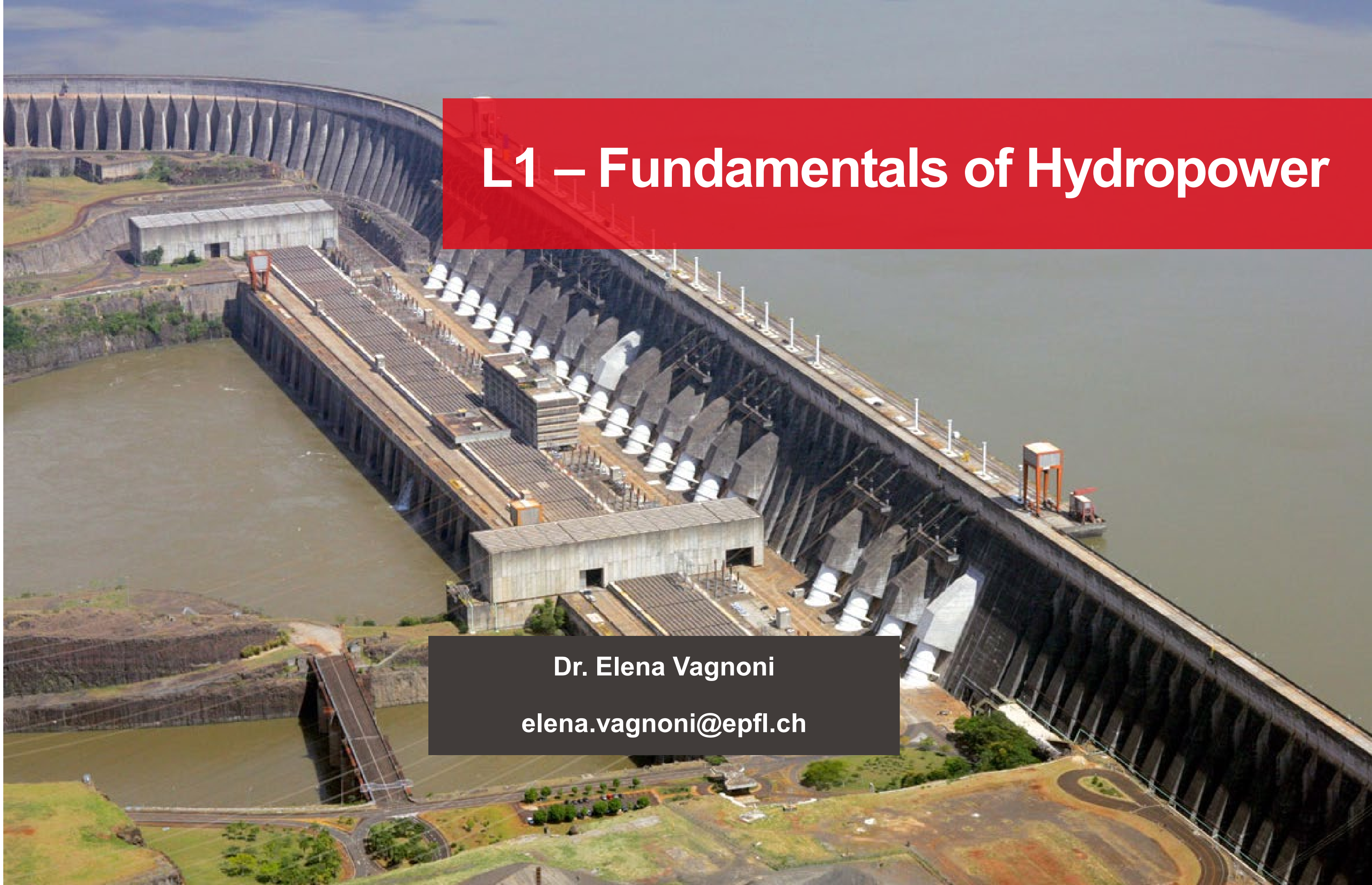

L1 – Fundamentals of Hydropower

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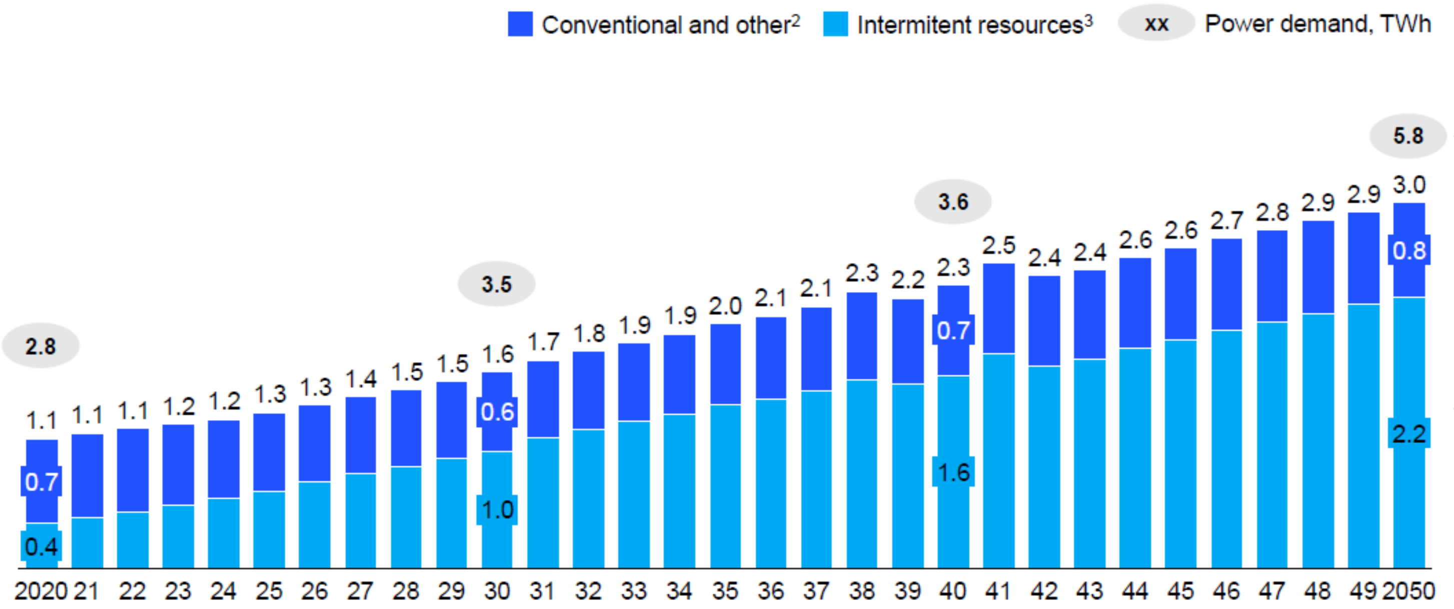
Topics of the lecture

- Hydropower statistics
- Types of hydropower plants
- Specific hydraulic energy

Hydropower Statistics

Wholesale decarbonisation of electricity is happening: paradigm changes in the power system

European power installed capacity[1],
TW



2x

Increase of electricity demand by 2050 (vs. 2020)

5x

Increase of intermittent generation capacity by 2050 (vs. 2020)

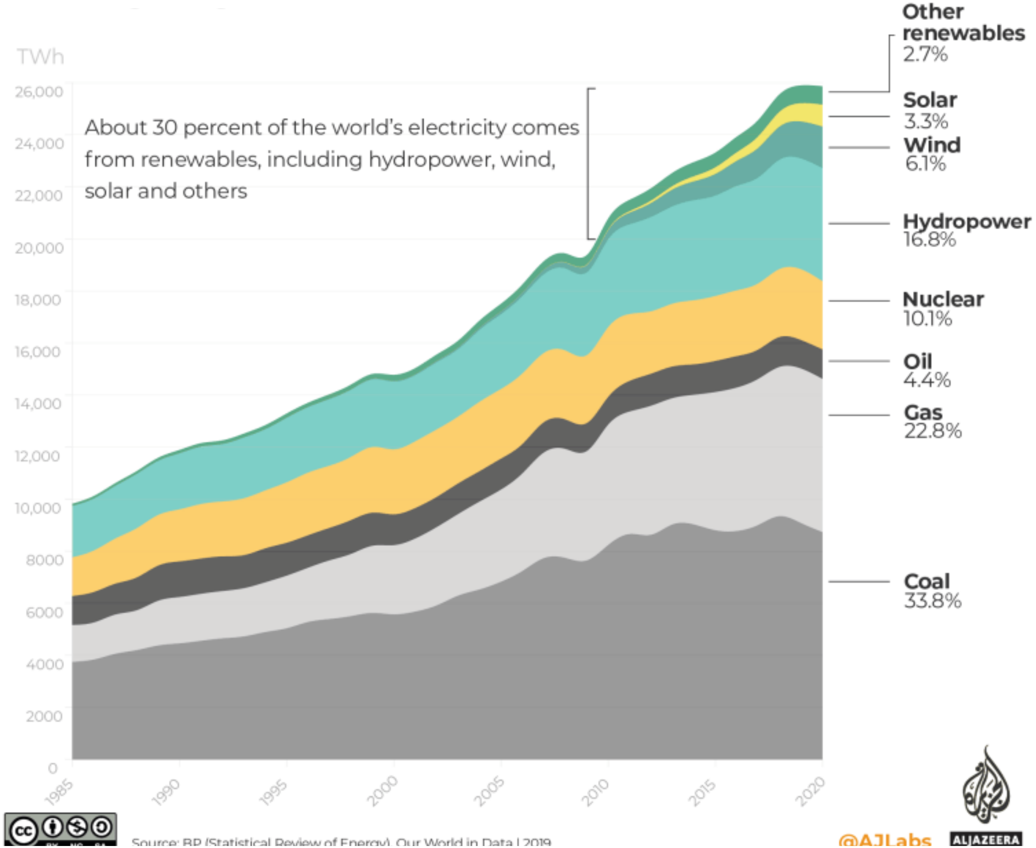
1. EU27+UK, 2022 Current Trajectory scenario
2. Gas, nuclear, oil, coal, biomass, hydrogen, geothermal, storage
3. Solar PV, CSP, wind onshore and offshore

Endorsement of flexibility and reliability from dispatchable energy sources is necessary

Hydropower Statistics

Global electricity production

- About 60% from fossil fuels
- About 17% from hydropower

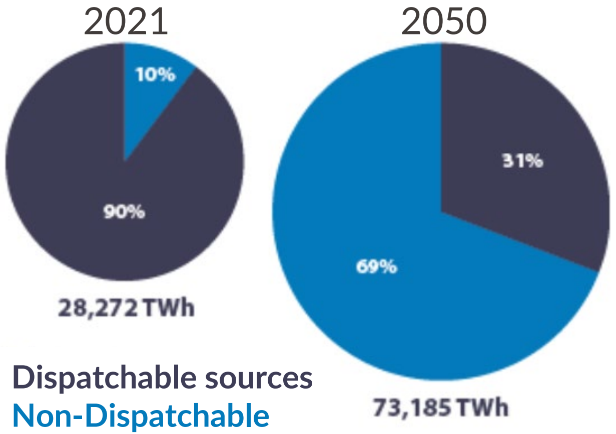


Hydropower Statistics

Global electricity production

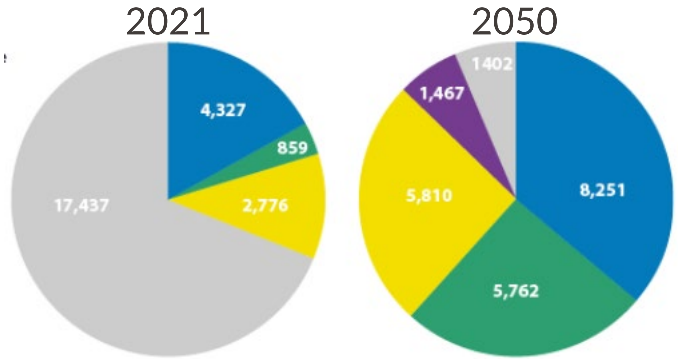
IEA Net zero projections

Share of global electricity production (TWh)



Dispatchable sources
Non-Dispatchable sources

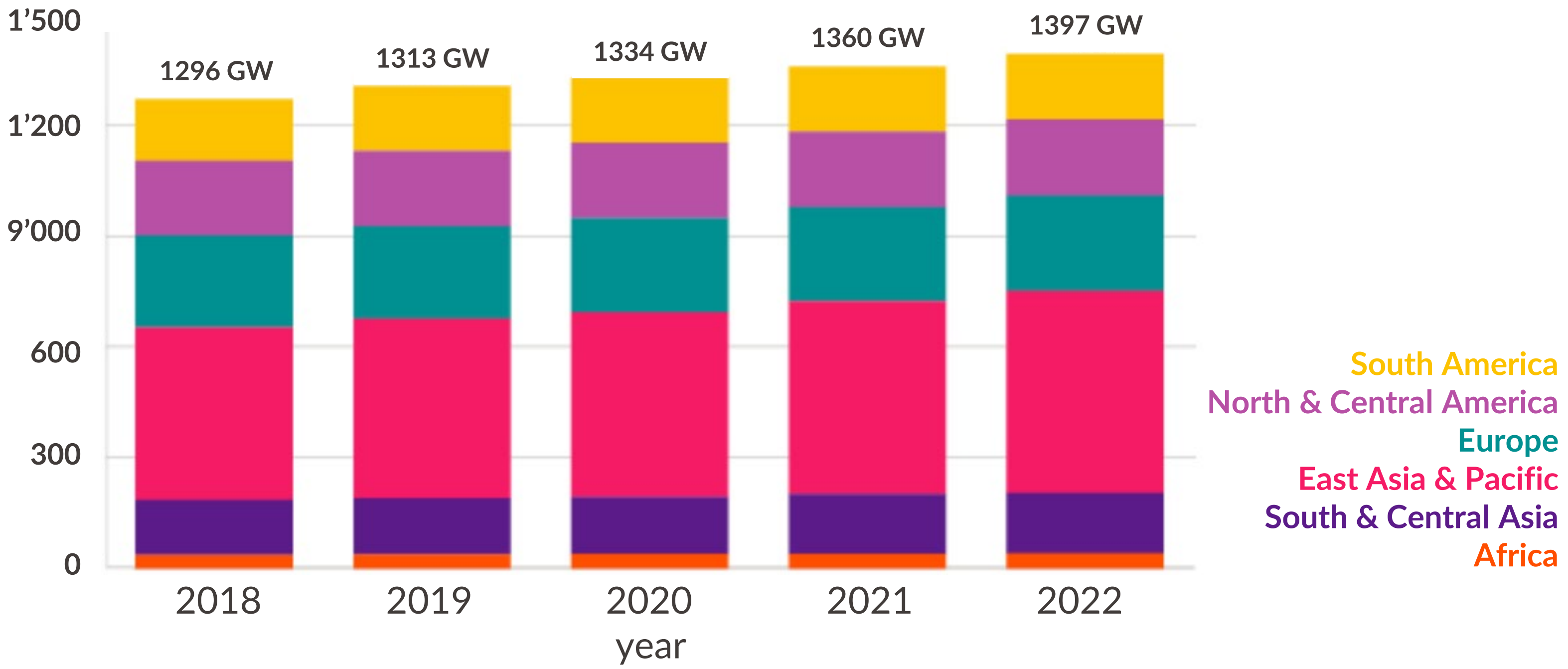
Dispatchable sources



Hydropower
Hydrogen
Other dispatchable renewables
Combustion plant
Nuclear

Hydropower Statistics

Hydropower global installed power capacity (GW)



Hydropower Statistics

Hydropower plants in the pipeline – 2023 statistics

Current global pipeline: 598 GW of new hydropower projects.

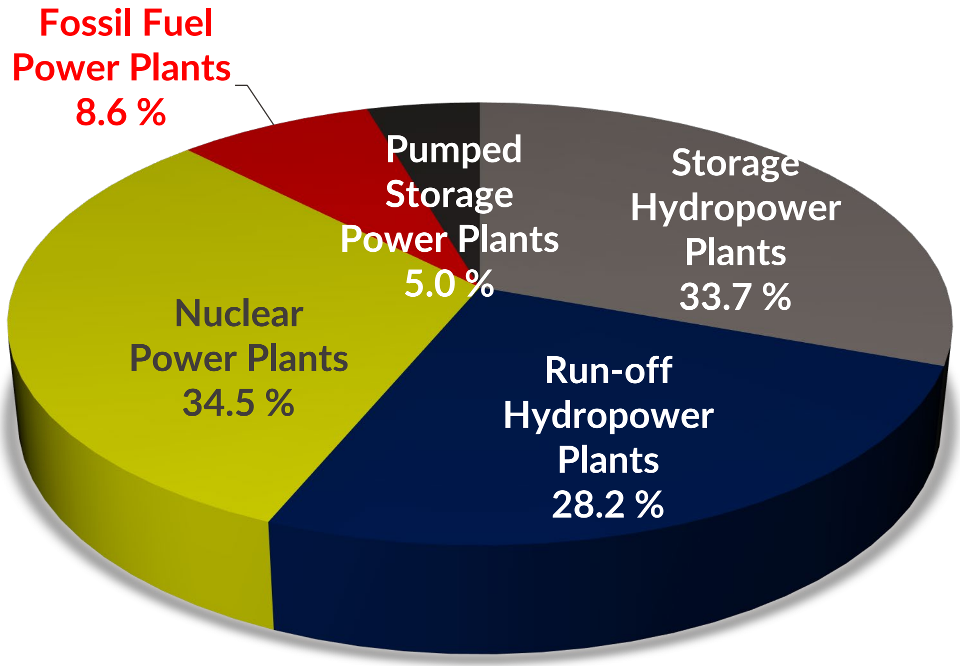
- **131 GW (22%) are under construction and 163 GW (27%) are regulator approved:** projects that have reached construction phase or that have received approvals from the local authorities and are waiting to start construction.
→ If these were all completed over the next 10 years, it would imply an average growth rate in the sector of ~30 GW per annum, which is not enough to be on-track with the net zero pathways.
- **197 GW are pending regulator approval**: this includes stations that have conducted feasibility studies and have submitted documentation to be approved by energy regulators.
- **107 GW are announced**: proposed stations at the earliest stage of development.

Types of Hydropower Plants

There are **four main types** of hydropower plants:

- **Storage hydropower**: typically a large system that uses a dam to store water in a reservoir.
- **Pumped storage hydropower**: similar to storage hydropower but with pumping capability.
- **Run-of-river hydropower**: a facility that channels flowing water from a river through a canal or penstock to spin a turbine (little or no storage facility).
- **Offshore hydropower**: a less established but growing group of technologies that use tidal currents or the power of waves to generate electricity from seawater.

Power capacity statistics in Switzerland



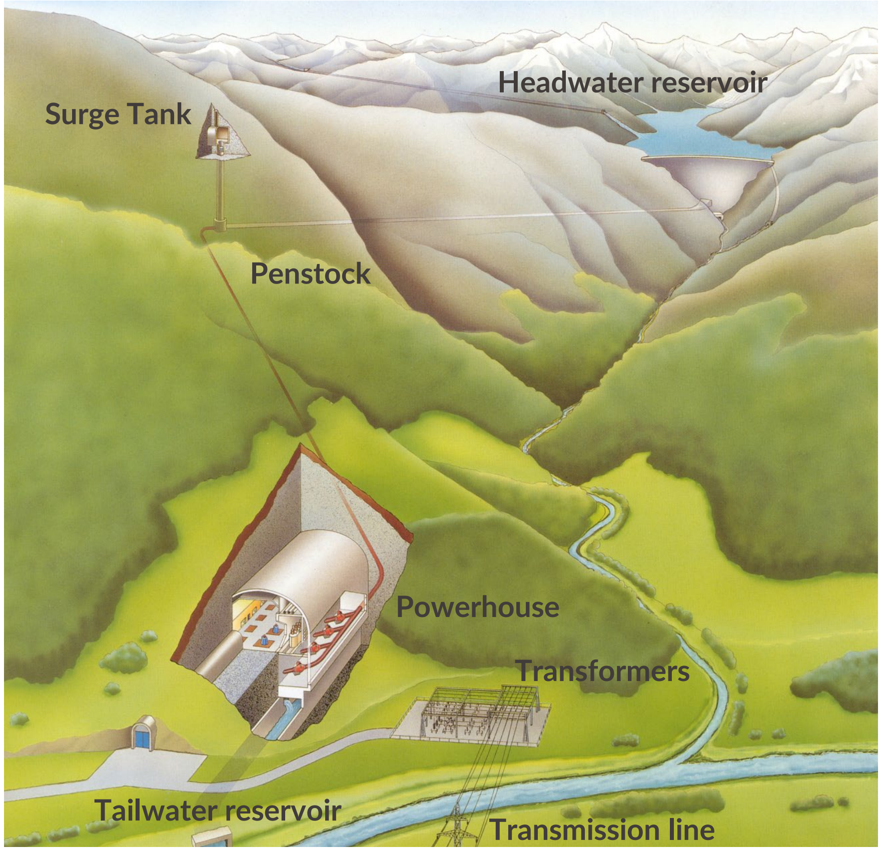
Types of Hydropower Plants

Storage Hydropower Plants

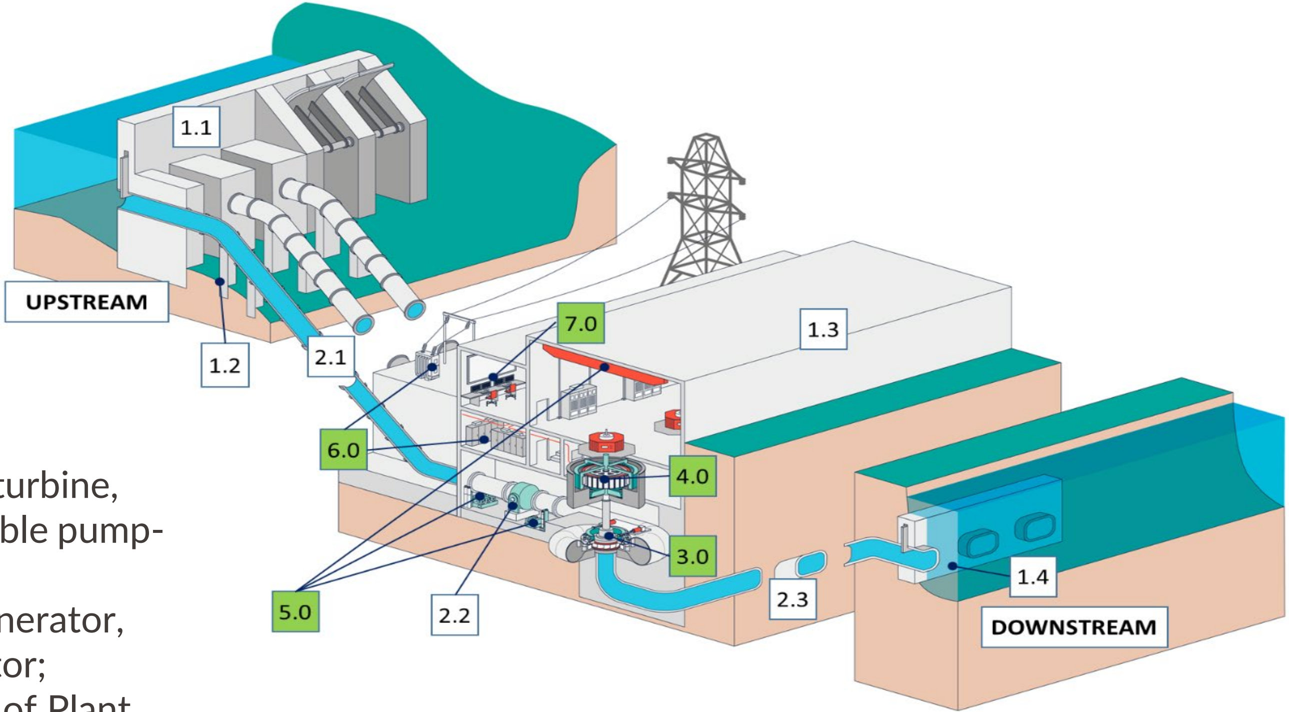
Electricity is produced by releasing water from the reservoir through a turbine, which activates a generator.

Storage hydropower provides base load as well as the ability to be shut down and started up at short notice according the demands of the system (peak load).

It can offer enough storage capacity to operate independently of the hydrological inflow for many weeks or even months.



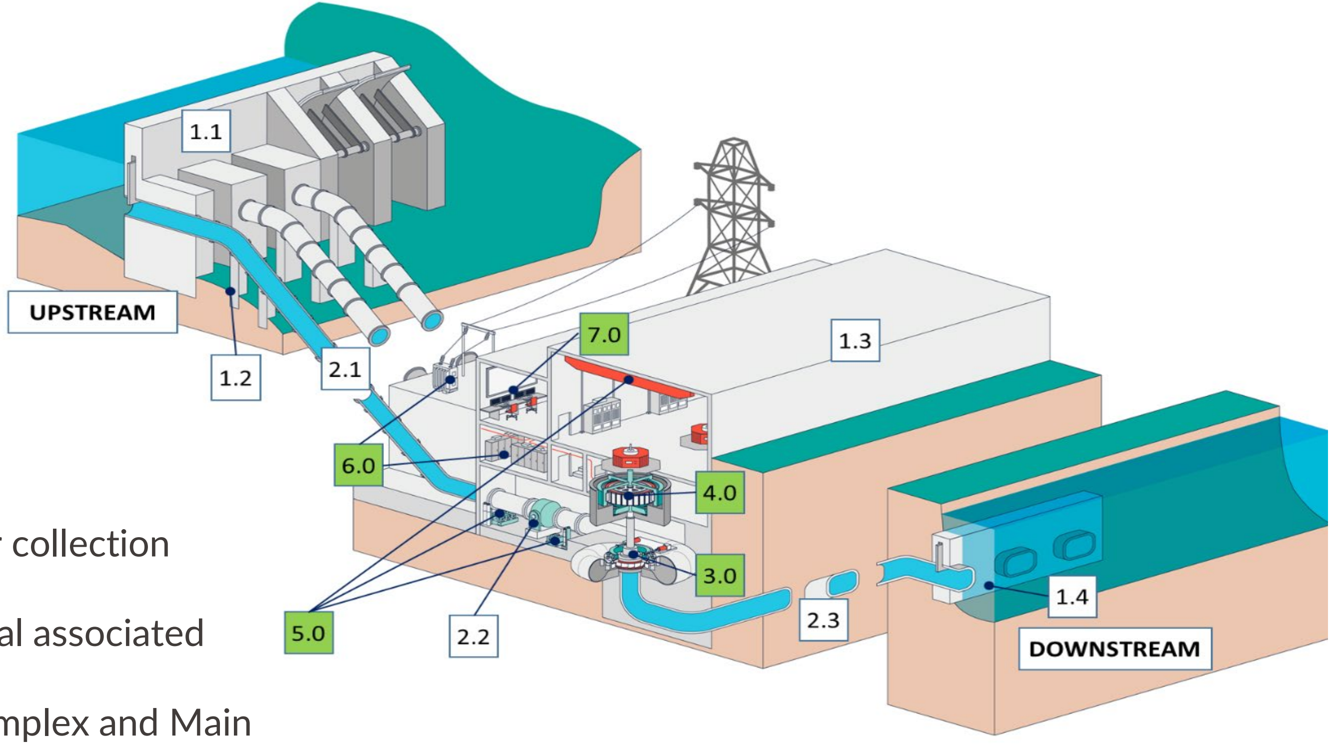
Overview of a storage hydropower plant



- 1.0 Water ways;
- 2.0 Hydromechanical;
- 3.0 Hydraulic machine, turbine, storage pump or reversible pump-turbine;
- 4.0 Electric machine, generator, motor or motor-generator;
- 5.0 Mechanical Balance of Plant (MBoP);
- 6.0 Electrical Balance of Plant (EBoP);
- 7.0 Control Systems.

XFLEX HYDRO project - IHA

Overview of a storage hydropower plant

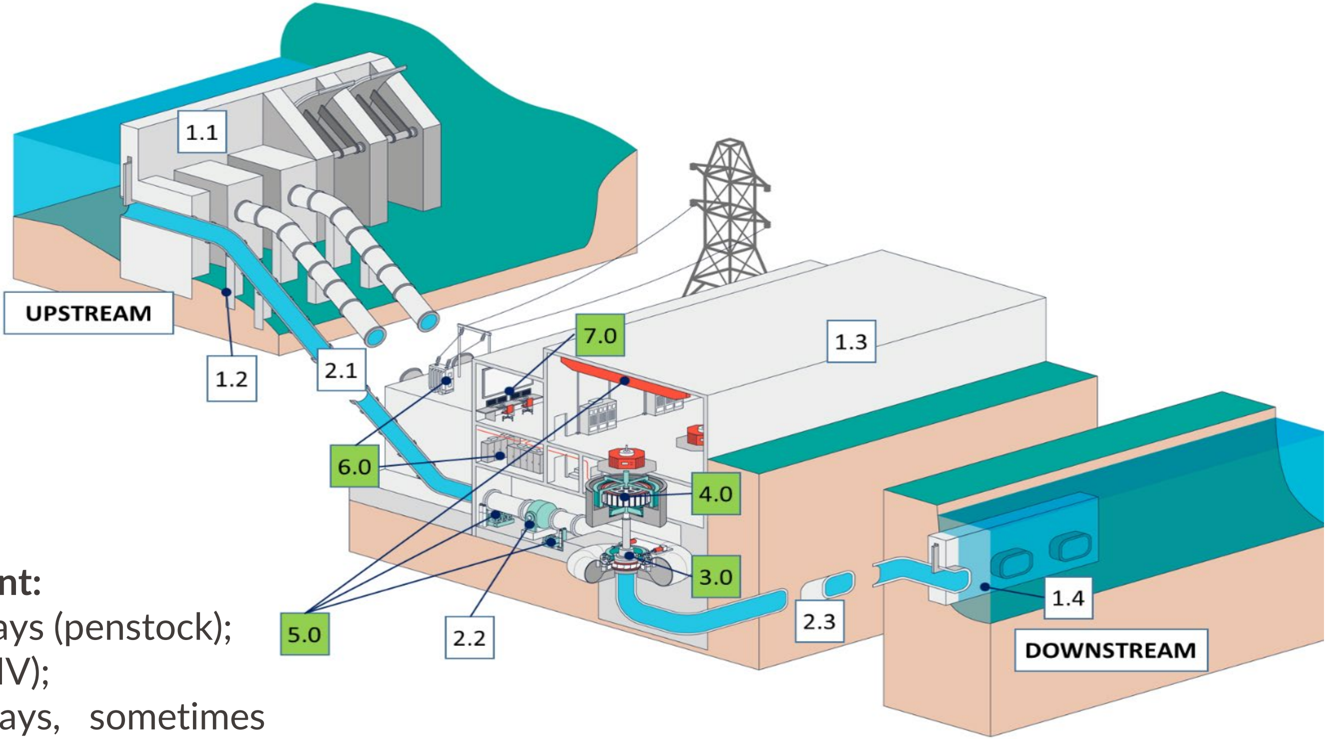


Water ways

- 1.1 Upstream water collection structures;
- 1.2 Hydromechanical associated works;
- 1.3 Powerhouse complex and Main structures/foundations;
- 1.4 Downstream water discharge structures.

Overview of a storage hydropower plant

Hydro mechanical equipment



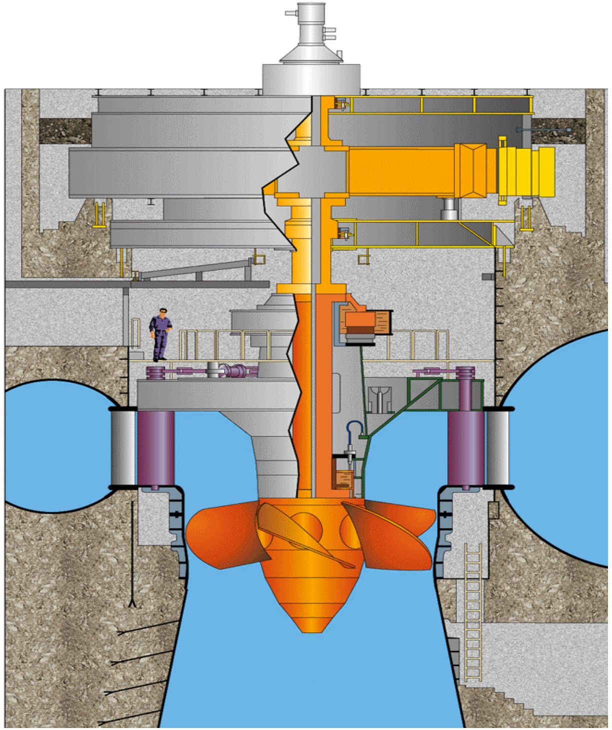
Hydro Mechanical equipment:

- 2.1 Headwater waterways (penstock);
- 2.2 Main Inlet Valve (MIV);
- 2.3 Tailwater waterways, sometimes designated just as "Tailrace").

Overview of a storage hydropower plant

Power unit

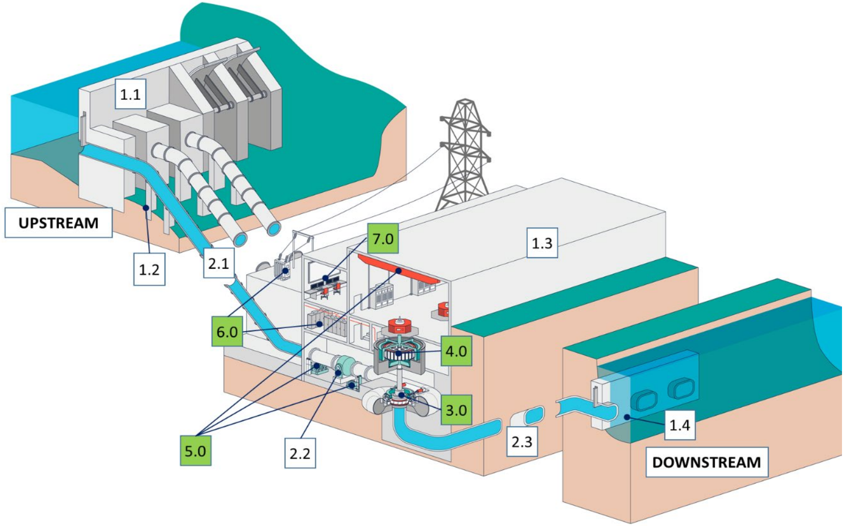
- Generator
  - Synchronous or Asynchronous machine
  - Excitation, Voltage Regulator
  - Cooling
  - Thrust Bearing
- Drive
  - Turbine
  - Speed Control (Governor)
  - Guide Bearings



Cachoeira Dourada,Br
115 MW - 34 m – 103 min-1

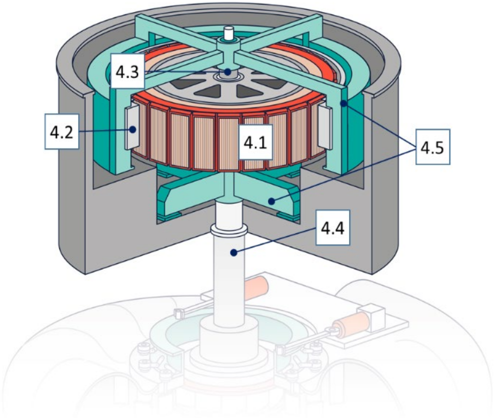
Overview of a storage hydropower plant

Power unit



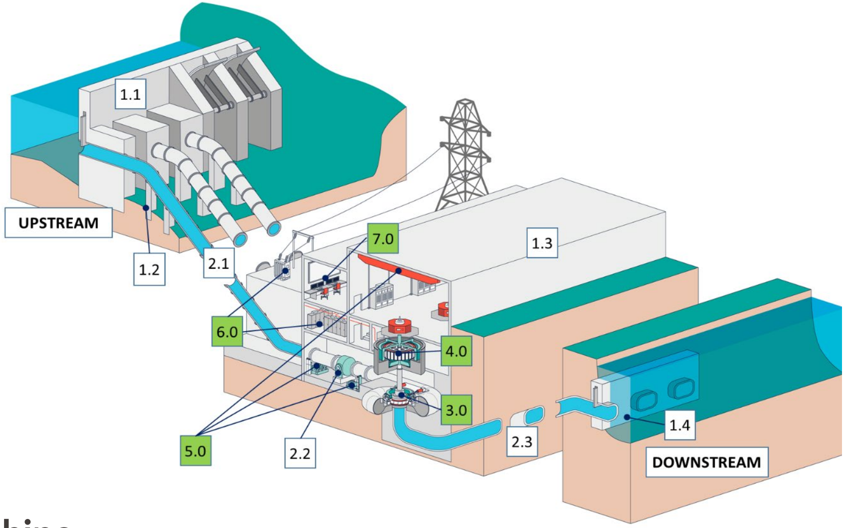
Electrical Machine

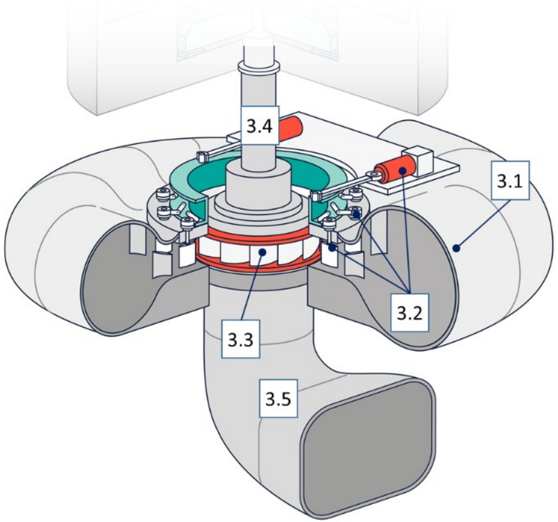
- 4.1 Rotor, the mobile part, coupled to the turbine through the shaft line;
- 4.2 Stator, the stationary part, surrounding the rotor and delivering or transmitting the electrical power in generating mode or in pumping mode;
- 4.3 DC excitation system;
- 4.4 Generator shaft line and bearings;
- 4.5 Brackets, upper and lower.



Overview of a storage hydropower plant

Power unit



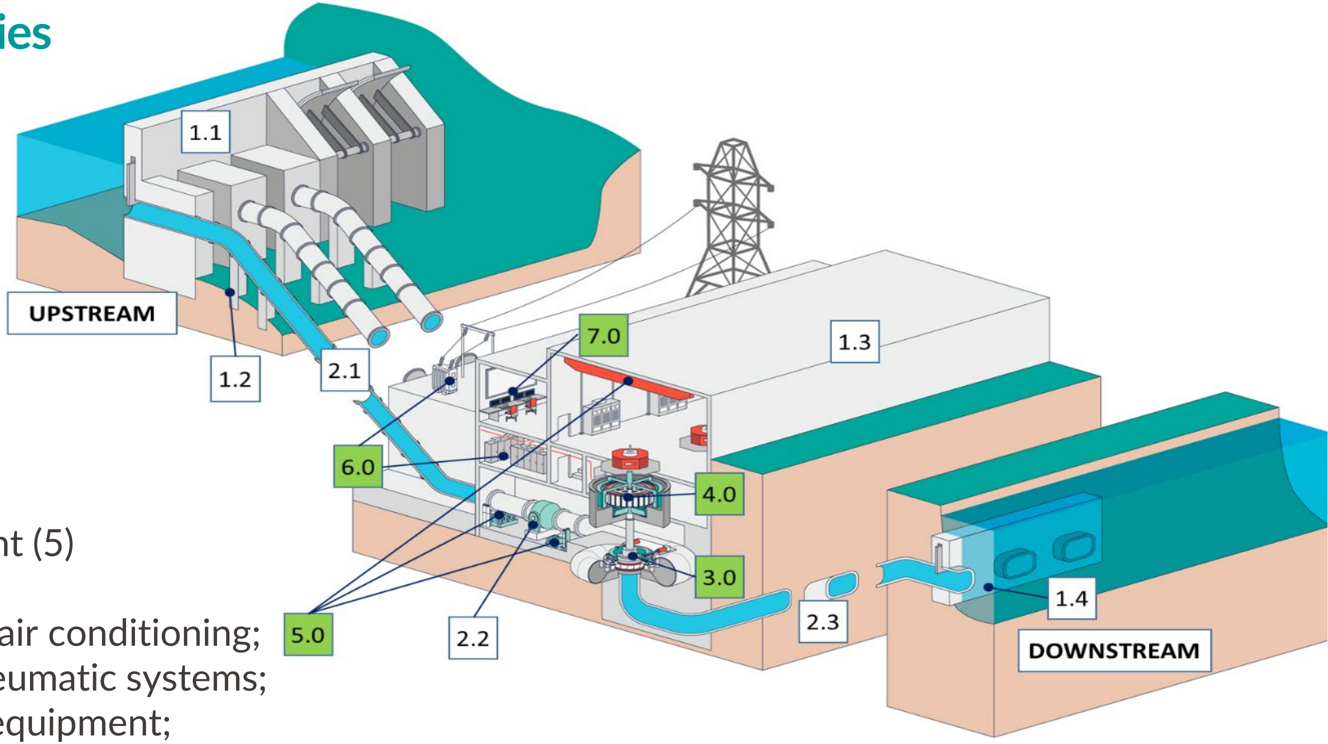


Hydraulic Machine

- 3.1 High-pressure case and pit liner;
- 3.2 Distributor;
- 3.3 Runner, Impeller;
- 3.4 Main shaft and bearings;
- 3.5 Draft tube.

Overview of a storage hydropower plant

Mechanical Auxiliaries

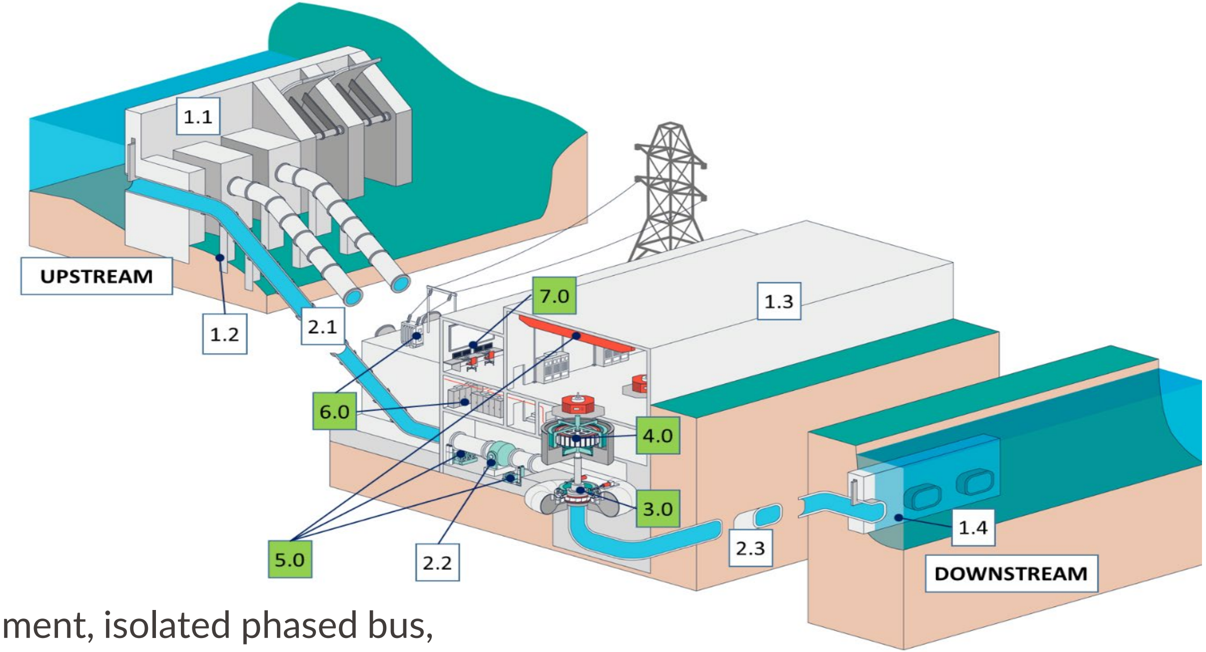


Mechanical Auxiliaries of Plant (5)

- Water cooling;
- Heat ventilation and air conditioning;
- Compressed air / pneumatic systems;
- Lifting and handling equipment;
- Lubrication and pressurized oil supply;
- Auxiliary systems including general powerhouse drainage, service and potable water, fire extinction systems.

Overview of a storage hydropower plant

Electrical Auxiliaries



Electrical Auxiliaries (6)

- High Voltage Equipment, isolated phased bus, switchyard, unit voltage transformers;
- Auxiliary Systems, power frequency converter, voltage source inverter type with control and backup.

Control System (7)

Example: Three Gorges Hydropower plant (China) is the largest hydropower project

- 14 + 12 Francis Turbines
- 700 MW Unit Max Power: 22.5 GW in total

→ Biggest hydropower plant in the world

- 110m Head

Example: Three Gorges Hydropower plant (China) is the largest hydropower project

- 14 + 12 Francis Turbines
- 700 MW Unit Max Power
- 110m Head

Spiral case →

Example: Three Gorges Hydropower plant (China) is the largest hydropower project

- 14 + 12 Francis Turbines
- 700 MW Unit Max Power
- 110m Head

Runner (inlet section)→

Example: Three Gorges Hydropower plant (China) is the largest hydropower project

- 14 + 12 Francis Turbines
- 700 MW Unit Max Power
- 110m Head

Runner (outlet section)→

Example: Three Gorges Hydropower plant (China) is the largest hydropower project

- 14 + 12 Francis Turbines
- 700 MW Unit Max Power
- 110m Head

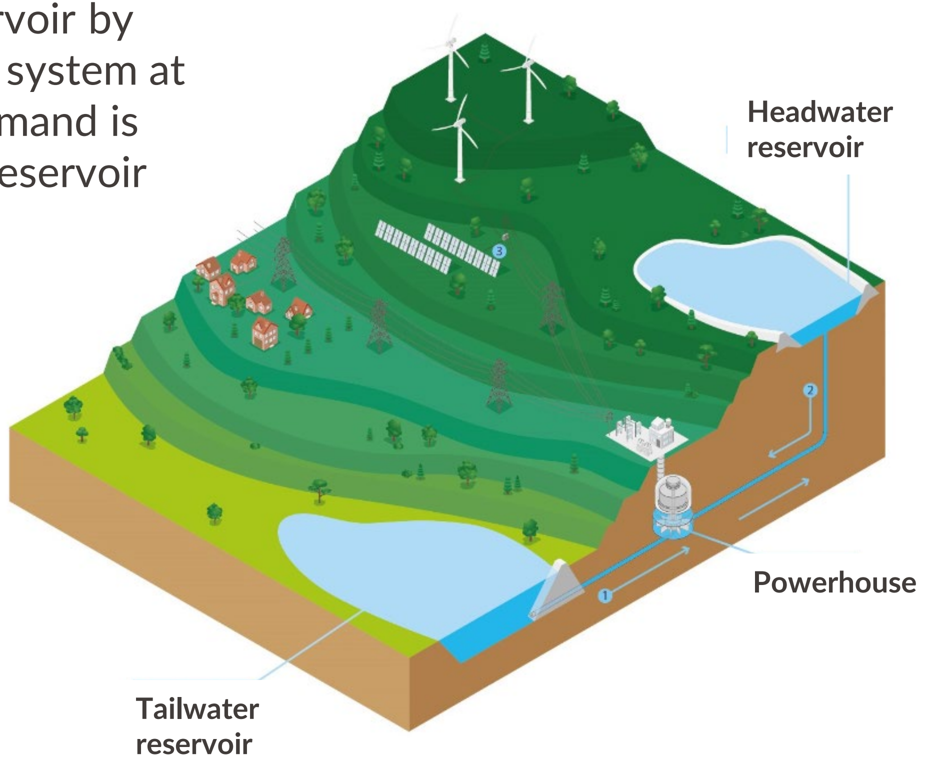
Draft tube cone →

Types of Hydropower Plants

Pumped-Storage Hydropower Plants

Provides peak-load supply, harnessing water which is cycled between a lower and upper reservoir by pumps which use surplus energy from the system at times of low demand. When electricity demand is high, water is released back to the lower reservoir through turbines to produce electricity.

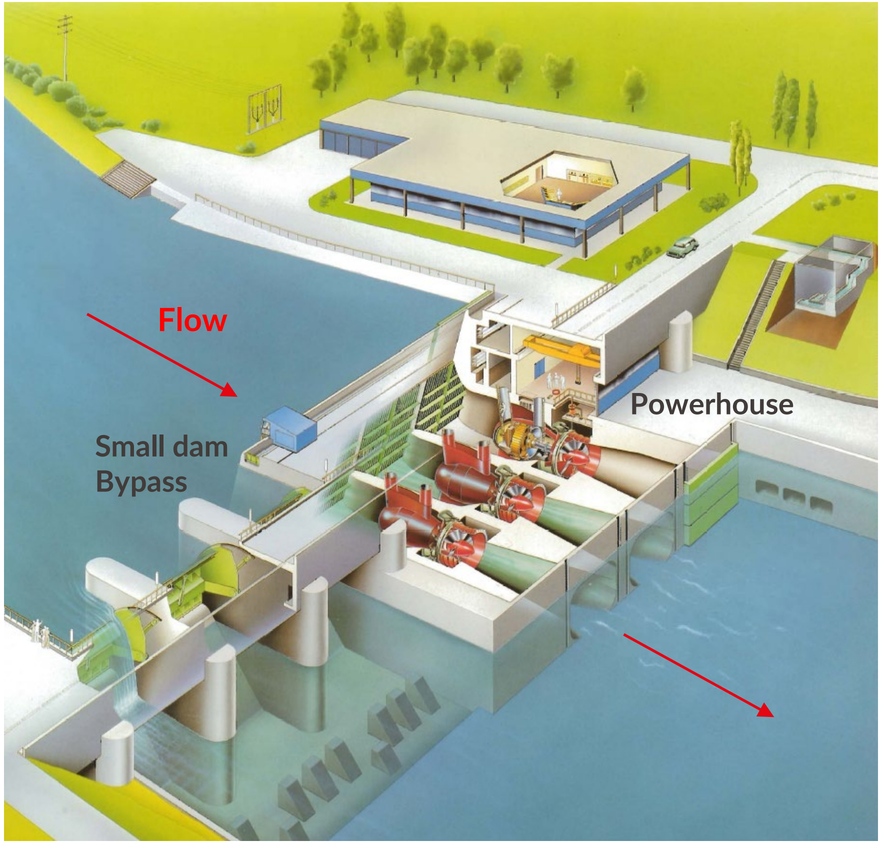
- **Open-loop:** with either an upper or lower reservoir that is continuously connected to a naturally flowing water source such as a river.
- **Closed-loop:** an 'off-river' site that produces power from water pumped to an upper reservoir without a significant natural inflow.



Types of Hydropower Plants

Run-of-River Hydropower Plants

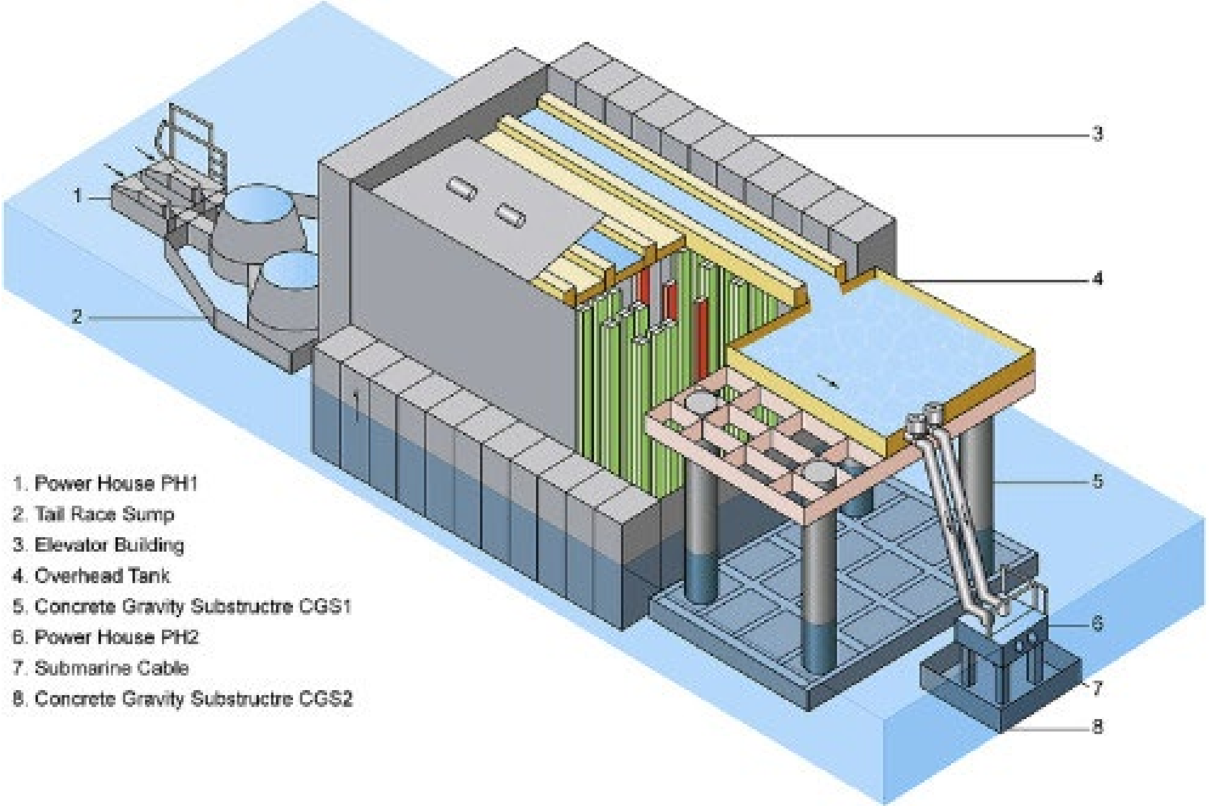
Run-of-river provides a continuous supply of electricity (base load), with some flexibility of operation for daily fluctuations in demand through water flow that is regulated by the facility.



Types of Hydropower Plants

Offshore Hydropower Plants

Offshore hydropower plant utilizes tidal currents and waves power to generate electricity from the ocean. It has enormous potential to a large amount to generate electricity, but still in the developing phase.

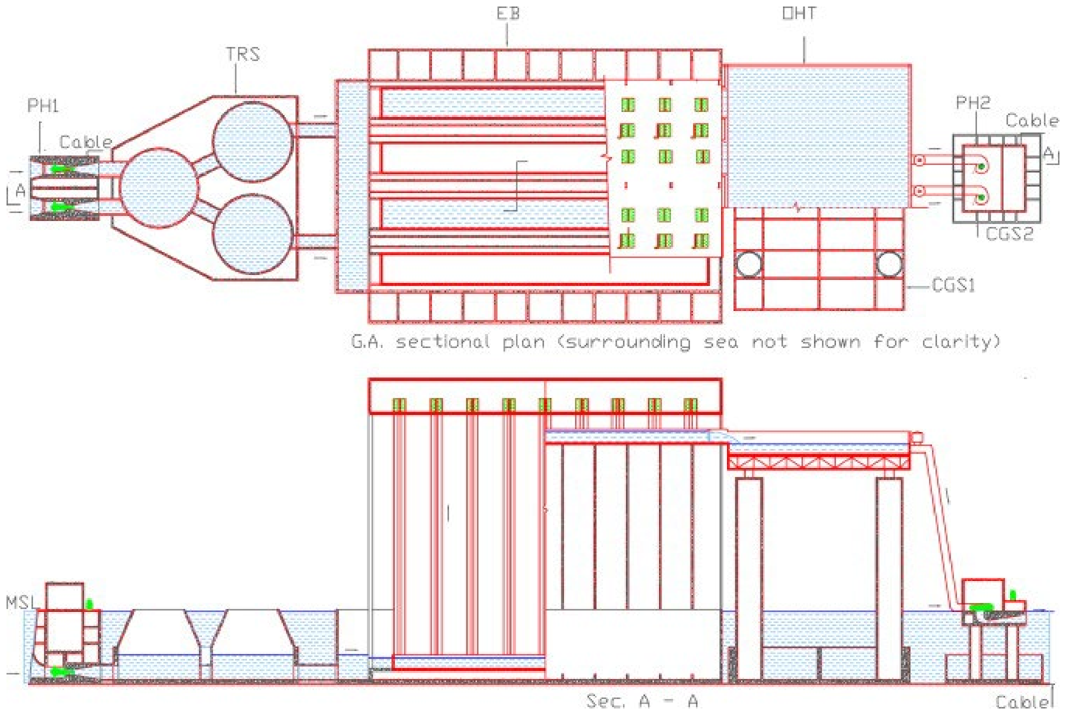


Types of Hydropower Plants

Offshore Hydropower Plants

WORKING PRINCIPLE:

1. Water is allowed to flow from the sea through the turbines located in PH1 to the TRS.
2. Water from TRS is continuously removed and power is generated when a sufficient head develops due to falling level in the sump.
3. Water from TRS flows into a pair of troughs located in an elevator building (EB) and transported vertically to an OHT, whilst another pair of empty troughs descend to base.
4. Water from OHT is led by penstocks to another set of turbines installed in PH2 located at sea level to produce more electricity, which is then transported to the grid.
5. This cycle is continuously repeated for maximum energy generation



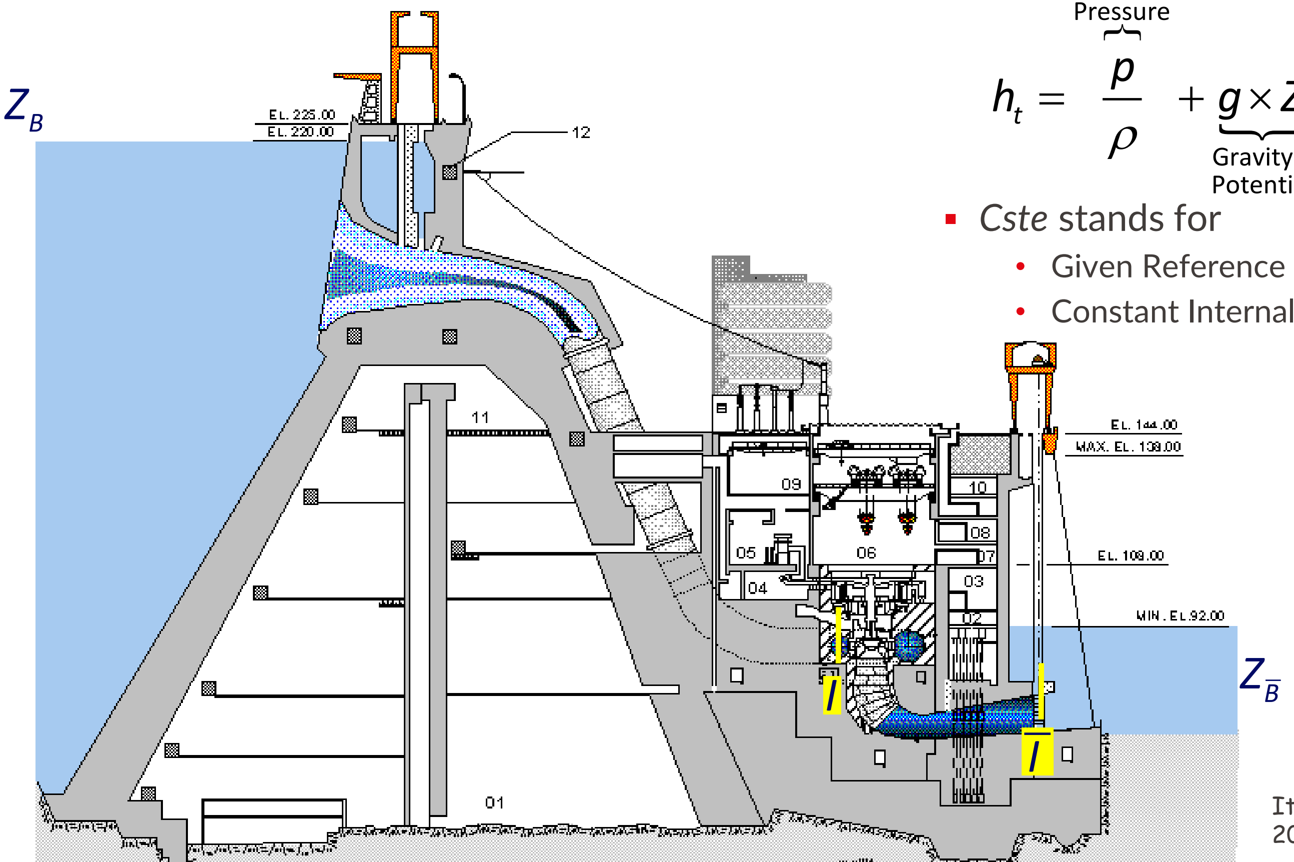
Specific Hydraulic Energy

Specific Energy Balance

- Local Mean Flow Specific Energy: Flow Property

$$h_t = \overbrace{\frac{p}{\rho}}^{\text{Pressure}} + \underbrace{g \times Z}_{\text{Gravity Potential}} + \frac{\overbrace{\vec{C}^2}^{\text{Kinetic}}}{2} + Cste \quad \left(\mathrm{J \cdot kg^{-1}}\right)$$

- *Cste* stands for
  - Given Reference Elevation Z_{ref} (e.g. Sea Level)
  - Constant Internal Specific Energy



Available Specific Hydraulic Energy

$$\boxed{\begin{aligned} E &\triangleq gH_I - gH_{\bar{I}} \\ &= g\left(Z_B - Z_{\bar{B}}\right) - \sum gH_r^T \end{aligned}}$$

Itaipú, Brazil/Paraguay
20 x 740 MW Francis

Specific Hydraulic Energy

Specific Energy Balance

- Headwater - High Energy Side $gH_B = \frac{p_{atm}}{\rho} + gZ_B + 0 = gH_I + \sum_{\text{Headwater Side}} gH_r$
- Low Energy Side - Tailwater Side $gH_{\bar{I}} = gH_{\bar{B}} + \sum_{\text{Tailwater Side}} gH_r$

$$gH_{\bar{B}} = \frac{p_{atm}}{\rho} + gZ_{\bar{B}} + 0$$

- Available Specific Energy for the Turbine

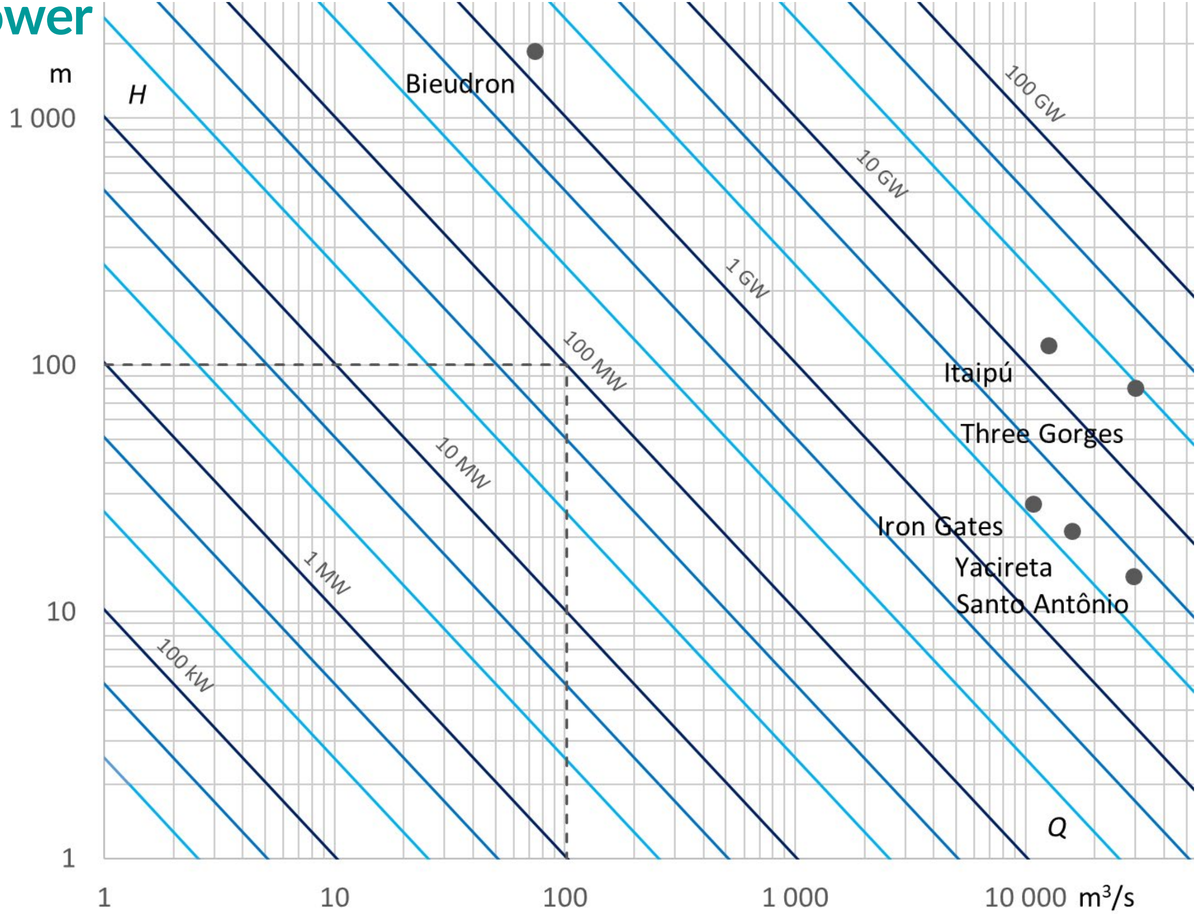
$$E = gH = gH_I - gH_{\bar{I}} = g \times \left(Z_B - Z_{\bar{B}}\right) - \sum gH_r$$

Head

Specific Hydraulic Energy

Available hydraulic power

$$\underbrace{P_h}_{\substack{\text{Hydraulic}\\ \text{Power}\\ (\mathrm{W})}} = \underbrace{\rho Q}_{\substack{\text{Mass}\\ \text{Flow}\\ (\mathrm{kg \cdot s^{-1}})}} \times \underbrace{gH}_{\substack{\text{Specific}\\ \text{Energy}\\ (\mathrm{J \cdot kg^{-1}})}}$$



Hydropower Plants Cassification

Classification		
By Types: - Storage - Pumped-storage - Run of river - Offshore	**By Head:** - High > 300 m - Medium 30 – 300 m - Low < 30 m	**Power Capacity:** - Large > 100 MW - Medium 25 – 100 MW - Small 1 – 25 MW - Mini 100kW – 1 MW - Micro < 100 kW

Example

Itaipu (Brasil) energy losses

- Compute the potential specific energy by knowing:

  $$Z_B = 220 \text{ m}; Z_{\overline{B}} = 99 \text{ m}$$

  $$g_{@\text{ Itaipu}} = 9.79 \text{ m} \cdot \text{s}^{-2}$$

- Assuming 2 % losses, compute available Specific Energy and the net Head

Example

Itaipu (Brasil) energy losses

- Potential specific energy: $g(Z_B - Z_{\overline{B}}) = 1'184.6 \text{ J}\cdot\text{kg}^{-1}$

  $Z_B = 220 \text{ m};\ Z_{\overline{B}} = 99 \text{ m}$

  $g_{@\text{ Itaipu}} = 9.79 \text{ m}\cdot\text{s}^{-2}$

- Assuming 2 % losses
  Available Specific Energy: $gH_I - gH_{\overline{I}} = \left(g\cdot(Z_B - Z_{\overline{B}})\right)\cdot\left(1-0.02\right) = 1'160.9 \text{ J}\cdot\text{kg}^{-1}$
  "Net Head": $H = 118.6 \text{ m}$

Many Thanks for your Kind Attention!