L1 – Hydraulic Machines Introduction and Fields of applications

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Topics of the lecture

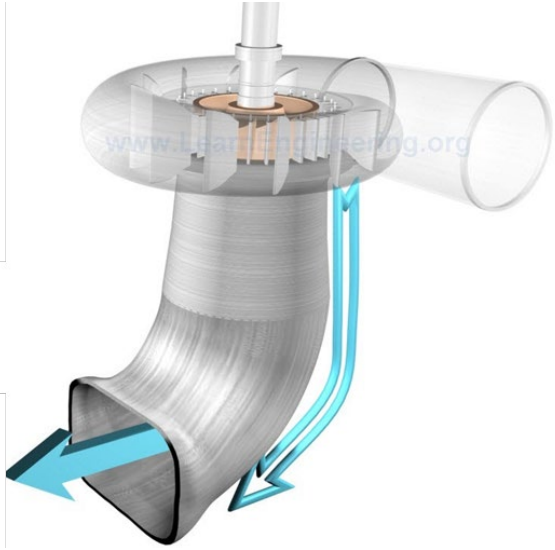
- Definitions
- Introduction to specific hydraulic energy
- Turbomachines Classification
- Fields of applications
  - Hydropower plants
  - Industrial Pumps Applications

Turbomachines definition

- Turbomachines are machines including stator and rotor elements that transfer energy between a rotor and a fluid.
- Energy transfer consists in the conversion between hydraulic energy and mechanical work

Remember! Mass and energy transfer are evaluated through:

- Mass balance equation
- First thermodynamic principle
- Second thermodynamic principle



Turbomachines definition

TURBOMACHINES

ROTOR

BLADES + CROWN + SHROUD

STATOR

DIFFUSER

VOLUTE with or without VANES

Turbomachines definition

ROTOR:

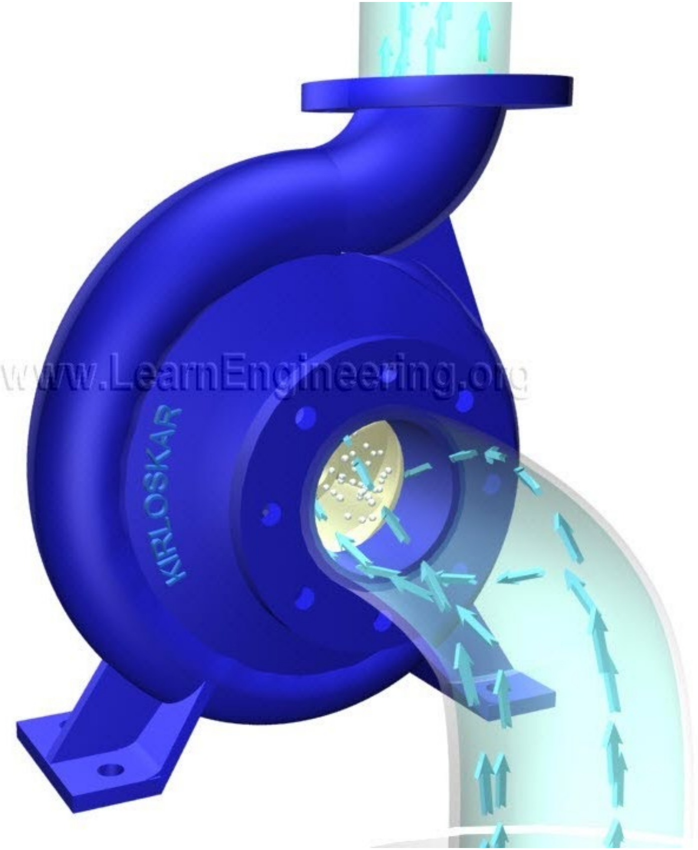
- it varies the momentum of the fluid → it varies the static and kinetic energy of the fluid
- In pumping mode, it transforms mechanical energy into fluid energy, while in generating mode, it converts fluid energy into mechanical energy available to the shaft.

DIFFUSER:

- Transforms the energy of the fluid
- In generating mode, it collects the fluid that comes out of the rotor and conveys it to the delivery pipe, converting kinetic energy into pressure energy
- In pumping mode, it directs the fluid towards the impeller, transforming its pressure energy into kinetic energy

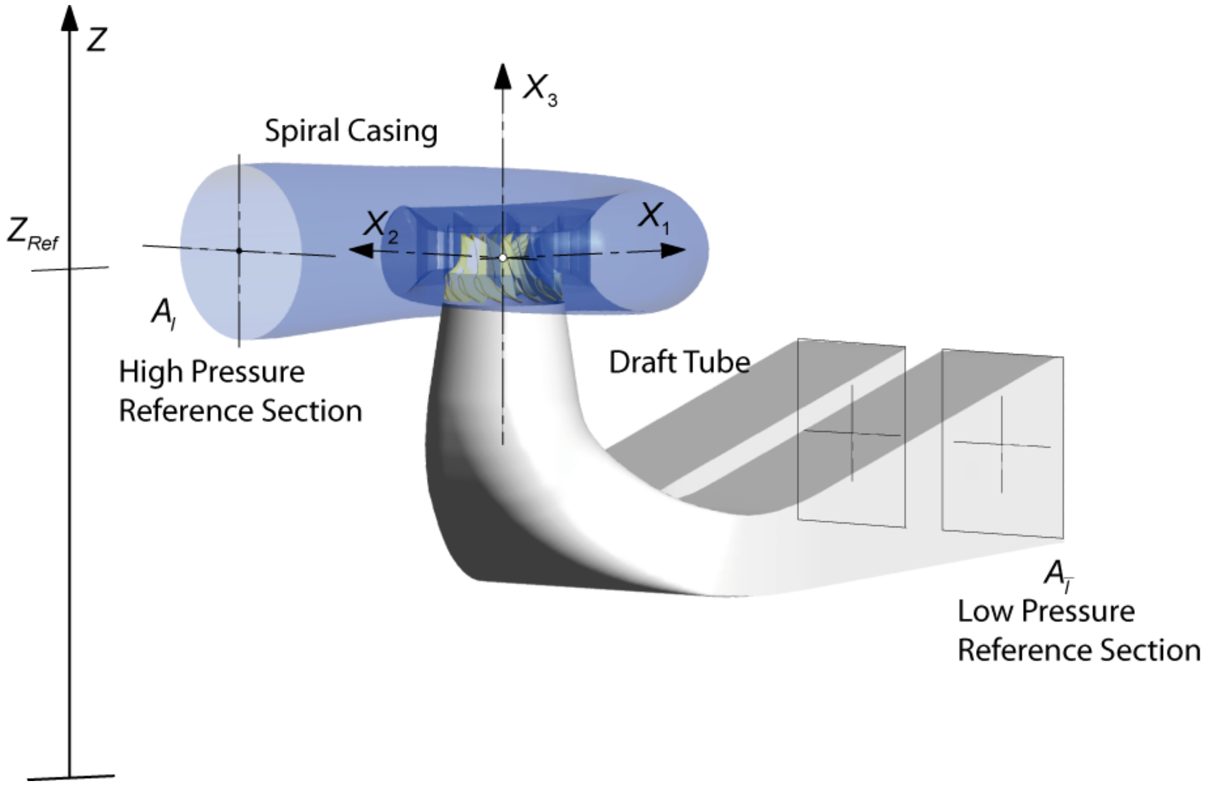
Turbomachines definition

- In turbomachines, the system is represented by **a mass flow**
- The exchange of energy occurs continuously through an always **open system**
- The **interaction between the flow and the walls** through which the fluid passes is evaluated
- The exchange of energy is based on the **change in the momentum imposed on the fluid by the machine**



Turbomachines definition

Frame of reference



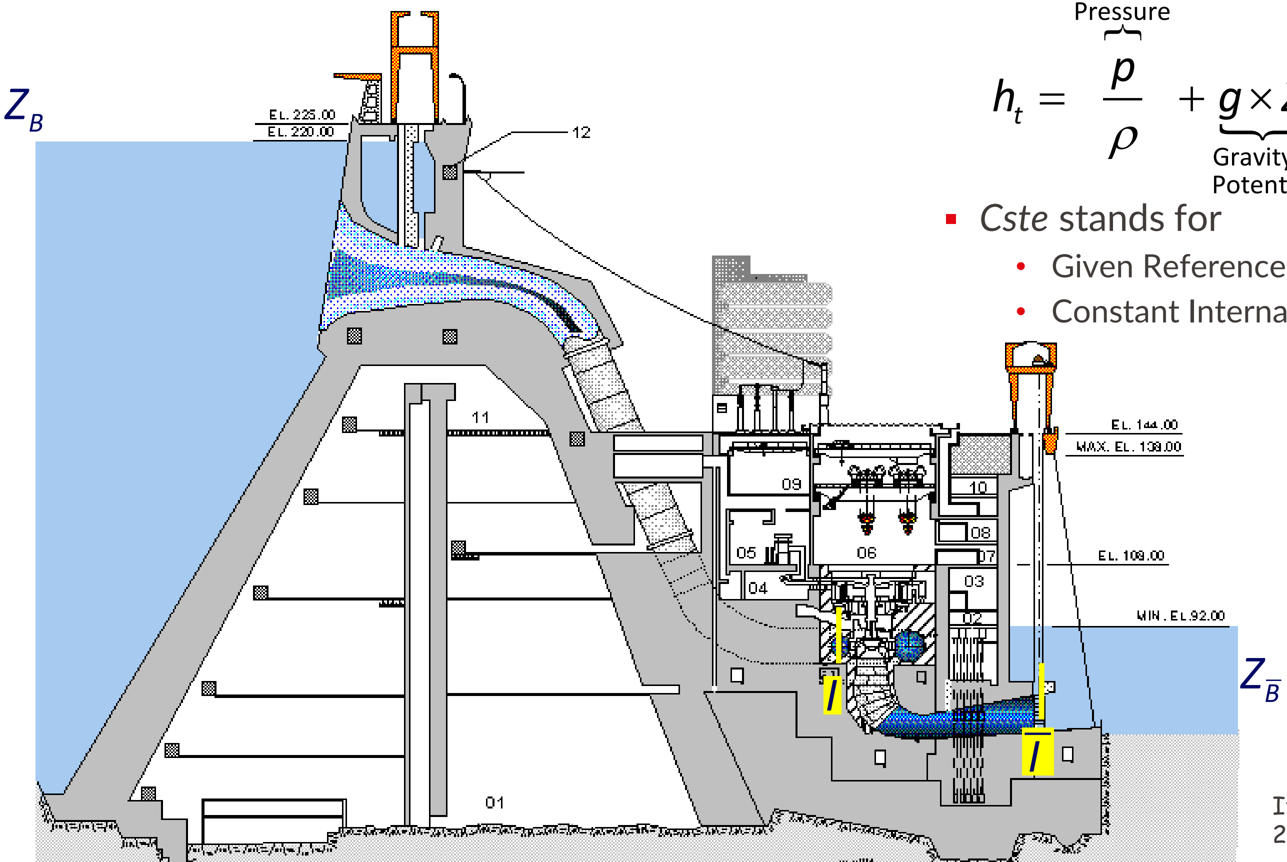
Specific Hydraulic Energy

Specific Energy Balance

- Local Mean Flow Specific Energy: Flow Property

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

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



Available Specific Hydraulic Energy

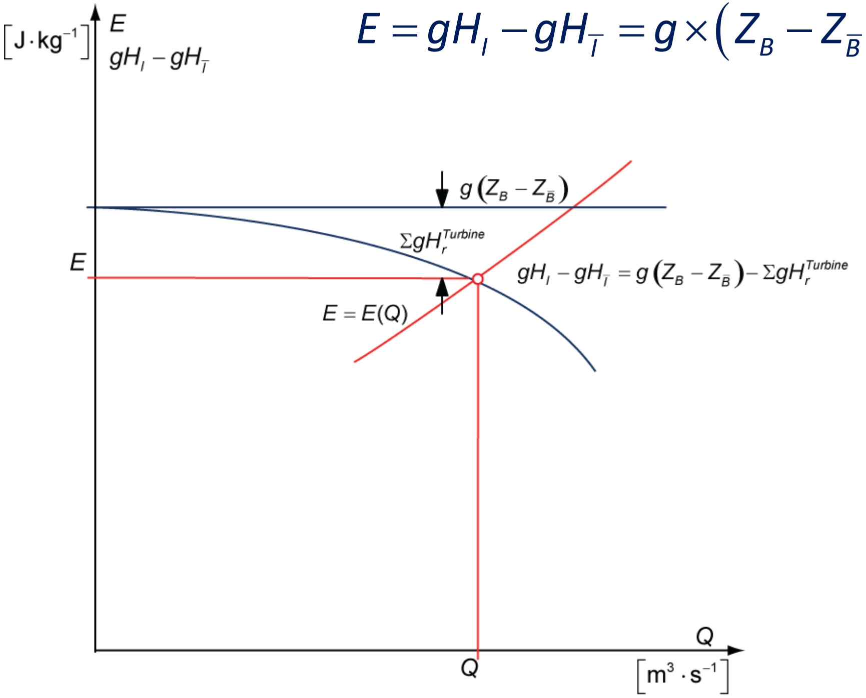
$$\boxed{\begin{aligned} E &\triangleq gH_I - gH_{\bar{I}} \\ &= g\left(Z_B - Z_{\bar{B}}\right) - \sum gH_r^T \end{aligned}}$$

Itaipú, Brazil/Paraguay
20 x 740 MW Francis

Specific Hydraulic Energy

Hydraulic Characteristics : generating mode

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



Specific Hydraulic Energy

Hydraulic Drive : generating mode

- Available Hydraulic Power

$$\underbrace{P_h}_{\frac{\mathrm{J}}{\mathrm{s}}} = \underbrace{\rho Q}_{\frac{\mathrm{kg}}{\mathrm{m}^3}\times\frac{\mathrm{m}^3}{\mathrm{s}}} \times \underbrace{E}_{\frac{\mathrm{J}}{\mathrm{kg}}} \quad (\mathrm{W})$$

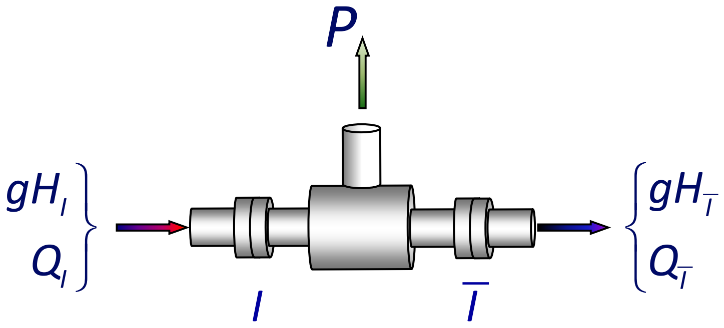
- Machine Power Output

$$P \quad (\mathrm{W})$$

- Turbine Efficiency

$$\eta^T = {P}/{P_h} \quad ; \eta^T \leq 100\ \%$$

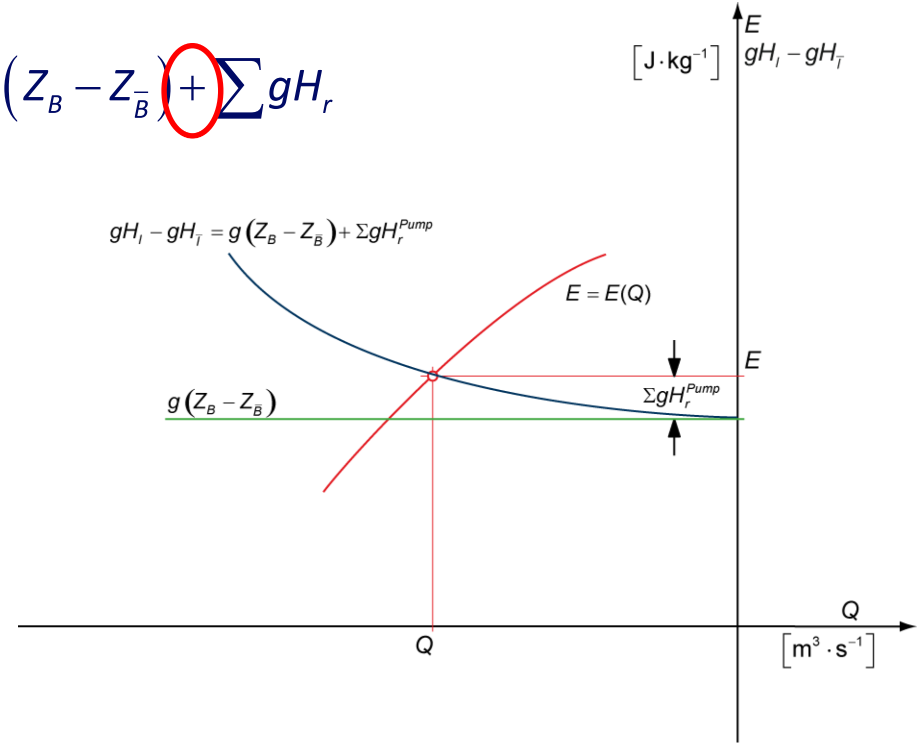
- Discharge and Driving Power Defined as Positive : $P \geq 0$



Specific Hydraulic Energy

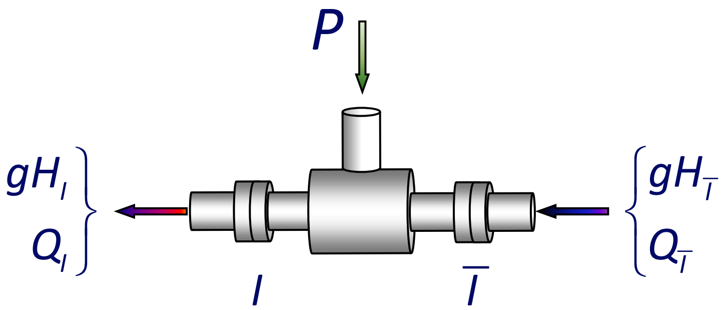
Hydraulic Characteristics: pumping mode

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



Specific Hydraulic Energy

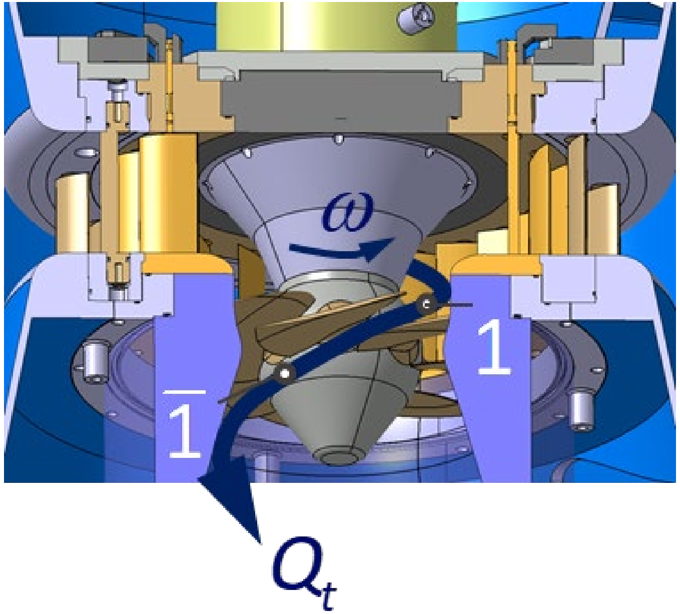
Hydraulic Brake : pumping mode



- Discharge and pumping power defined as negative $P \leq 0$
- Hydraulic Power Output $P_h = \rho \times Q \times E \quad (\mathrm{W})$
- Power Input $P \quad (\mathrm{W})$
- Pump Efficiency $\eta^P = \dfrac{P_h}{P}$

Classification of Hydraulic Runners

Runner/impeller specific energy transfer



Brillant Extension Project, British Columbia, Canada, Kaplan Turbine CAD Model, PF2 EPFL Test Rig

- Traversing Discharge

  $Q_t \quad \left(\mathrm{m}^3 \cdot \mathrm{s}^{-1}\right)$

- Transferred Specific Energy

  $gH_1 - gH_{\bar{1}} = E_t \pm E_{rb} \quad \left(\mathrm{J} \cdot \mathrm{kg}^{-1}\right)$

- Power Transfer

  $P_t = \rho Q_t E_t \quad (\mathrm{W})$

Classification of Hydraulic Runners

Runner/impeller specific energy transfer

- Transferred Specific Energy

$$gH_1 - gH_{\bar{1}} = E_t \pm E_{rb} \quad \left(\mathrm{J \cdot kg^{-1}}\right)$$

- Specific Energy

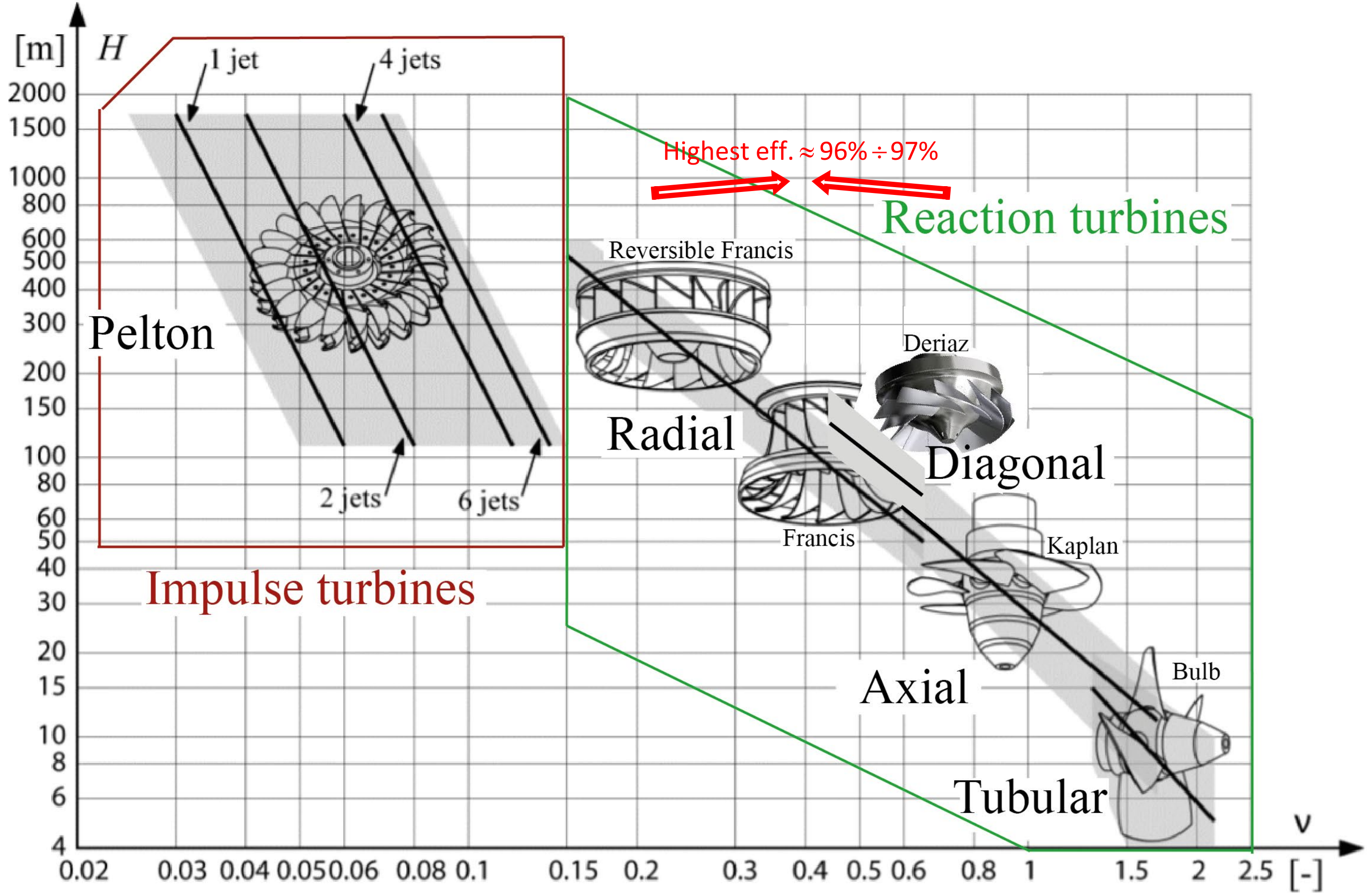
$$gH = \frac{p}{\rho} + gZ + \frac{C^2}{2} \quad \left(\mathrm{J \cdot kg^{-1}}\right)$$

- Specific Energy Balance:

$$E_t = \overbrace{\underbrace{\left(\frac{p_1}{\rho} - \frac{p_{\bar{1}}}{\rho}\right)}_{\text{Displacement}} + \underbrace{\left(\frac{C_1^2}{2} - \frac{C_{\bar{1}}^2}{2}\right)}_{\text{Impulse}}}^{\text{Reaction}} + \underbrace{\left[gZ_1 - gZ_{\bar{1}}\right]}_{\text{Water Wheel}} \pm \underbrace{E_{rb}}_{Loss}$$

$$\left(\mathrm{J \cdot kg^{-1}}\right)$$

Classification of Hydraulic Runners



Head $= H$ (m)

Discharge $= Q$ $\left(m^3 \cdot s^{-1}\right)$

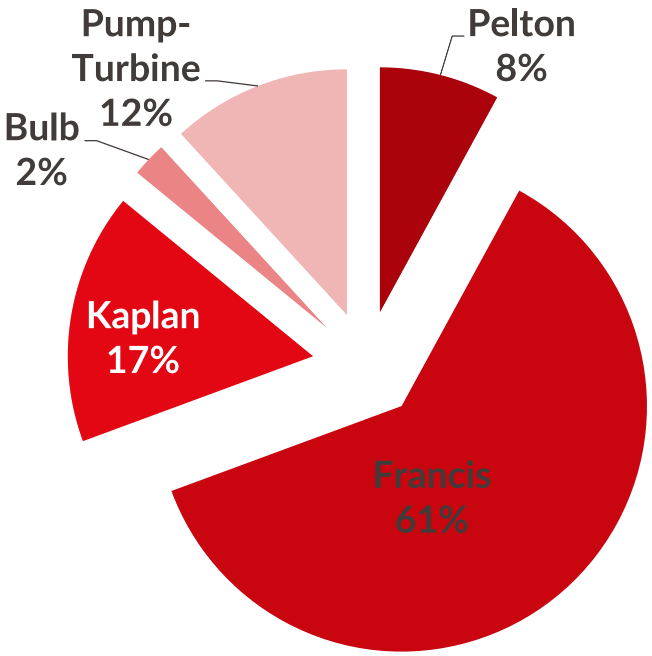
Speed $= N$ $\left(\min^{-1}\right)$

$$\nu = 2^{\frac{1}{4}} \pi^{\frac{1}{2}} \times n \times \frac{Q^{\frac{1}{2}}}{E^{\frac{3}{4}}}$$

Classification of Hydraulic Runners

Hydropower International market in 2010

- Breakdown by Types of Turbines
  - 1’038 GW Installed Capacity in 2010
  - 1’000 GW to be built before 2050 Greenfields Project



EPFL

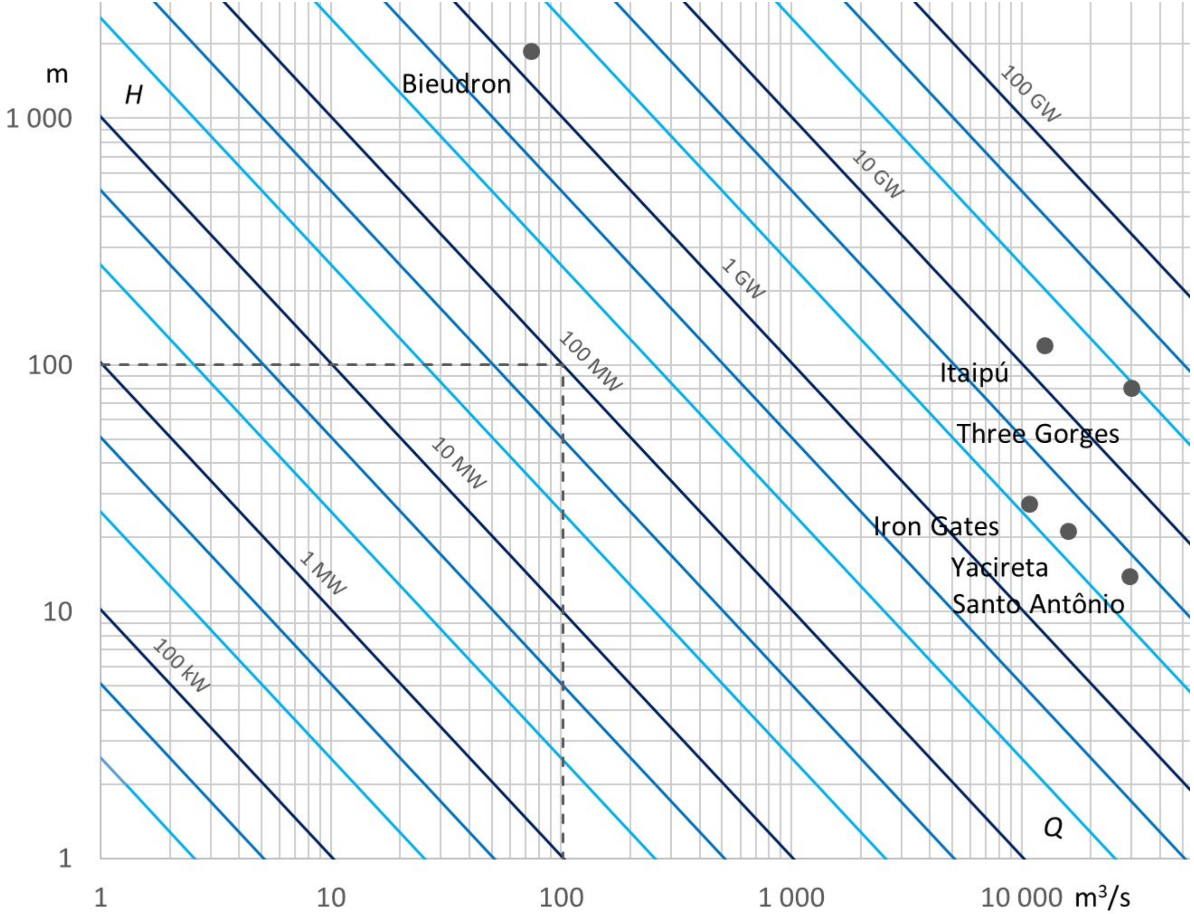
Hydropower Plants

A hydropower plant transforms the hydraulic energy of a watercourse, whether it is natural or artificial, into renewable electricity.

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

Hydropower Plants

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



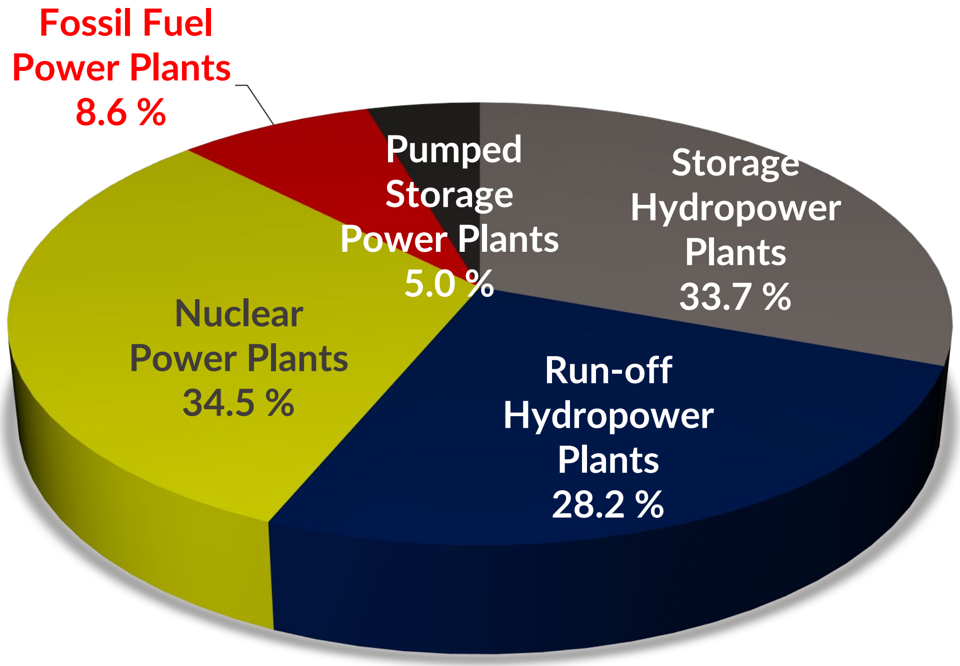
Hydropower Plants
Types

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

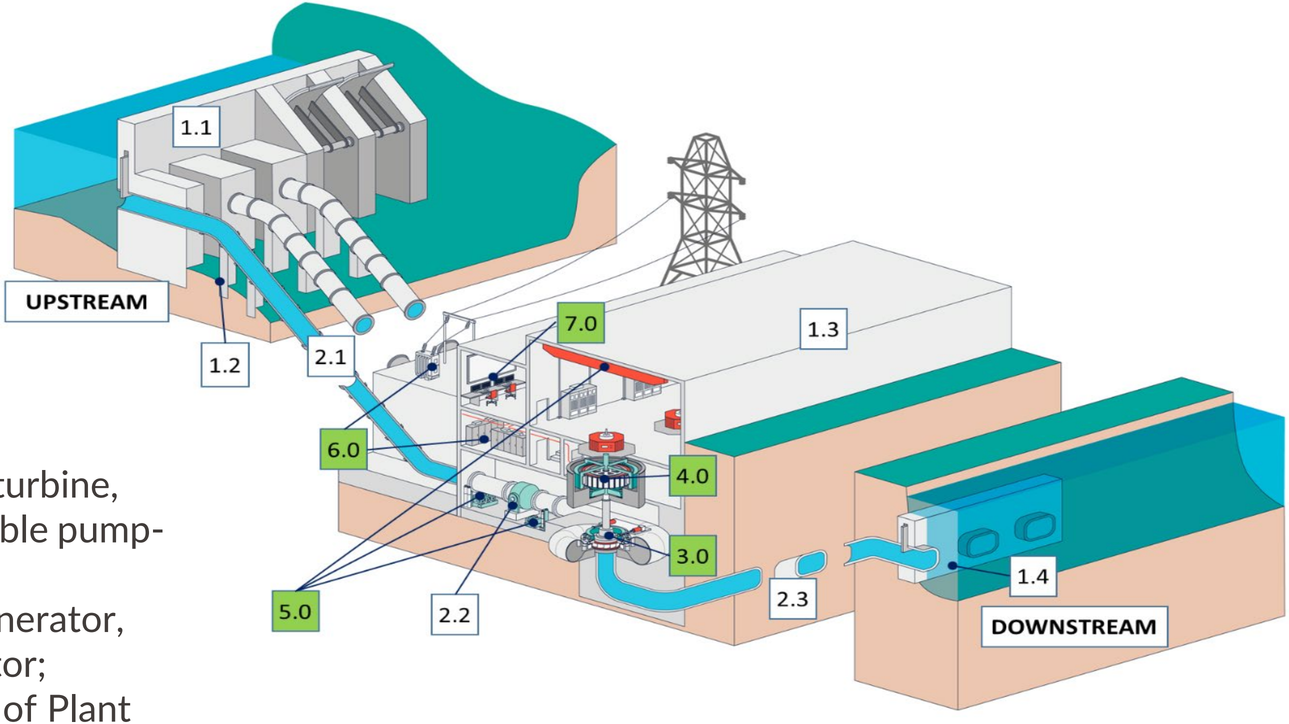
- **Storage hydropower**: typically a large system that uses a dam to store water in a reservoir.
- **Pumped storage hydropower**: similar to storage hydropower but with pumping capability.
- **Run-of-river hydropower**: a facility that channels flowing water from a river through a canal or penstock 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.

Types of Hydropower Plants

Swiss Scenario



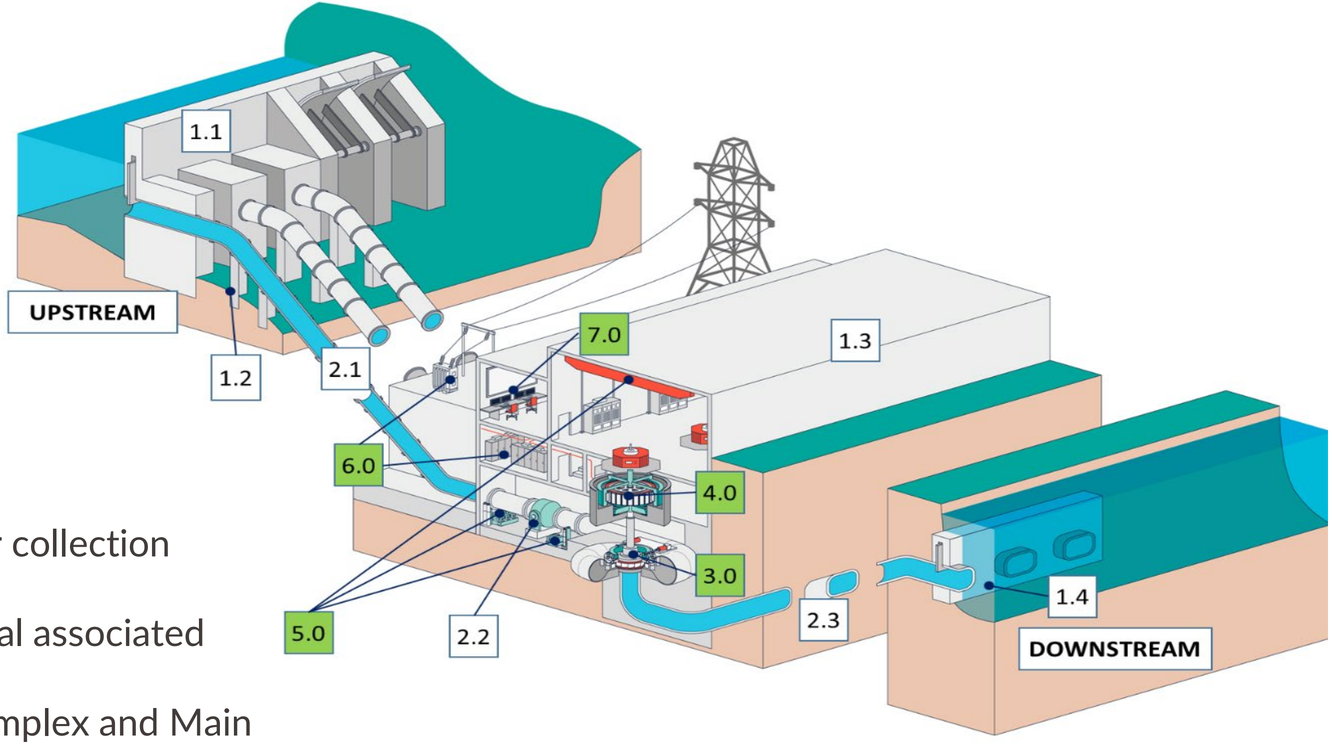
Overview of a storage hydropower plant



- 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

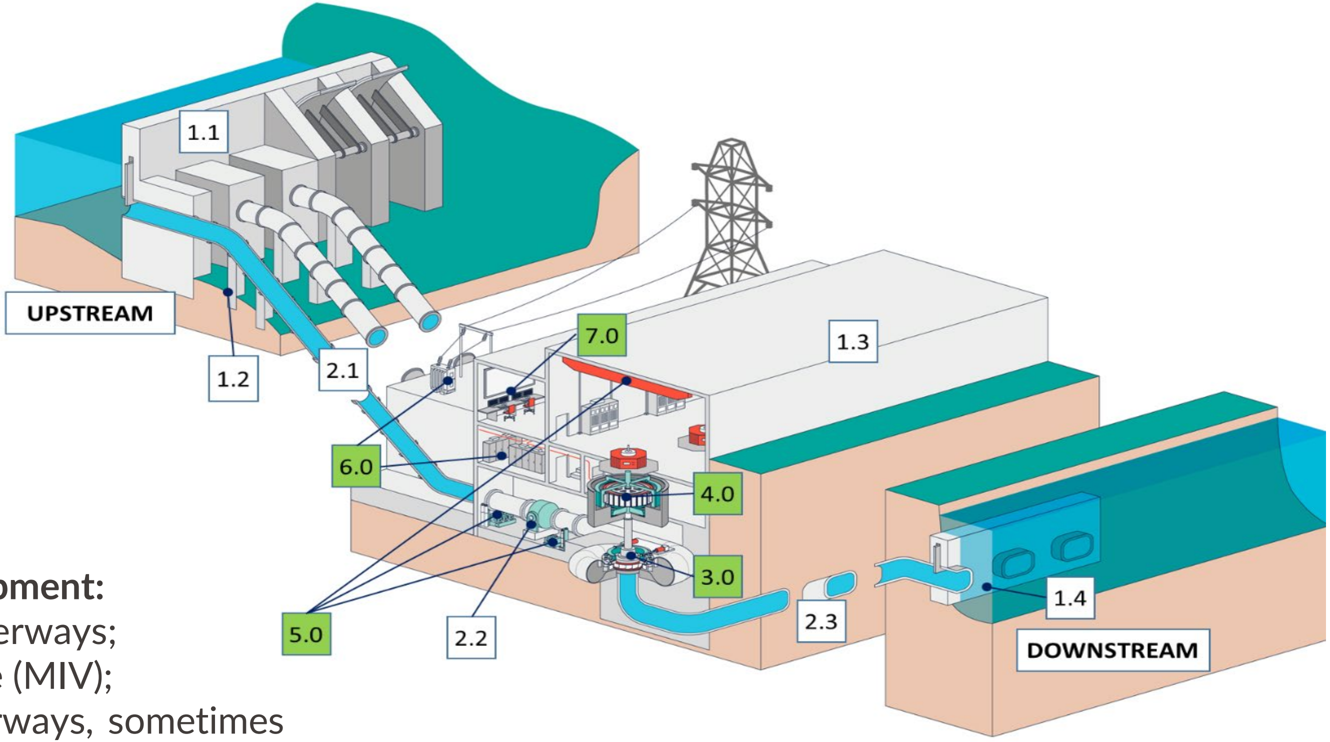


Water ways

- 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



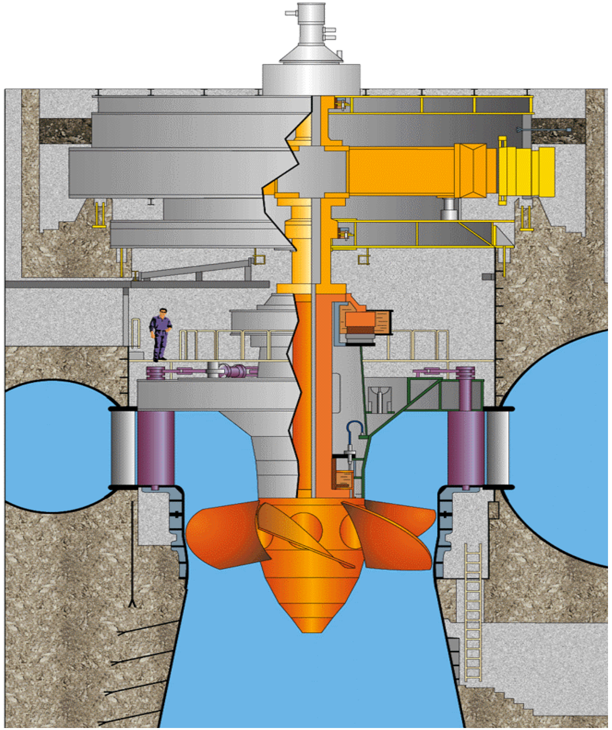
Hydro Mechanical equipment:

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

Overview of a storage hydropower plant

Power unit

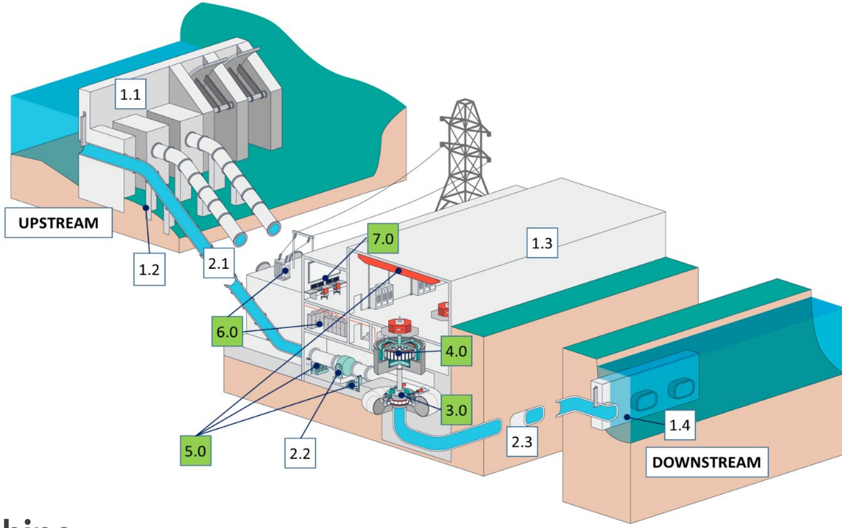
- Generator
  - Synchronous or Asynchronous machine
  - Excitation, Voltage Regulator
  - Cooling
  - Thrust Bearing
- Drive
  - Turbine
  - Speed Control (Governor)
  - Guide Bearings



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

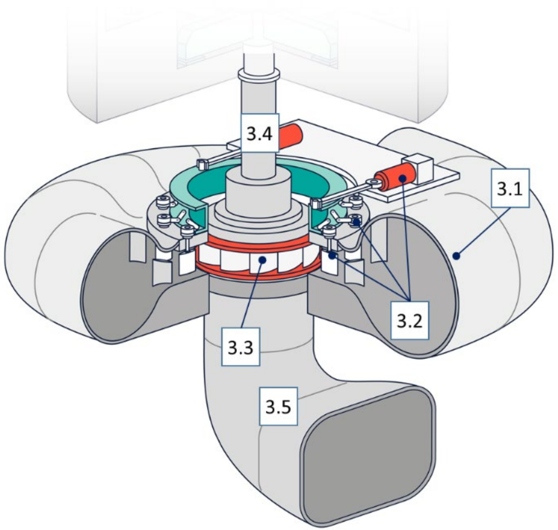
Overview of a storage hydropower plant

Power unit



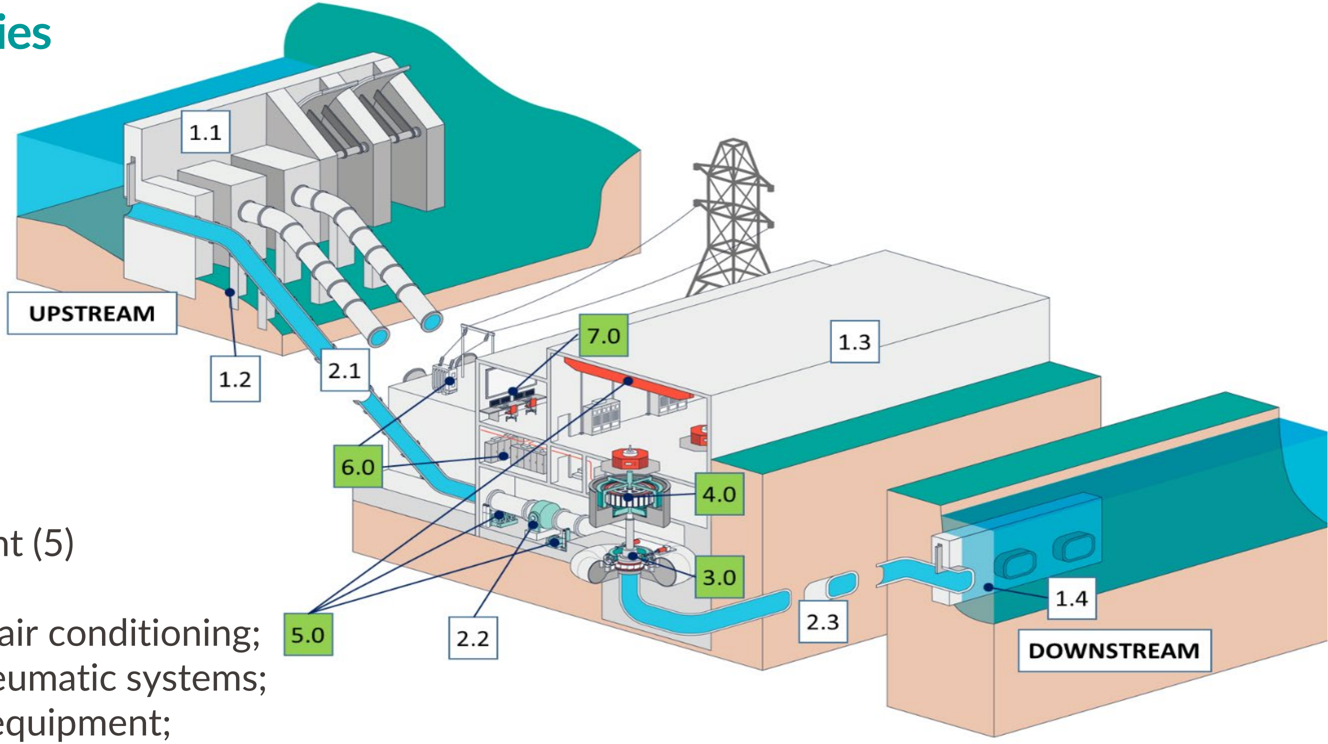
Hydraulic Machine

- 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;
- 3.6 Auxiliaries.



Overview of a storage hydropower plant

Mechanical Auxiliaries

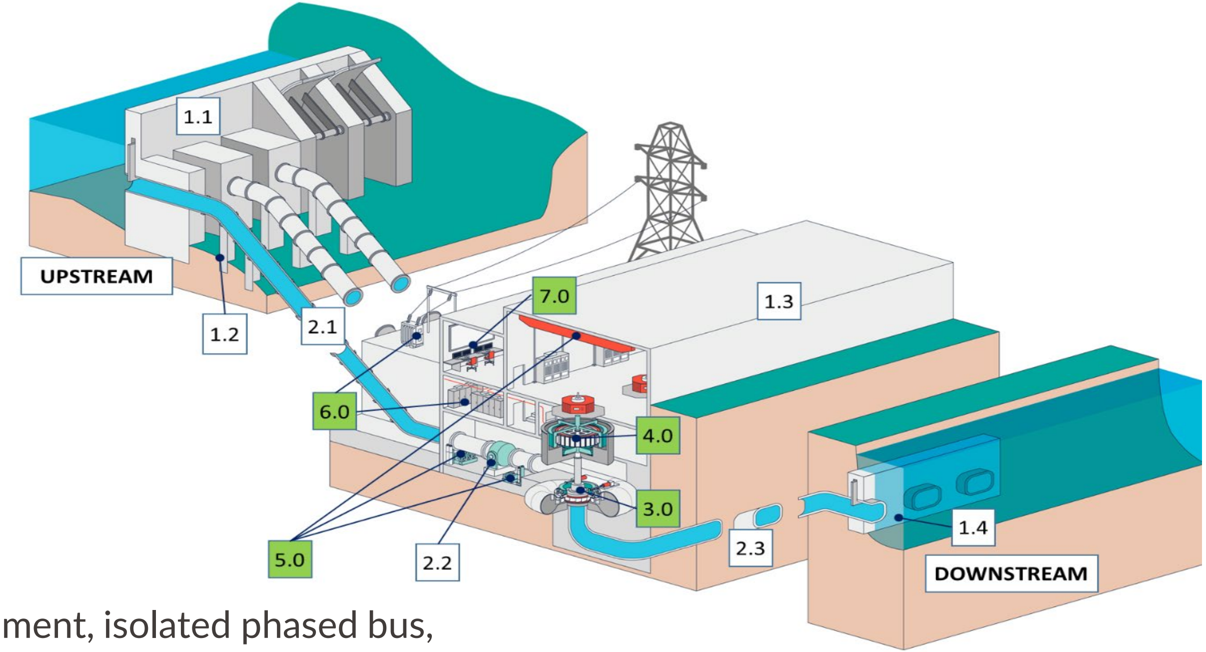


Mechanical Auxiliaries of Plant (5)

- 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 of field of application: 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 of field of application: Three Gorges Hydropower plant (China) is the largest hydropower project

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

Spiral case →

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

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

Draft tube cone →

Centrifugal Pumps

Centrifugal pumps are widely used to move water from one location to another or circulate water within a circuit. They are also used to provide high-pressure jetting of water or other liquids or chemicals.

Classification	
Flow orientation: - Radial - Mixed-flow - Axial	**Number of stages:** - Single stage - Two stage - Multistage

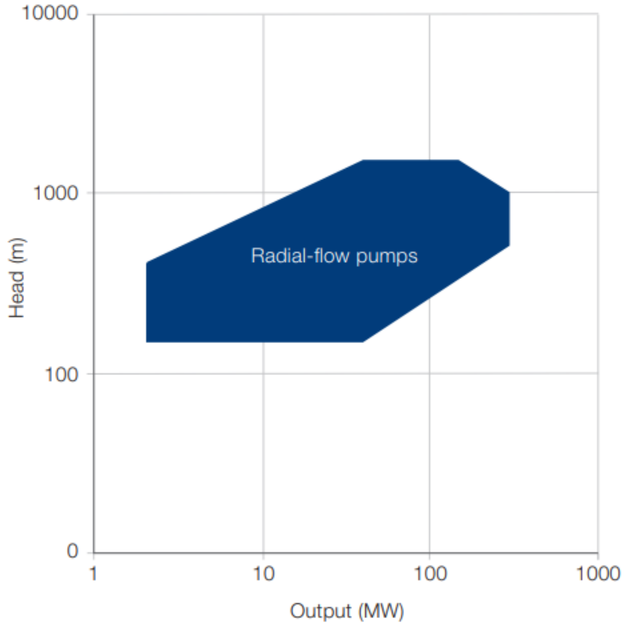
Pumps types are very numerous and with specific characteristics depending on the use, the liquid or multiphase mixing, temperature and the required energy.

EPFL

Centrifugal Pumps

Radial flow pumps as Storage pumps

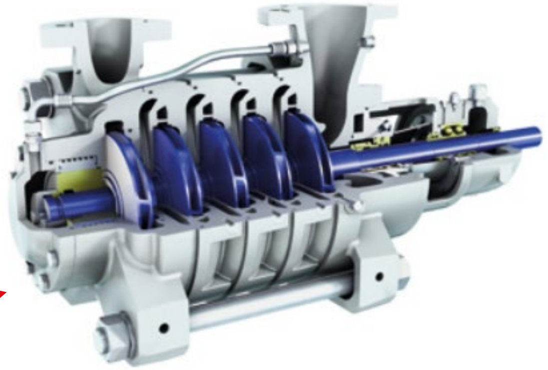
Pumps for storage applications are mainly of the radial-flow type. Depending on the application conditions the construction, can be a single or double-flow, single- and multi-stages

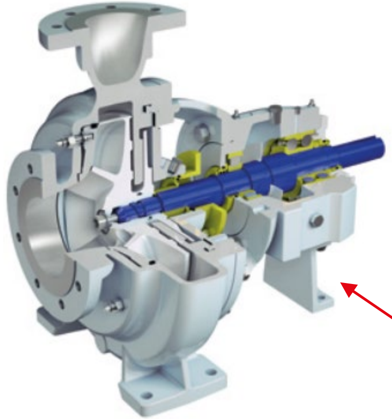


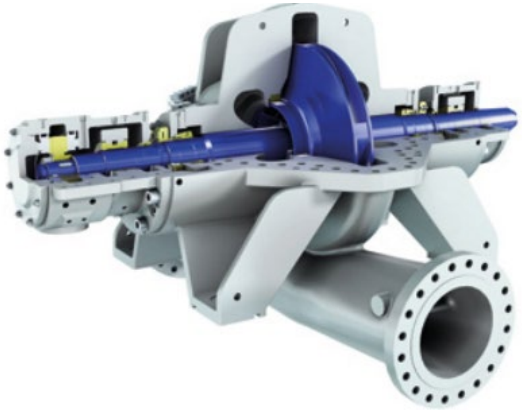
VOITH
Engineered Reliability

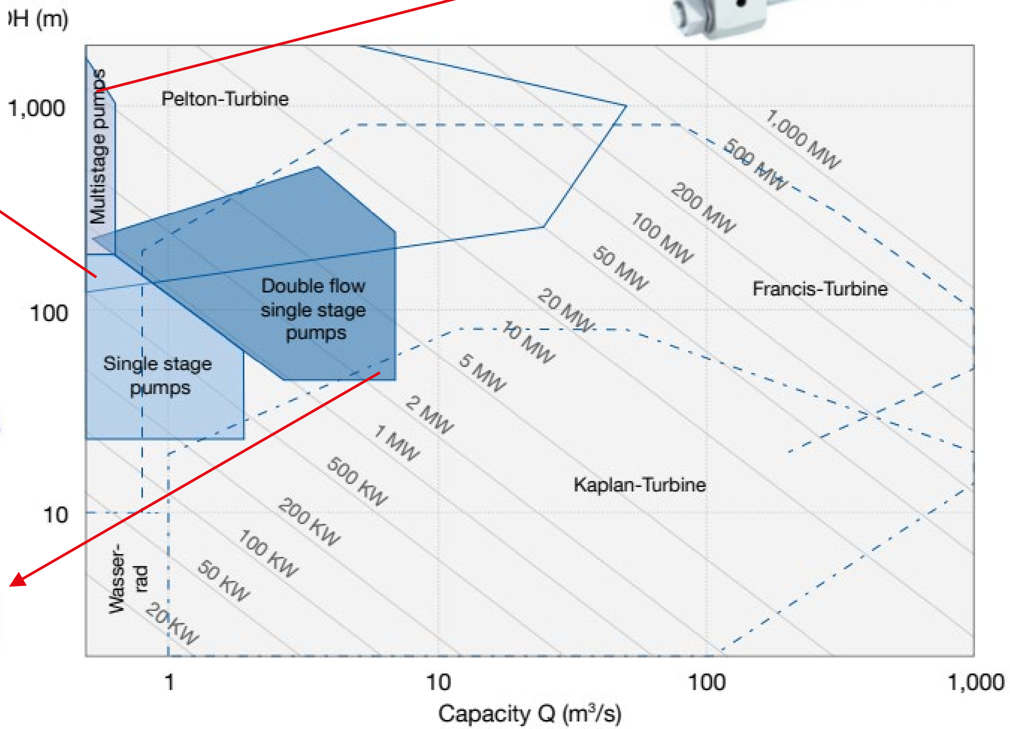
Centrifugal Pumps

Radial flow pumps as Storage pumps





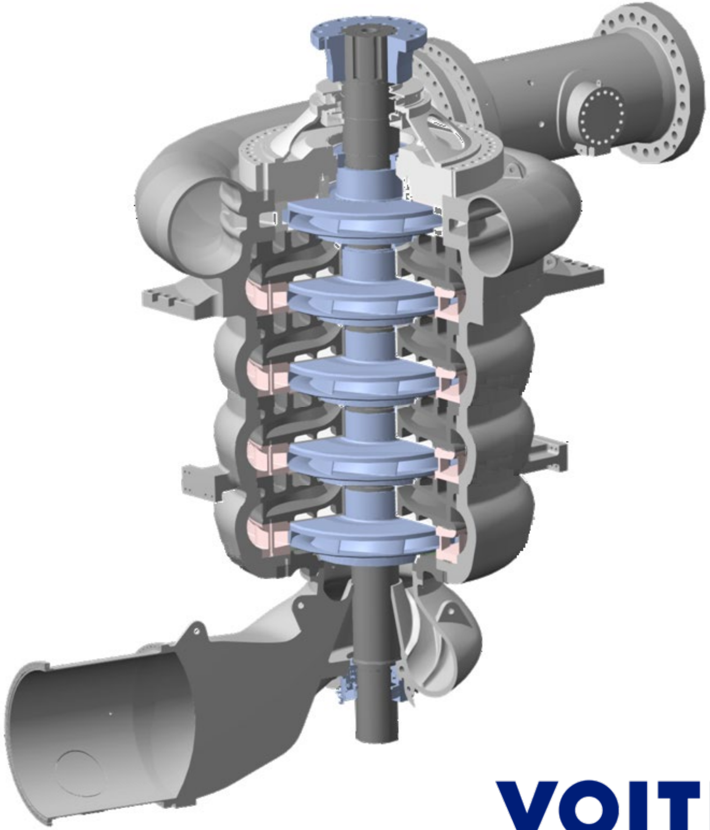




Centrifugal Pumps as storage pumps

FMHL +, Veytaux II pumped storage plant (Switzerland)

- 2 vertical multistage pumps
- 5 stages radial flow pump
- 120 MW Unit Power



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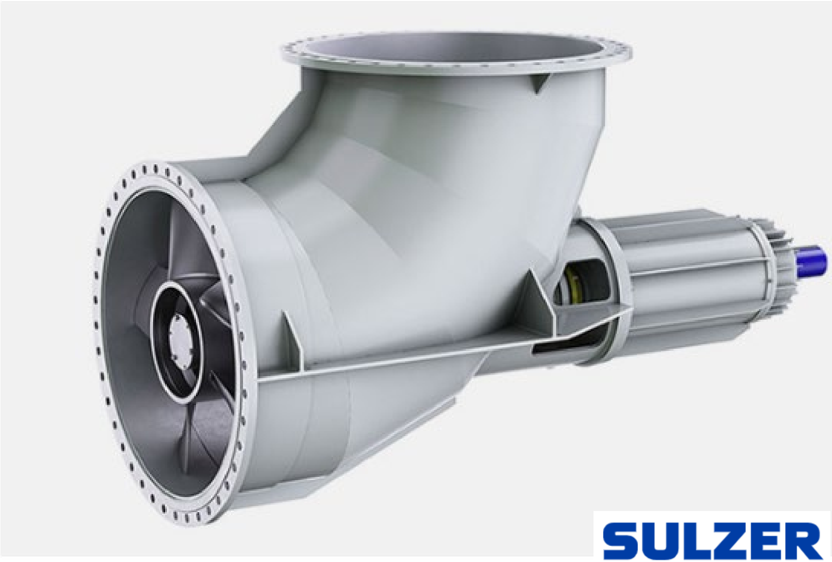
Centrifugal Pumps

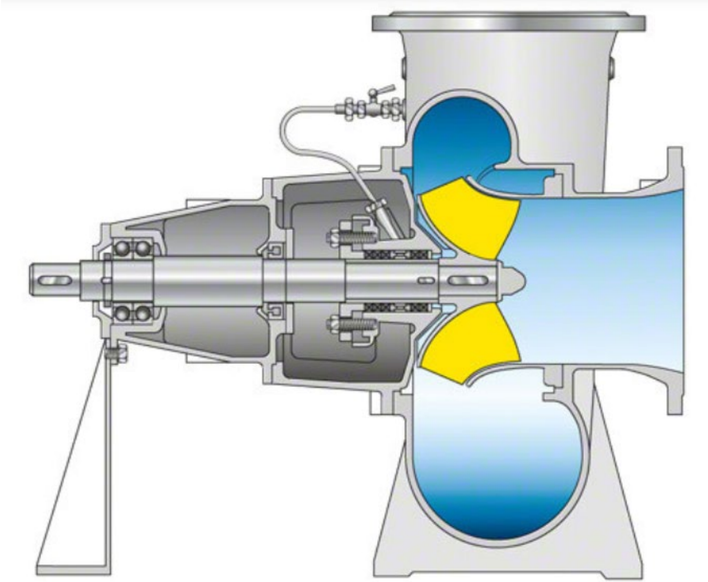
Mixed-flow and axial flow pumps

Axial flow pumps



Low head pumping applications, typically up to 15m

Mixed-flow pumps



Small- Medium head pumping applications, typically up to 60m

EPFL

Industrial Pumps applications

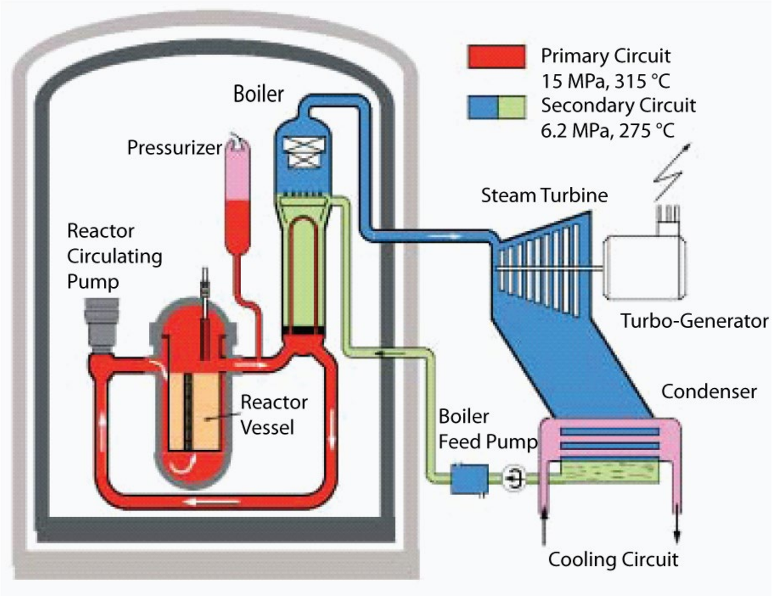
- Power Plants: auxiliaries
- Chemical Industry
- Oil & Gas
- Paper Mills
- Food Processing
- Irrigation
- Water Treatment Plants
- Mining
- Waste and recycling
- Military (aircraft fuel systems, shipboard hydraulic systems, and ground support equipment.)

Industrial Pumps applications

Nuclear power plants

Auxiliaries pumps:

- Main Circulating Pumps
- Reactor Cooling Pumps
- Boiler Feed Pumps

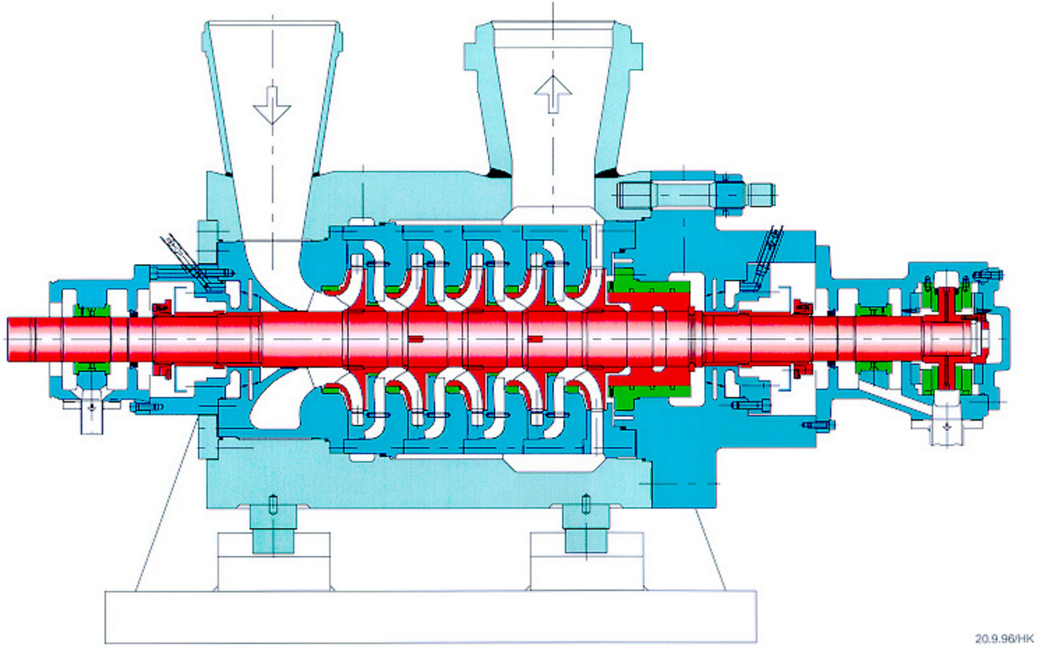


Gösgen, PWR 950 MW

Industrial Pumps applications

Nuclear power plants

Boiler Feed Pump: multistage radial pump



Industrial Pumps applications

Oil & Gas

- Water Injection Pumps
- Sea Water Lift Pumps
- Multiphase Pumps
- Pipeline Pumps
- Fire Fighting Pumps
- Process Pumps

  → High density fluids and solids particles
- Auxiliary Pumps (e.g. cooling or recirculation)

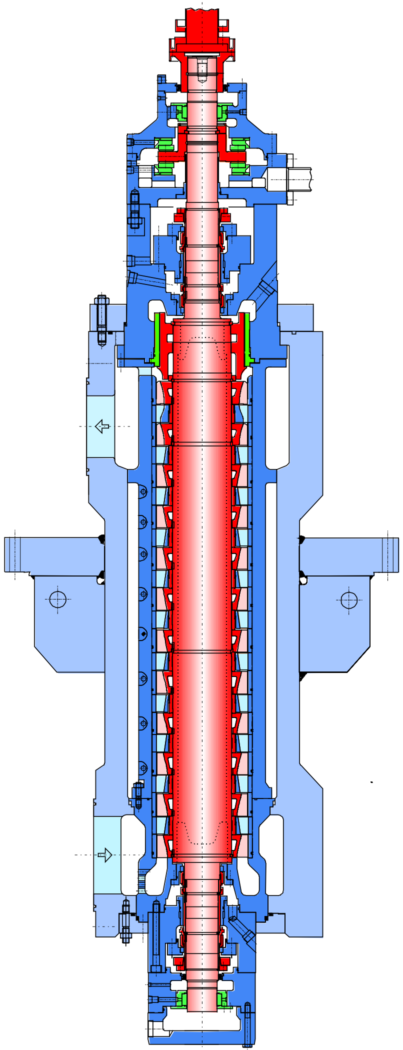
Industrial Pumps applications

Oil & Gas

Multiphase Pump

- Total volume flow up to 4000 m^3/h
- Differential pressure up to 80 bar
- Gas liquid ratio up to 95 %
- Power up to 5000 kW

Installation on Dunbar platform



THANK YOU

For your kind attention

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