

Hydropower

Lecture 1



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Water cycle

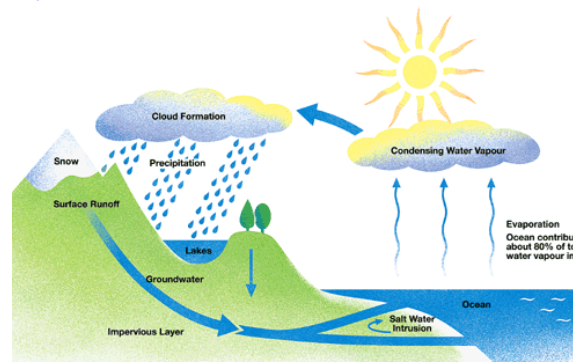


Rivers/
Streams



Sea

Rain / Snow fall



Solar
energy



evaporation



Hydropower



Source: <https://www.energy.gov/articles/hydropower-vision-new-report-highlights-future-pathways-us-hydropower>

Hydropower is the energy captured from moving water in the form of mechanical energy or electricity.

In the past it was used for mechanical applications such as grinding of grain, lifting water for irrigation etc. However, presently, it is mostly used for production of electricity.



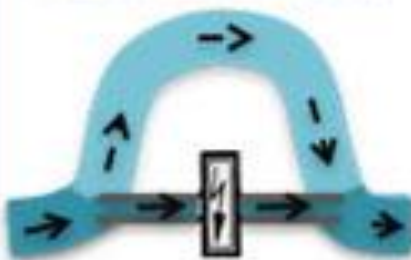



Mechanical use of hydropower began thousands of years ago by the Egyptians and Greeks while its usage to produce electricity started in 1880s in USA.

Hydropower is indirectly related to solar energy.

Hydropower has a successful track record of delivering reliable and affordable electricity for more than a century and it is a major contributor to world energy supplies.

Hydropower is one of the most economical forms of electricity.

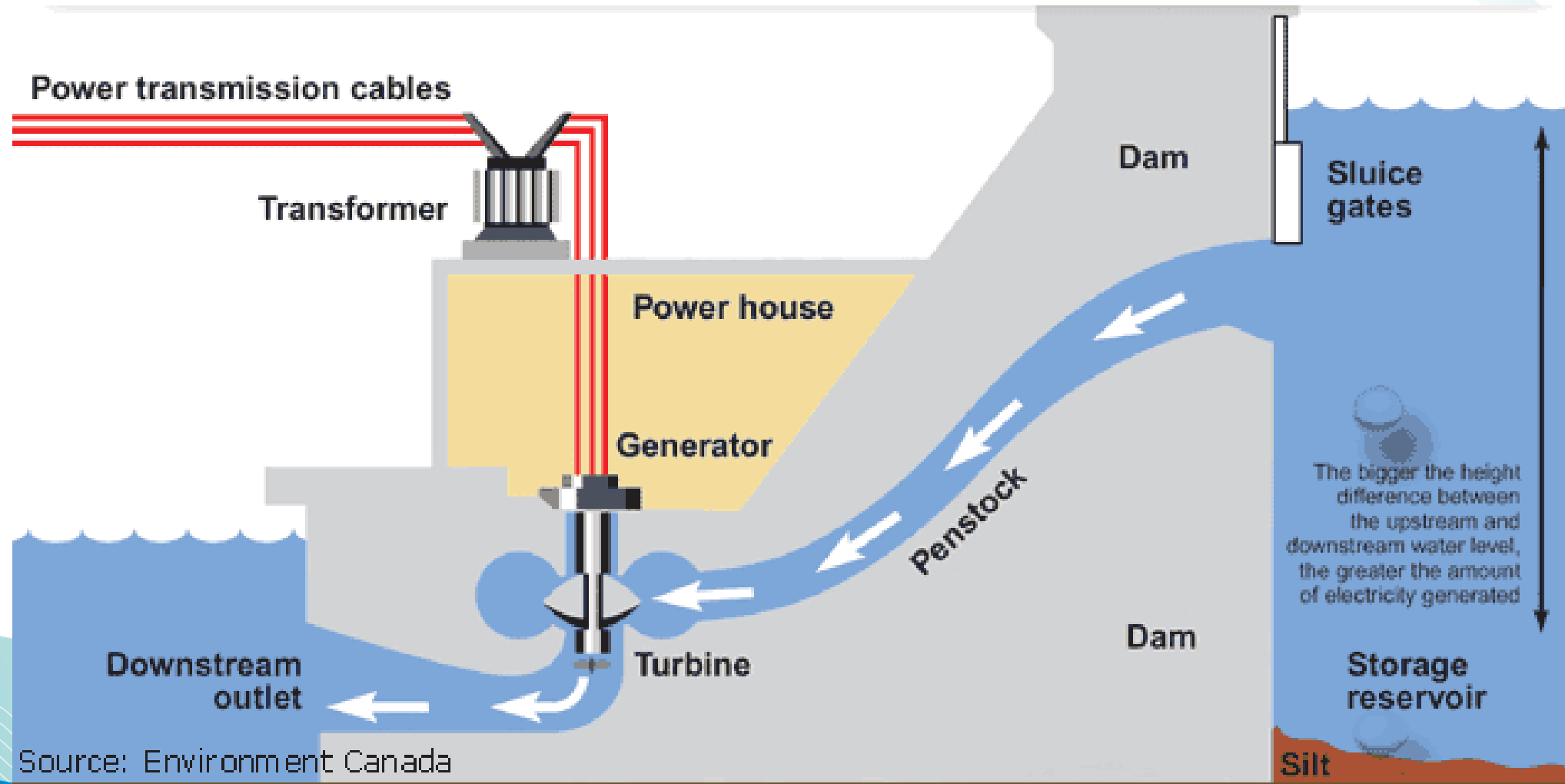
Characteristics of hydropower plants

Arrangement	Gross head	Possibility of storage Use of water	Type of turbines
<p>Without water diversion</p> 	<p>high</p> <p>200 m</p> <p>160 m</p> <p>mean</p> <p>120 m</p>	<p>Run-of-river</p> 	<p>Pelton</p> 
<p>With water diversion</p> 	<p>80 m</p> <p>40 m</p> <p>low</p> <p>(ref.) 0 m</p>	<p>Storage</p>  <p>Pumped-storage</p> 	<p>Francis</p>  <p>Kaplan Bulb Straflo ...</p> 

Source: <https://hydropower-europe.eu/about-hydropower-europe/hydropower-energy/>

In general hydropower plants, can be characterised according to the criteria arrangement, gross head, possibility of storage and types of turbines

Components of a typical hydropower plant



Source: Environment Canada

Source: Environment Canada

Advantages of Hydropower

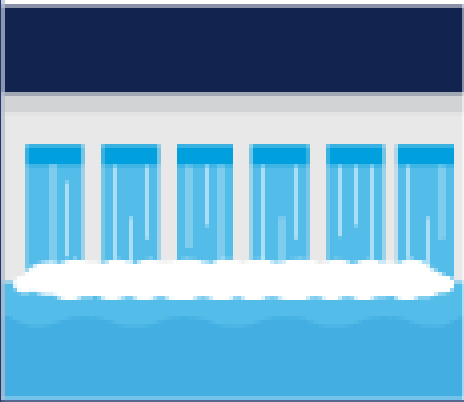
- Renewable energy supply without the direct emission of CO₂ and with an energy pay-back during its technical lifetime.
- High efficiency, production can be easily adapted to the demand (very flexible and timely response to peak energy demands).
- In-country energy, creating jobs and financial resources in remote areas.
- Improvement of infrastructure along with potential for recreational and tourism activities.
- Contribution to flood and drought protection.
- Facilitating navigation on the large rivers in Europe.



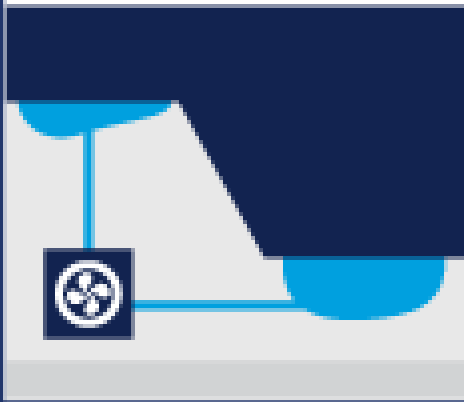
Source: <https://balkangreenenergynews.com/45-mw-brezice-hydropower-plant-on-river-sava-inaugurated/>

Types of hydropower

STORAGE HYDROPOWER



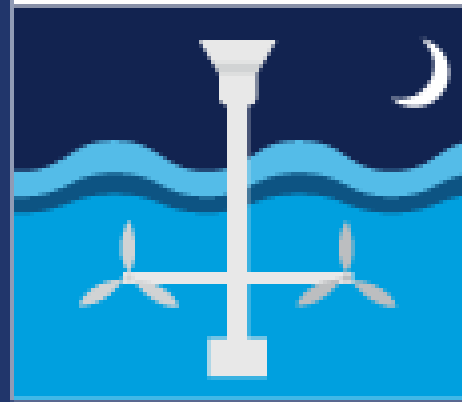
PUMPED STORAGE HYDROPOWER



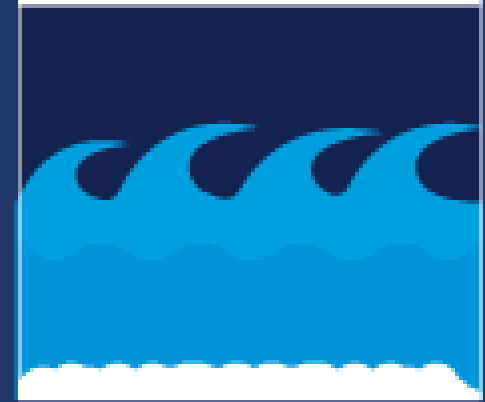
RUN-OF-RIVER HYDROPOWER



TIDAL POWER



WAVE POWER



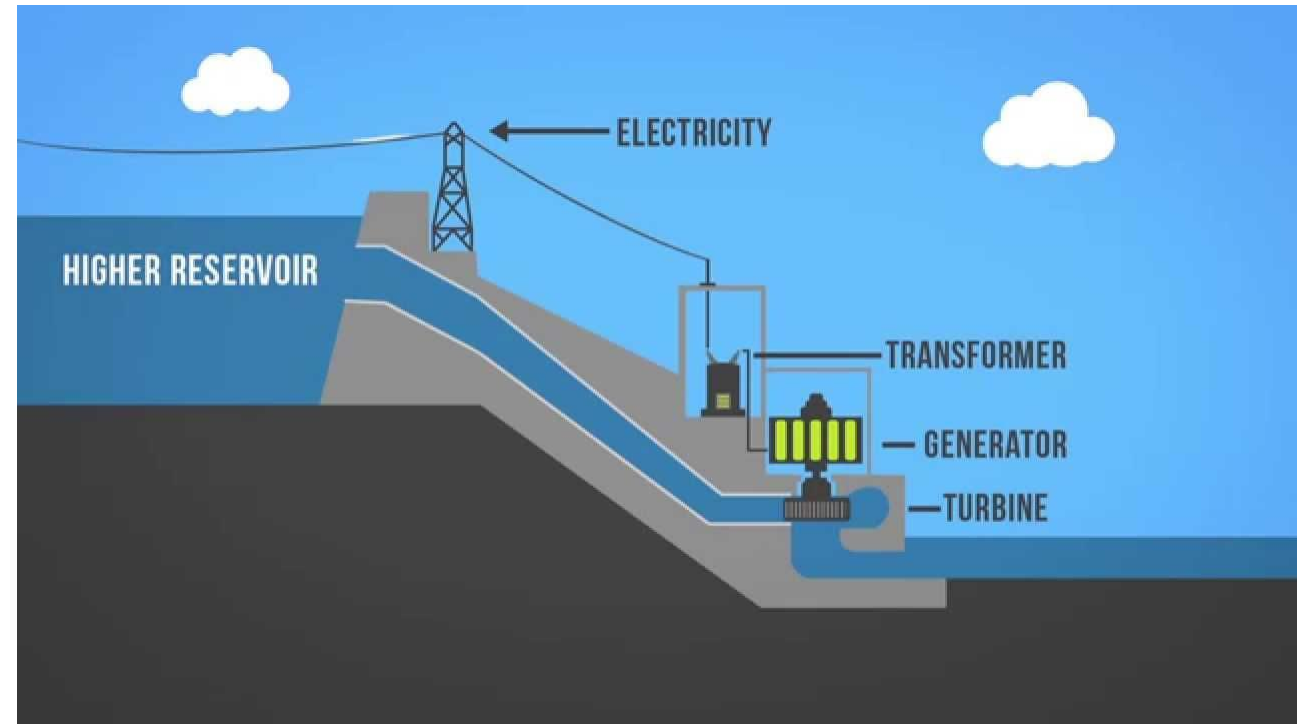
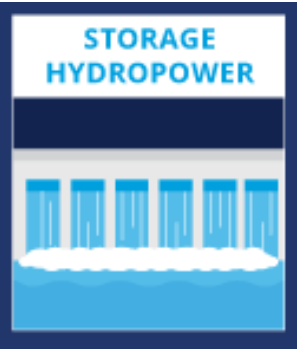
Source: EnergySage

Types of hydropower

In order to generate electricity, a large-scale hydropower (LHP) plant uses the kinetic (moving) energy of water in lakes or reservoirs.

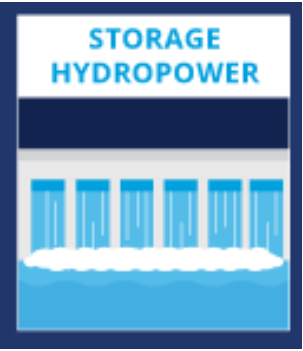
The water flows through a penstock, which channels the water to the turbine. When flowing water turns a turbine, its kinetic energy is converted to mechanical (machine) energy.

The turbine turns the generator rotor, which then converts this mechanical energy into electricity. After the water has flowed through the turbine blades, the water is released for such purposes as irrigation, domestic and industrial use or to generate electricity again in another hydroelectric power plant located downstream.



Source: <https://www.youtube.com/watch?v=q8HmRLCgDAI>

Types of hydropower



Dams raise the water level of a stream or river to an elevation needed to create water pressure or "head."

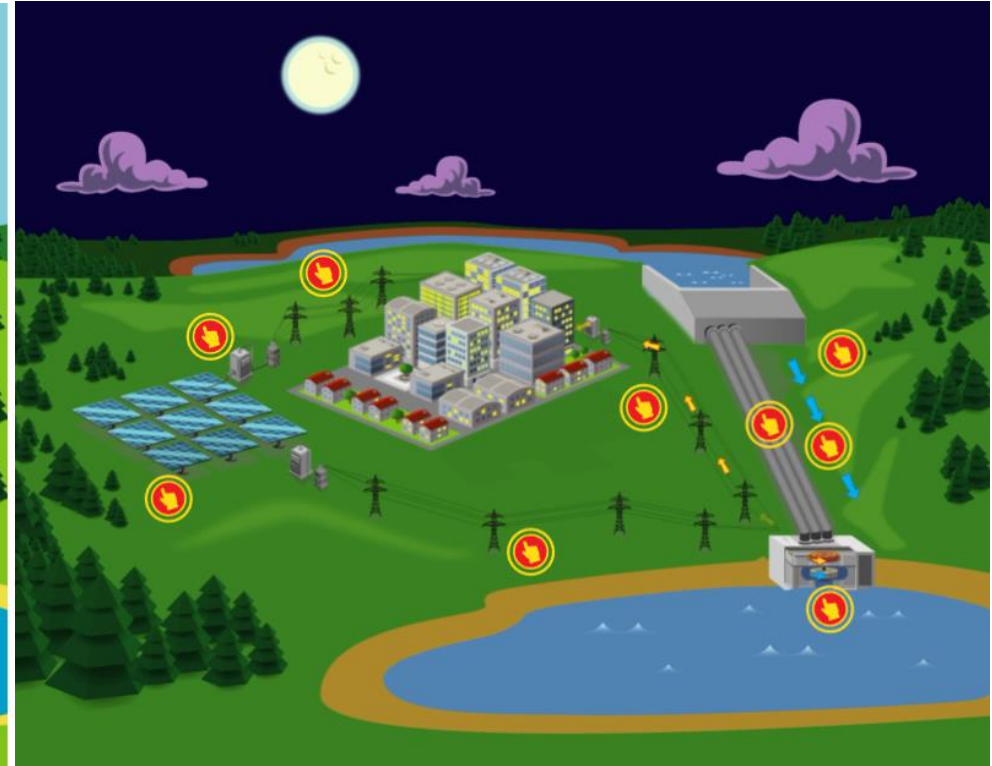
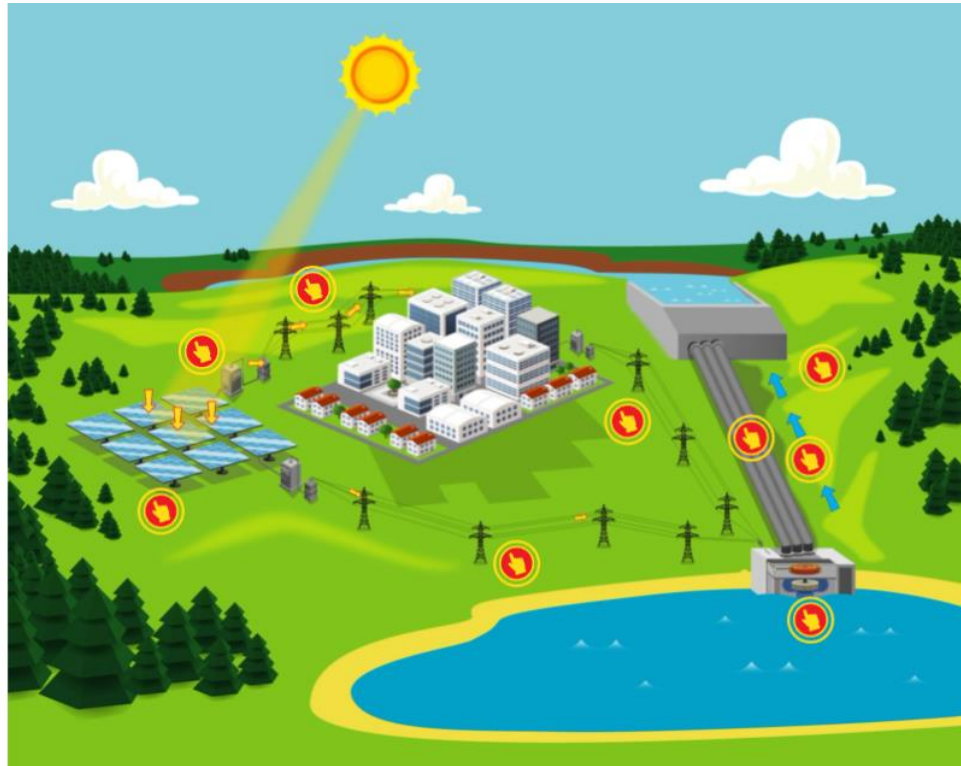
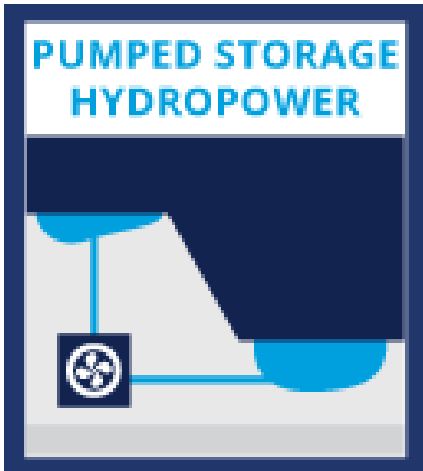
Dams may create secondary benefits such as flood control, recreation opportunities and water storage.



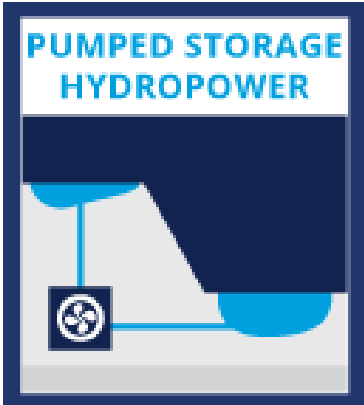
Source: <https://www.istockphoto.com/photo/people-walking-on-edge-of-stausee-mooserboden-dam-kaprun-austria-gm1207302776-348531908>

Types of hydropower

Pumped storage is a method of keeping water in reserve for peak period power demands. It works like a giant battery. During the night, water is pumped from a low lake to a storage pool above the power plant at a time when customer demand for energy is low, and electricity is cheaper. The water is then released through the turbine-generators at times when demand is high and a heavy load is placed on the system.



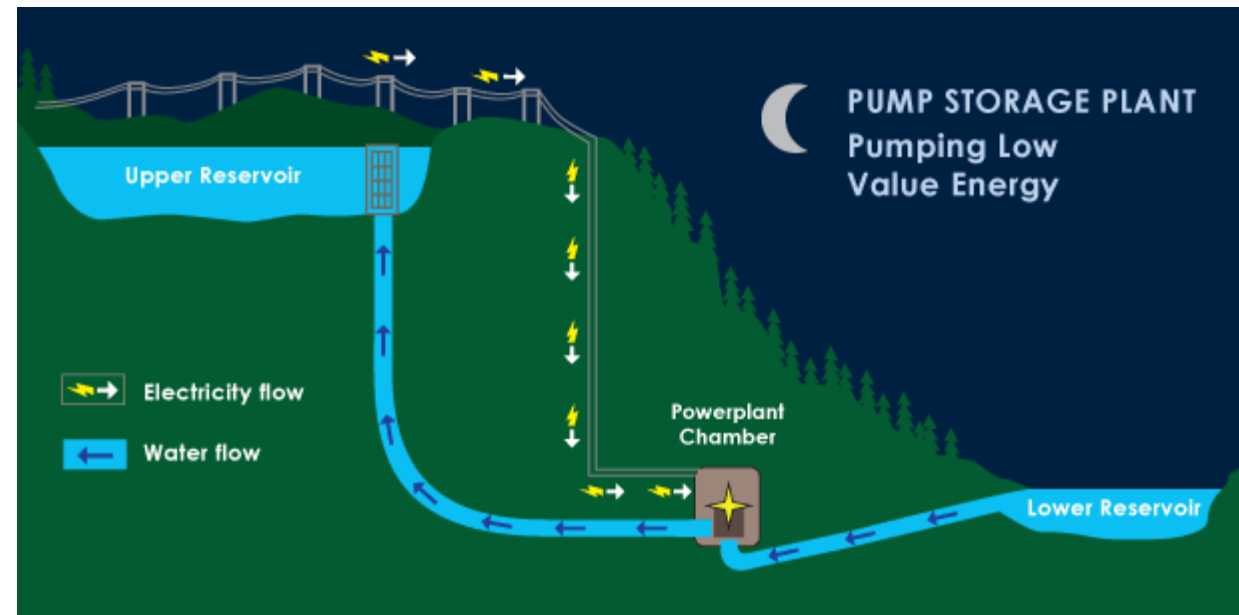
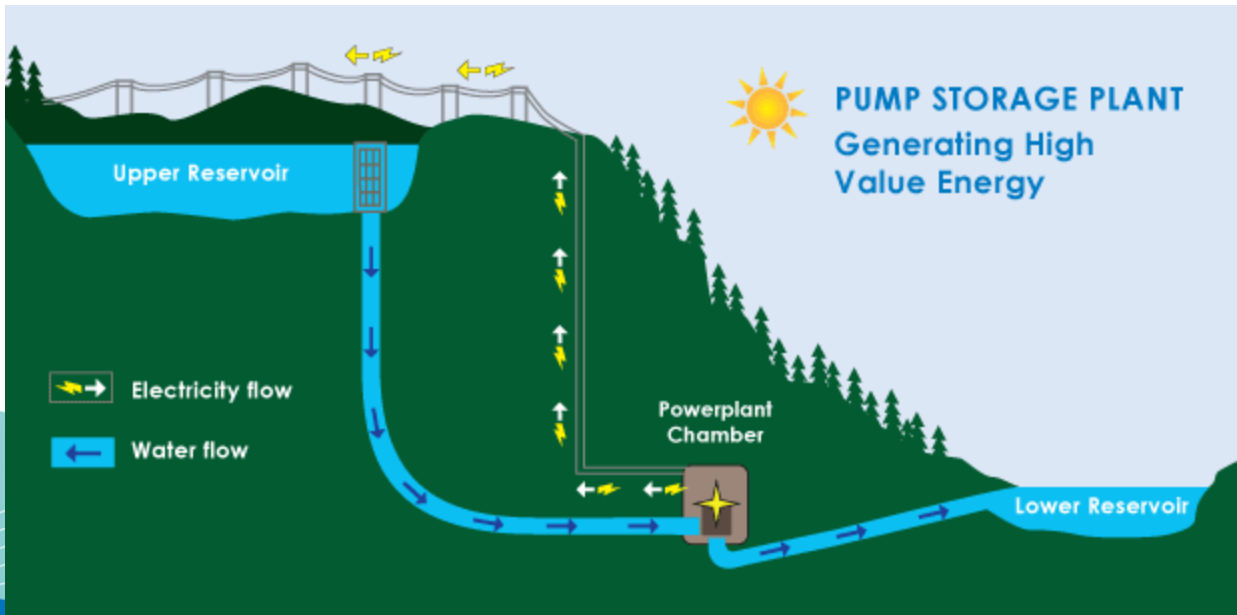
Types of hydropower



Pumped Storage:

During periods of high demand, water is allowed to run from the upper reservoir, through the turbines to the lower reservoir to generate electricity.

When there is surplus electricity on the grid, turbines act in reverse and pump water from lower reservoir to the upper reservoir.



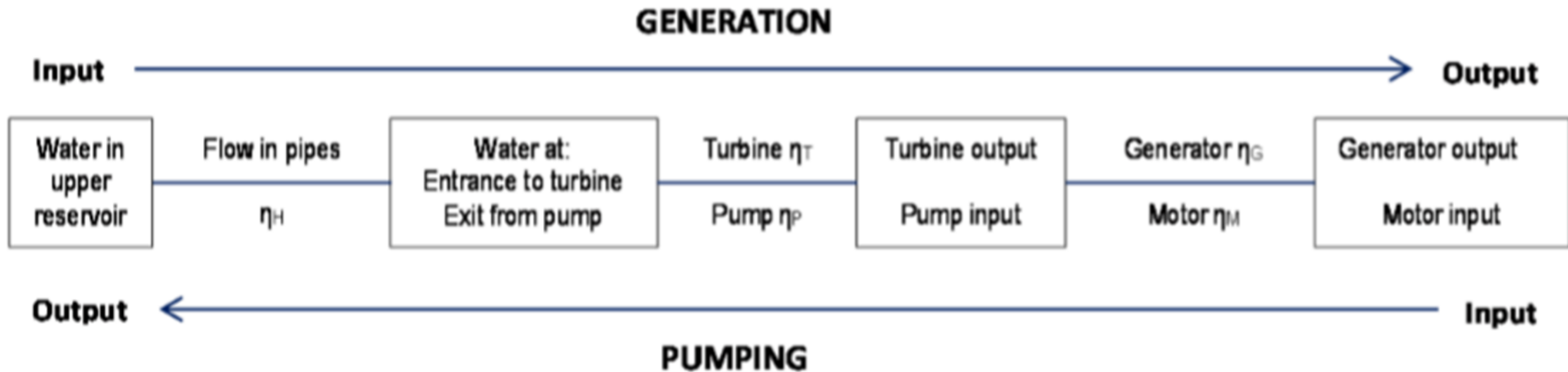
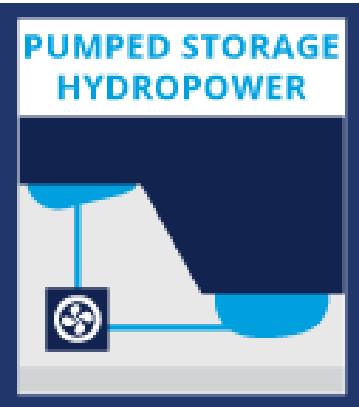
Key features:
Fine control of grid system
Rapid response time

Source: <http://www.cleanbalancepower.com/about-pumped-storage.html>

Types of hydropower

Pumped Hydro Storage (PHS) cycle efficiency.

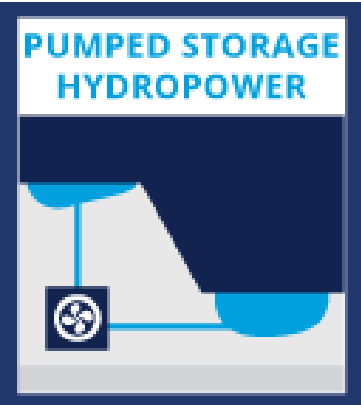
The cycle efficiency of a typical PHS ranges between 65% and 77% (Papantonis, 1995), while the main drawback of such systems is their high capital cost, directly related to the need for the construction of at least two reservoirs, preferably close to consumption.



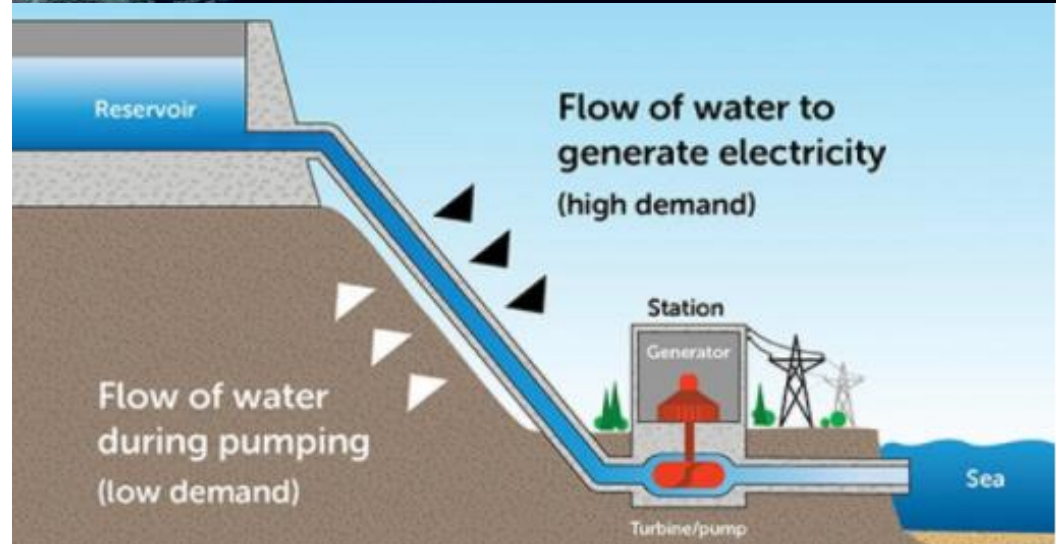
$$\eta_{\text{cycle}} = \eta_H \times \eta_T \times \eta_G \times \eta_M \times \eta_P$$

Types of hydropower

Seawater Pumped Hydro Storage (PHS) Japan



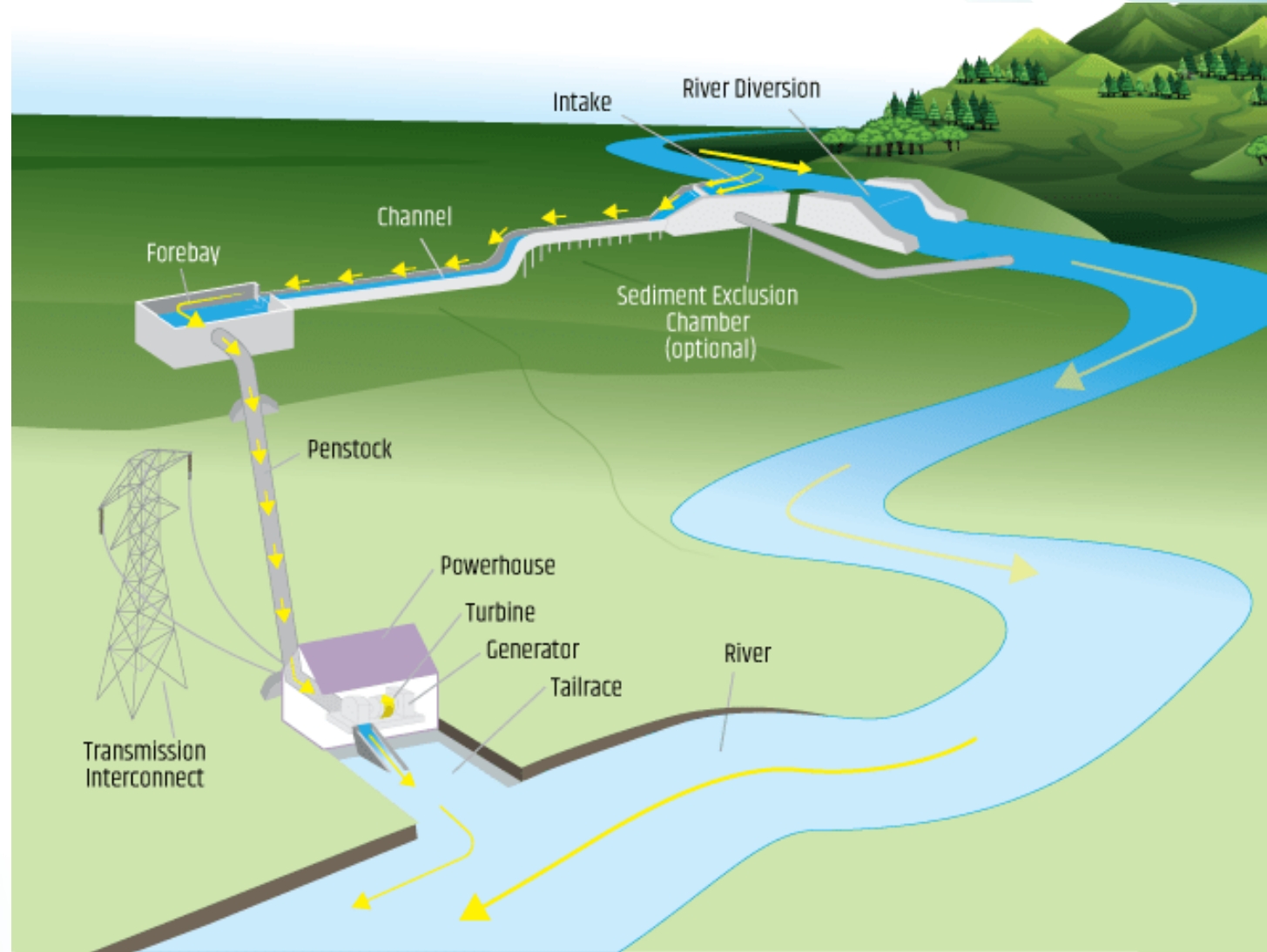
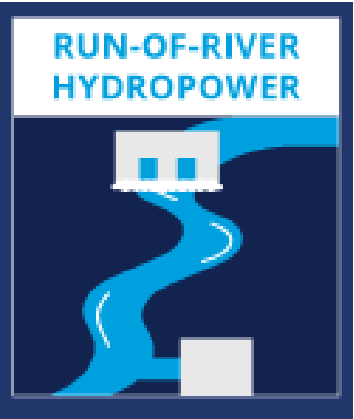
World's first sea water pumped storage facility
Power generation capacity: 30 MW
Upper reservoir is approximately 150m
above sea level with an effective storage
capacity of 564,000 m³



Types of hydropower

Another type of hydropower plant is the run-of-the-river hydroelectricity.

Run-of-river systems do not rely on large storage reservoirs, but rather divert river water to drive turbines, and then discharge the water back into the river system. These hydropower schemes are most often used for micro and small scale hydropower, but can also be large-scale projects.





Types of hydropower

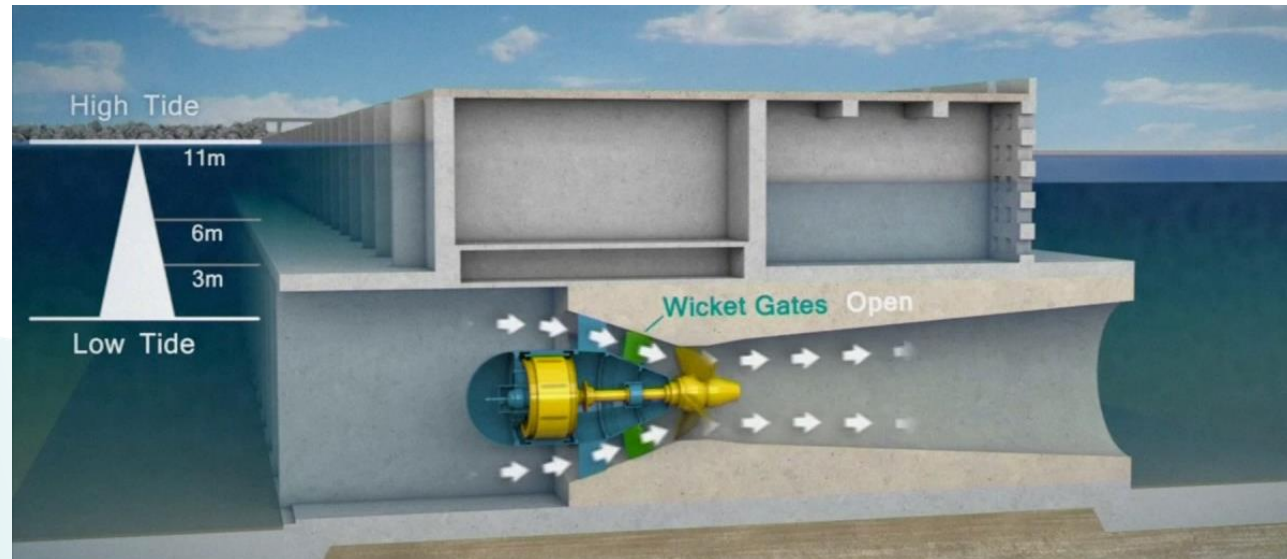
Tidal power is a method of large-scale hydropower that uses the motion of the ocean's tides to generate electricity.

There are two types of tidal power: tidal range and tidal stream.

Tidal range systems trap huge volumes of water in a large basin and when then drains through a tidal estuary (river mouth – discharge) to drive water turbines built into a dam.

Tidal streams are built in narrow channels around headlands.

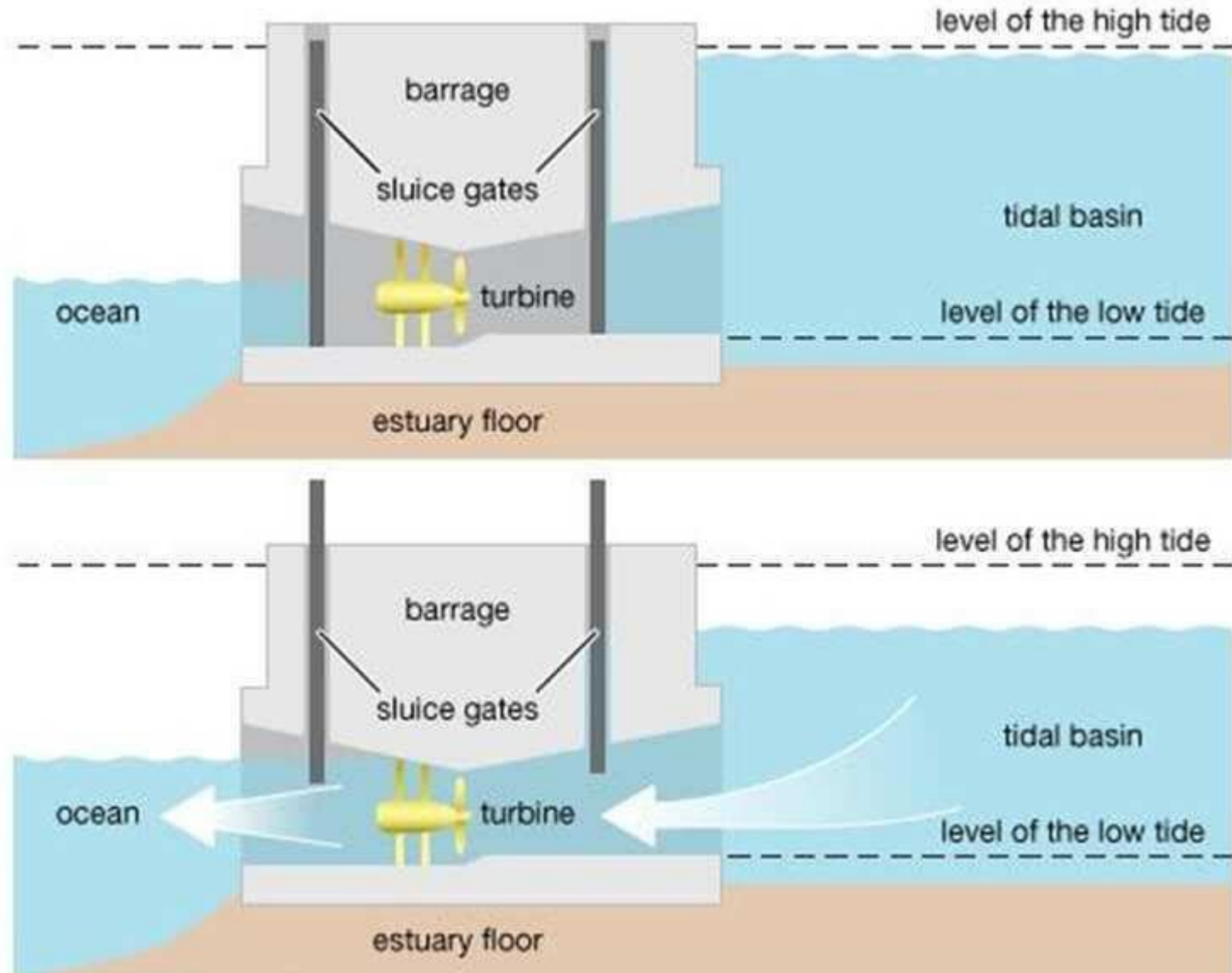
The energy produced by fast flowing tidal currents can be harnessed by using underwater turbines that are fixed on the seabed or estuary floor



Source: https://www.youtube.com/watch?v=2U4_p3AjoKo



Types of hydropower



Source: https://www.researchgate.net/publication/329141142_Advancement_of_direct_drive_generator_systems_for_offshore_renewable_energy_production/figures?lo=1



Types of hydropower

Average power output from a tidal barrage can be calculated by the following equation

$$P = (\rho g A h^2)/2T$$

Where

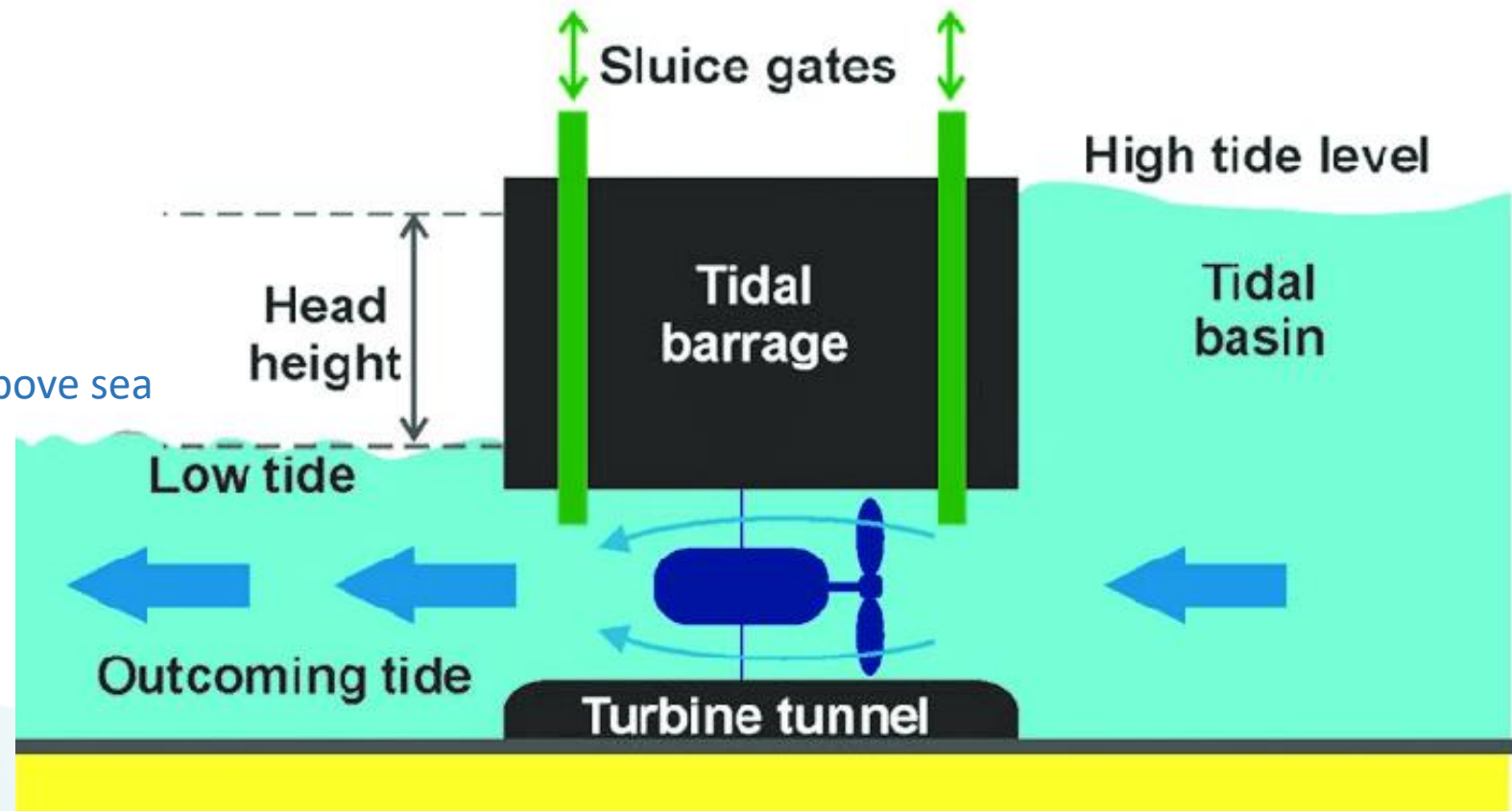
P: average power output

ρ : density of water (1000 kg/m³),

g: acceleration due to gravity (9.81 m/s²), A is the surface area of basin (m²),

h: height of water held behind barrage above sea level, also called as tidal range (m)

T: tidal time period



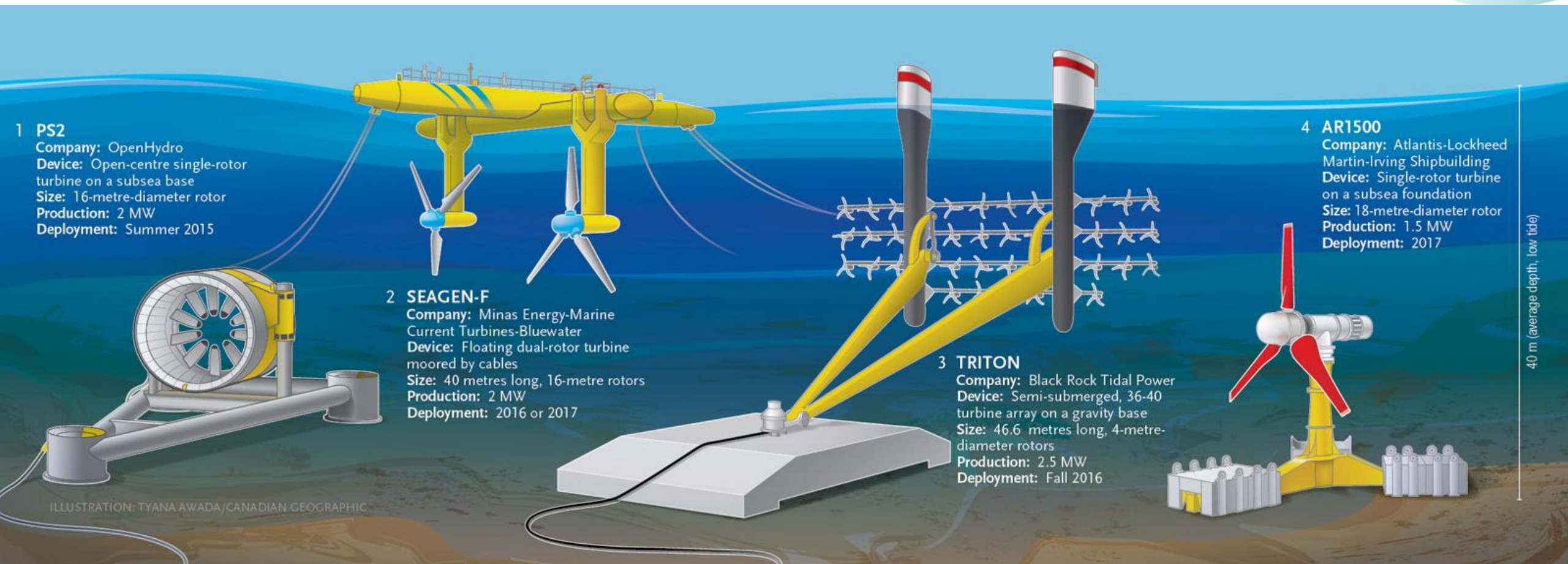
Source:

https://www.researchgate.net/publication/343879181_A_Preliminary_Study_and_Analysis_of_Tidal_Stream_Generators/figures?lo=1



Types of hydropower

Tidal stream turbines



1 PS2
Company: OpenHydro
Device: Open-centre single-rotor turbine on a subsea base
Size: 16-metre-diameter rotor
Production: 2 MW
Deployment: Summer 2015

2 SEAGEN-F
Company: Minas Energy-Marine Current Turbines-Bluewater
Device: Floating dual-rotor turbine moored by cables
Size: 40 metres long, 16-metre rotors
Production: 2 MW
Deployment: 2016 or 2017

3 TRITON
Company: Black Rock Tidal Power
Device: Semi-submerged, 36-40 turbine array on a gravity base
Size: 46.6 metres long, 4-metre-diameter rotors
Production: 2.5 MW
Deployment: Fall 2016

4 AR1500
Company: Atlantis-Lockheed Martin-Irving Shipbuilding
Device: Single-rotor turbine on a subsea foundation
Size: 18-metre-diameter rotor
Production: 1.5 MW
Deployment: 2017

ILLUSTRATION: TYANA AWADA/CANADIAN GEOGRAPHIC

40 m (average depth, low tide)

Source: <https://www.canadiangeographic.ca/article/nova-scotias-first-stream-tidal-turbine-starts-producing-power>



Types of hydropower

Financial & environmental aspects of tidal power

High capital investment

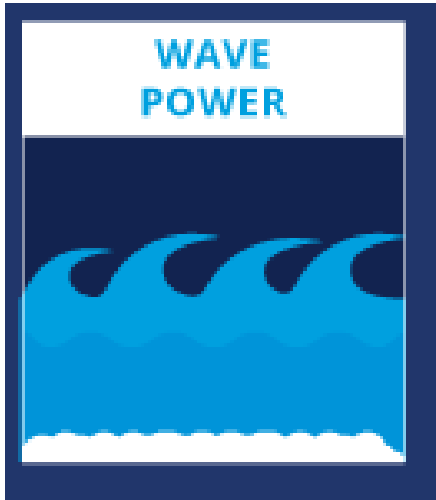
Long payback periods

Negative impact on aquatic and shoreline ecosystems

Difficulty in providing tidal energy to coastal communities

Change in water levels

Types of hydropower



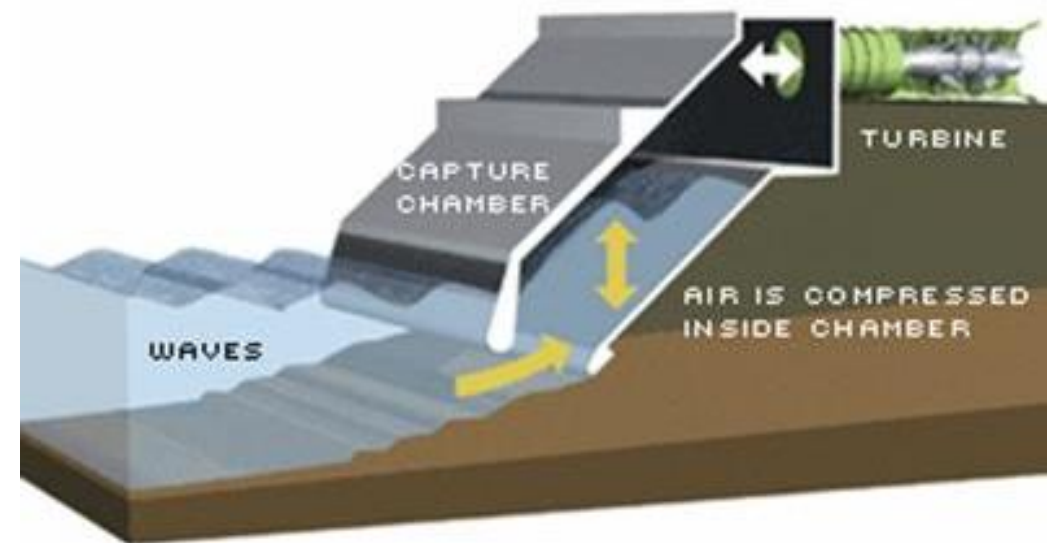
Wave power is a form of renewable energy that can be harnessed from the motion of the waves.

There are several methods of harnessing wave energy that involve placing electricity generators on the surface of the ocean.



Source: <https://www.esi-africa.com/top-stories/south-africa-wave-energy-power-plant-development/>

South Africa's nearly 3,000 km coastline is ideal for electricity generation using sea wave energy technology.



Source: <http://coolmyplanet.com/wavepower/>

Types of hydropower

The hydroelectric energy is ranked on a large and small scale.

Small scale hydropower plants differs significantly from large scale in terms of environmental impact.

Large scale hydropower plants require the construction of dams and huge reservoirs with significant impact on the immediate environment

Type	Power Output	Applicability
Large (described in this factsheet)	> 100 MW	Large urban population centres
Medium (described in this factsheet)	10 – 100 MW	Medium urban population centres
Small (see small scale hydropower)	1 – 10MW	Small communities with possibility to supply electricity to regional grid.
Mini (see small scale hydropower)	100 kW – 1MW	Small factory or isolated communities.
Micro (see small scale hydropower)	5 – 100kW	Small isolated communities.
Pico (see small scale hydropower)	<5kW	1 – 2 houses.

Pros & Cons of **small-scale hydropower** plants

The operating principle of small hydropower plants is based on the exploitation of dynamic energy of surface water, conversion of the dynamic into kinetic energy and then into electrical energy.

PROS

- High rate energy efficiency 30-67%
- Minimum nuisance
- Quality of the water

CONS

- Low energy efficiency compared to conventional energy sources.
- No capacity to store water in a reservoir.
- Maximum output period



Advantages of **hydropower**

Hydropower promotes sustainable development through delivering energy in an economically viable, environmentally sound and socially responsible way.

- ❑ Hydro turbines are much more compact than wind turbines.
- ❑ Hydropower contributes to fresh water storage.
- ❑ Hydropower projects are large scale energy storage solutions.
- ❑ Hydropower fosters national energy security.
- ❑ Hydro is controllable and therefore much more reliable than wind and PV.

Disadvantages of **hydropower**

- ❑ Hydroelectricity requires a flow of water and a head (fall of water) which implies rain and a hilly topography. Therefore it is not universally applicable.
- ❑ Dams can disrupt natural seasonal changes in the river, and local ecosystems can be adversely affected.
- ❑ Flooding large areas of land can displace both human and animal populations, which need to be relocated.
- ❑ Constructing large storage or pumped storage hydropower plants involves blocking, diverting the natural flow of river systems. This implies the simultaneous blocking of important migration routes for fish.
- ❑ Dams are expensive to build, and due to drought may become useless or produce less power than originally planned.
- ❑ Dams can break in a massive flash flood.

Classification of Dams

Dams are usually classified into the following four types.

- Arch
- Gravity
- Embankment
- Buttress

Determining which category and type of dam to build is dependant on many factors such as topography, geological conditions, availability of materials, spillway size and location, and environmental considerations.

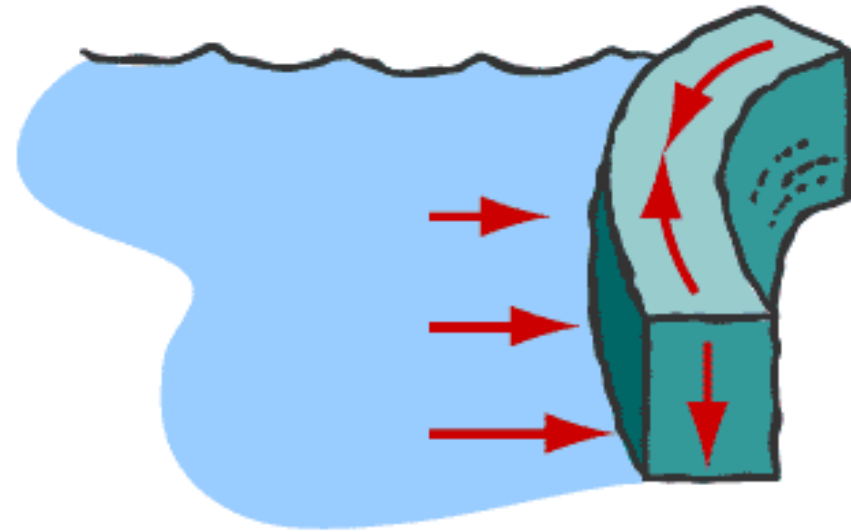
Classification of Dams

Arch Dams



They are good for narrow, rocky locations. They are curved, and the natural shape of the arch holds back the water in the reservoir.

Arch dams are thin and require less material than any other type of dam.



Forces

The arch squeezes together as the water pushes against it. The weight of the dam also pushes the structure down into the ground.

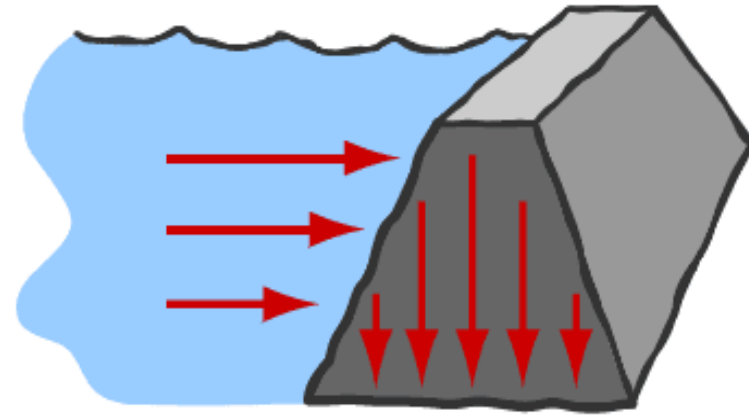
Classification of Dams

Gravity Dams



These are massive dams that resist the thrust of water entirely by their own weight.

Most gravity dams are expensive to build because they require a huge amount of concrete.



Forces

Water pushes against the gravity dam, but the heavy weight of the dam pushes down into the ground and prevents the structure from falling over.

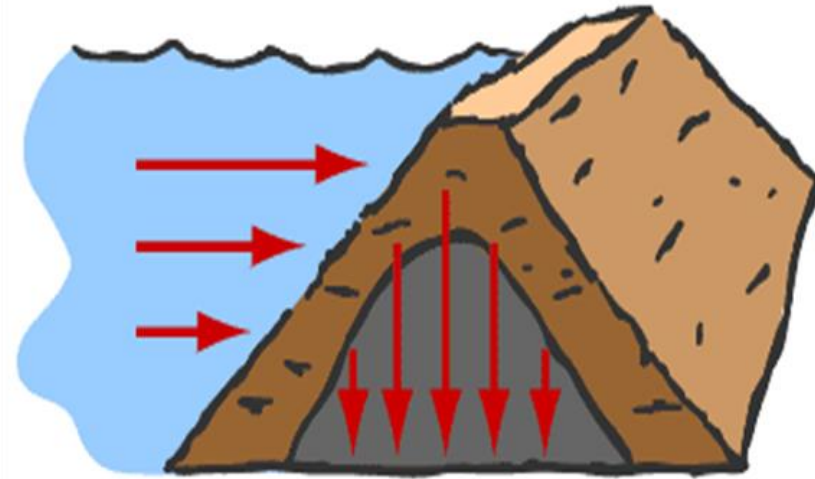
Classification of Dams

Embankment Dams



They are massive dams made of earth and rock. Like gravity dams, embankment dams rely on their heavy weight to resist the force of the water.

But embankment dams are also armed with a dense, waterproof core that prevents water from seeping through the structure.



Forces

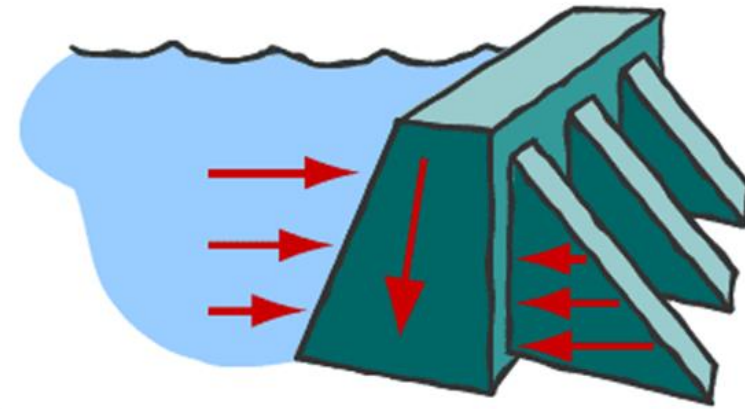
Water pushes against the embankment dam, but the heavy weight of the dam pushes down into the ground and prevents the structure from falling

Classification of Dams

Buttress Dams



They may be flat or curved with a series of supports, or buttresses, brace the dam on the downstream side. Most buttress dams are made of reinforced



Forces

Water pushes against the buttress dam, but the buttresses push back and prevent the dam from toppling over. The weight of the buttress dam also pushes down into the ground.

Dam failure

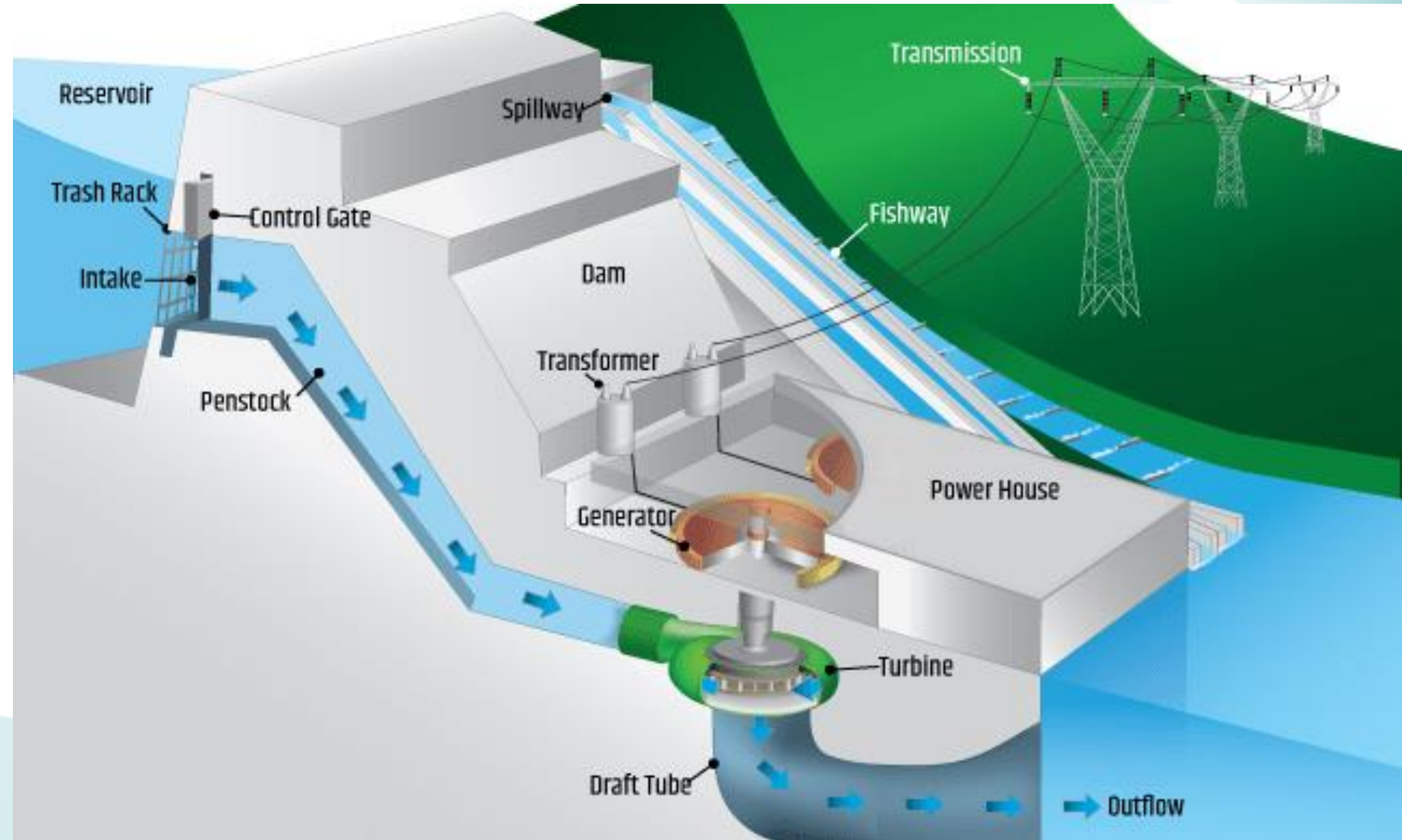


Large scale hydropower

The fast moving water is driven inside the tunnel in order to rotate turbines, creating in that way mechanical energy.

A generator converts this energy into electricity.

The water, contrary to what happens to it with fossil fuels, after the electricity production can be also used for other purposes.



Large scale hydropower

Three Gorges Dam - China

Built upon - Yangtze River

Reservoir area – 1,084 km²

Dam height – 181 m

Hydraulic head – 80.6m

Flow rate – (600 – 950) m³/s

Installed capacity – 22.5 GW

Turbines – 32 each with installed capacity of 700MW and 2 smaller (each

50MW) Francis turbines

Annual average power generation ~ 112 TWh



Large scale hydropower

Itaipu – Brazil & Paraguay

Installed Capacity – 14 GW

Dam height – 196m

Hydraulic Head – 118 m

Reservoir area – 1,350 km²

Turbine type – 20 Francis turbines each 700MW capacity and 93.8% efficient

Annual energy production - 96.58 TWh.

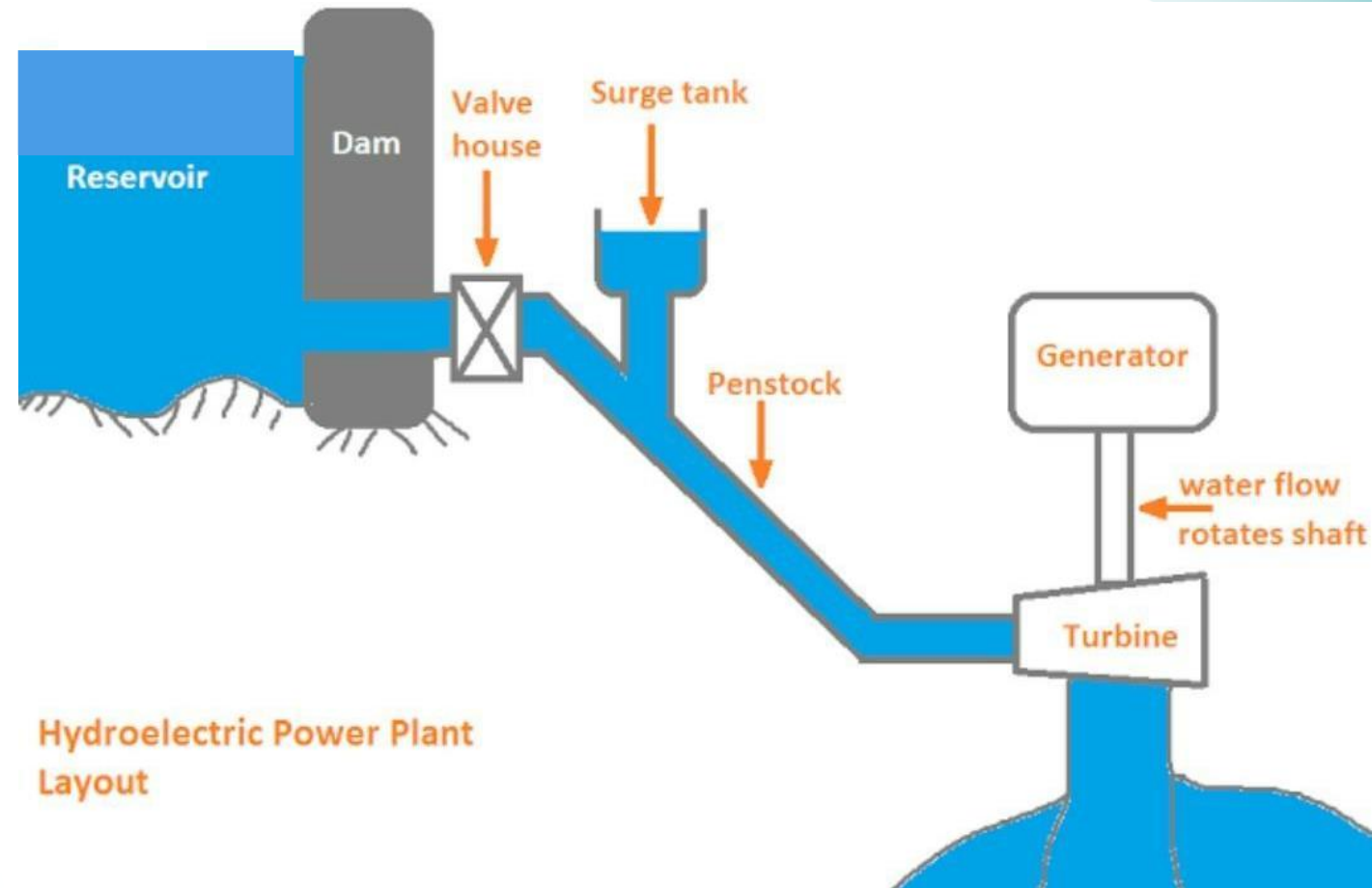


Hydropower constructions

Primary components required to construct a hydroelectric power plant.
Dam, pressure tunnel, surge tank, valve house, penstock, and powerhouse.

The **dam** is an artificial concrete barrier constructed across the way of the river. The catchment area behind the dam creates a huge water reservoir. The **pressure tunnel** takes water from the dam to the valve house.

In the **valve house**, there are two types of valves available. The first one is main sluicing valve and the second one is an automatic isolating valve. The sluicing valves control the water flowing to the downstream and automatic isolating valves stop the water flow when the electrical load is suddenly thrown off from the plant. Automatic isolating valve is a protecting valve does not play any direct role control the flow of water to the turbine. It only operates during emergency to protect the system from burst out.



Hydropower constructions

Primary components required to construct a hydroelectric power plant. **Dam, pressure tunnel, surge tank, valve house, penstock, and powerhouse.**

The **penstock** is a steel pipeline of suitable diameter connected between the valve house and powerhouse. The water flows down from upper valve house to lower powerhouse through this penstock only.

The **surge tank** is a protective accessory associated with hydroelectric power plant. It is situated just before the valve house. The height of the tank must be greater than the head of the water stored in the water reservoir behind the dam. This is an open top water tank.

In the **powerhouse** there are water turbines and alternators and switchgear systems to generate and then facilitate transmission of electricity.

