Section Three: Hydropower (Water Energy)

What is Hydroelectric Energy?

Hydroelectricity is a form of renewable energy that generates electricity by using moving water. Instead of burning fuel, it converts the natural motion of water into electrical power.

Key idea:

- Water at height has potential energy.
- As it flows downward, this becomes kinetic energy.
- Turbines convert this motion into electricity.

Hydropower is considered renewable because the water cycle continually replenishes rivers and reservoirs.

Benefits:

- Highly efficient (often above 85%).
- Reliable and controllable output.

Where Does Hydroelectric Power Come From?

Hydroelectric generation relies on locations where water is moving or can be controlled.

Main sources of moving water

- Waterfalls (e.g., Niagara Falls)
- Flowing rivers
- Reservoirs behind dams

Example:

- Niagara Falls produces millions of kilowatts of electricity — enough to power millions of homes

In the UK:

- Hydropower contributes a small but important part of electricity generation capacity.

Types of Hydroelectric Applications

1. Reservoir (Dam-Based) Hydropower


How it works

- Water is stored behind a dam at height.
- Controlled release spins turbines.

Key physics

- Uses gravitational potential energy:

$$P = \rho g h Q$$

The equation is used to calculate the maximum theoretical power available from flowing water in a hydroelectric system.
It shows how much energy per second (power) can be produced from water falling through a height.

Where:

Symbol	Meaning	Units
P	Power produced	Watts (W)
ρ (rho)	Density of water	kg/m³
g	Acceleration due to gravity	m/s²
h	Height difference (head)	m
Q	Water flow rate	m³/s

1 Density of Water (ρ)

Density tells us how much mass of water exists in a given volume.
For fresh water:

$$\rho \approx 1000\ kg/m^3$$

This means:
1 cubic metre of water = **1000 kg**
More mass flowing through the turbine means **more energy available**.

2 Gravitational Acceleration (g)

$$g \approx 9.81\ m/s^2$$

This represents the strength of Earth's gravitational field.
Gravity is what causes water stored at height to fall and produce energy.

3 Head Height (h)

Head is the vertical distance between:

- the water surface in the reservoir
- the turbine location

The higher the water falls, the more gravitational potential energy it has.
This energy comes from:

$$E = mgh$$

🚰 **Flow Rate (Q)**

Flow rate measures how much water passes through the turbine every second.

Units:

$$m^3/s$$

Example:

- Q = 50 m³/s means 50 cubic metres of water flow each second.

More water flowing = more energy transferred.

📊 **Example Calculation**

Suppose:

- Head height $h = 50\,m$
- Flow rate $Q = 20\,m^3/s$
- Density $\rho = 1000\,kg/m^3$

Then

$$P = 1000 \times 9.81 \times 50 \times 20$$
$$P = 9{,}810{,}000\,W$$
$$P \approx 9.8\,MW$$

So the plant could produce **about 9.8 megawatts of power (theoretical)**.

⚠️ **Real Hydroelectric Plants Are Less Efficient**

The equation assumes **100% efficiency**, but real systems lose energy due to:

- turbine friction
- generator losses
- turbulence
- pipe resistance

🧠 **Key Insight**

The equation shows two main ways to increase hydropower:

Increase the height *h*

Tall dams produce more power.

Increase the flow rate *Q*

More water passing through the turbine increases power.

Advantages

✅ Reliable and controllable output

✅ Can meet peak electricity demand

Limitations

❌ Expensive construction

❌ Environmental impacts from flooding

2. Run-of-River Hydropower

How it works

- Uses natural river flow.
- Minimal water storage.

Physics idea

- Lower head height → depends more on flow rate than height.

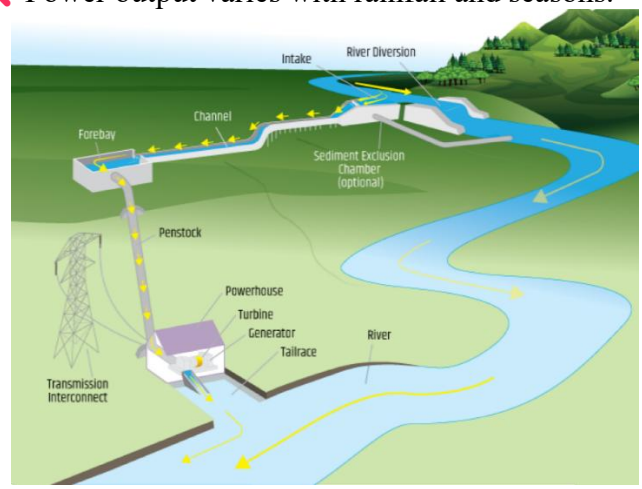
Advantages

✅ Smaller environmental impact

✅ Lower cost than large dams

Limitations

❌ Power output varies with rainfall and seasons.



3. Pumped Storage Hydropower

How it works

- wo reservoirs at different heights.
- Excess electricity pumps water uphill.
- Water released later to generate electricity

Important note

👉 This is mainly energy storage, not a primary energy source.

4. Tidal Hydropower (Often grouped with hydro)

Types

- Tidal barrage — dam across estuary.
- Tidal stream — underwater turbines.

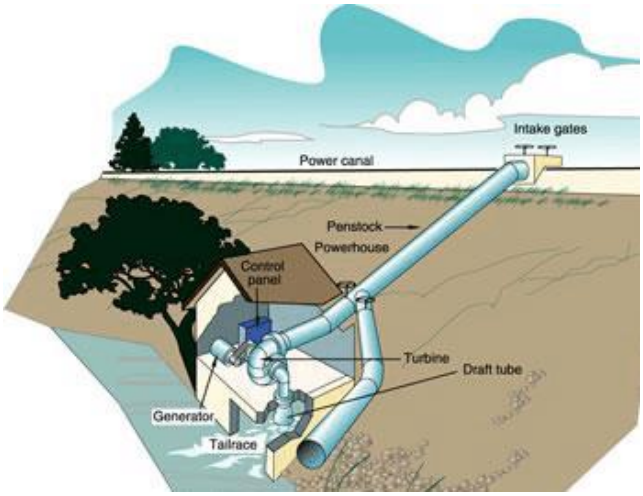
Physics source

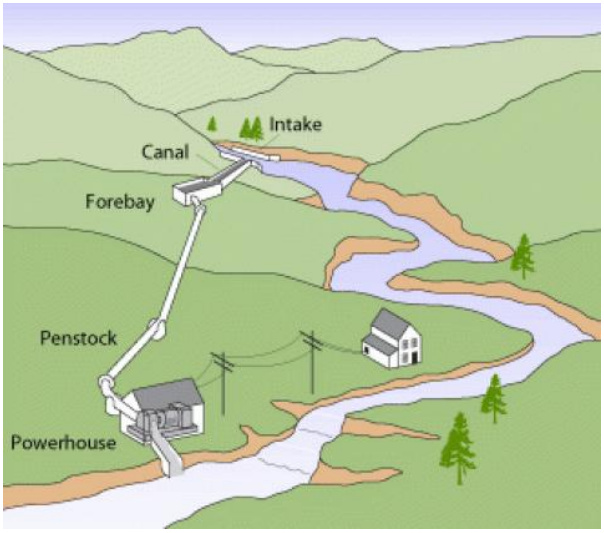
- Gravitational forces from Moon and Sun drive tides.

Advantages

✅ Extremely predictable energy source.

5. Micro and Pico Hydropower





Scale

- Micro hydro: up to ~100 kW
- Pico hydro: under 5 kW

Applications

- Remote homes
- Off-grid communities
- Sustainable small-scale projects

Quick Comparison Table

Type	Storage	Power Size	Main Use
Reservoir Dam	Large	Very large	Base & peak power
Run-of-River	Minimal	Small–medium	Continuous local generation
Pumped Storage	Two reservoirs	Very large	Energy storage/grid stability
Tidal	Natural tides	Medium–large	Predictable renewable
Micro/Pico Hydro	Minimal	Small	Off-grid supply

Advantages of Hydroelectric Power:

🌱 Renewable Energy Source

- Uses natural water flow.
- No fuel is burned.

🌍 Clean Energy

- Produces no carbon dioxide emissions during operation

💷 Low Running Costs

- Once built, maintenance costs are relatively low.
- Cost is about £50,000 annually for a 500kW plant

⚡ Reliable & Flexible

- Output can be increased quickly by releasing more water.
- Useful for meeting peak electricity demand.

🛡️ Safe Technology

- Long lifespan.
- Mature engineering methods.

Limitations and Disadvantages of Hydroelectric Power

💰 High Initial Construction Cost

- Dams and power stations require huge investment.
- Example: Niagara Power Plant construction cost around US$800 million (1957)

🌿 Environmental Impacts

Possible issues include:

- Flooding habitats and farmland.
- Affecting fish migration.
- Changes to river ecosystems.

📍 Limited Suitable Locations

- Requires:
    - Reliable rainfall
    - Suitable terrain
    - Large reservoirs

  Example: The UK has a limited number of reservoirs (around 273 mentioned in your lesson)

🌧️ Dependence on Weather and Hydrology

- Drought or reduced rainfall lowers power output.

Key Facts to Remember :

Hydroelectric energy = electricity from moving water.

- Energy changes:
  Potential → Kinetic → Mechanical → Electrical.
- Advantages:
  - Renewable
  - Clean
  - Reliable
  - Low operating cost
- Disadvantages:
  - Expensive to build
  - Environmental effects
  - Limited locations