UNIVERSITÀ DEGLI STUDI DI TRIESTE

Summer School on Energy Giacomo Ciamician

Hydropower

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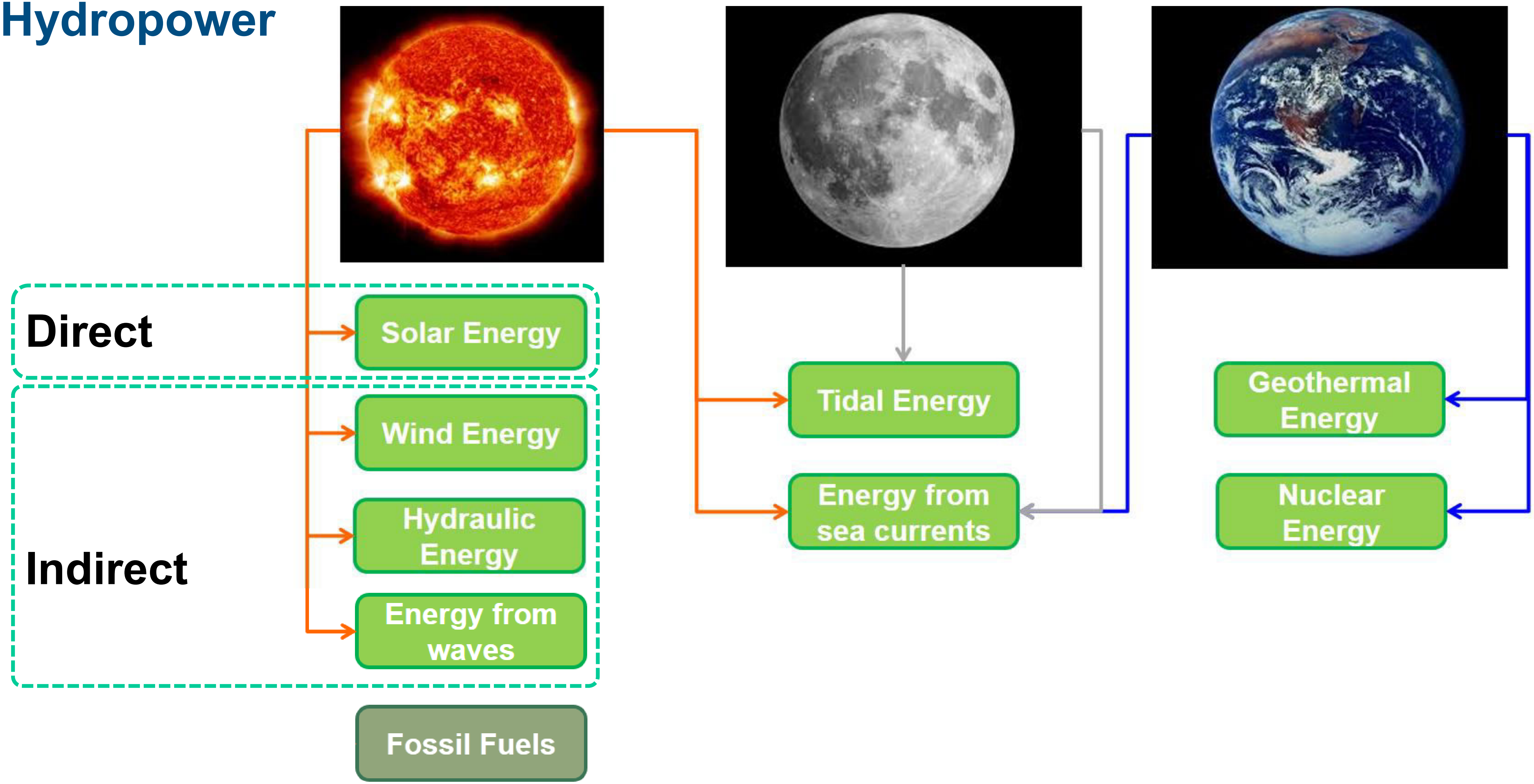
Hydropower

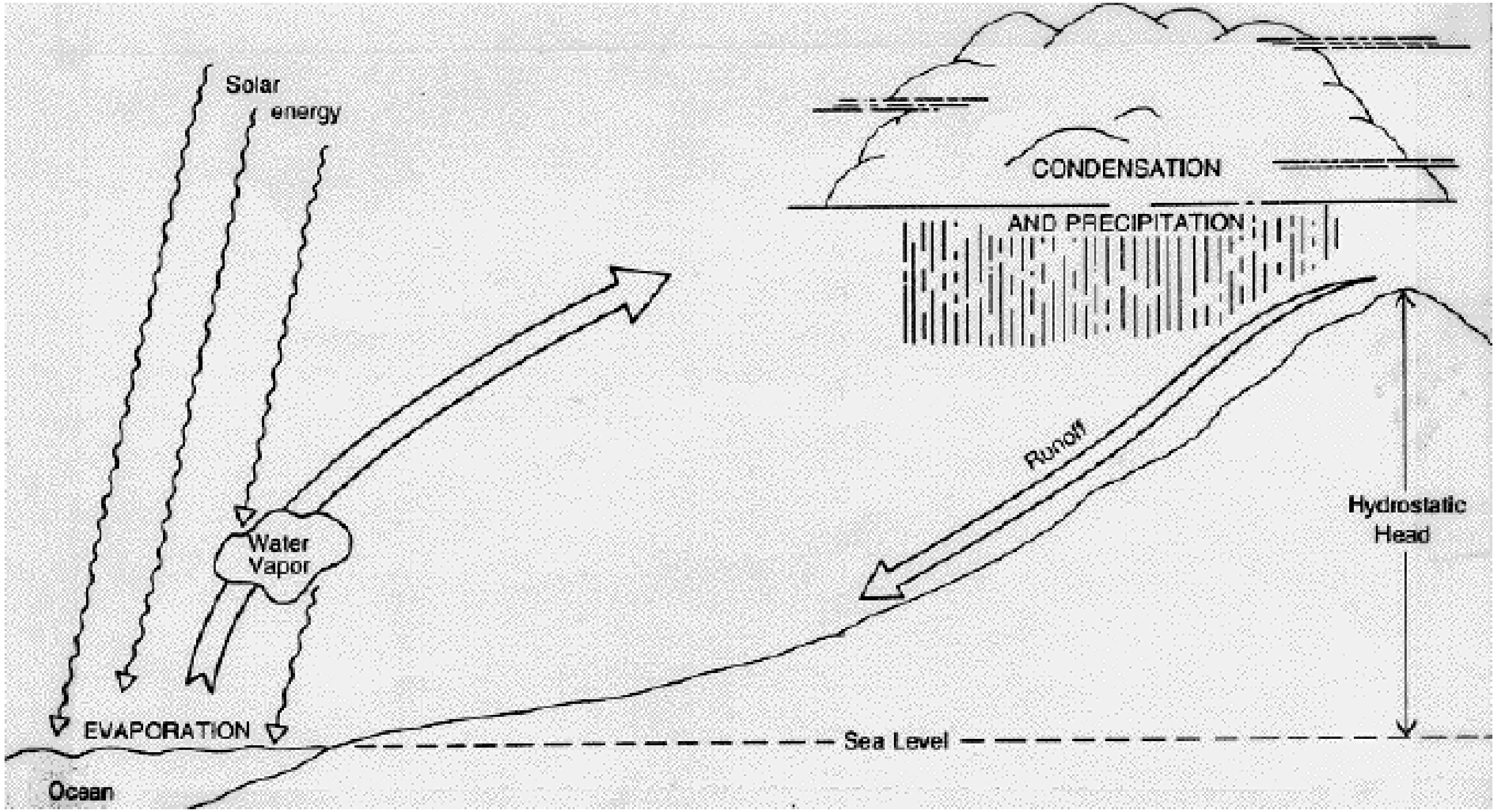


Direct
Solar Energy
Indirect
Wind Energy
Hydraulic Energy
Energy from waves
Fossil Fuels
Tidal Energy
Energy from sea currents
Geothermal Energy
Nuclear Energy

Hydropower

The hydro power potential comes from the rain…

….then it's an "energy condensate" of solar radiation



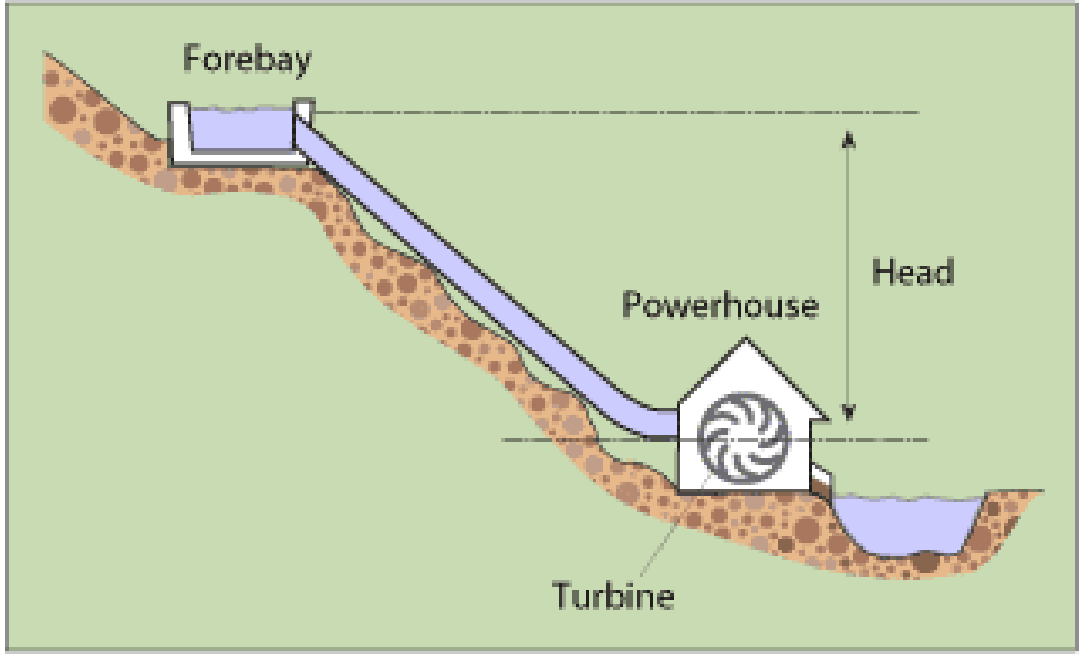
Hydropower

Power potential is evaluated as:

- **WATED HEAD (H)**
- **AVAILABLE FLOW (Q)**

$$E_{id}\,[J] = m \cdot g \cdot H$$

$$P_{id}\,[W] = \dot{m} \cdot g \cdot H = (\rho \cdot Q) \cdot g \cdot H$$



Hydropower in past years

Generation of mechanical power through a conversion of water potential is one of the oldest ways for power generation.

- ✓ Chap conversion equipment
- ✓ Highly Effective
- ✓ Easy to manage and regulate

- I century b.C.: first description of an horizontal axis water mill in "*De Architectura*" from Vitruvio.

Hydropower in past years

- Past centuries: development of water mills for cereal grinding, fabric production, irrigation, wood cut, etc.

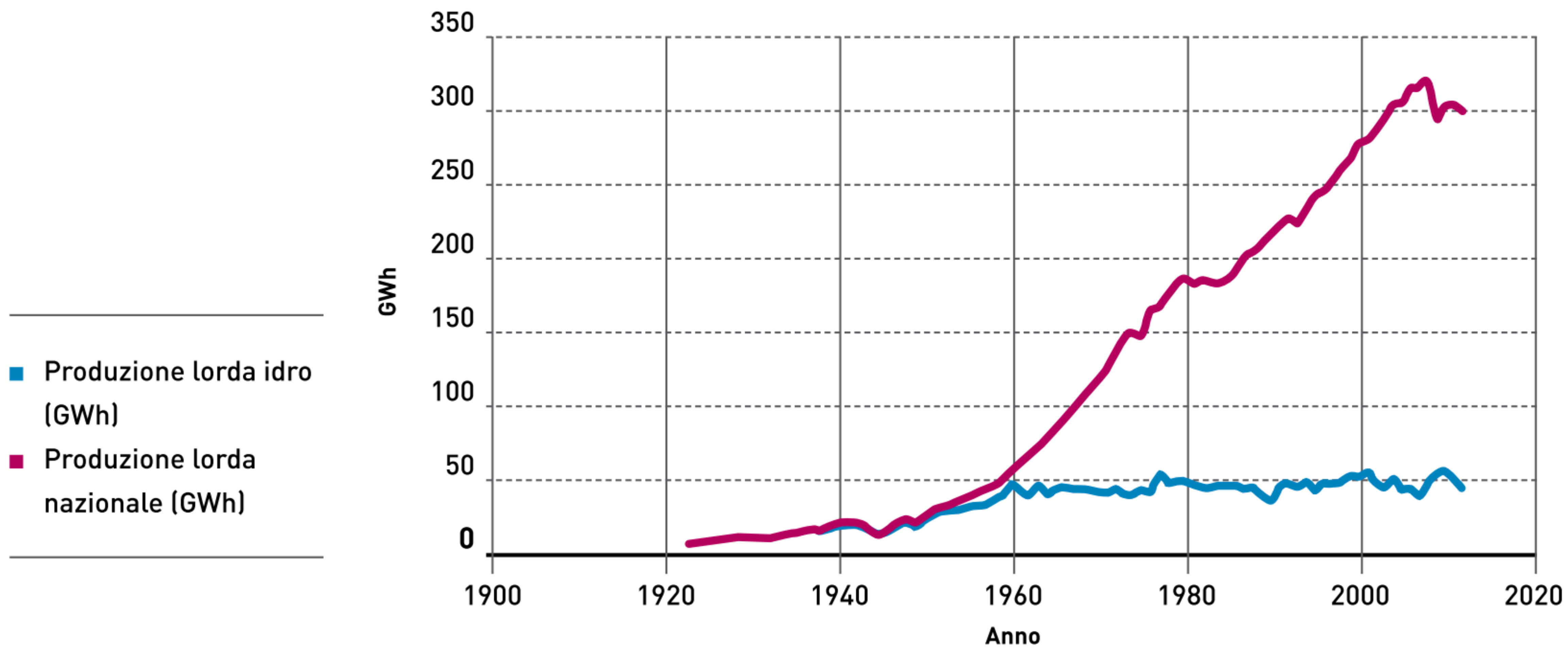
- End of XIX century: expansion of hydro power generation in the world

  First big plant in Italy: 1890, Isoverde (Soc. Acquedotto de Ferrari Galliera –Genova), 3 turbines for a total power of 1,200 kW

  Simultaneous development of distributed small hydro

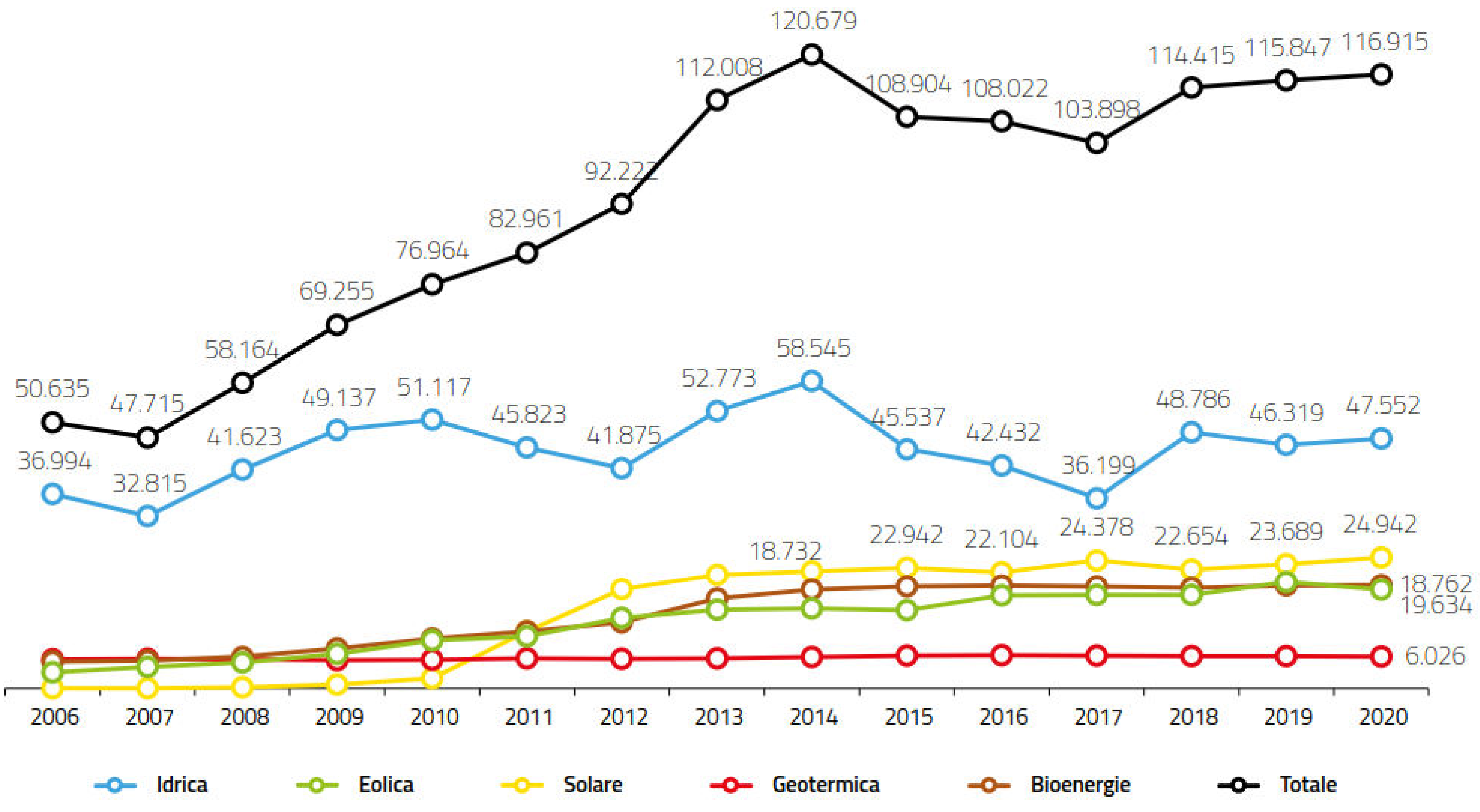
✓ Long service life

Hydropower in past years



Hydropower: statistics

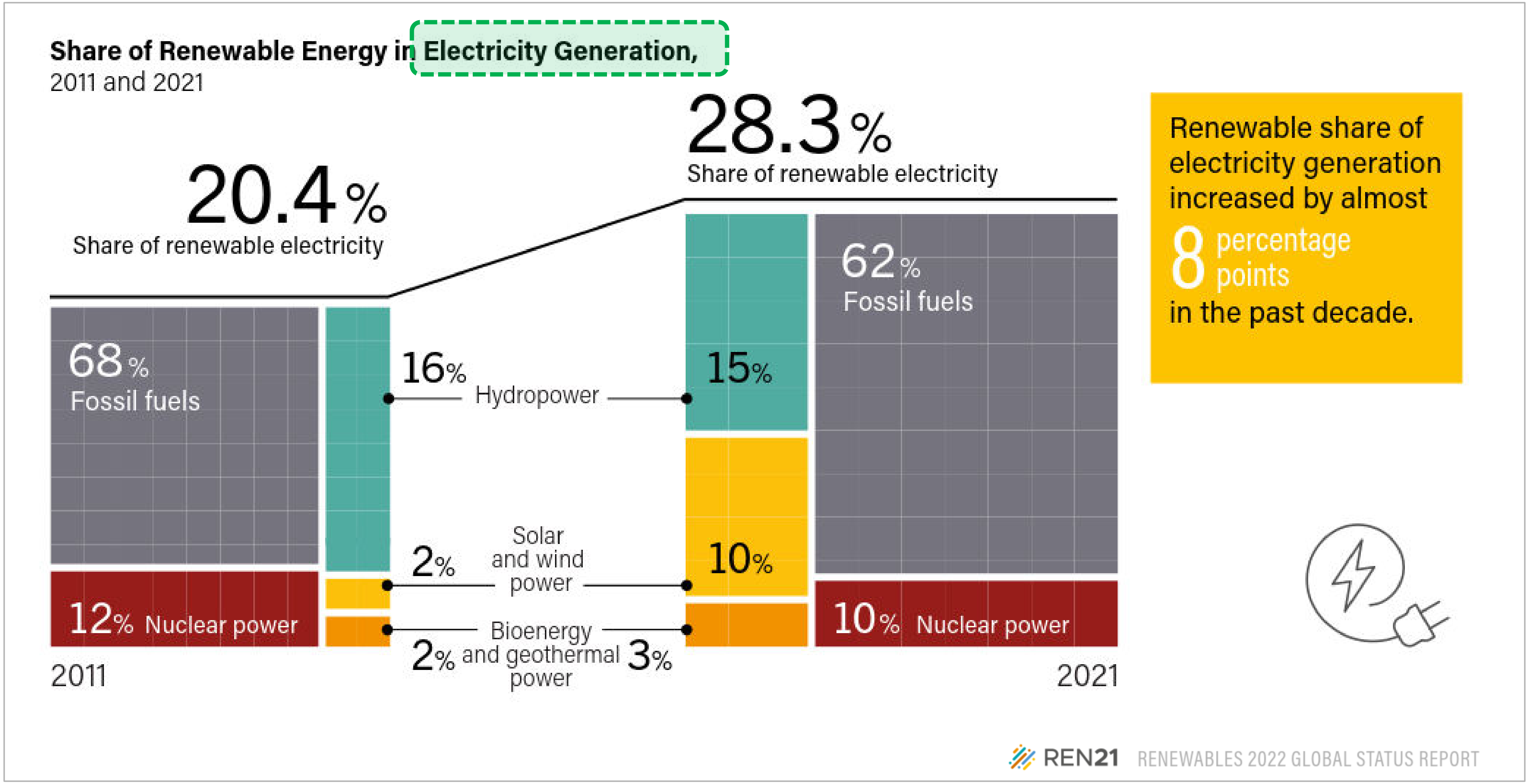
In Italy 13-16% of electrical power generation comes from hydro (average production of 45.7 TWh/year).



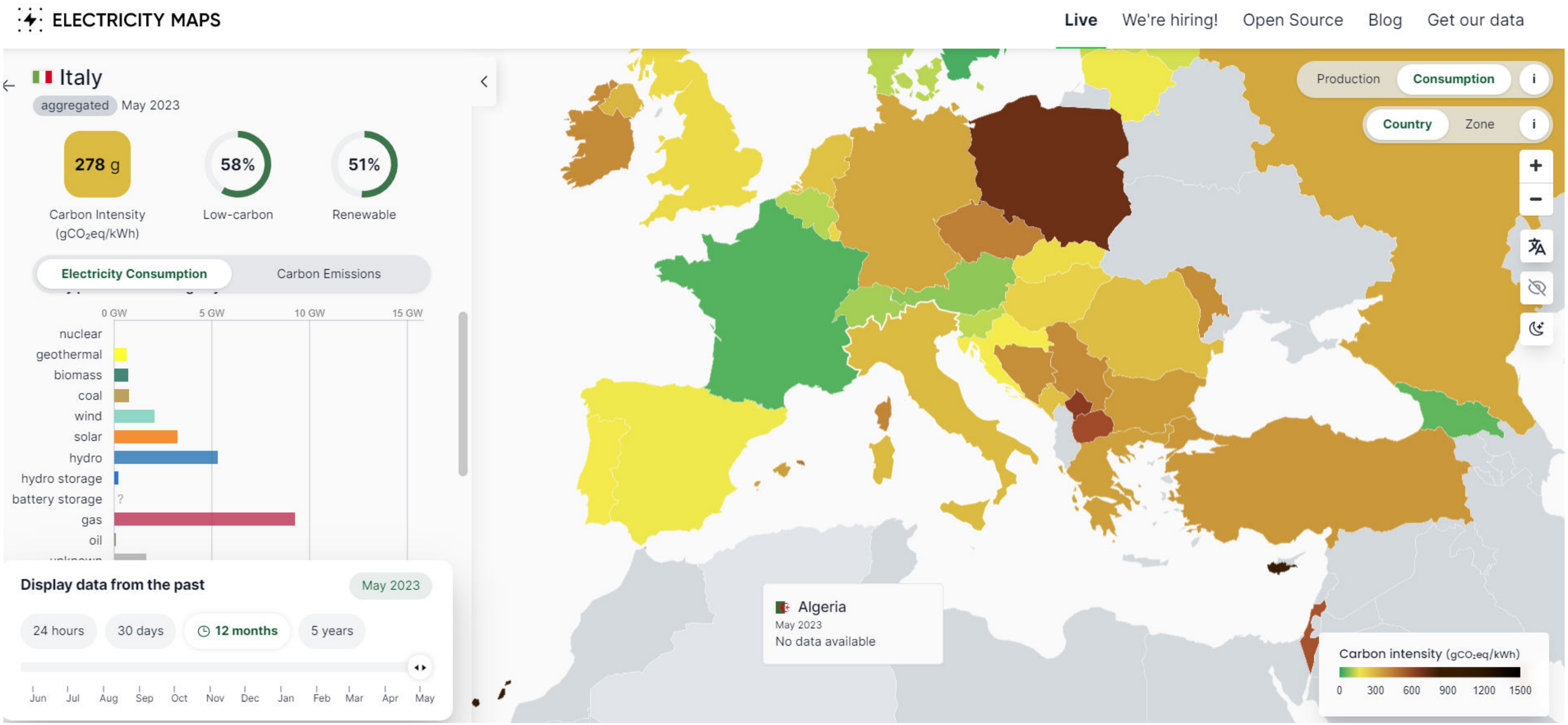
GWh

Rapporto statistico GSE 2020

Hydropower in the world



Hydropower in the world



https://app.electricitymaps.com/zone/IT

Hydropower in the world

The Itaipù dam

Paraná River (border between Brazil and Paraguay)

- Highest energy production in the world 103 TWh in 2016
- P = 20x700 MW = 14 GW
- Francis turbines
- H = 118 m
- Q = 14’000 m^3/s

Hydropower development

Most of countries in European area already exploited most of the available potential:

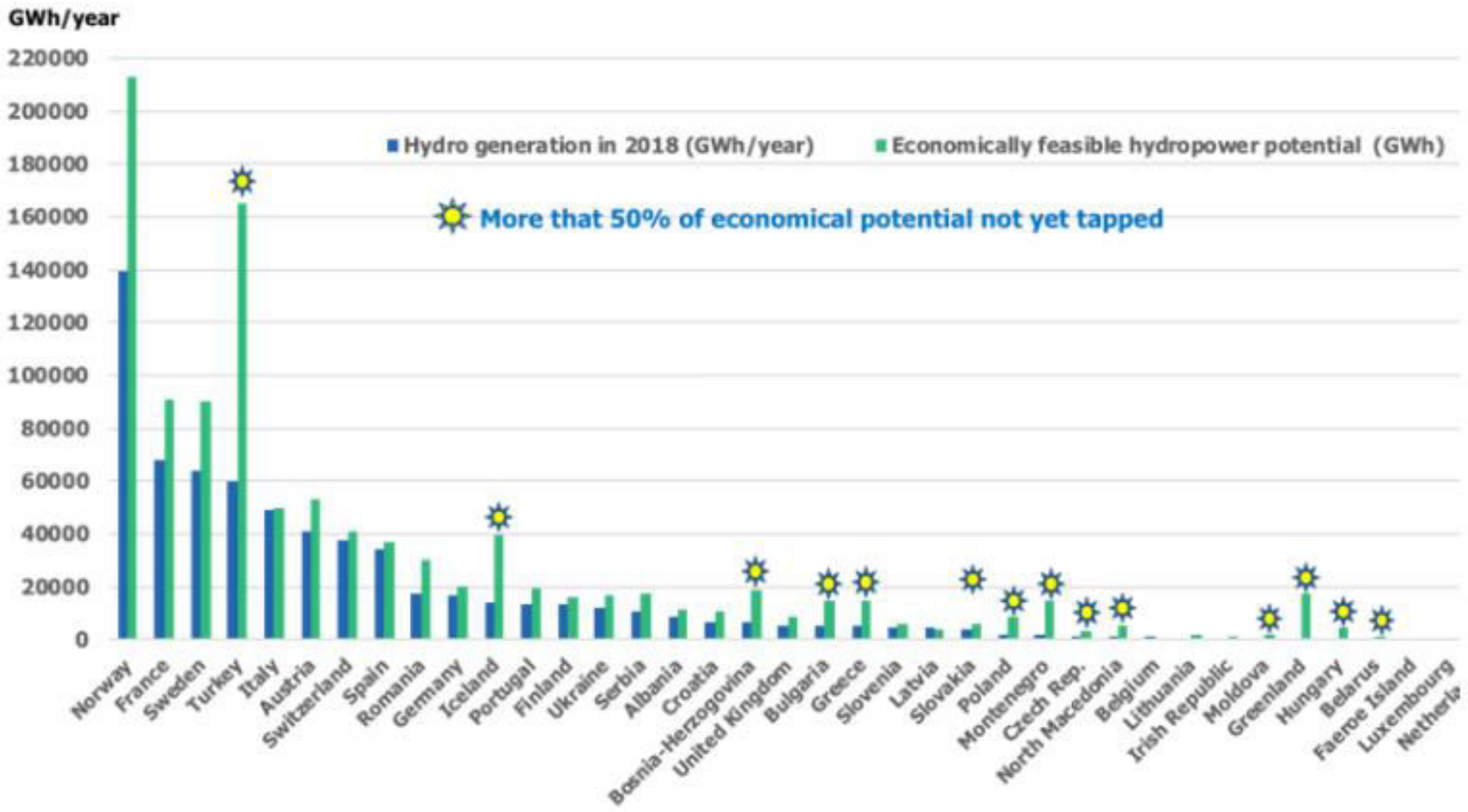


Figure 1. Generation and extension potential of hydropower in countries in the European region (according to Hydropower & Dams World Atlas 2019). Italy placed in 5th.

Hydropower development

Most of countries in European area already exploited most of the available potential:

- **most of the "good locations" have been already exploited**
- **environmental impact**
- **opposition (NIMBY)**

Is it possible a further development of hydro in developed countries?

Small and residual Hydro

Revamping of existing plants

New/revamping of pumped-hydro plants

Classification

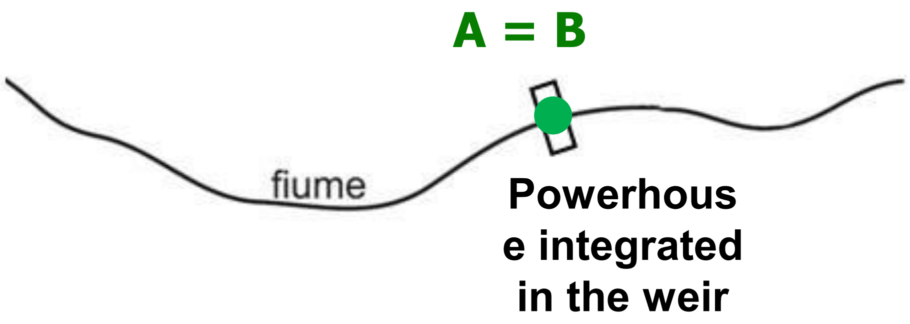
I. - Weir integrated plant
- Diversion Channel plants

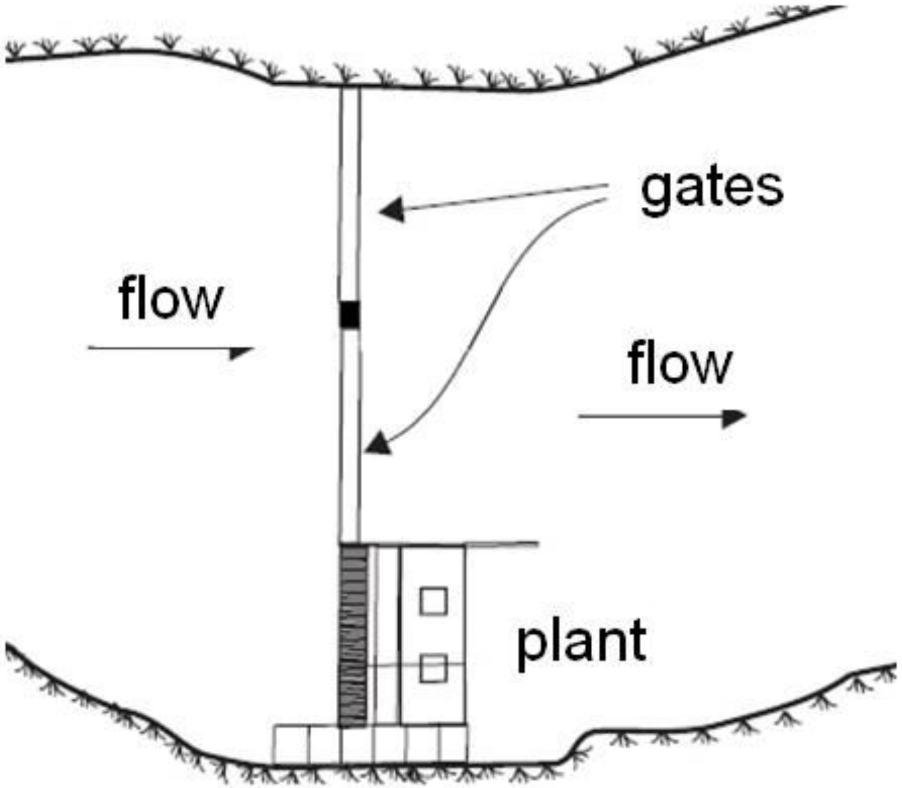
II. - Storage plants
- Run-of-river plants

III. - High head
- Medium head
- Low and very low head

I classification: weir-integrated

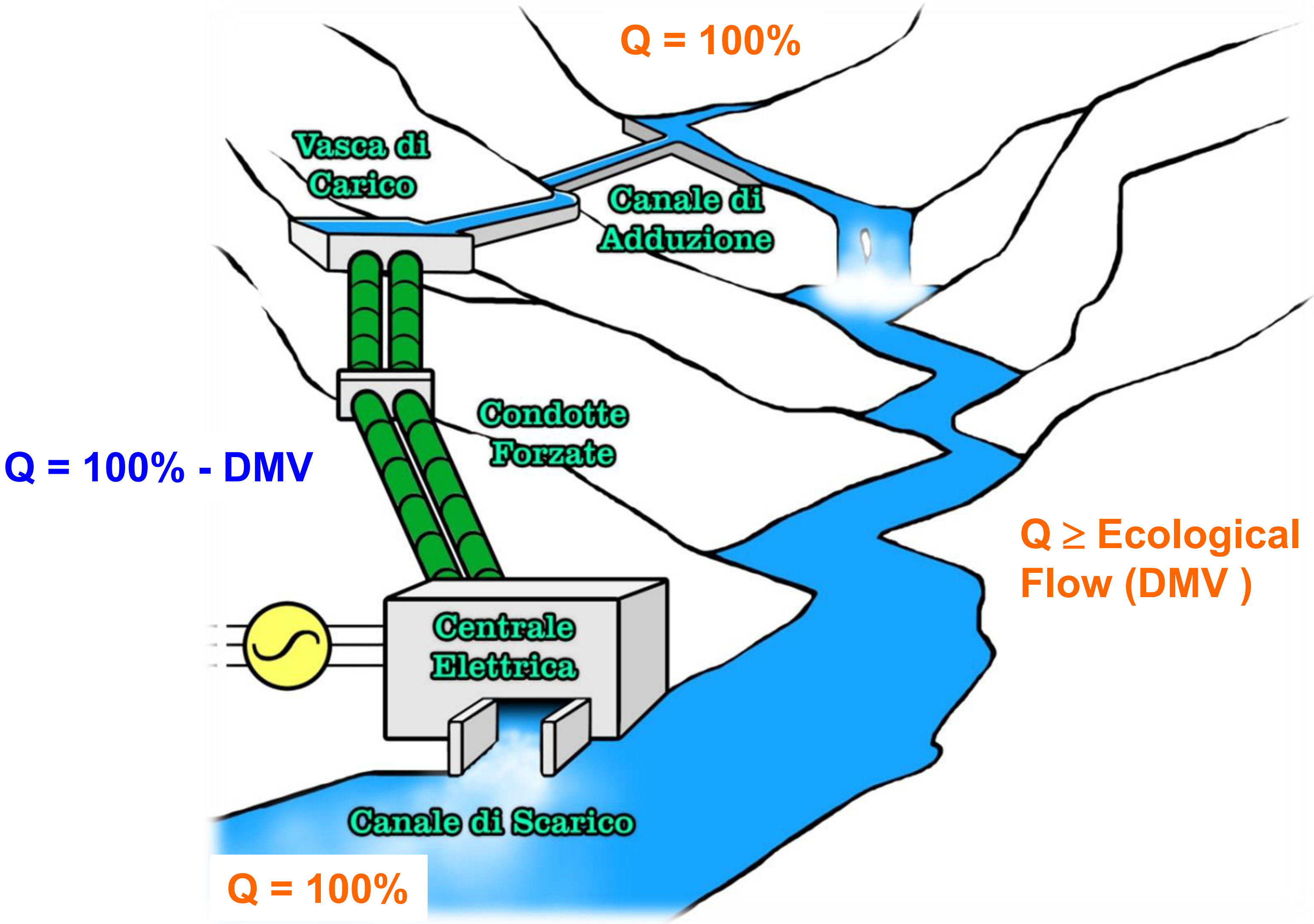
A = intake point
B = discharge point





I classification: diversion channel

A = intake point
B = discharge point



Ecological flow :

Maintains the essential processes required to support healthy river ecosystems

I classification:
diversion channel

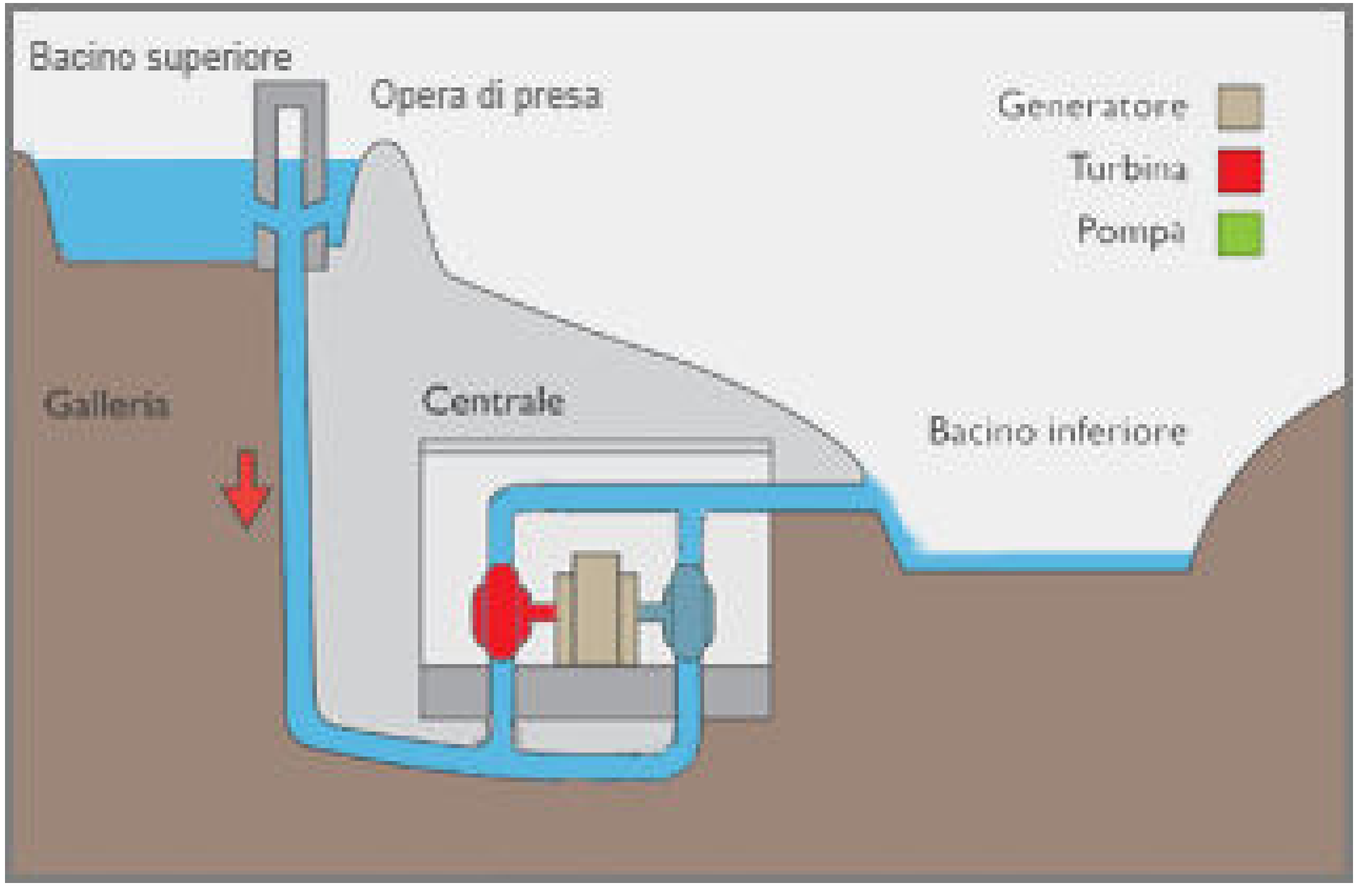
Video

https://www.youtube.com/watch?v=S3MQJSDoTuw

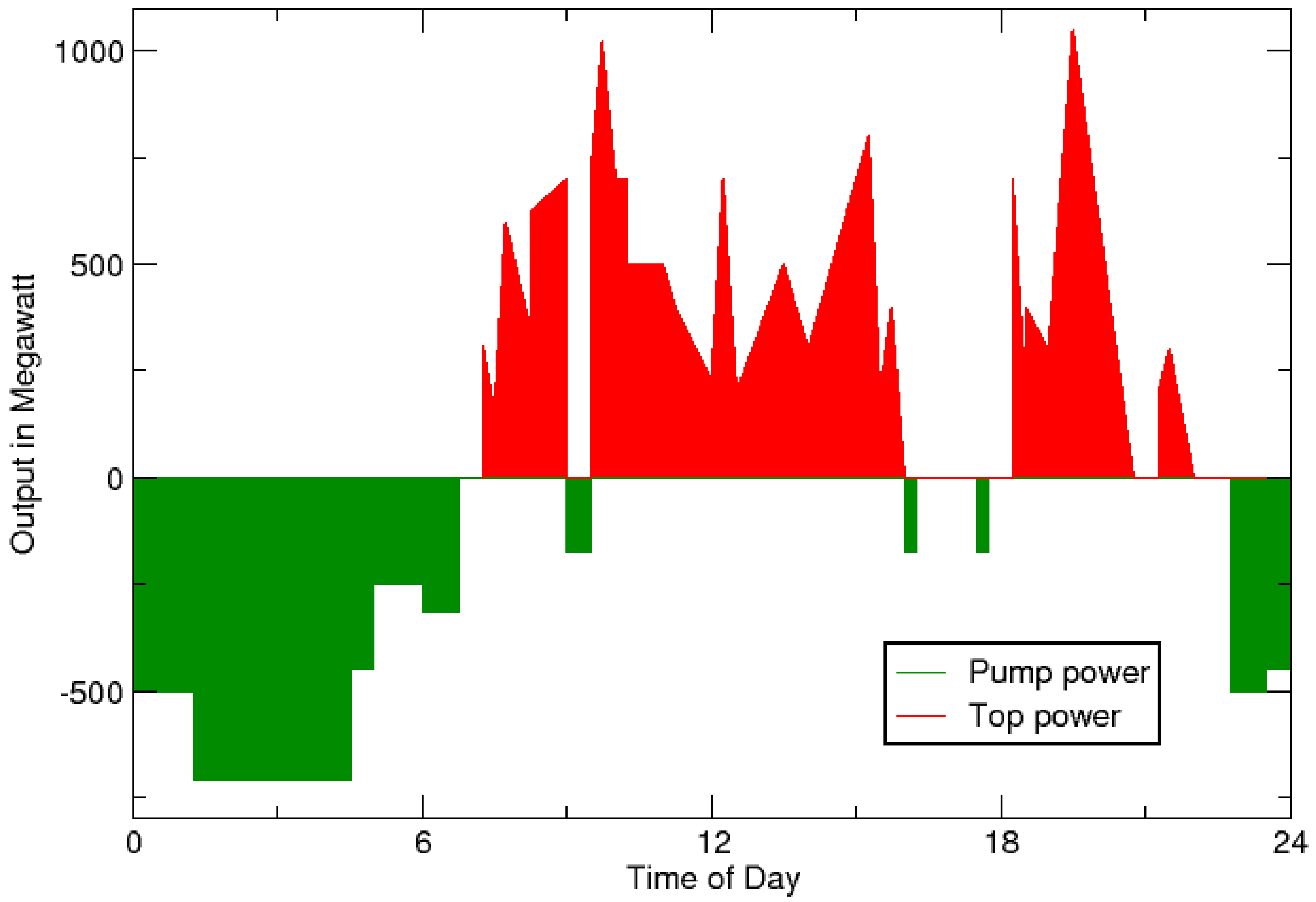
II classification: water storage

- Run-of river plants: filling rate < 2h
- Storage plants: filling rate > 2h
- Pumped hydro

II classification: water storage



II classification: water storage



III classification: hydraulic head

- **High head (>100m)**
  diversion channel needed (both storage or run-of-river)

- **Medium head (30 – 100 m)**
  diversion channel needed (both storage or run-of-river)

- **Low head (2 - 30 m)**
  both weir-integrated (very low head) or with diversion channel
  in most cases run-of-river

Plant overview

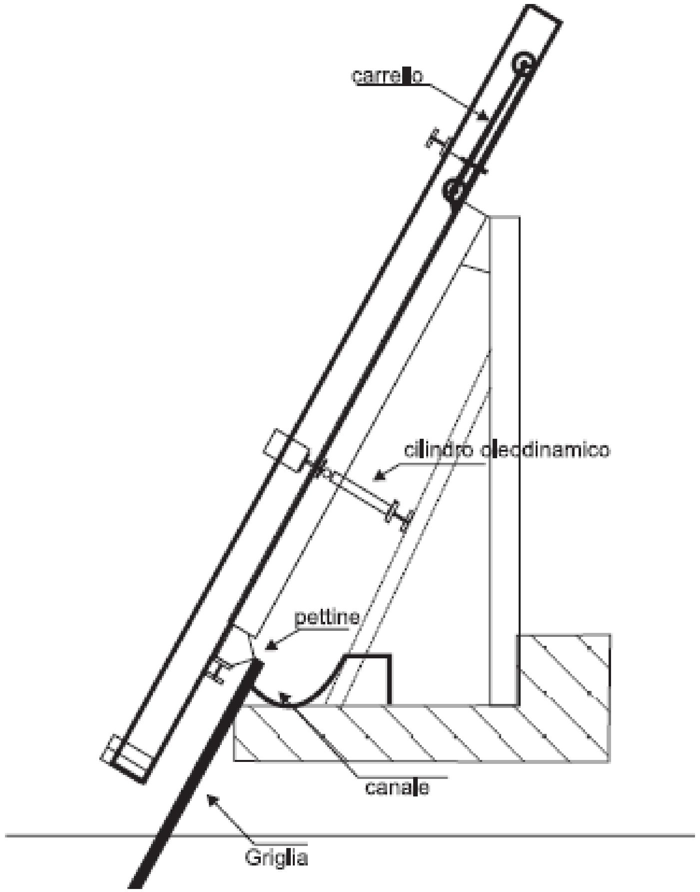
Intake weir (Enel – Agordo)

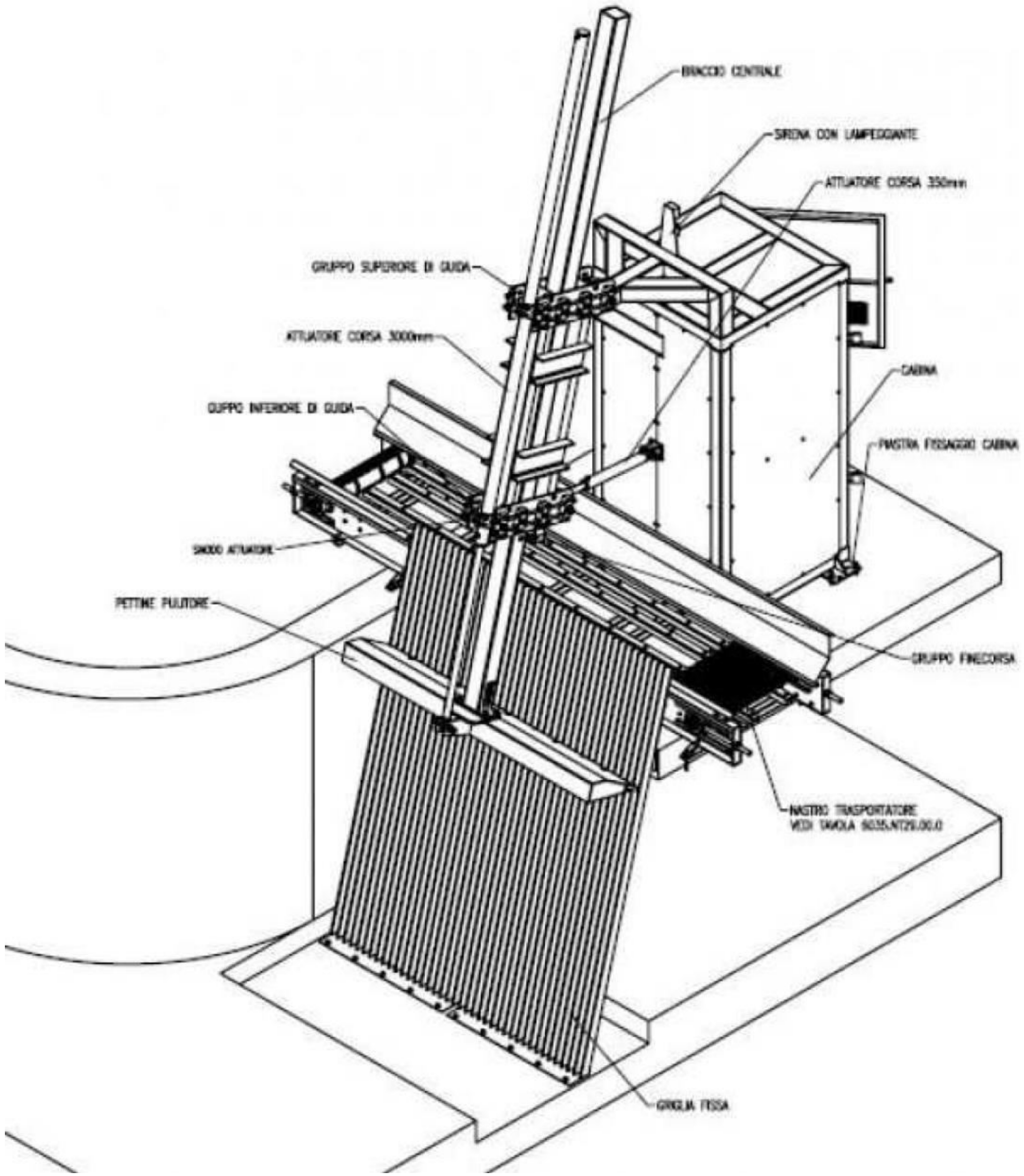
Plant overview

Intake weir (Enel – Agordo)

Plant overview

Metal screen (beginning of diversion channel)





Plant overview

Metal screen

(beginning of diversion channel)

Plant overview

Concrete diversion channel

Plant overview

Penstocks

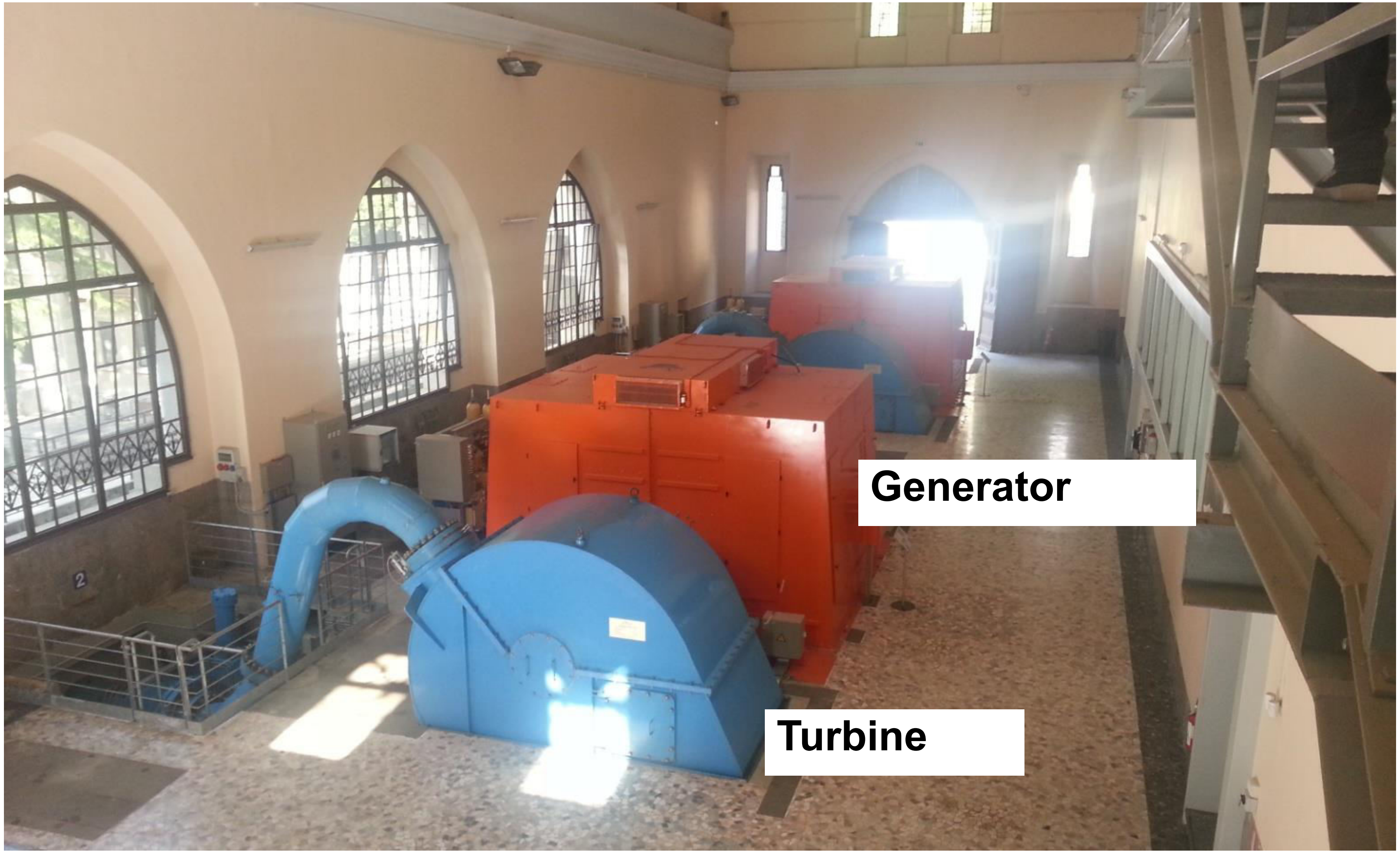
Plant overview

Powerhouse

Plant overview

Penstock inlet in the powerhouse

Plant overview

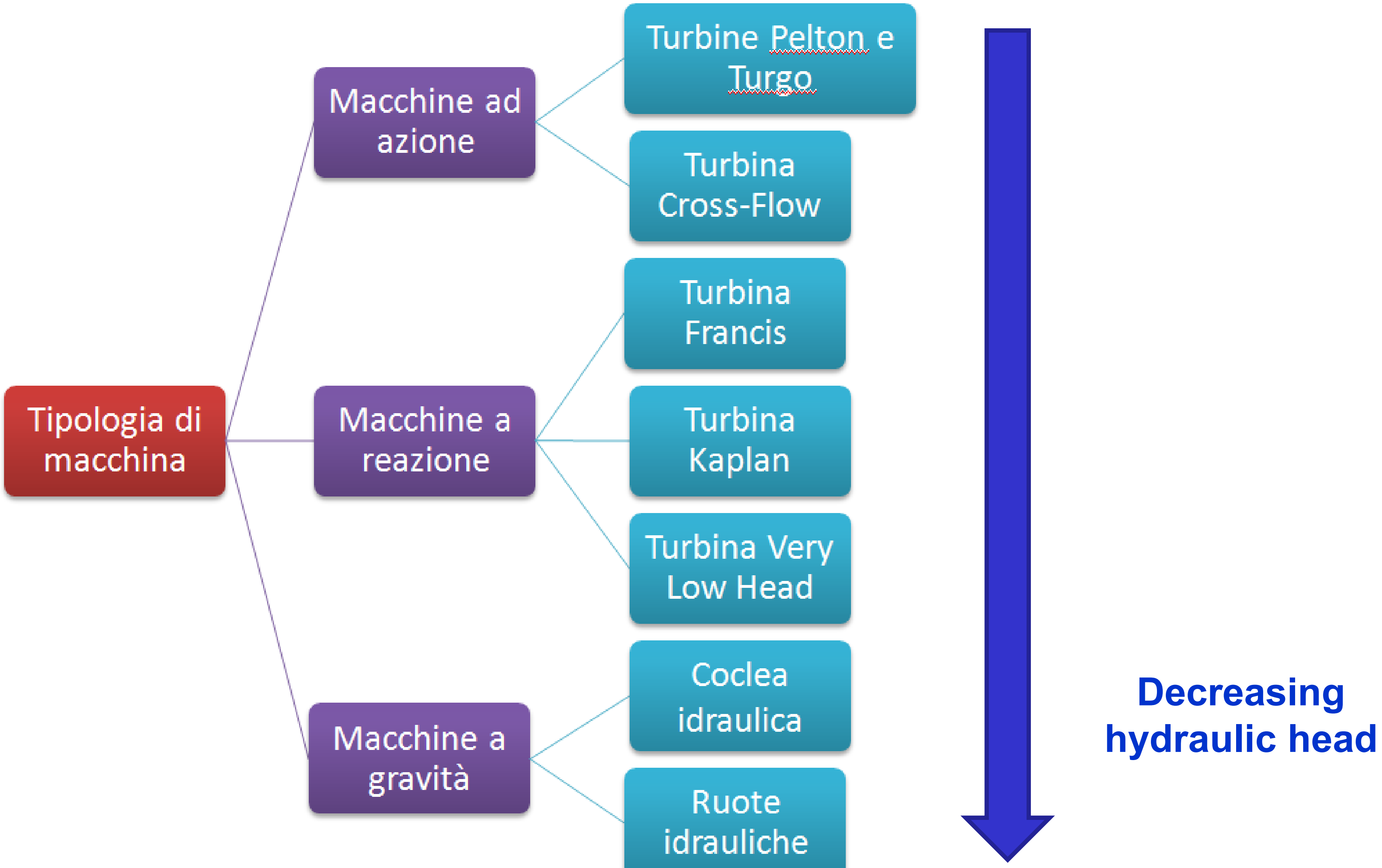


Powerhouse (pelton turbines)

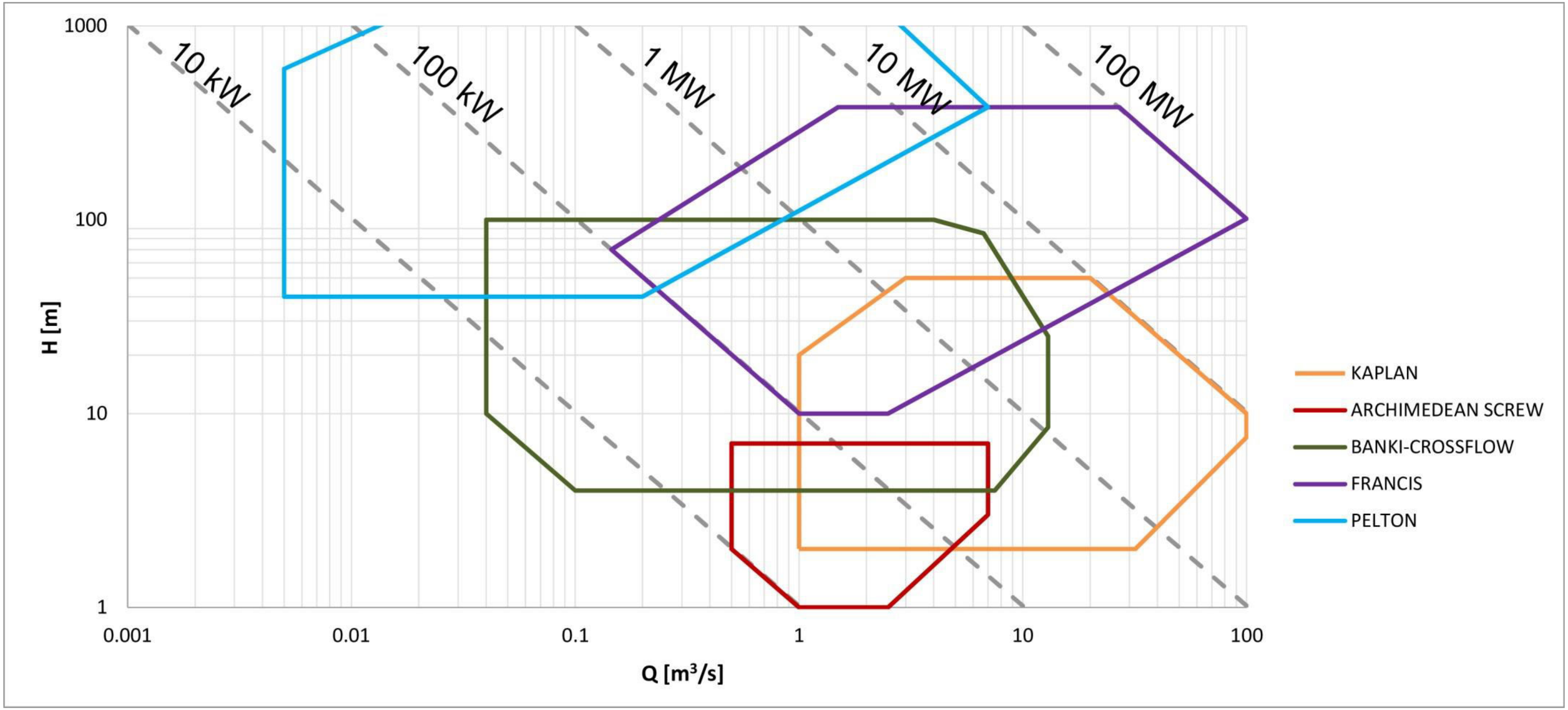
Plant overview

Tailrace channel

Hydraulic machines



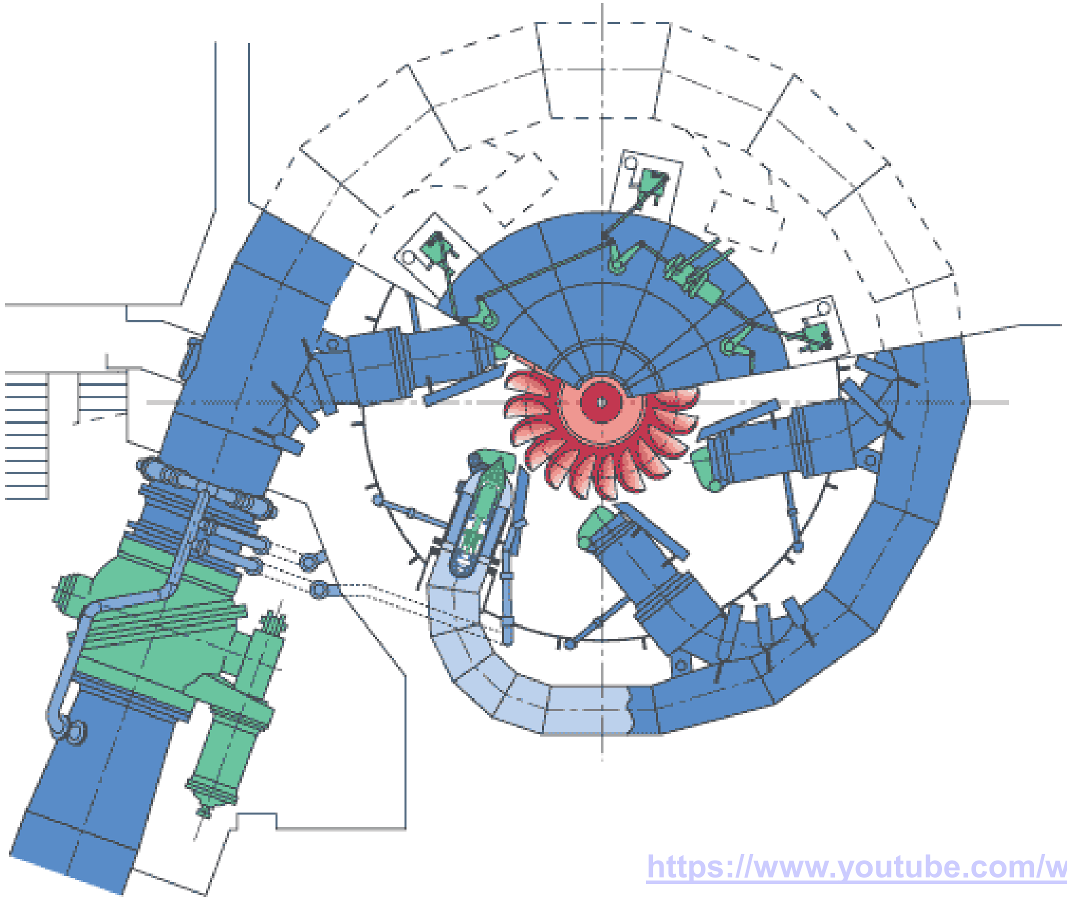
Hydraulic machines



Pelton turbine

High head: 60 - 1300 m

Relatively small flows: 0.02 - 7 m^3/s

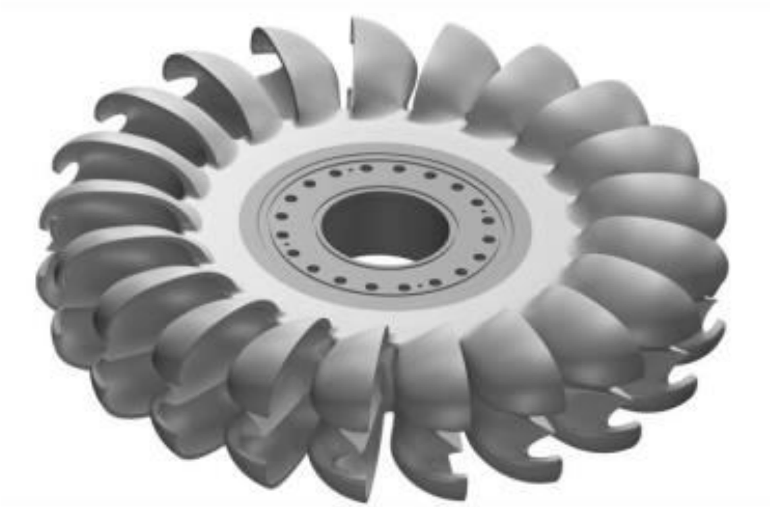


Video

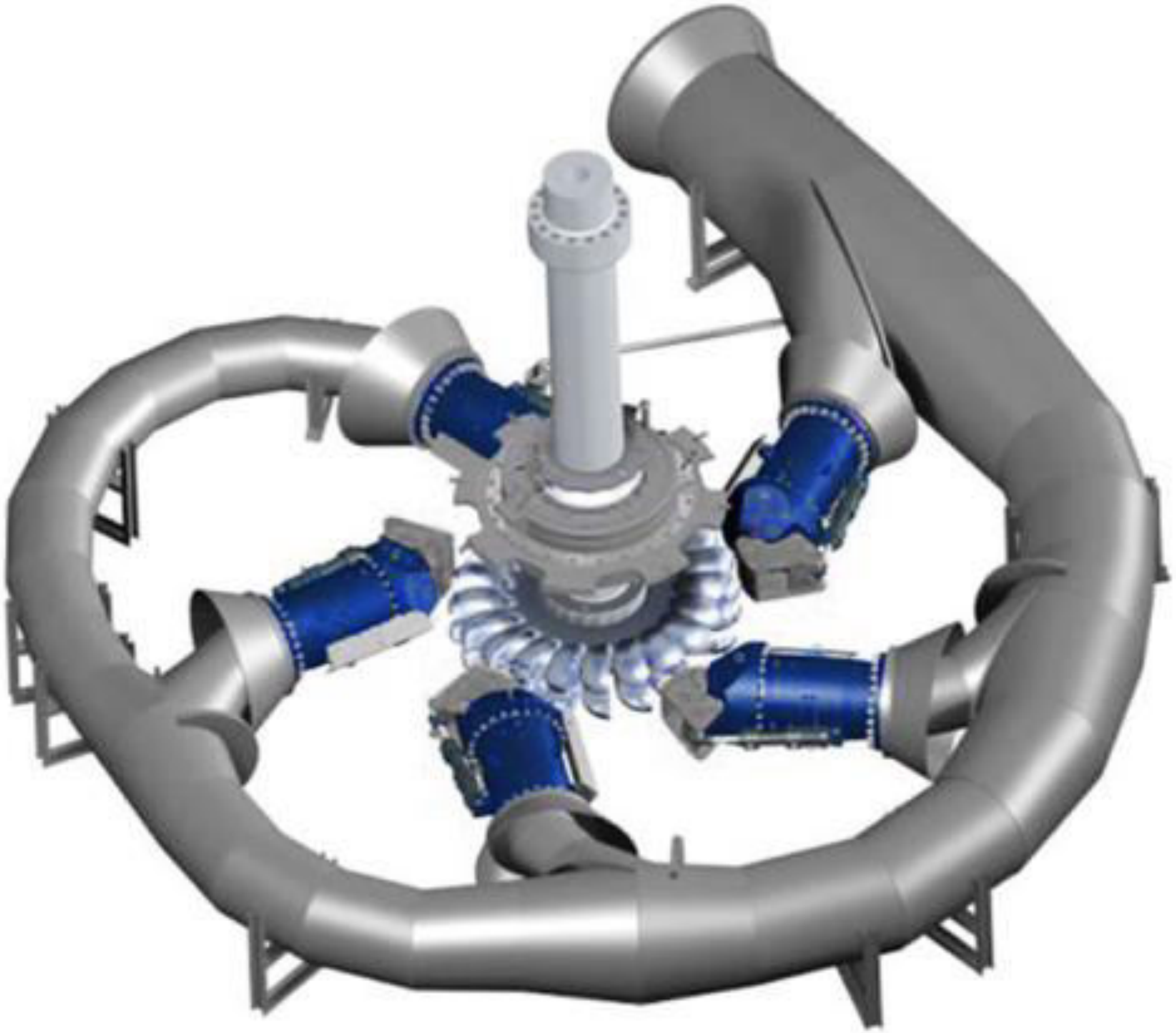
https://www.youtube.com/watch?v=3PoeMQeHePo

Pelton turbine

Vertical axis, multiple jet turbine

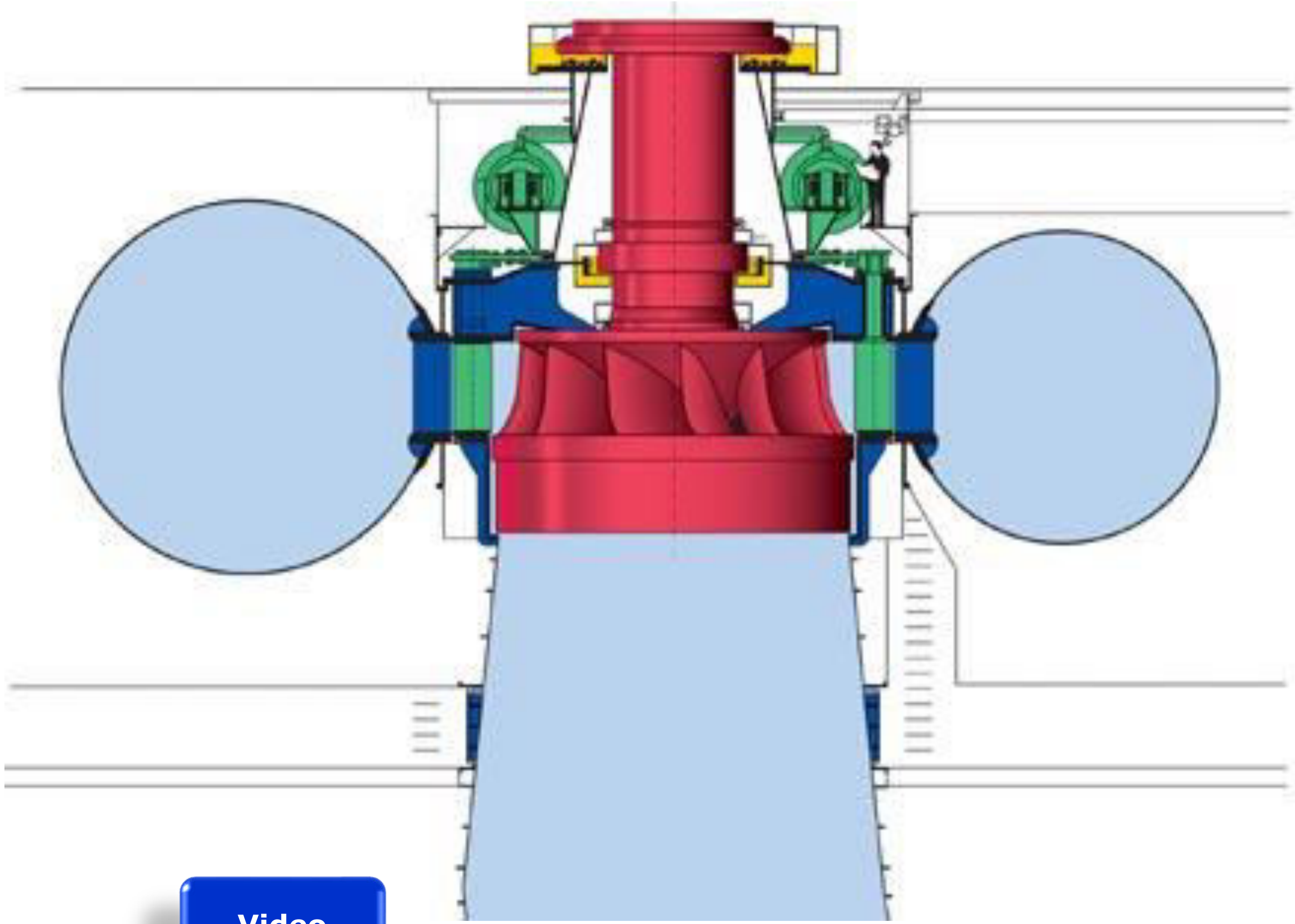


b)



Francis turbine

- Reaction turbine
- Up to very high flows per single turbine 2-100 m^3/s
- Head: 20 – 500 m
- Firstly introduced in 1849
- Low efficiency at partial loads
- Susceptible to cavitation



Video

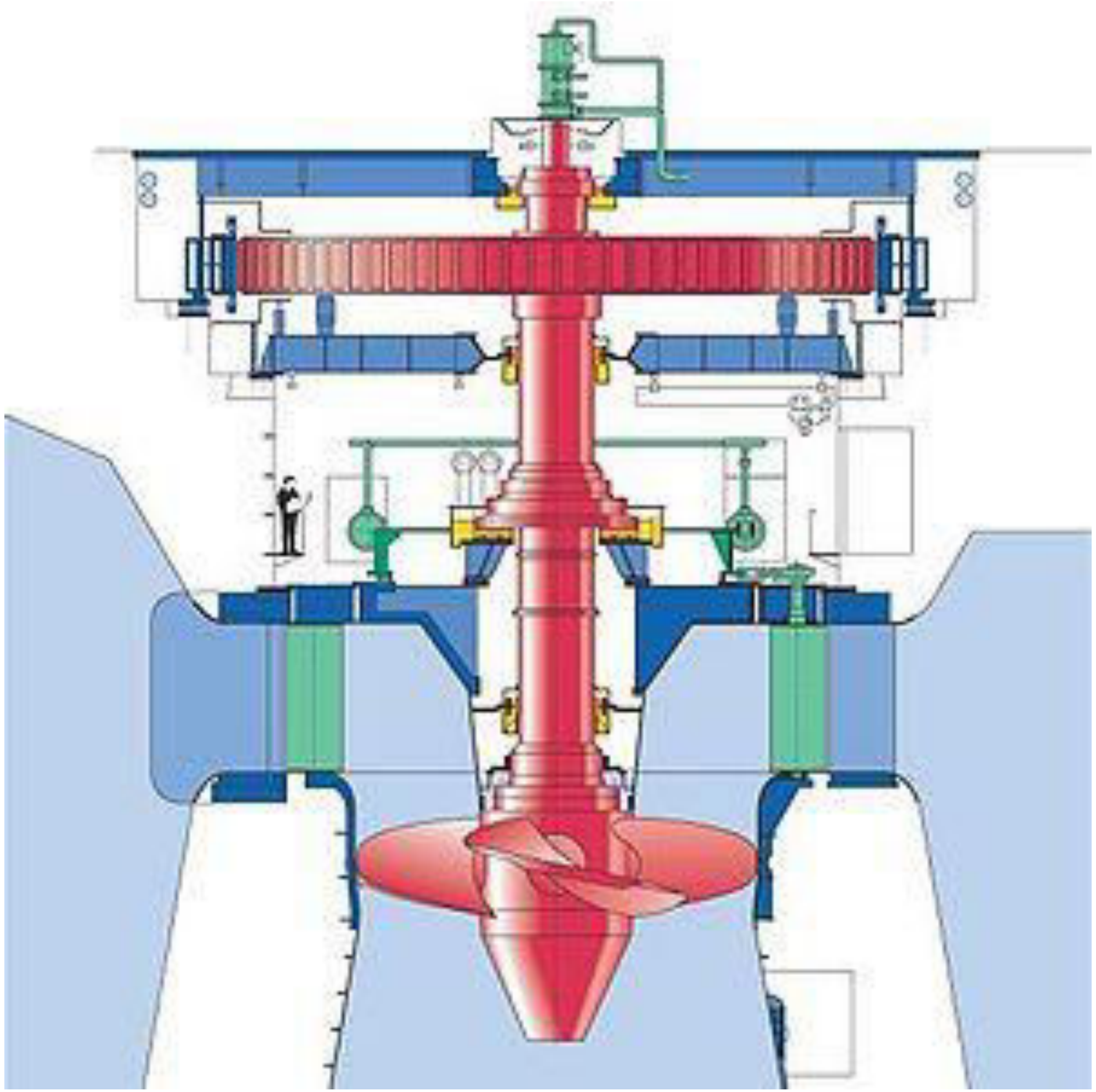
https://www.youtube.com/watch?v=pbliwh4-R2I

Kaplan turbine

- Reaction turbine

- Up to very high flows per single turbine 2-100 m^3/s
- Head: 2.5 – 40 m
- High efficiency at nominal flow-rate

- Expensive regulation devices required to achieve good partial load efficiency
- A well shaped diffuser is required
- Susceptible to cavitation



Video

https://youtu.be/0p03UTgpnDU

Kaplan turbine

LARGE BULB TURBINES FOR TIDAL STREAM EXPLOITATION

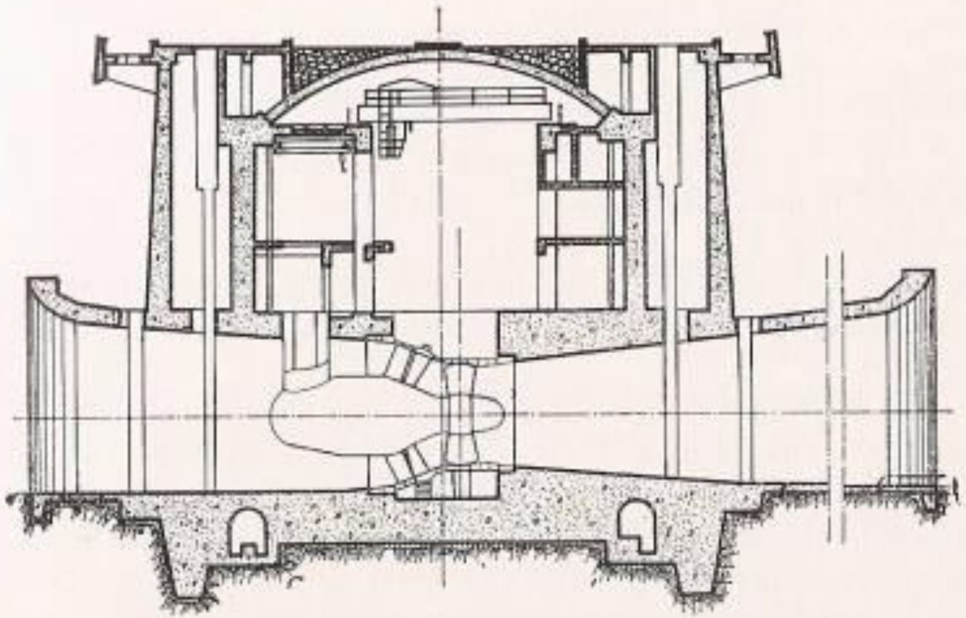


Fig. 40. - Sezione longitudinale della centrale della Rance con gruppi reversibili da 10 000 kW. ($H = 11$ m; $Q = 110$ m³/s; $n = 94$ giri/min).

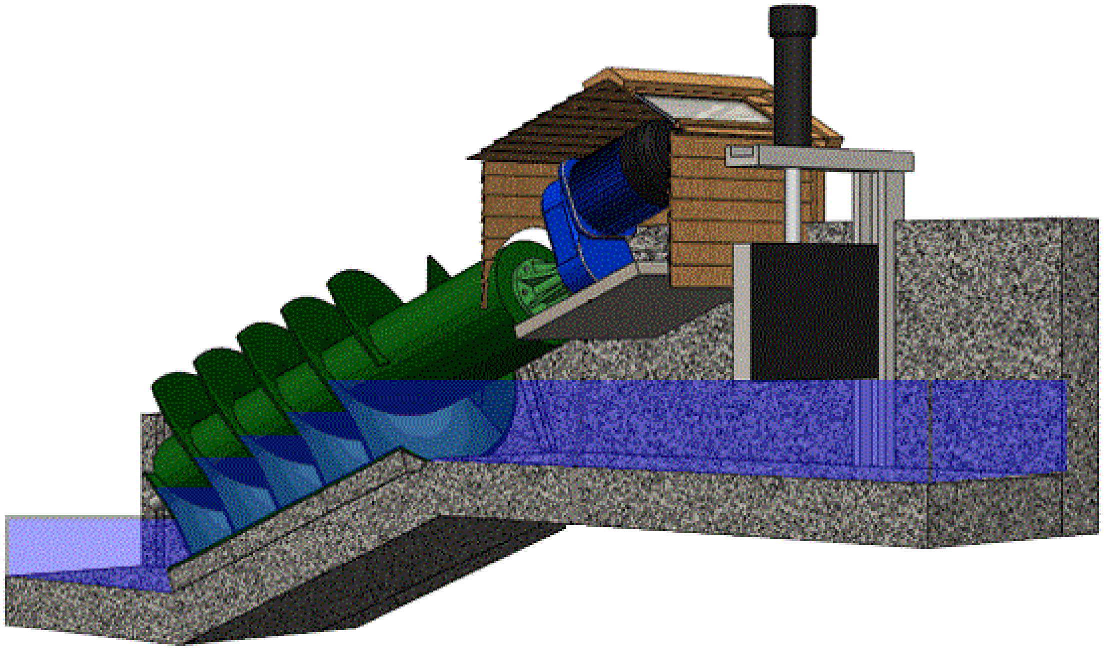
The oldest one in France……

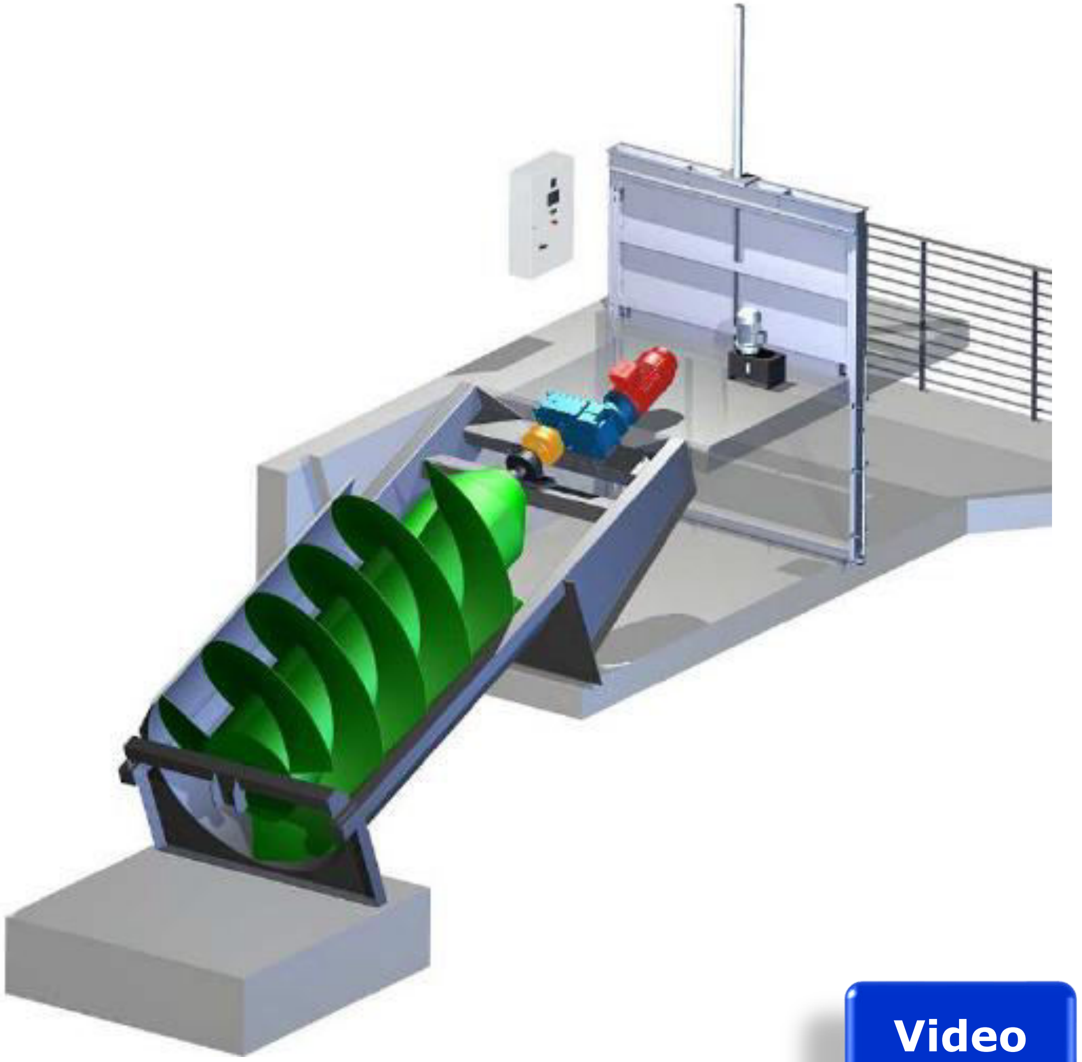
LA RANCE, FRANCE

- 24 x 10 MW
- Runner diameter 5,35 m
- Built 1961 - 1967
- Multiple mode operation
- Pump-turbines for both flow directions
- Successful operation since 40 years !
- Basin area 22 km²

Archimedes Screw Generator (ASG)

- Positive displacement machine
- Working range H = 1 – 6m
  Q < 7 m^3/s

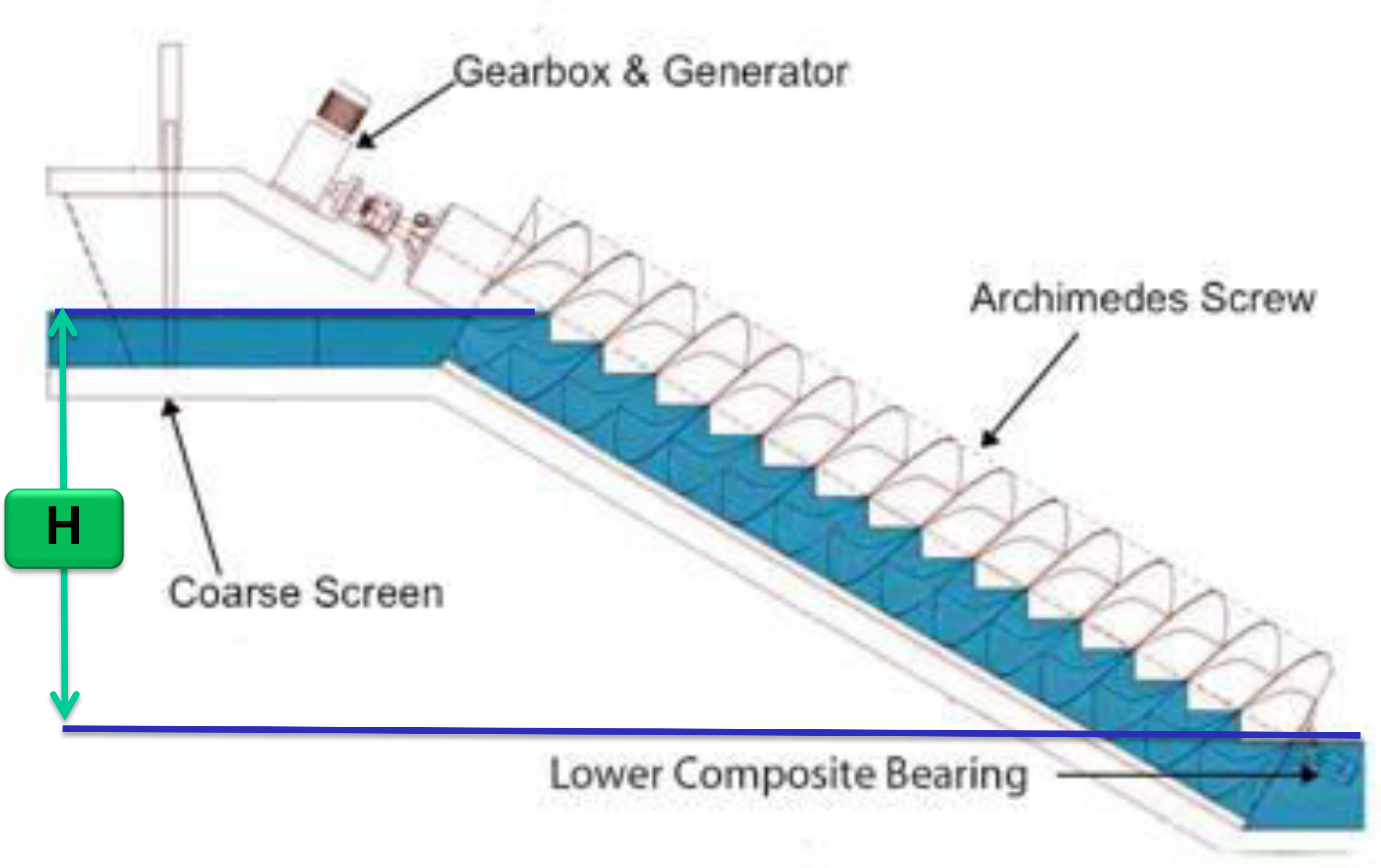




Video

https://www.youtube.com/watch?v=bGViZ4p3Fuw

Archimedes Screw Generator (ASG)

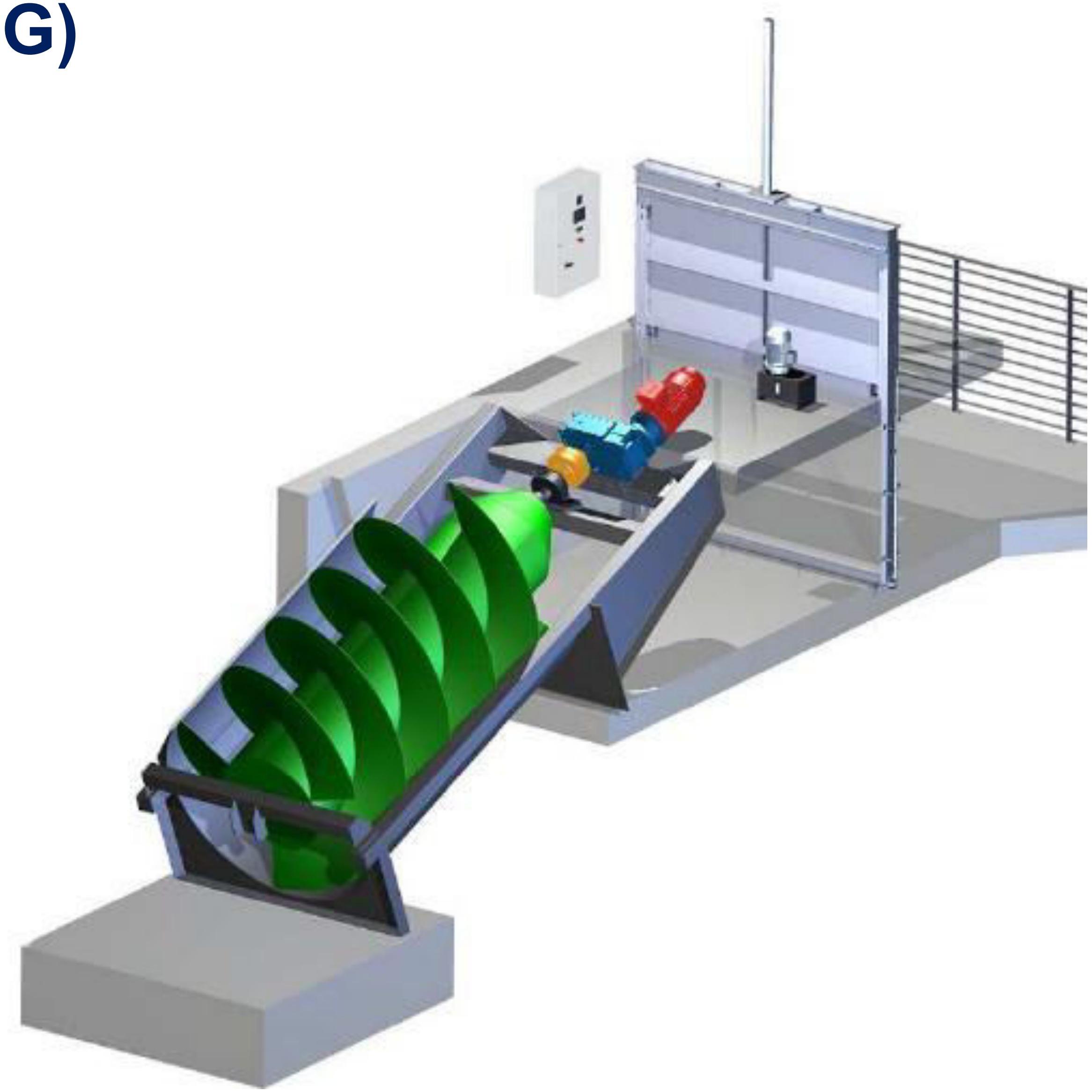


Archimedes Screw Generator (ASG)

- Positive displacement machine
- Working range H = 1 – 7m
  Q < 7 m^3/s

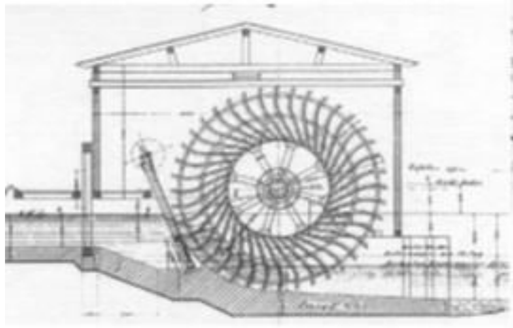
- Low speed – long lasting mechanics
- High efficiency at partial load
- Possible transit of debris
- Low cost and low maintenance
- Reduction of civil works
- Fish-Friendly (downstream dir.)
- Cost < Kaplan and VLH

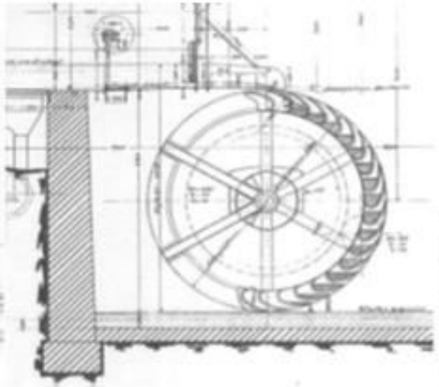
- Limited flow and head range
- Efficiency < than Kaplan @ Qn
- Visual impact

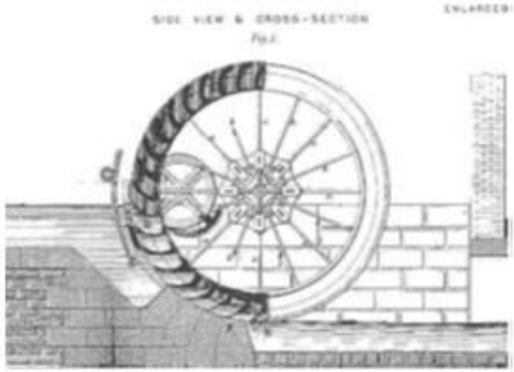


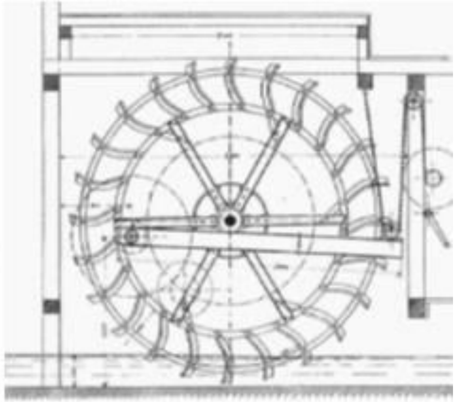
Hydraulic Wheels

Undershot | Overshot | Breastshot | Stream wheel









- Simple and robust hydraulic machine
- Low specific power
- High specific costs (€/kW)

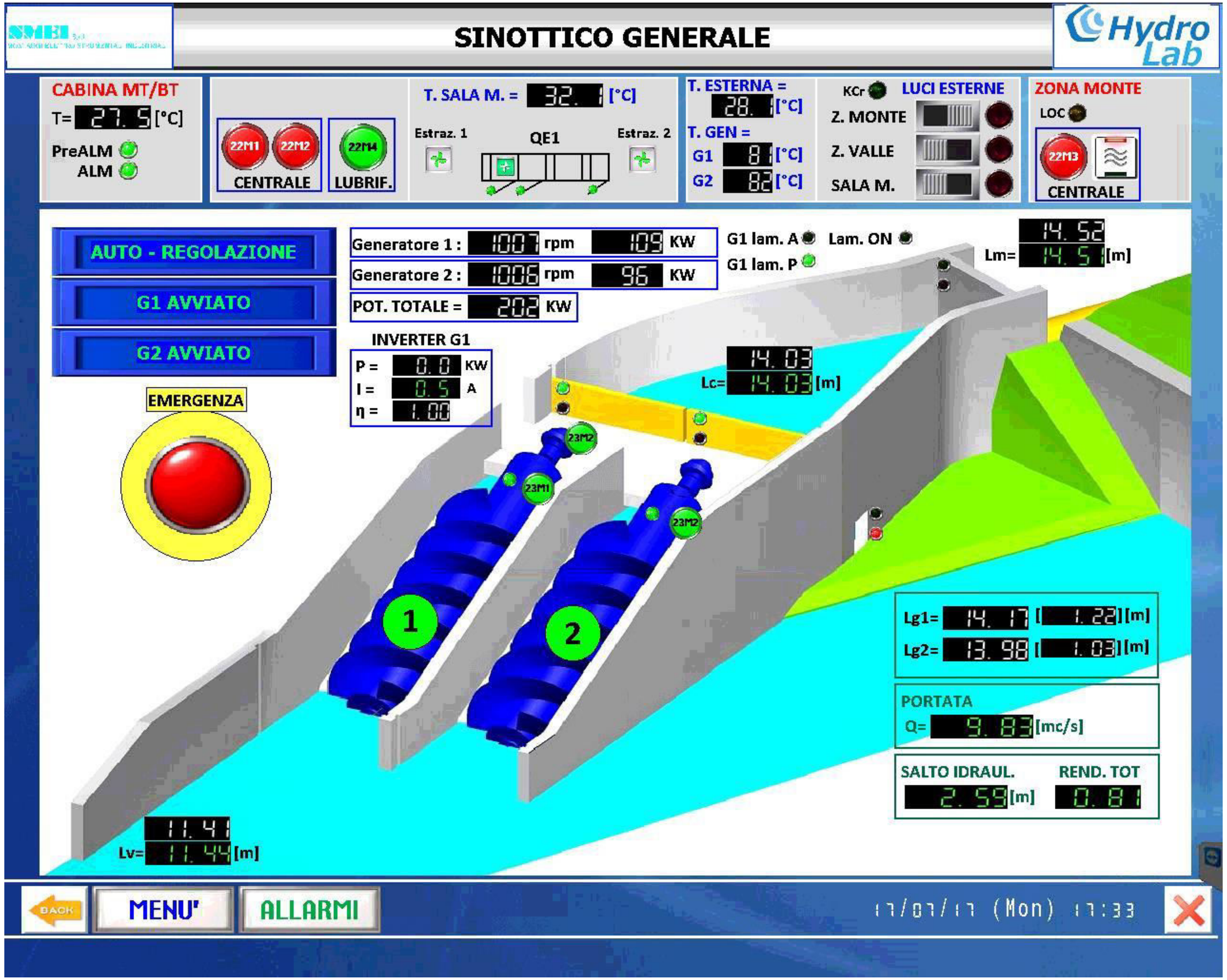
Case study Archimedes Screw Generator

Case study Archimedes Screw Generator

Case study Archimedes Screw Generator

Case study Archimedes Screw Generator

Example of remote control system



Choice of the turbine

HPP DESIGN

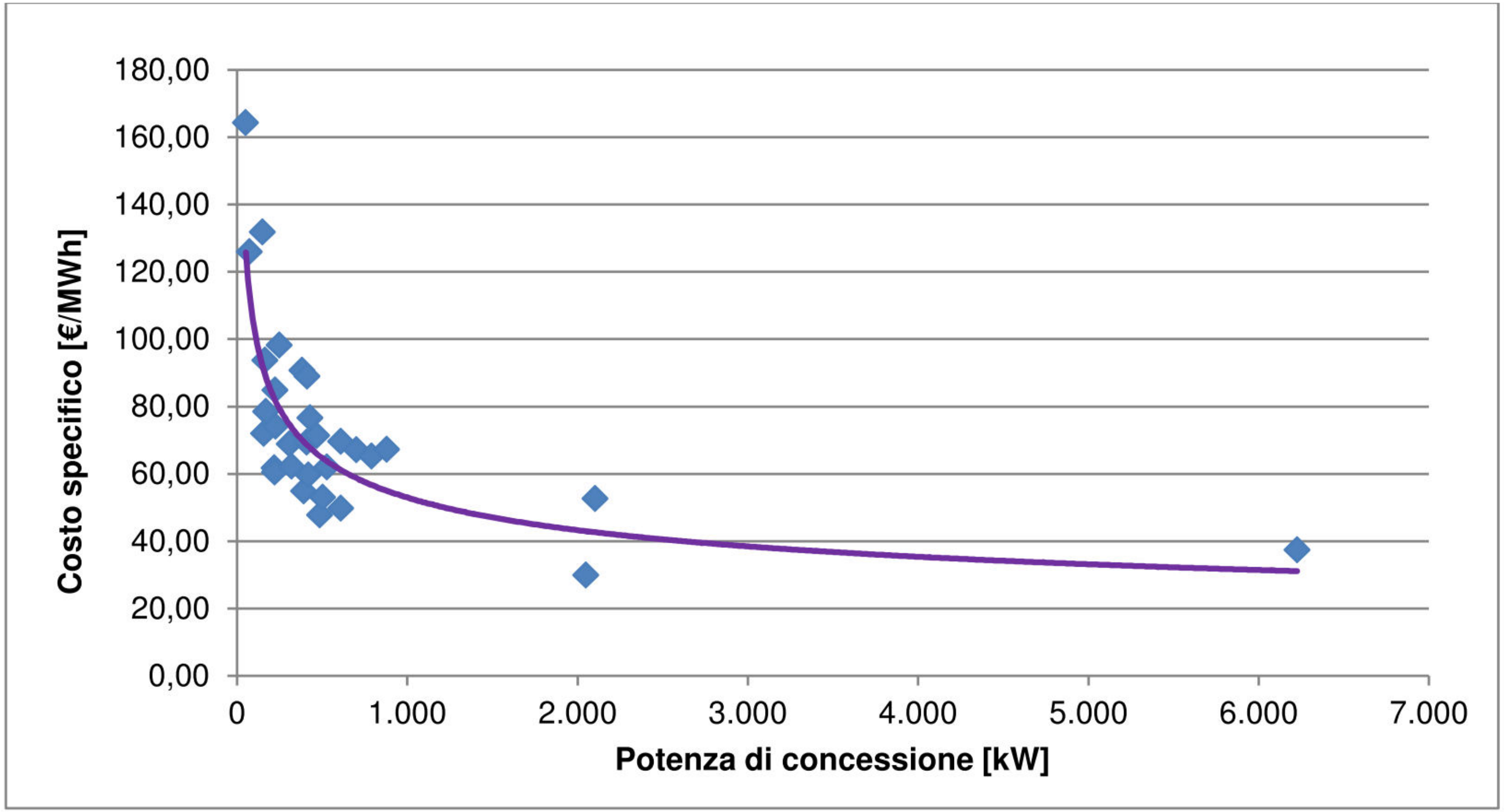
https://hpp-design.com/

Cost of the plant

The specific cost (€/kWh) of an hydro power plant is normally higher than other RES due to the big civil works required but the capacity factor could be very high

- **Civil cost: 30% - 70%**

Cost of the plant - LCOE



REFERENCE: APER, 2013

Conclusions

Benefits:

- Clean energy production
- High number of equivalent hours (high energy production to installed power ratio)
- Programmable (storage plants) or predictable (run-of river plants) energy production with smooth power variations.
- High investment cost on one hand, but very long service life and low O&M costs on the other hand.
- EU potential for revampings and small-hydro

- Environmental impact to be carefully evaluated

Critical points:

- Permitting procedure (high costs, long times, uncertain result)
- High specific cost for small plants (up to 10'000 €/kW)

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Thank you!

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Levi Cases

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IEEE Industrial Electronics Society
IES Italy Chapter

ALOT INNOVATION FOR SUSTAINABILITY