Renewable Energy Systems

11

Buchla, Kissell, Floyd

Chapter Outline

Energy from Water 11

Renewable Energy Systems
Buchla, Kissell, Floyd

Moving water has kinetic energy that can be converted to useful work directly or by using it to generate electricity. The amount of kinetic energy in a moving substance was given by the equation:

$$W_{KE} = \frac{1}{2}mv^2$$

Question:

What is the meaning of each variable in the equation and what are its units?

Answer:

W_{KE} = kinetic energy in J
m = mass in kg
v = velocity in m/s.

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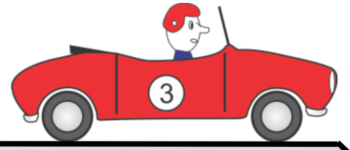
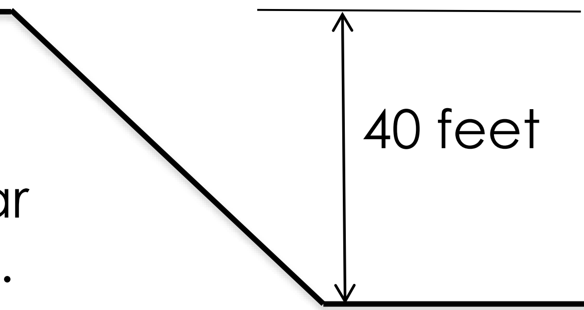
Water behind a dam or any object above a reference point posses potential energy, which is the energy of *position*. Potential energy is given by the equation:

$$W_{PE} = mgh$$





Example

What is the potential energy in joules of the car and driver? The car and driver weigh 1400 lbs.

1 lb = 0.454 kg; 1 ft = 0.305 m

Solution

$$W_{PE} = mgh = (1400 \text{ lb})\left(\frac{0.454 \text{ kg}}{\text{lb}}\right)\left(\frac{9.8 \text{ m}}{\text{s}^2}\right)(40 \text{ ft})\left(\frac{0.305 \text{ m}}{\text{ft}}\right) = 76 \text{ kJ}$$

When energy is transformed from potential to kinetic energy, some will be lost to friction (heat).

Example

What is the speed of the car in the previous example if 70% of the energy is transformed to kinetic energy? The car had a potential energy of 76 kJ and a mass of 636 kg.

Solution

$$W_{KE} = (0.70)(W_{PE}) = (0.70)(76\text{ kJ}) = 53.2\text{ kJ}$$

$$W_{KE} = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2W_{KE}}{m}} = \sqrt{\frac{2(53.2\text{ kJ})}{636\text{ kg}}} = 12.9\text{ m/s (29 mi/h)}$$

11-1 Energy in Moving Water

Water behind a dam posses potential energy which is converted to kinetic energy as it falls. Each cubic meter weighs 1000 kg and the distance it falls relative to a reference is called the **head**.

Example

Assume the head on a dam is 30 m.

(a) What is the W_{PE} for one m^3 of water at the top of the reservoir?

(b) If this passes a turbine in 1 s, what total power does it represent? (Ignore friction).

Solution

(a) $$W_{PE} = mgh = (1000\text{ kg})\left(\frac{9.8\text{ m}}{\text{s}^2}\right)(30\text{ m}) = 294\text{ kJ}$$

(b) $$P = \frac{W}{t} = \frac{294\text{ kJ}}{1\text{ s}} = 294\text{ kW}$$

11-1 Energy in Moving Water

The energy in moving water can be thought of as potential energy plus the kinetic energy, Summarizing:

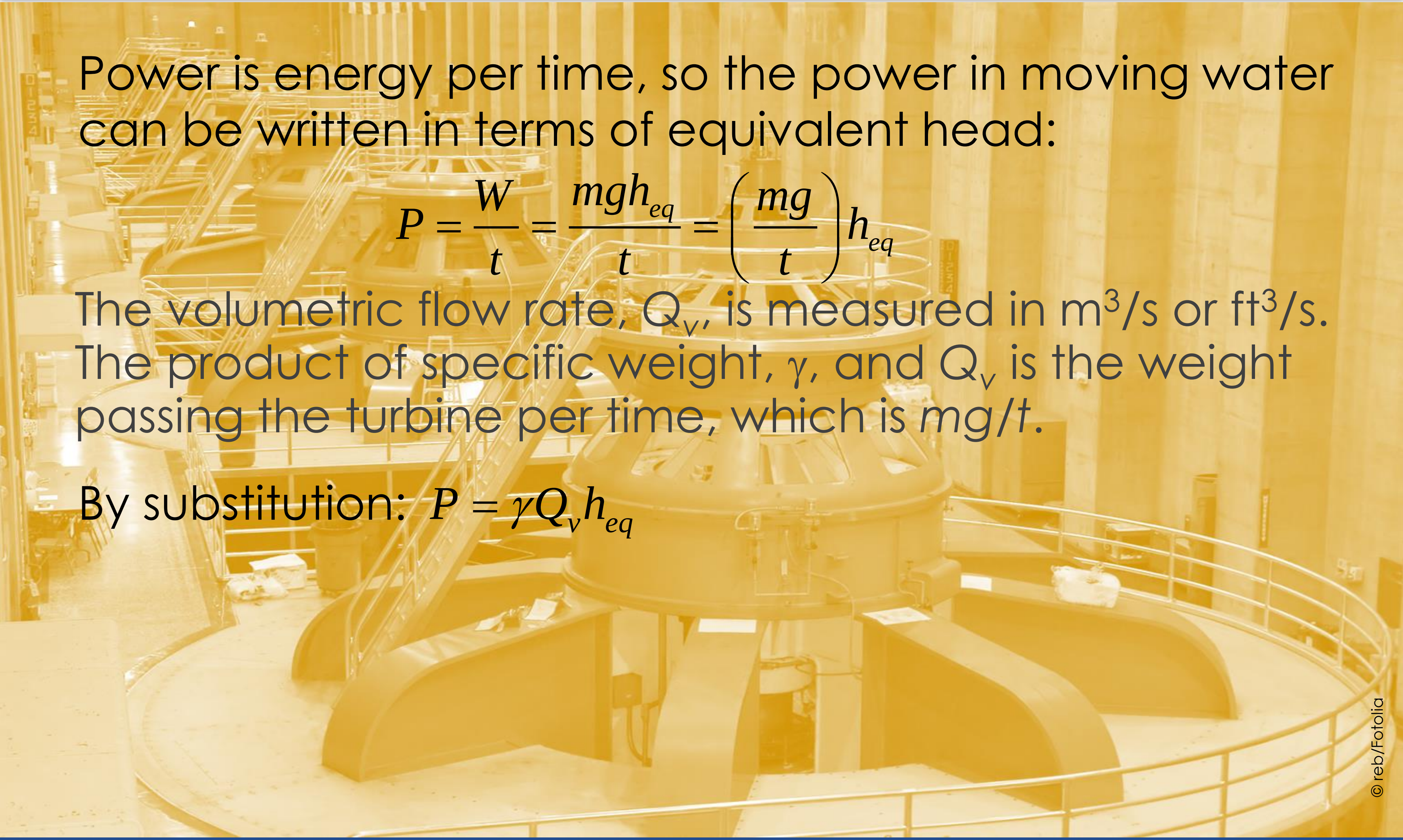
1) potential energy due to elevation,
2) potential energy due to pressure and
3) kinetic energy due to motion.

The equivalent head, h_{eq} is:

$$h_{eq} = h + \frac{p}{\gamma} + \frac{v^2}{2g}$$

h = height in meters,
p = pressure in N/m^3,
γ = specific weight of water (9807 N/m^3)
v = velocity in m/s
g = gravitational constant (m/s^2)

11-1 Energy in Moving Water



Power is energy per time, so the power in moving water can be written in terms of equivalent head:

$$P = \frac{W}{t} = \frac{mgh_{eq}}{t} = \left(\frac{mg}{t}\right)h_{eq}$$

The volumetric flow rate, Q_v, is measured in m^3/s or ft^3/s. The product of specific weight, γ, and Q_v is the weight passing the turbine per time, which is *mg*/*t*.

By substitution: $P = \gamma Q_v h_{eq}$

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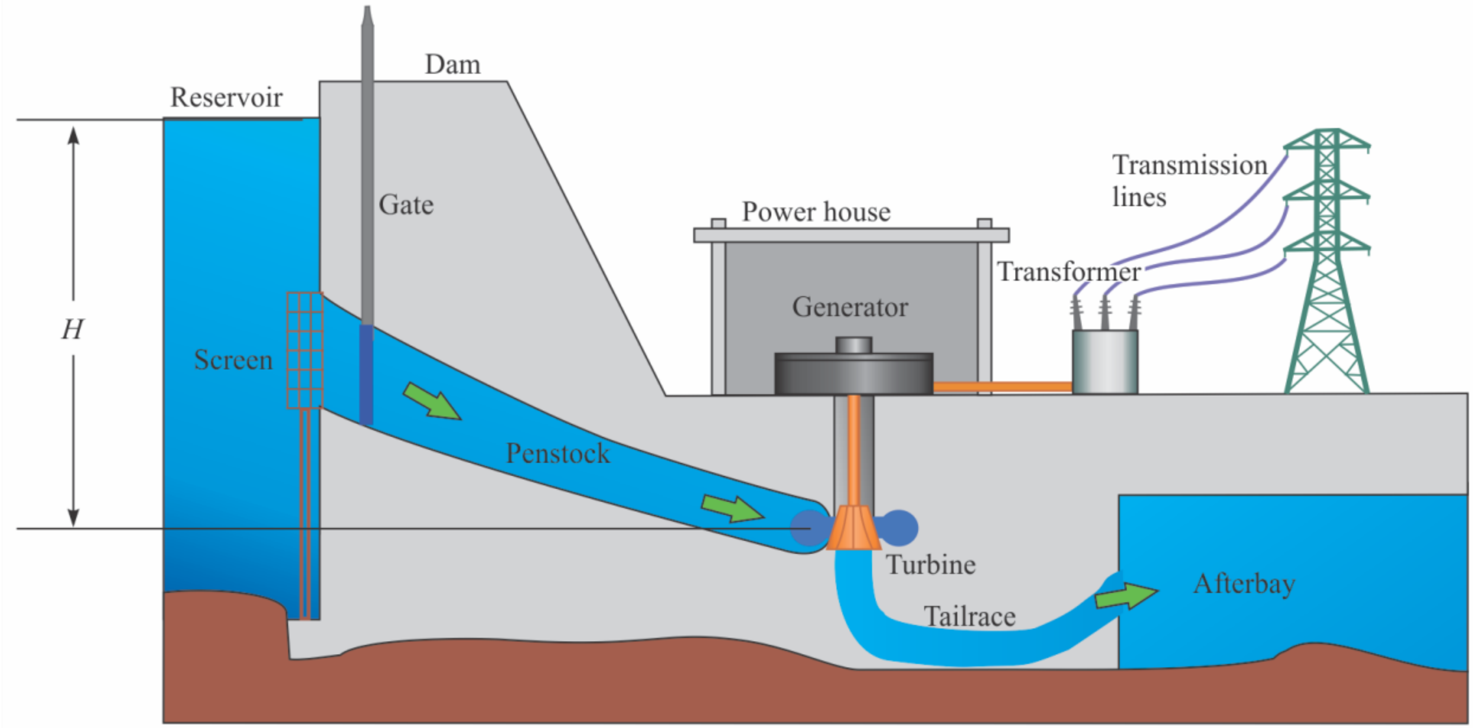
11-2 Hydroelectric Dam Operation

In a conventional hydroelectric generating system, stored water is allowed to flow through a penstock and used to spin a turbine/generator, generating electricity. Large dams will have multiple penstocks and turbines.



11-2 Hydroelectric Dam Operation

A very useful concept for renewable energy systems in mountainous areas is pumped storage. If the idea is applied to renewable systems, the storage water can be used when the resource is not available. Currently it is mostly used to help power companies level loads.

The Cabin Creek pumped storage power plant is located in Colorado and consists of two reservoirs connected by a tunnel. It has a total installed generating capacity of 320 megawatts in two reversible pump-turbine units.

Source: courtesy of XCEL Energy

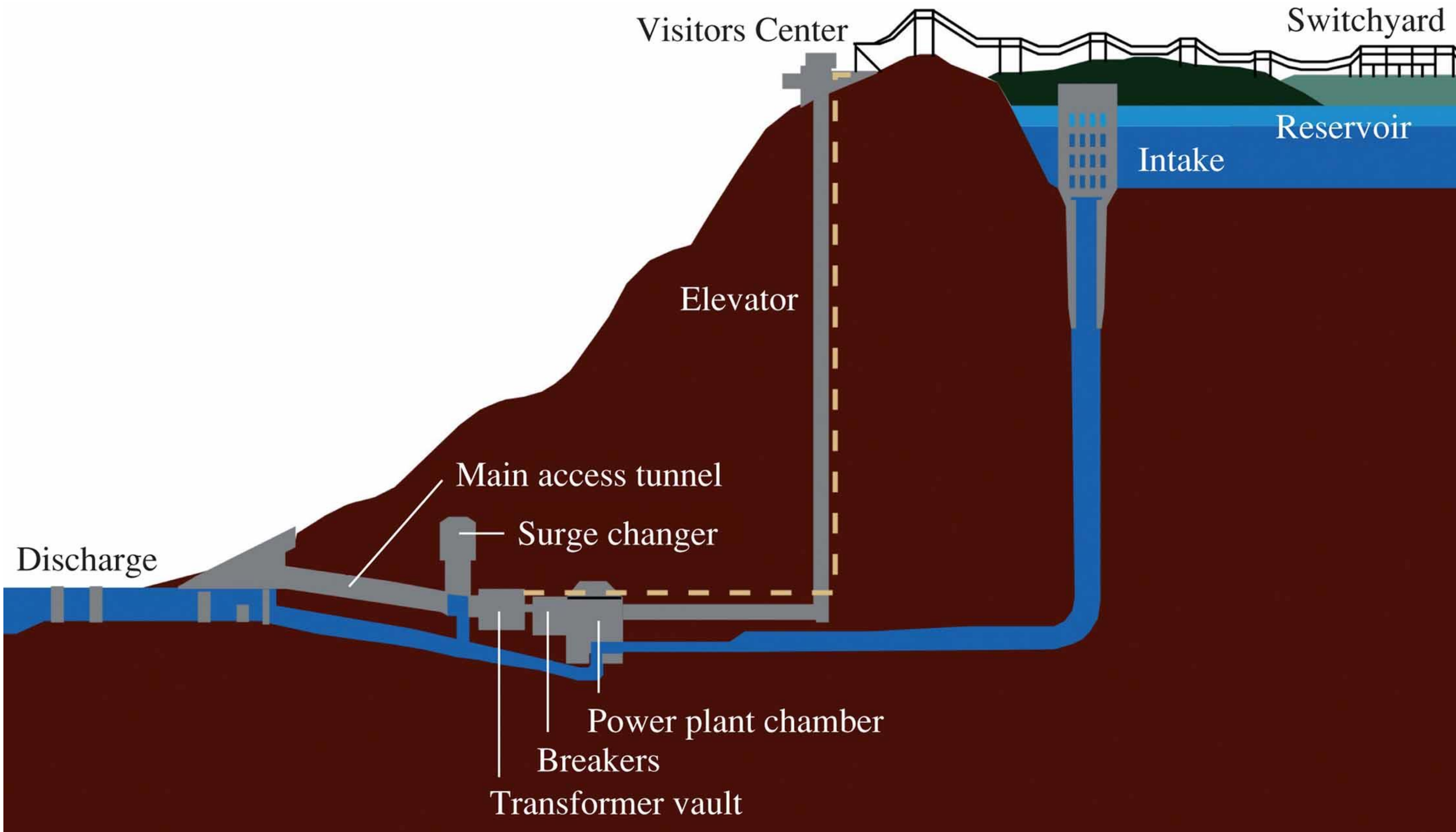
A very large pumped storage plant is the Helms Pumped Storage Plant, located high in a remote area of the Sierra Nevada Mountains. This is the largest hydroelectric and pumped storage facility in the California electric system and consists of three units. The rotors alone weigh 1 million pounds and are 20 feet in diameter and 10 feet high.

Helms produces 1,212 MW by moving water from the upper reservoir, which is Courtright Lake to a reservoir that is 1700 feet below at Lake Wishon.

Photo courtesy of Pacific Gas and Electric Co.

11-2 Hydroelectric Dam Operation

Raccoon Mountain pumped storage plant in Tennessee:



11-2 Hydroelectric Dam Operation

Run-of-the-River systems are hydroelectric systems that primarily use the kinetic energy in flowing rivers to generate electricity. They may have a water storage area associated with it, called pondage.

The photo shows a small run-of-the-river system in King Cove, AK, which helped offset expensive power from diesel generators. This plant generates only 800 kW of power. Very small systems like this are useful in remote villages and in developing countries.

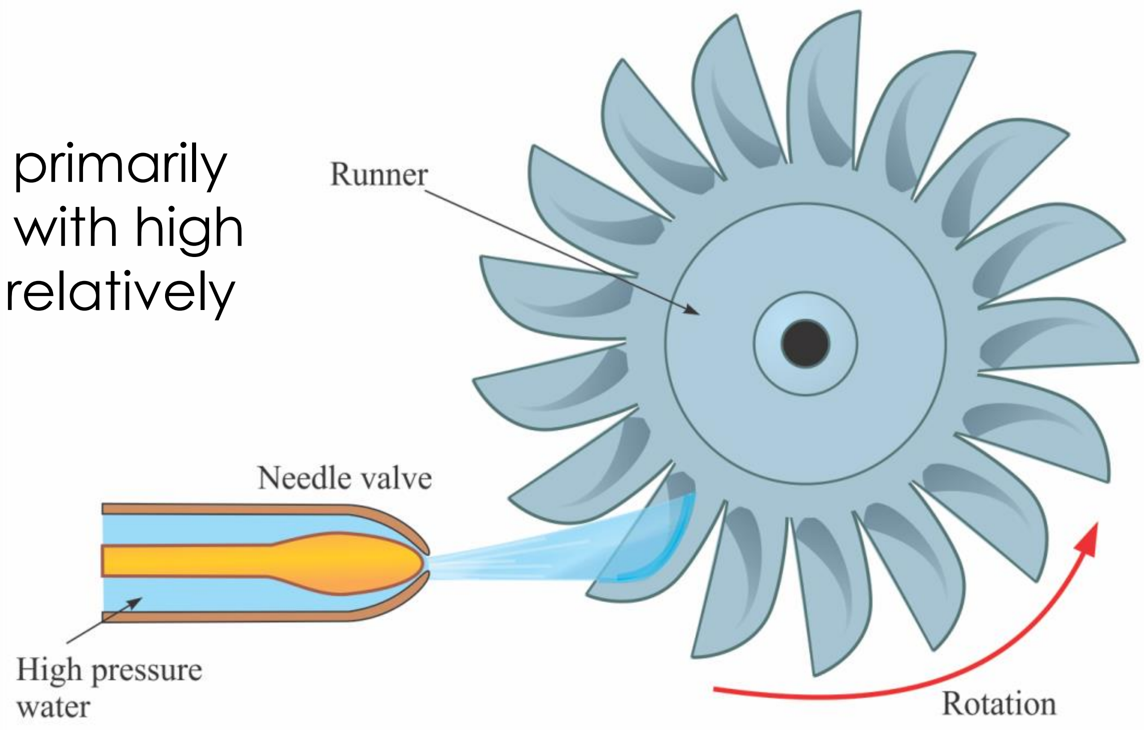
Source: NREL

11-3 Water Turbines

There are two classifications of water turbines:

1. An **impulse turbine** is a rotary engine that changes the direction of a high velocity fluid, thus converting kinetic energy into mechanical rotating energy.

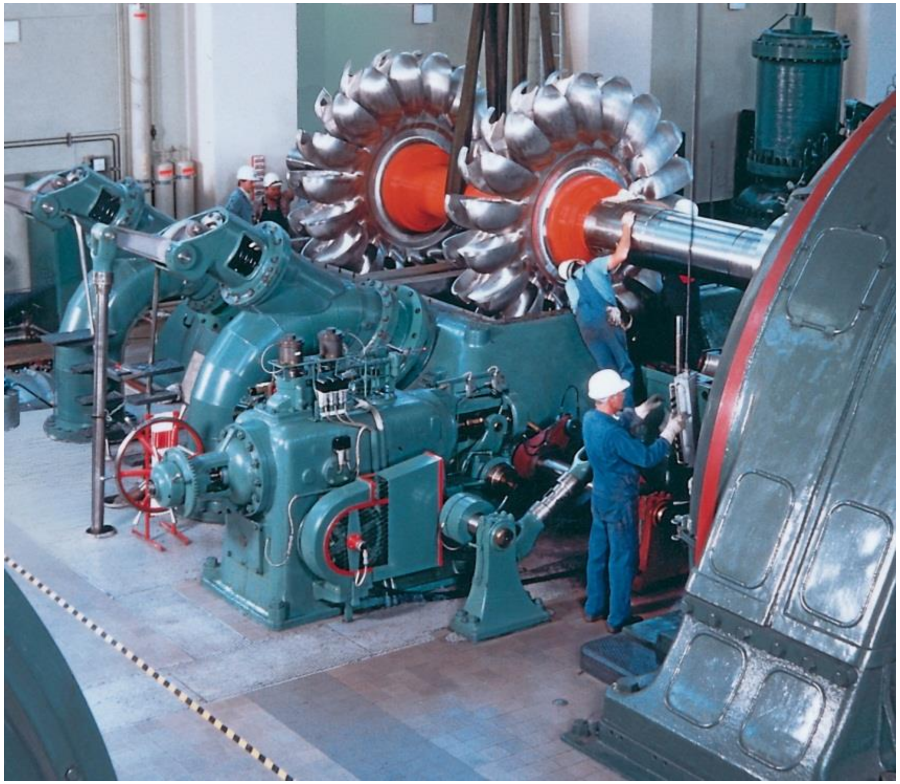
Impulse turbines are primarily used in applications with high pressure heads and relatively lower flow rates.



11-3 Water Turbines

Pelton and Turgo turbines are examples of impulse turbines. Notice the double cups on these Pelton turbines, a innovation by William Doble, an employee of Pelton.

The double cups split the water flow in half and causes the water to make a U-turn in the bucket, which transfers most of the momentum of the water to the wheel.



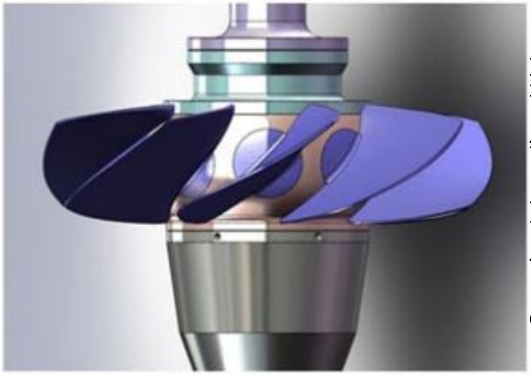
courtesy of Voith Hydro GmbH & Company

11-3 Water Turbines

2. R**eaction turbines** are the second type; they develop torque from the pressure of water and are submerged at all times. Think of action-reaction as in Newton's third law as the propulsion method.

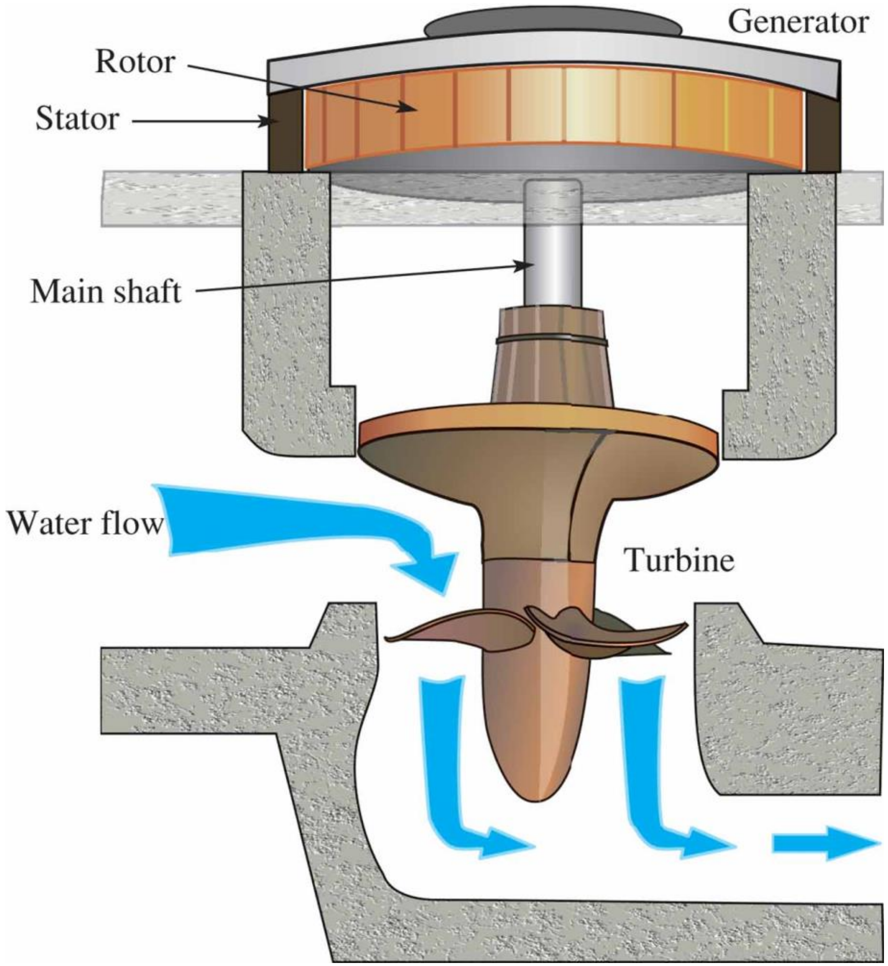
The Francis turbine is the most widely used reaction turbine and is used in moderate-head, high-volume applications. The Kaplan turbine is a propeller type reaction turbine used in low-head applications such as run-of-the river systems.

Francis turbine



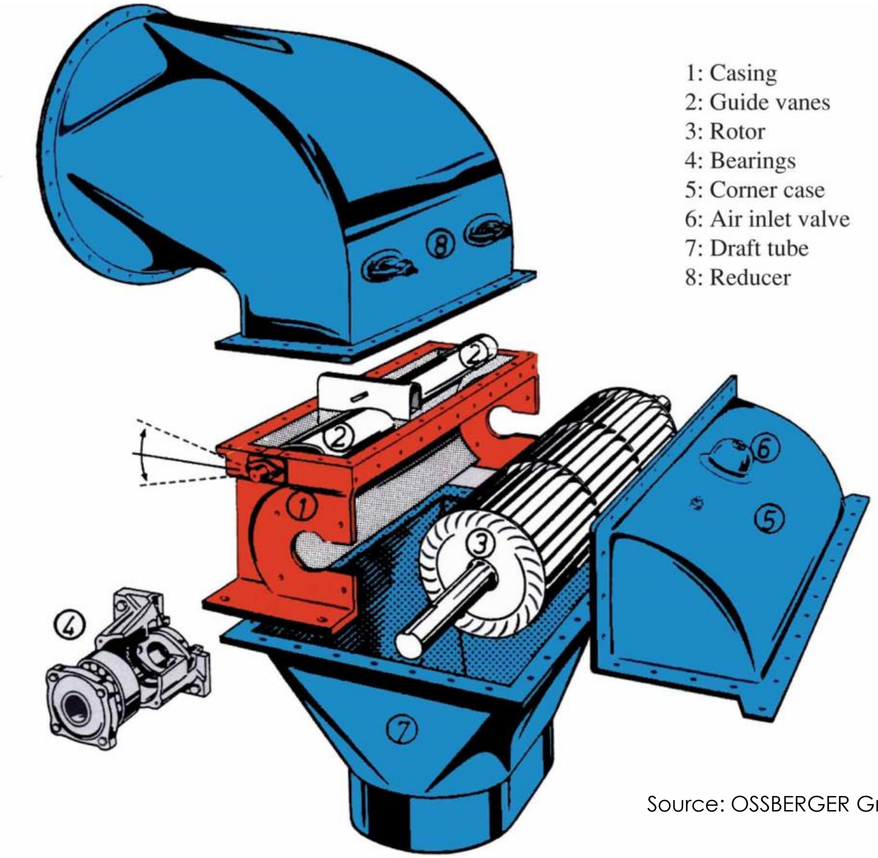
Kaplan turbine

A typical installation of a Kaplan turbine is illustrated here.



11-3 Water Turbines

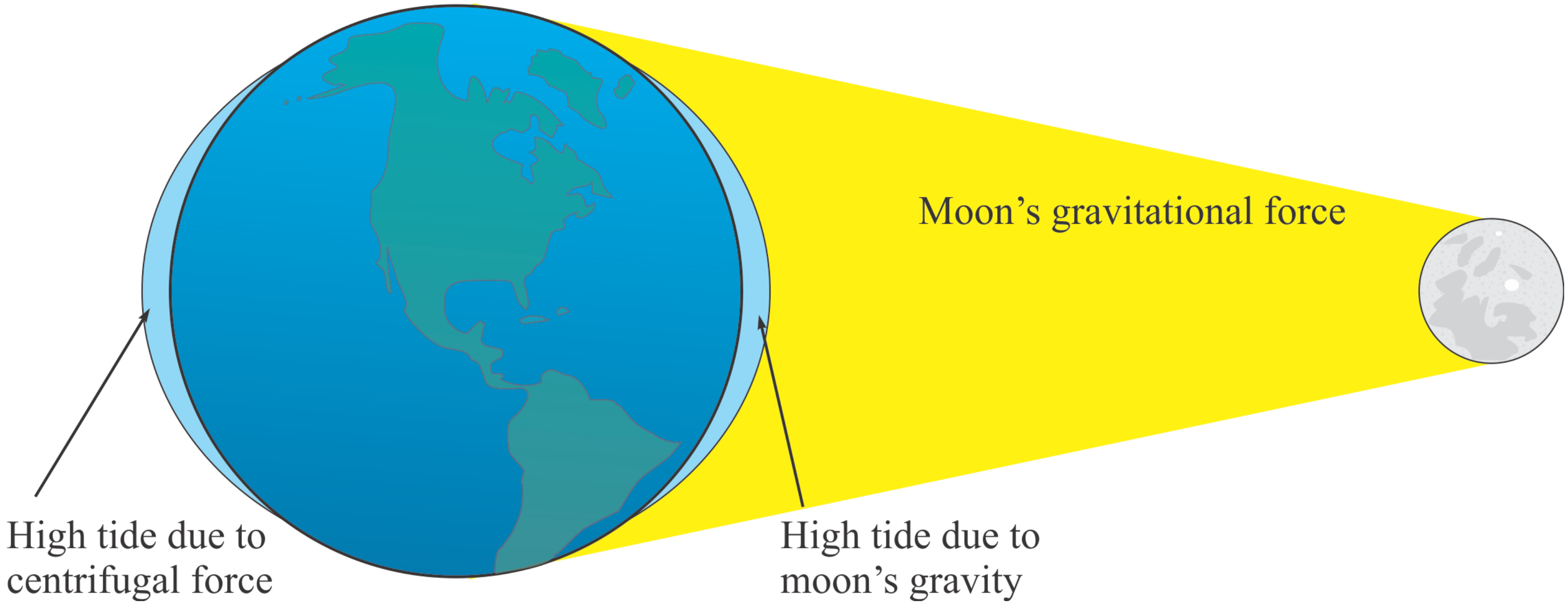
A cross-flow turbine is an impulse turbine used in smaller hydro plants with relatively large flow. They can operate effectively with a low head.



Source: OSSBERGER GmbH + Co.

11-4 Tidal Power Generation

There is a huge amount of power in ocean tides, which move primarily by the influence of the moon, so are quite predictable and occur every 12 h and 25 m. The moon's gravity produces a tidal bulge on one side of the earth and centrifugal force causes a second tidal bulge at the same time on the opposite side.



11-4 Tidal Power Generation

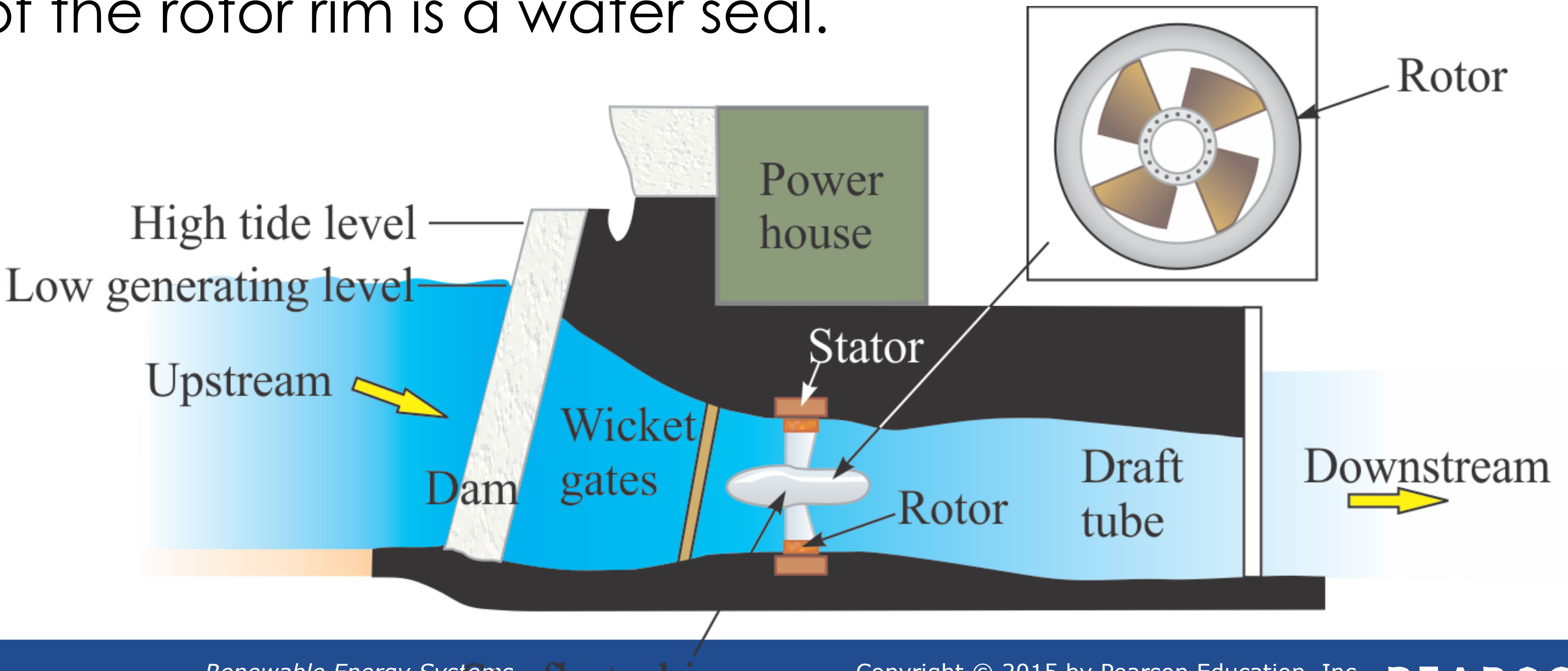
A few locations in the world can take advantage of a natural estuary, harbor or river by trapping water behind a barrage dam and taking advantage of the inflowing and/or outflowing water to generate power.

The Annapolis Tidal Power Station is located in the Bay of Fundy and is the only such station in North America. It is rated at 20 MW; power varies depending on the tides. It has been in operation since 1984.

Courtesy of Nova Scotia Power

11-4 Tidal Power Generation

The turbines at Annapolis Tidal Power Station use a unique but older design called a Straflo turbine. It is similar to a Kaplan turbine but with larger blades. The Straflo is a rim generator, in which the rotor is attached to the periphery of the blades of the runner. At the end of the rotor rim is a water seal.



11-4 Tidal Power Generation

The energy in the water behind a barrage can be calculated from considering gravitational potential energy. Recall that W_{PE} is given by $W_{PE} = mgh$

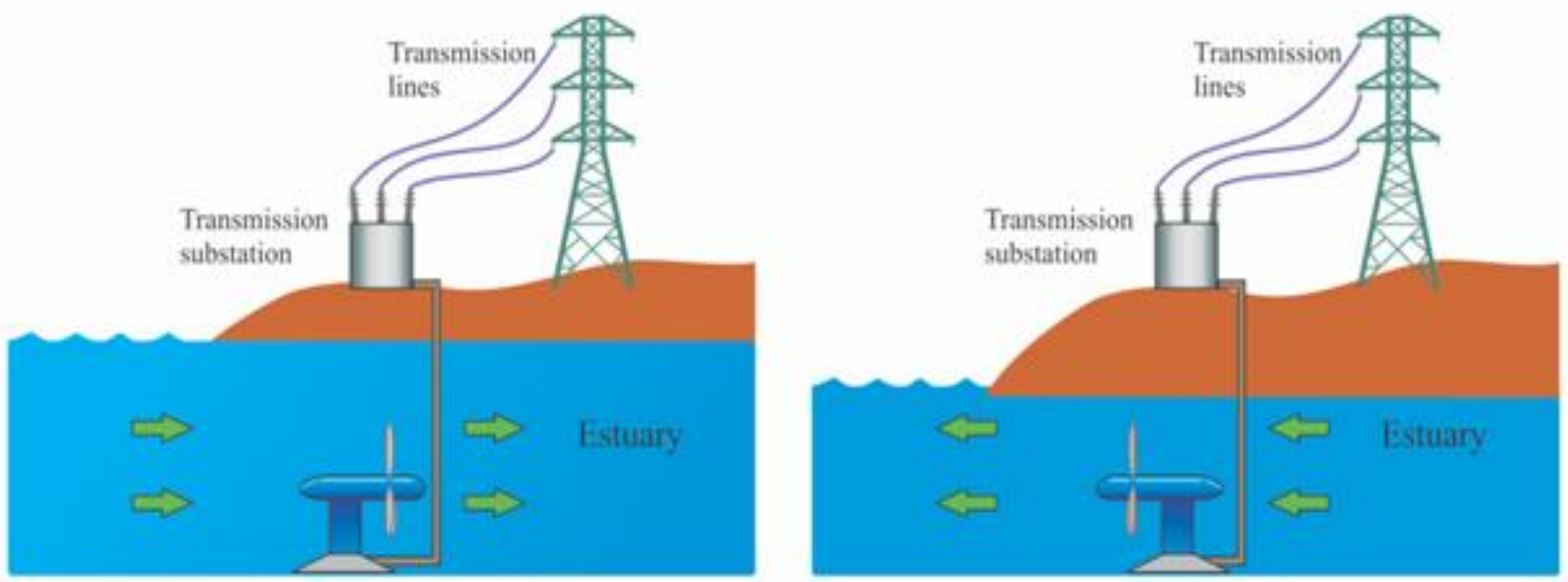
Substituting ρAh for mass, and using ½ the maximum height of the tidal basin to account for average height, we obtain:

$$W_{PE} = \frac{1}{2}(\rho Ah)gh = \frac{1}{2}\rho Agh^2$$

W_{PE} is the energy stored in J
h is the maximum height of the vertical tide in m
A is the horizontal area of the barrage basin in m^2
ρ is the density of seawater = 1025 kg/m^3
(Fresh water density = 1000 kg/m^3)
g is the gravitational constant = 9.8 m/s^2.

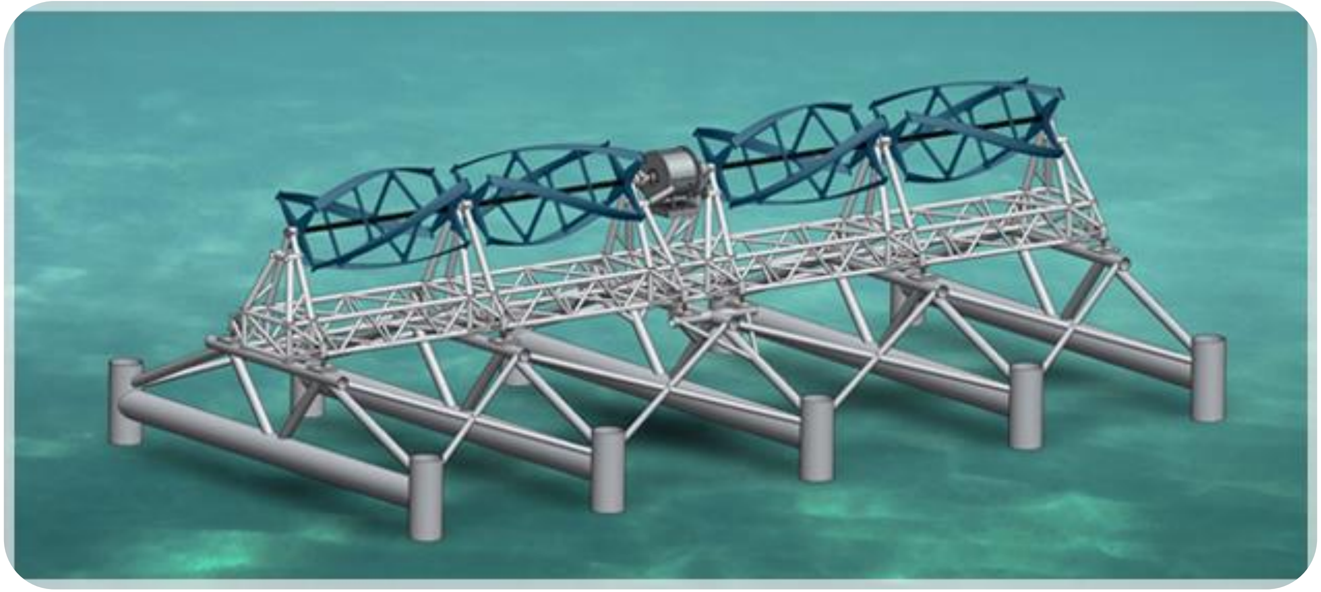
11-4 Tidal Power Generation

Another method for generating power from the tides is a **tidal stream generator**, which is anchored to the bottom. The generator can generate power from incoming (flood) or outgoing (ebb) tide.



11-4 Tidal Power Generation

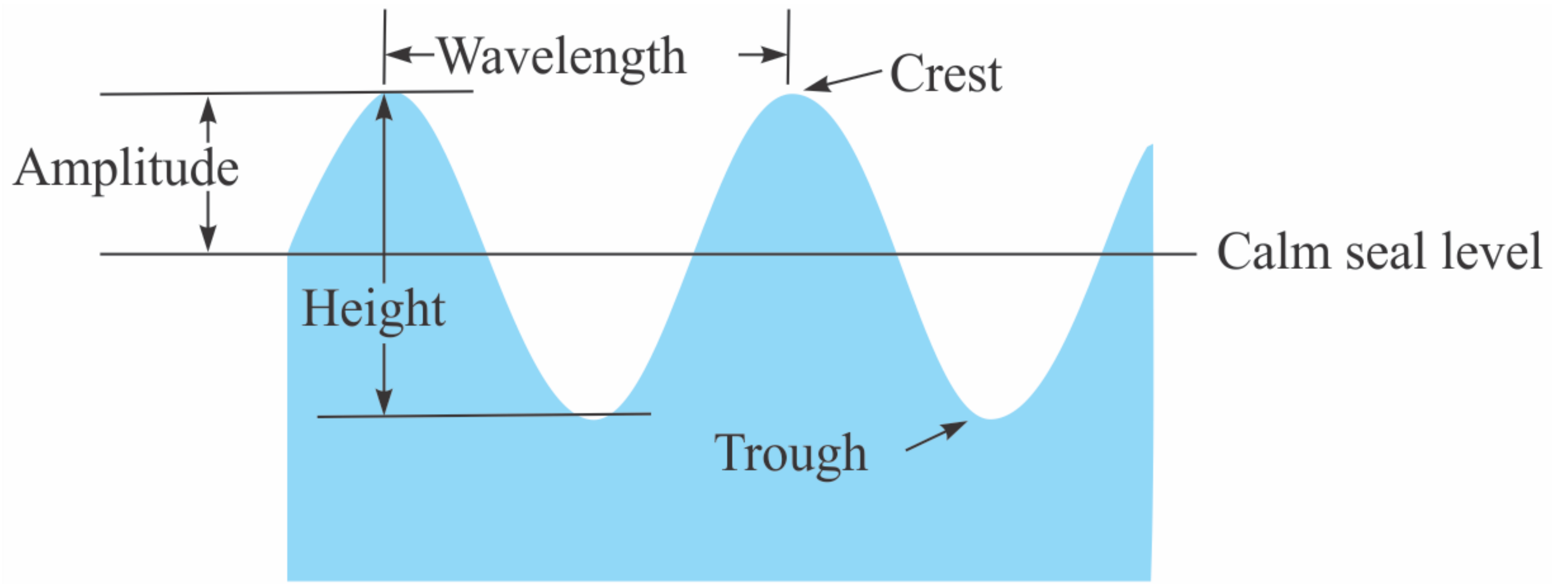
A crossflow turbine is another form of tidal stream generator with the advantage of moving in the same direction regardless of the direction of the tidal currents. The generator (in center) can generate power from incoming (flood) or outgoing (ebb) tides.



Courtesy of Ocean Renewable Energy

11-5 Wave Power Generation

Water waves are created by wind moving across large stretches of water, creating waves that are a combination of transverse and longitudinal so individual waves move in an elliptical pattern. some definitions for waves are:

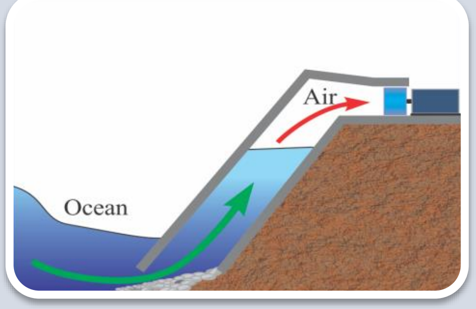


11-5 Wave Power Generation

Energy converters are classified into three basic types.

Source: NREL

Source:Pelamis Wave Power Ltd.



Point absorbers that have an upper and lower section that move relative to each other.

Attenuators that have relative motion between large floating sections.

Terminating devices that can trap the up and down motion to generate winds in a tube.

Selected Key Terms

Attenuator	With respect to wave energy devices, it is a device that extracts energy from wave power by converting relative motion between large semi-submerged cylindrical sections to electricity.
Francis turbine	A reaction type water turbine that directs water from the outer circumference towards the center of a runner. Water flows through a scroll case which is a curved tube that diminishes in size with a shape similar to a snail shell.
Impulse turbine	A rotary engine that changes the direction of a high velocity fluid, thus converting kinetic energy into mechanical rotating energy.
Kaplan turbine	A reaction type water turbine that uses propellers with adjustable blades. The turbine is usually placed in a spiral casing called a volute.

Selected Key Terms

Oscillating water column	A fixed device for producing electrical power from waves. It consists of a large tube that extends over a cliff and into the ocean. Wave action causes water to rise in the tube and displace air, which rotates a wind turbine.
Pelton turbine	An impulse turbine in which water moves under it (impulse) rather than water falling over it. It is among the most efficient types of water turbines.
Point absorber	A floating wave energy converter that is in a fixed in position. It bobs up and down from wave motion. The motion with respect to a fixed reference is captured and the energy converted to electricity.
Reaction turbine	A rotary engine that develops torque by reacting to the pressure of a fluid moving through the turbine, thus primarily converting potential energy into mechanical rotating energy.

Selected Key Terms

Run-of-the-river (ROR)	A hydroelectric system that uses river flow to generate electricity. The system may include a small dam with storage for water but many do not.
Tidal barrage system	A system designed to convert tidal power into electricity by trapping water behind a dam, called a tidal barrage dam, and generating power from the inflow and/or the release of water.
Tidal stream generator (TSG)	An electrical generating system that uses a water turbine to turn a generator and produce electrical power when a stream of water caused by tides or a river flow past it.

true/false quiz

1. In the equation, $P = \gamma Q_v h_{eq}$, the γ stands for the volumetric flow rate.

true/false quiz

2. The potential energy in water behind a dam is converted to kinetic energy to spin a turbine and generator.

true/false quiz

3. Run-of-the-River systems primarily use the kinetic energy in flowing rivers to generate electricity.

true/false quiz

4. Impulse turbines are primarily used in applications with low heads and relatively high flow rates.

true/false quiz

5. The turbine pictured here is a Kaplan turbine.

true/false quiz

6. A cross-flow turbine can work in low head hydro plants or in tidal streams.

PEARSON

true/false quiz

7. The tides are primarily caused by the gravitational pull of the sun on the earth.

8. A barrage dam is used to trap tidal waters and use the flow to generate electricity.

true/false quiz

9. The vertical distance from the trough of a wave to the crest is called the amplitude.

true/false quiz

10. One type of wave energy converter is called an attenuator.

true/false quiz

Answers:

1. F
2. T
3. T
4. F
5. F
6. T
7. F
8. T
9. F
10. T