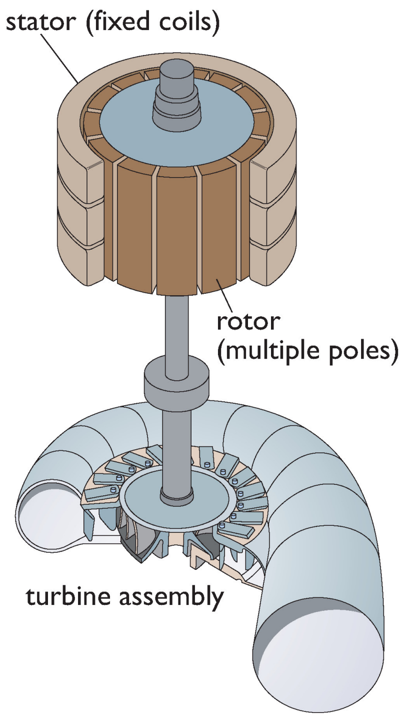
Turgo

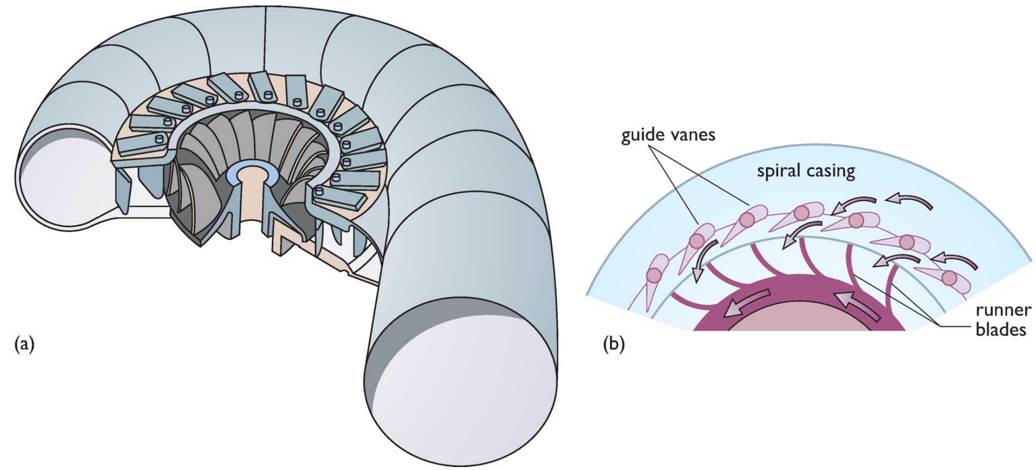
- **Cross-flow turbine** is another impulse type. The water enters as a flat sheet rather than a round jet. It is guided on to the blades, travels across the turbine and meets the blades a second time as it leaves.

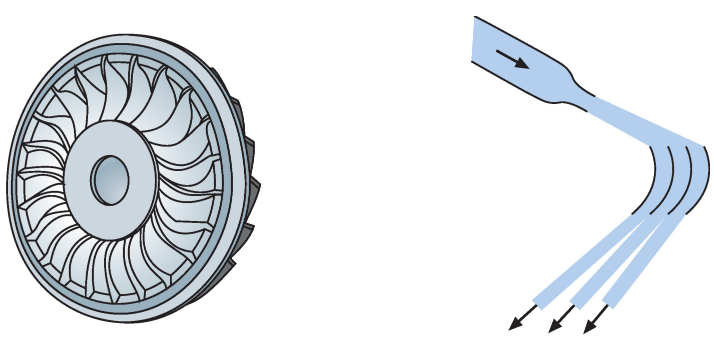


Crossflow

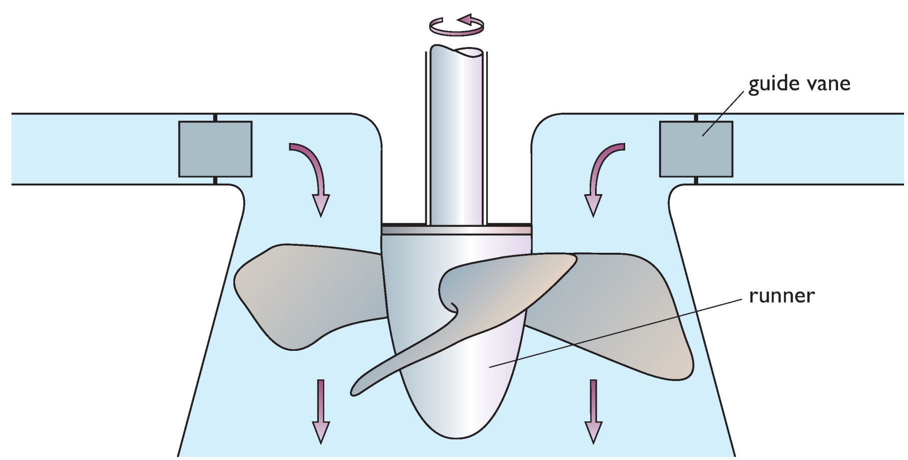
Turbine with Water Flows



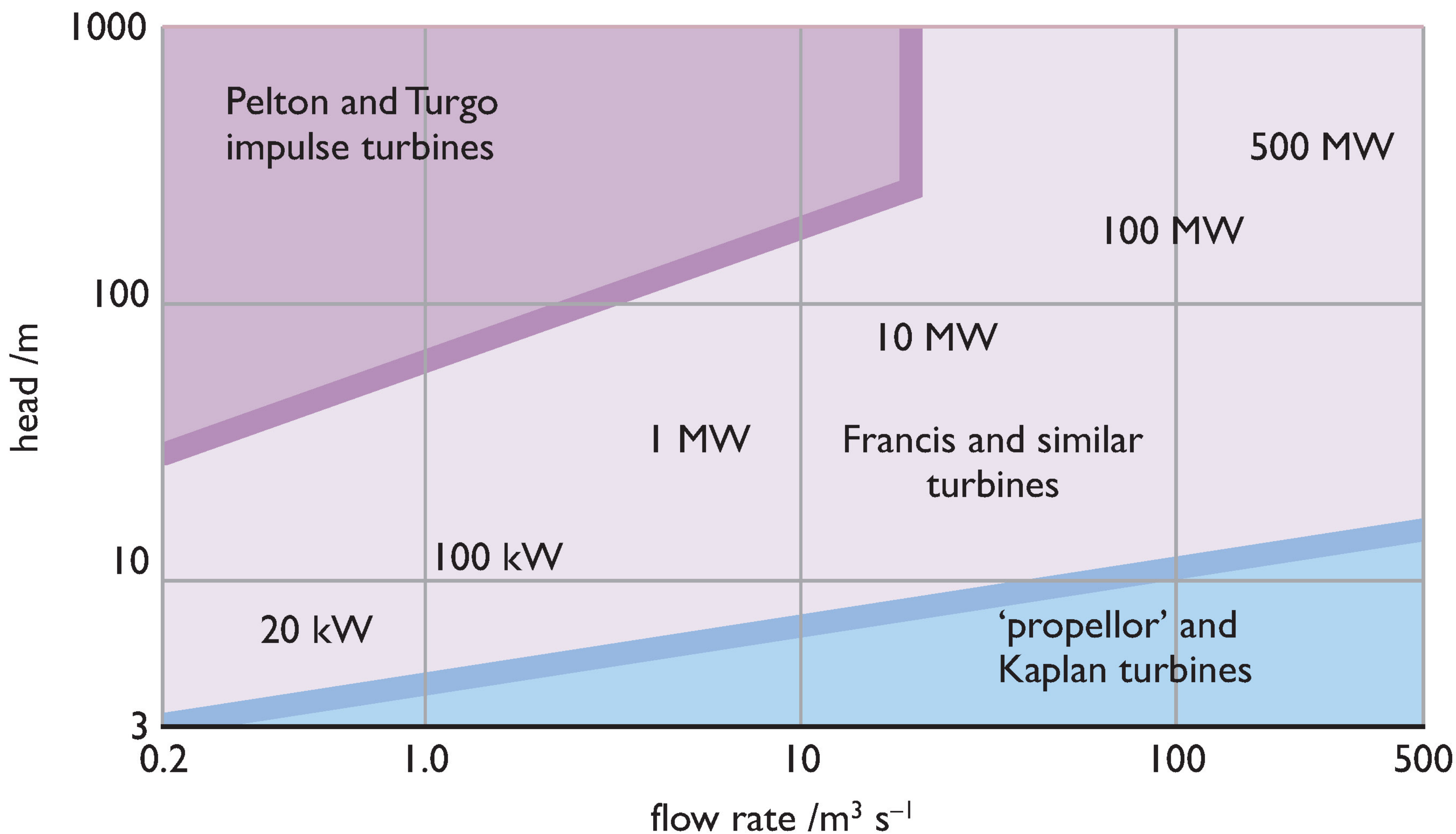




(a) runner (b) water flow



Ranges of Applications



Pelton Turbine Design

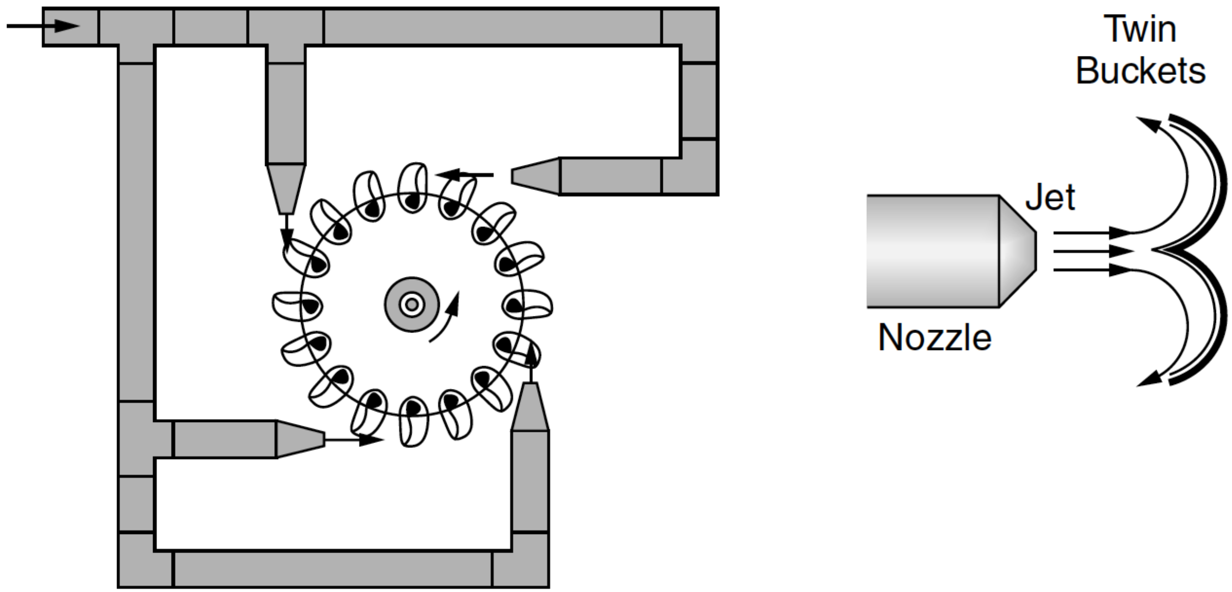


Figure: A four-nozzle Pelton turbine.

- Water squirts out of nozzles onto sets of twin buckets.
- The buckets are carefully designed to extract as much of the water’s kinetic energy as possible while leaving enough energy in the water to enable it to leave the buckets w/o interfering with the incoming water.
- Typical efficiency: 70–90%.

Determine Jet Size

- Determine the flow velocity by the net head $H_{N:}$

$$H_N = \frac{v^2}{2g} \qquad \text{so that} \qquad v = \sqrt{2gH_N}$$

- Relate jet diameter with the flow rate Q: $Q = vA = \sqrt{2gH_N}\left(\frac{\pi}{4}\right)nd^2$

- Solving for jet diameter: $\boxed{d = \frac{0.949}{(gH_N)^{1/4}}\sqrt{\frac{Q}{n}}}$

Q: A penstock provides 150 gpm (0.334 cfs) with 50 ft of head to a Pelton turbine with 4 nozzles. Assuming jet and nozzle diameters are the same, pick a nozzle diameter.

$$d = \frac{0.949}{(32.2\ \text{ft/s}^2 \times 50\ \text{ft})^{1/4}}\sqrt{\frac{0.334\ \text{ft}^3/\text{s}}{4}} = 0.0433\ \text{ft} = 0.52\ \text{in.}$$

Economics of Hydroelectricity

Potential investors in hydroelectricity need to know how much each kWh of output will cost:

- capital cost (dominant factor)
- O&M costs
- lifetime and capacity factor
- external factors (discount rate)

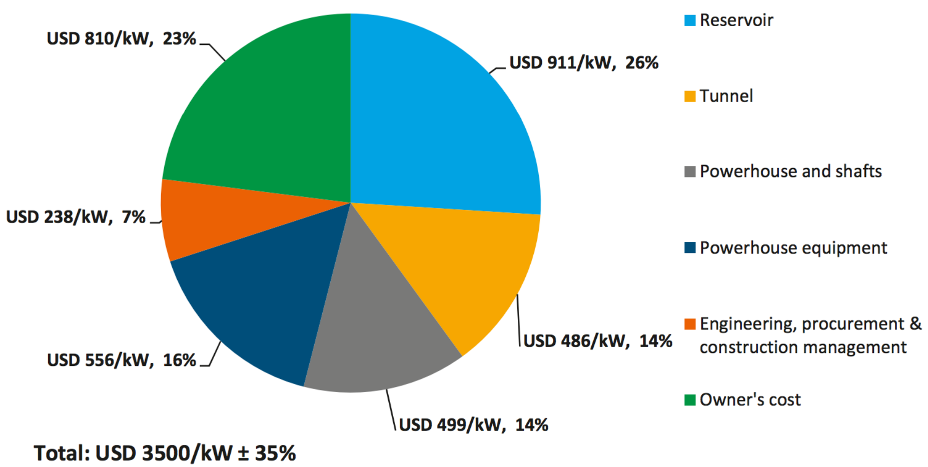


Fig: Cost breakdown of an indicative 500 MW Greenfield hydropower project in the US.

- Hydroelectricity is well-established: the water-control systems, turbo-generators and output controls
- Expected lifetime of 20–25 years for the machinery, and 50–100 years for the external structures.

Cost Breakdown

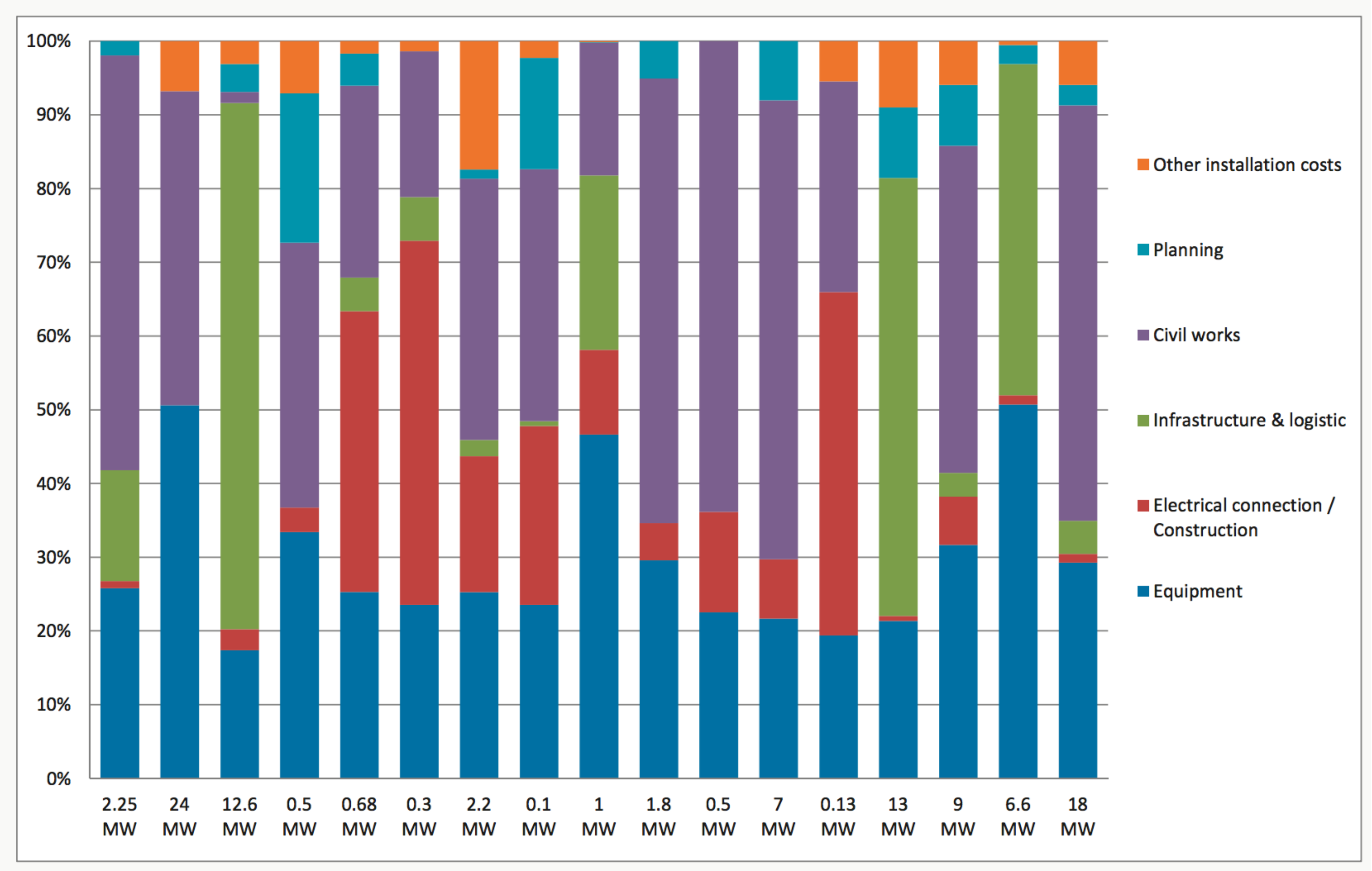


Fig: Cost breakdown for small hydro projects in developing countries.

LCOE

Table: Typical installed costs and LCOE of hydropower projects

	Installed costs (USD/kW)	Operations and maintenance costs (%/year of installed costs)	Capacity factor (%)	Levelised cost of electricity (2010 USD/kWh)
Large hydro	1 050 – 7 650	2 – 2.5	25 to 90	0.02 – 0.19
Small hydro	1 300 – 8 000	1 – 4	20 to 95	0.02 – 0.27
Refurbishment/upgrade	500 – 1 000	1 – 6		0.01 – 0.05

Note: The levelised cost of electricity calculations assume a 10 % cost of capital

Investment cost (USD/kW)	Discount rate (%)	LCOE (US cents/kWh)	Lifetime (years)	LCOE (US cents/kWh)
1 000	3	1.7	80	1.5
1 000	7	2.5	80	2.4
1 000	10	3.2	80	3.2
2 000	3	3.5	80	2.9
2 000	7	5.1	80	4.8
2 000	10	6.5	80	6.3
3 000	3	5.2	80	4.4
3 000	7	7.6	80	7.3
3 000	10	9.7	80	9.5

Note: base case assumes an economic life of 40 years, a 45 % capacity factor and 2.5 % of capital costs per year for O&M.
Source: IPCC, 2011.

Hydro as A Component of Power Systems

Few large power stations operate in isolation, and the extent to which a proposed plant can form a useful part of a supply system is important with the ideal characteristics being:

- constant availability
- a reserve energy store to buffer variations in input
- no correlation in input variations between power stations
- rapid response to changing demand
- an input which matches annual variation in demand
- no sudden or unpredictable changes in input
- a location which does not require long transmission lines.

Environmental Impact

- In operation it releases no CO_2, and negligible quantities of the oxides of sulfur and nitrogen that lead to acid rain
- It produces no particulates or chemical compounds such as dioxins that are directly harmful to human health
- It emits no radioactivity
- Dams may collapse, but they will not cause major fires
- Associated with positive environmental effects such as flood control or irrigation, and in some cases, its development leads to a valued amenity.

Physical Effects

- **Hydrological:** The construction process of a major hydroelectric dam itself can cause widespread disturbance, and the effect on a fragile eco-system can be long-lasting.
- **Dam failures:** A US study (DoE, 2005) found that only 2400 of the country's 80,000 dams had hydroelectricity plants. So, it is not surprising to find only 5-6 hydroelectric plants in the world list of major dam failures.
- **Silt:** Silt accumulation build-up reduces the volume of stored water and consequently the hydro potential of a site.
- **Fish:** France has many dams constructed during the early 20th century on rivers previously used by Atlantic fish, and as licenses became due for renewal in the 1990s, stringent requirements were introduced for the construction of fish ladders or similar passages.
- **Methane**: The vegetable matter that would normally decay in the air to produce CO_2 could decay anaerobically under water to produce methane (CH_4).

Social Effects

Table 6.6 Summary of arguments for and against the dam

Issue	Criticism	Defence
Cost	The dam will far exceed the official cost estimate, and the investment will be unrecoverable as cheaper power sources become available and lure away ratepayers.	The dam is within budget, and updating the transmission grid will increase demand for its electricity and allow the dam to pay for itself.
Resettlement	Relocated people are worse off than before and their human rights are being violated.	15 million people downstream will be better off due to electricity and flood control.
Environment	Water pollution and deforestation will increase, the coastline will be eroded and the altered ecosystem will further endanger many species.	Hydroelectric power is cleaner than coal burning and safer than nuclear plants, and steps will be taken to protect the environment.
Local culture and natural beauty	The reservoir will flood many historical sites and ruin the legendary scenery of the gorges and the local tourism industry.	Many historical relics are being moved, and the scenery will not change that much.
Navigation	Heavy siltation will clog ports within a few years and negate improvements to navigation.	Shipping will become faster, cheaper and safer as the rapid waters are tamed and ship locks are installed.
Power generation	Technological advances have made hydrodams obsolete, and a decentralized energy market will allow ratepayers to switch to cheaper, cleaner power supplies	The alternatives are not viable yet and there is a huge potential demand for the relatively cheap hydroelectricity
Flood control	Siltation will decrease flood storage capacity, the dam will not prevent floods on tributaries, and more effective flood control measures are available	The huge flood storage capacity will lessen the frequency of major floods. The risk that the dam will increase flooding is remote.