Water Resources Engineering and Management

(CIVIL-466, A.Y. 2024-2025)

5 ETCS, Master course

Lecture 5-1: Hydropower and energy production

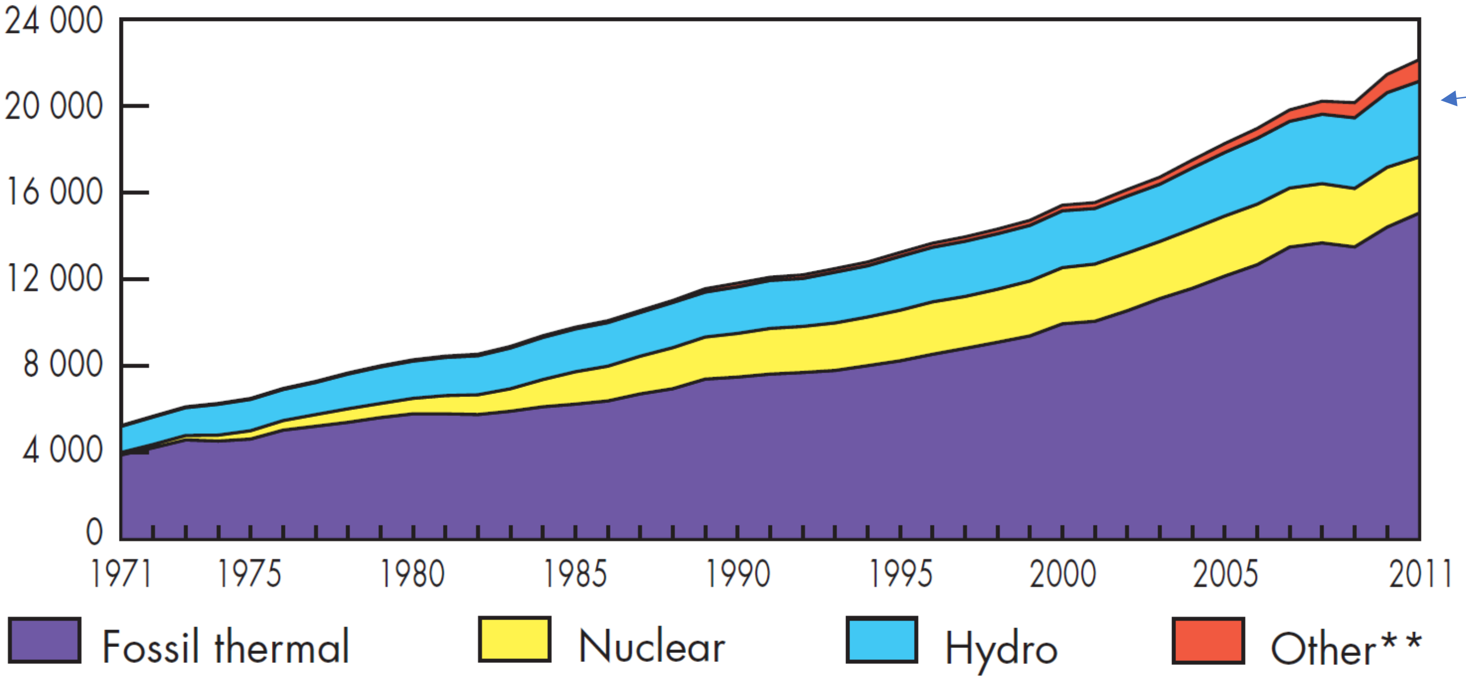
Prof. P. Perona

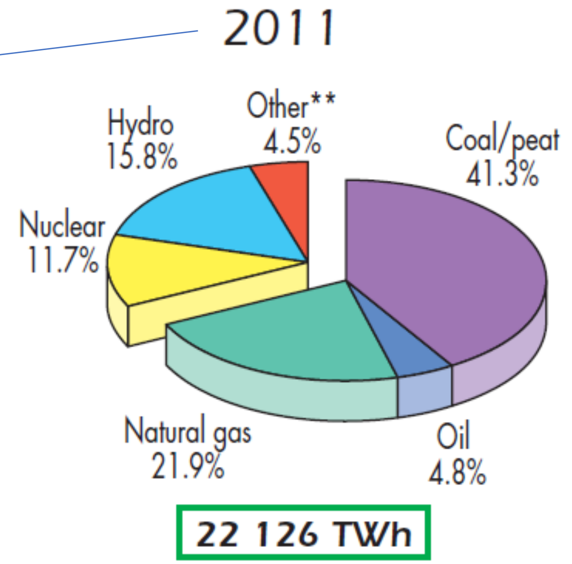
Platform of hydraulic constructions

Traditional water uses: Energy production

World electricity generation (1971-2011), in TWh

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

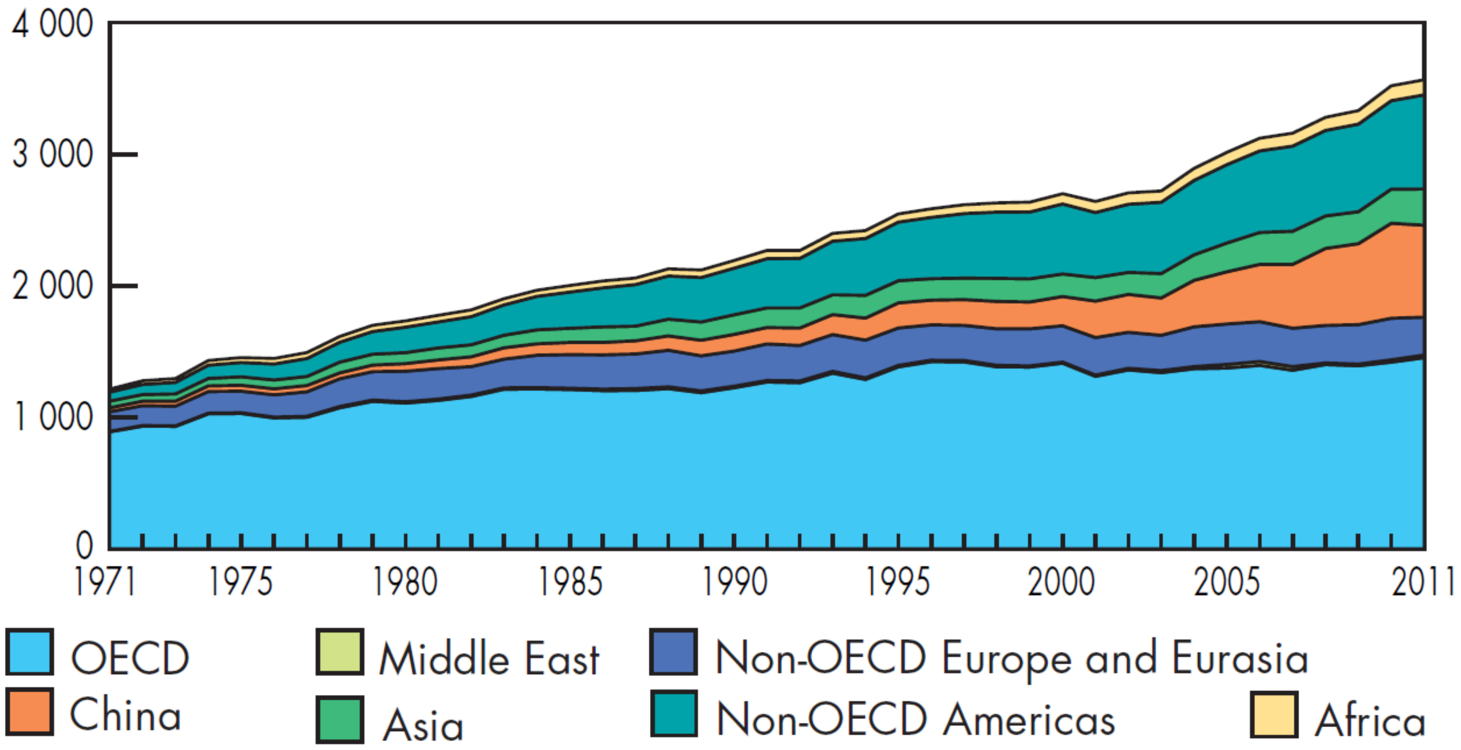


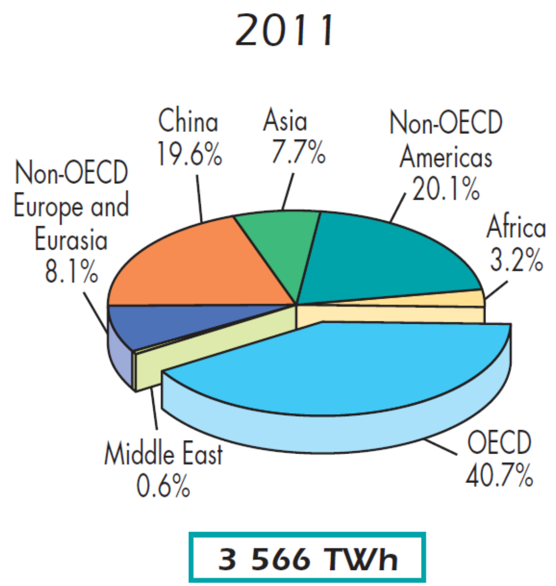


**Other includes geothermal, solar, wind, biofuels

Courtesy of A. Rinaldo

Hydropower production (1971-2011), in TWh





OECD: Organization for Economic Co-operation and Development

Courtesy of A. Rinaldo

By countries

installed power

Net installed capacity	GW
People's Rep. of China	194
United States	101
Brazil	81
Canada	75
Japan	48
Russian Federation	47
India	38
Norway	30
France	25
Italy	22
Rest of the world	338
World	**999**

yearly energy production

Producers	TWh	% of world total
People's Rep. of China	699	19.6
Brazil	428	12.0
Canada	376	10.5
United States	345	9.7
Russian Federation	168	4.7
India	131	3.7
Norway	122	3.4
Japan	92	2.6
Venezuela	84	2.3
Sweden	67	1.9
Rest of the world	1 054	29.6
World	**3 566**	**100.0**

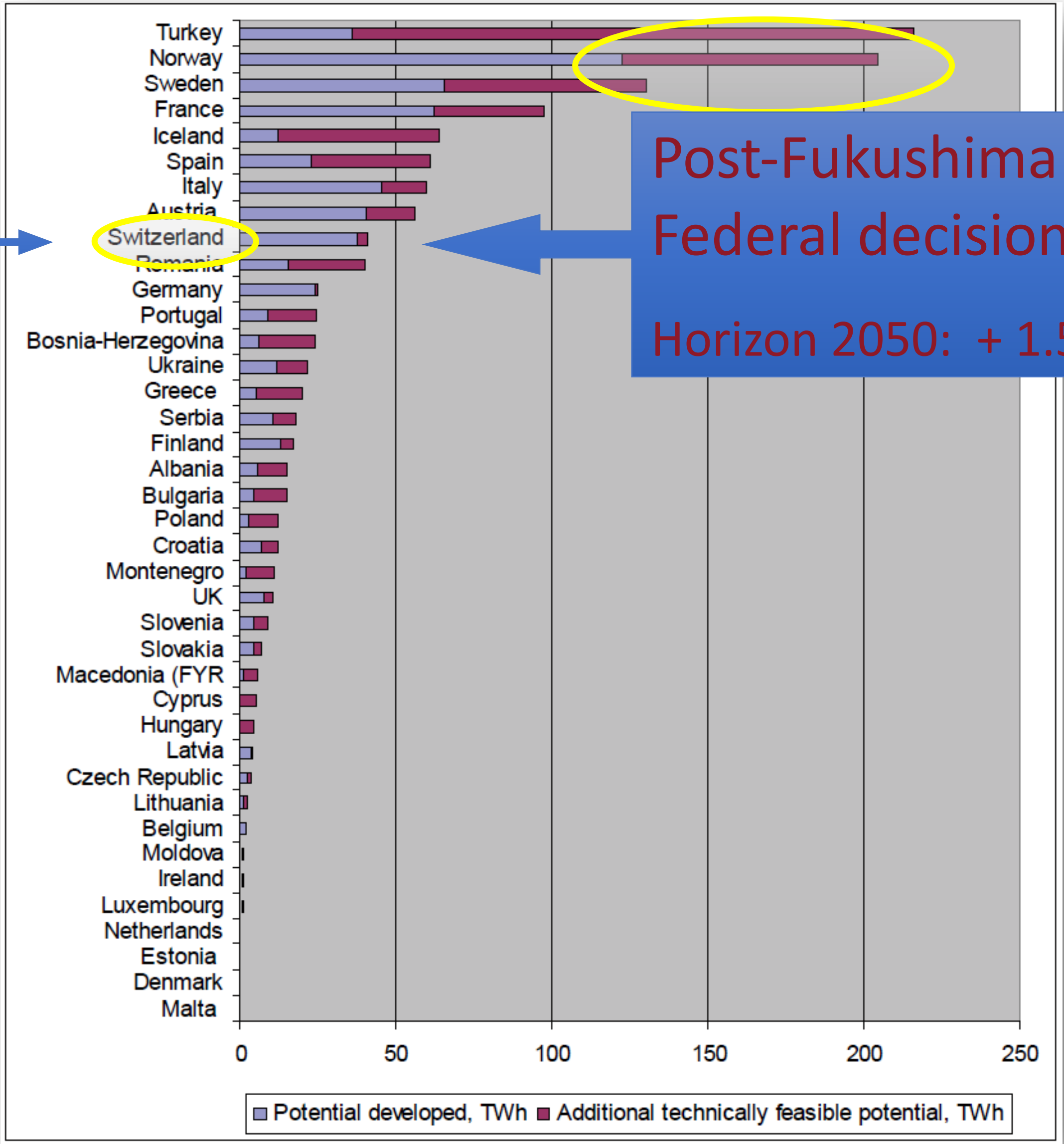
plant factor: ratio between the actual and the potential energy production

Courtesy of A. Rinaldo

Potential vs feasible potential (Europe)

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

SWITZERLAND



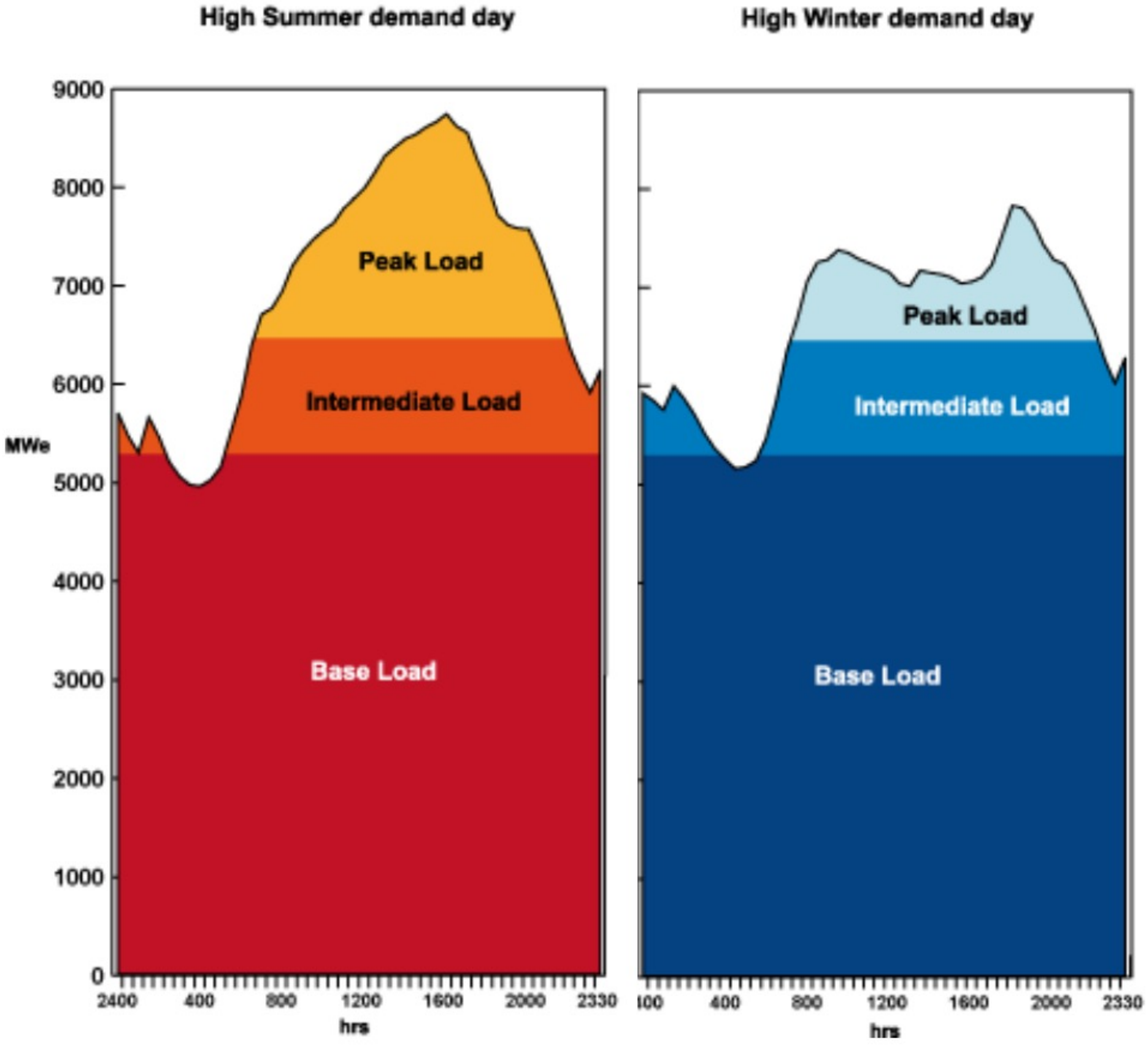
Post-Fukushima
Federal decision 2012

Horizon 2050: + 1.5 ÷ 3.2 TW

Existing and potential future energy production from hydropower in Europe

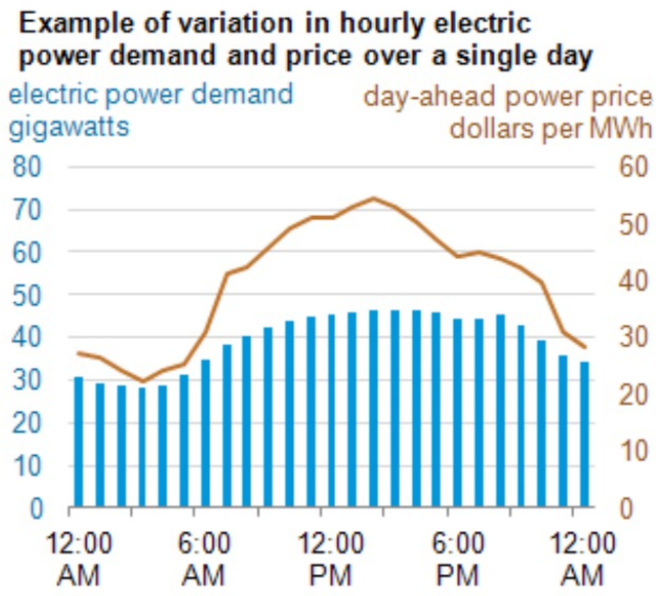
Source : World Hydro Atlas Industry Guide (2010)

Hydroelectric generation: daily electricity demand



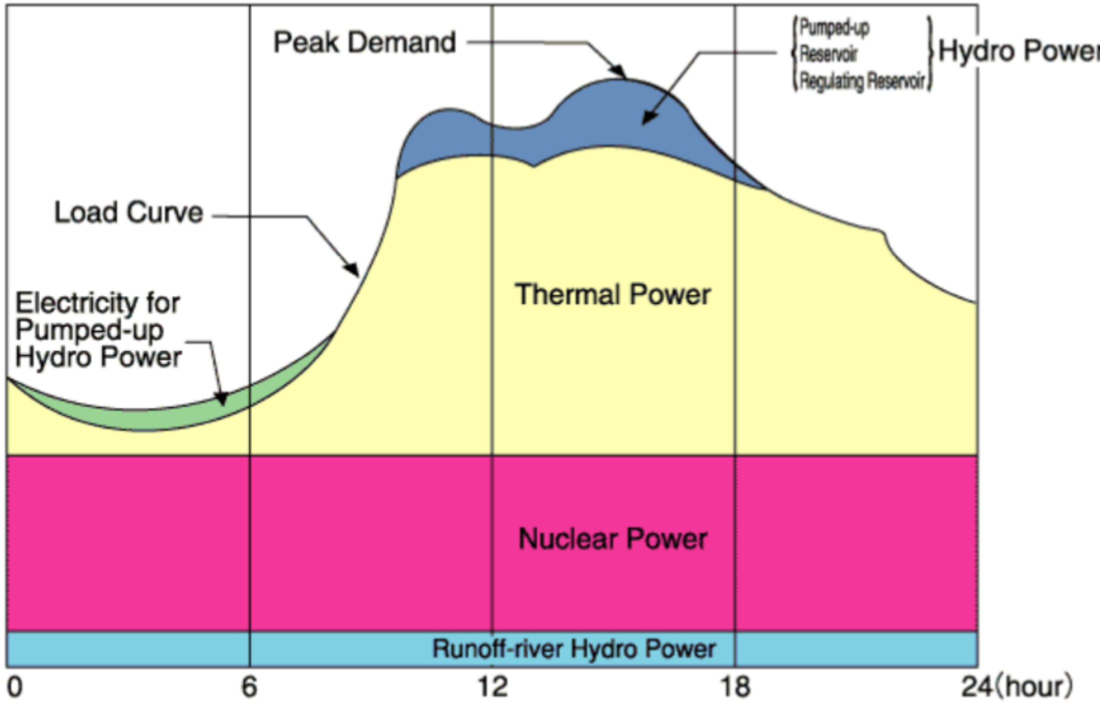
Electrical energy cannot be efficiently stored, therefore it needs to be produced when demanded.

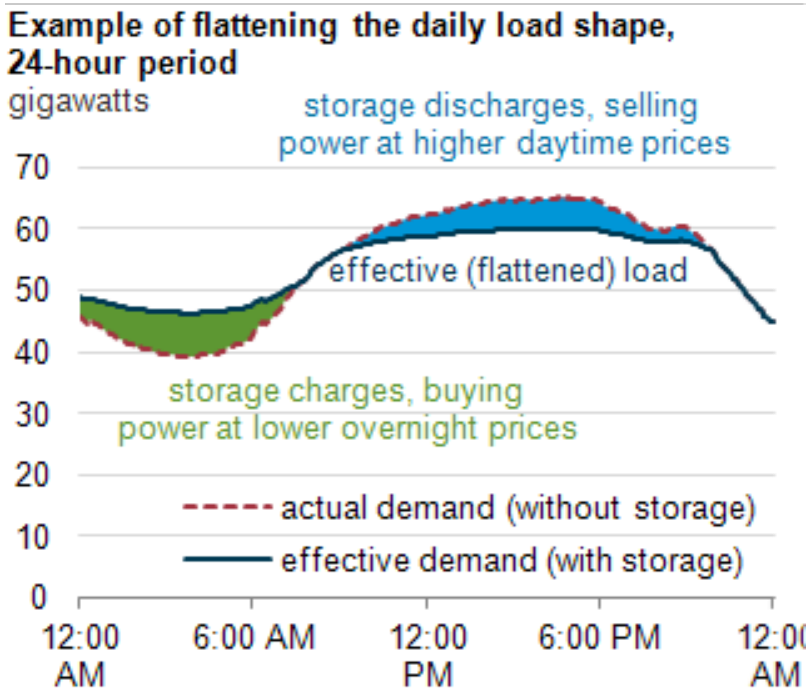
Typical plant factor of hydropower plants is low (20-40%) because they are used to cover the peak demand (when the price is higher) being extremely quick in starting and shutting down.



Courtesy of A. Rinaldo

Hydroelectric generation: meeting energy demand





The excess of energy produced during night (at low selling price) can be stored as potential energy pumping water to an elevated reservoir.

Hydroelectric power plants with the possibility to pump water back to the upper reservoir are called "pumped storage".

Courtesy of A. Rinaldo

Hydropower schemes

Traditional hydropower with storage

Type: partially-consumptive (evaporation); large upstream reservoir to store water and regulate the water release to face daily, seasonal and interannual fluctuations of input streamflow and energy demand.

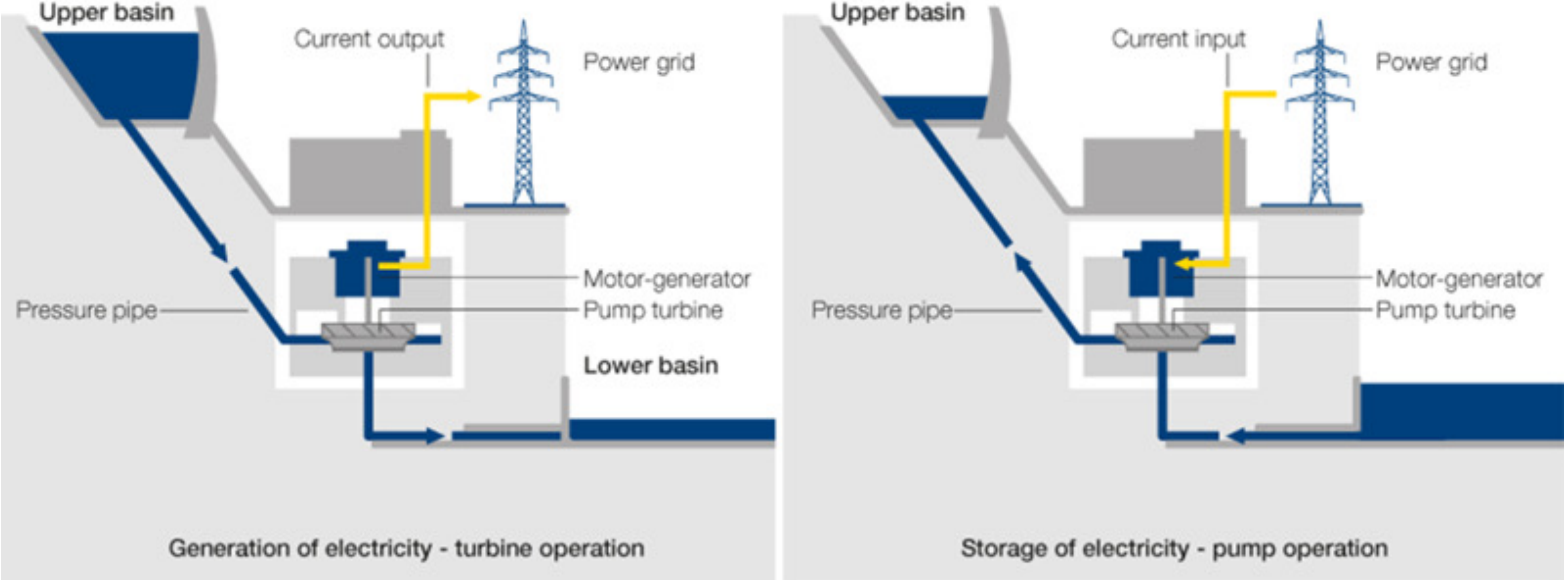
Gravity concrete dam: solid concrete structure that uses its weight to withstand the hydrostatic force exerted by the water.

Concrete arch dam has a curvature design that arches across a canyon. The arch distributes water pressure to the canyon walls. They require less concrete than the gravity dam but they must have solid rock walls as anchors.

Earthen embankment dam consists of compacted earth material with a core of clay or low permeable material to avoid seeping.

Hydropower scheme

Traditional hydropower with storage and pumping

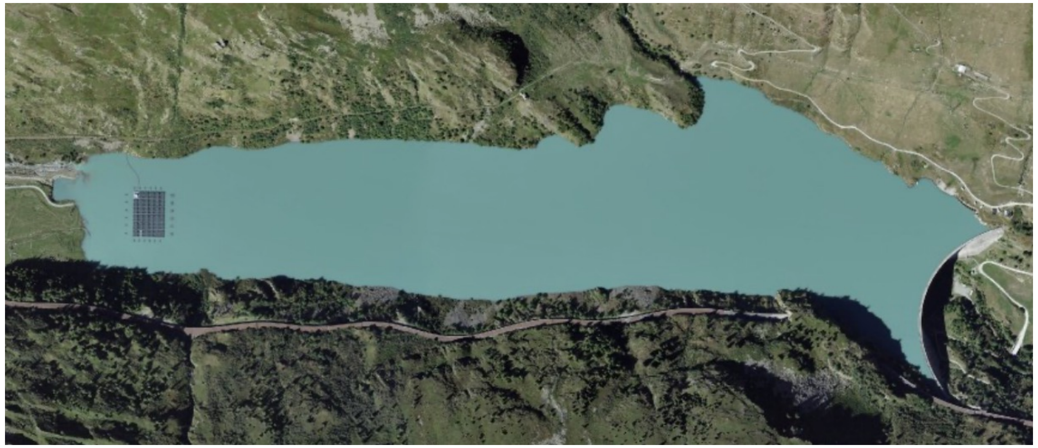


Scheme of a pumped-storage power plant. In this example, the same hydraulic machine can operate as a turbine or as a pump. In other cases separate machines (a pump and a turbine) are connected to the same motor- generator.

New solutions integrating solar energy (solar farms)

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

Floating on lake



Fixed on reservoir walls

https://www.innotech-safety.com/en/newsroom-detail/the-largest-alpine-solar-plant-muttsee-switzerland

Hydropower schemes

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

Traditional hydropower run-of-river

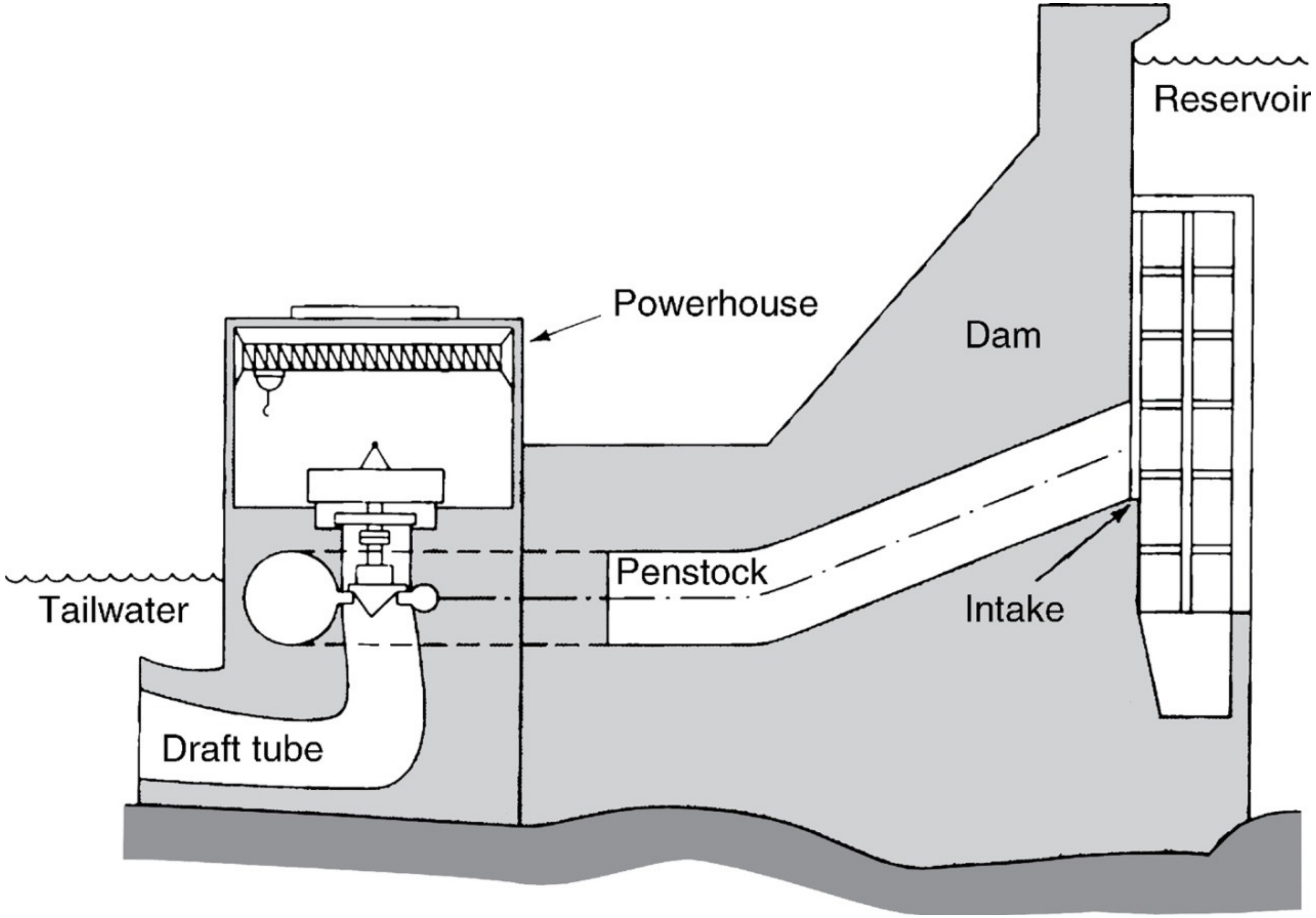
Type: traditional, non-consumptive use

Source: Alpiq - Flumenthal

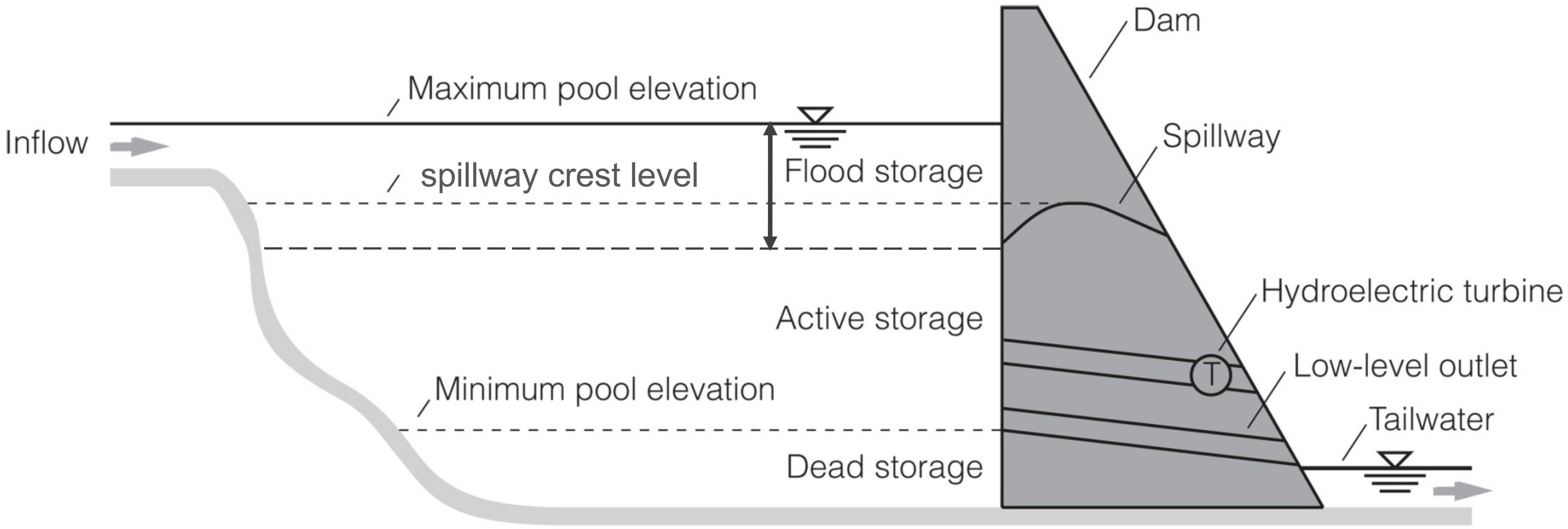
Source: Alpiq - Gösgen

Run-of-river: energy production is related to the instantaneous flow rate in the river. No upstream storage to possibly regulate the release. Typically characterized by low head.


fish ladder


Reservoir
Powerhouse
Dam
Penstock
Tailwater
Intake
Draft tube

Reservoir side



dead storage reserved for sediment accumulation.
active storage. Storage available for various uses: water supply, irrigation, navigation, hydropower generation.
Flood storage: reserved for flood control. It is kept unused to temporary store floodwater during storm event.

How much power (and energy)?

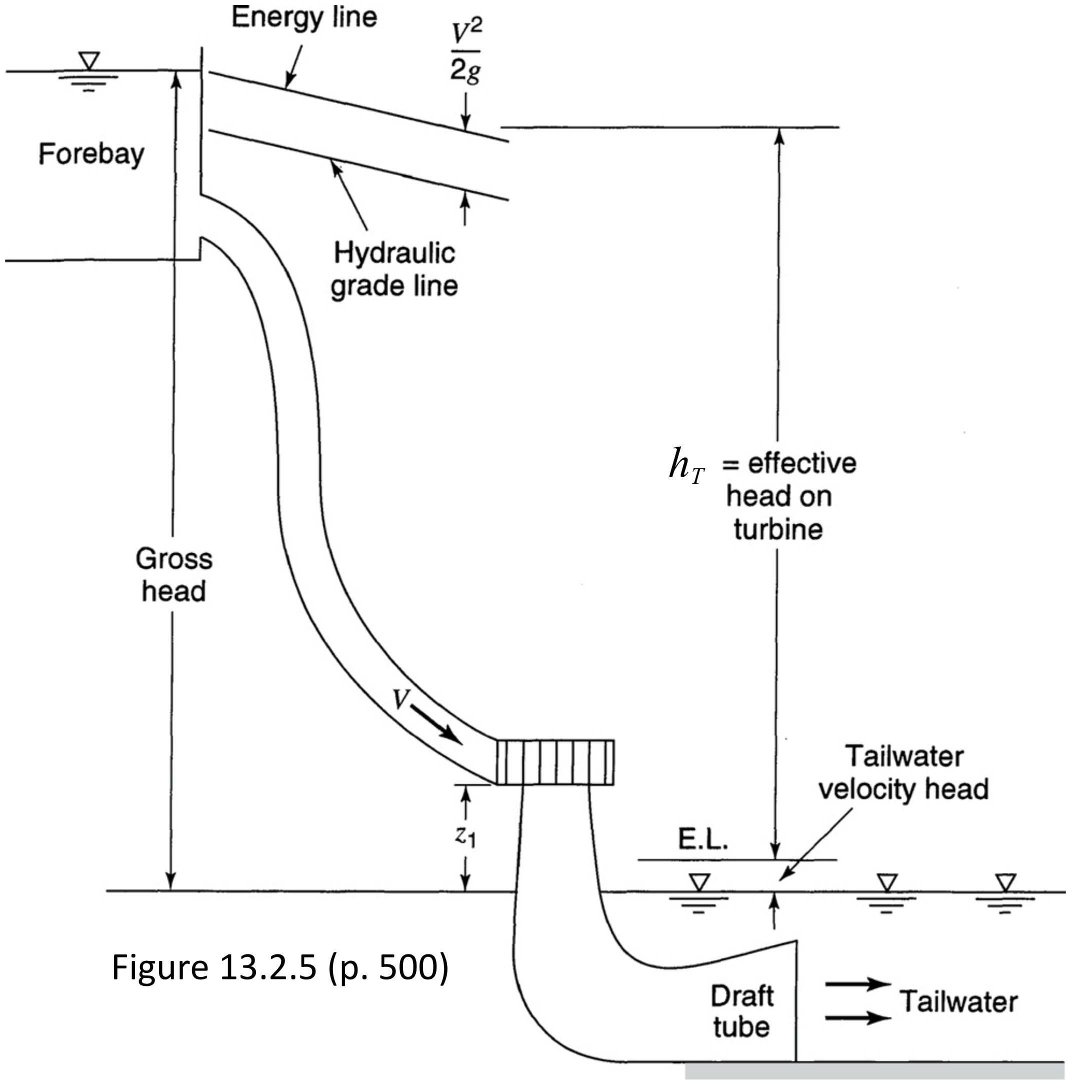


Figure 13.2.5 (p. 500)

power produced by the turbine

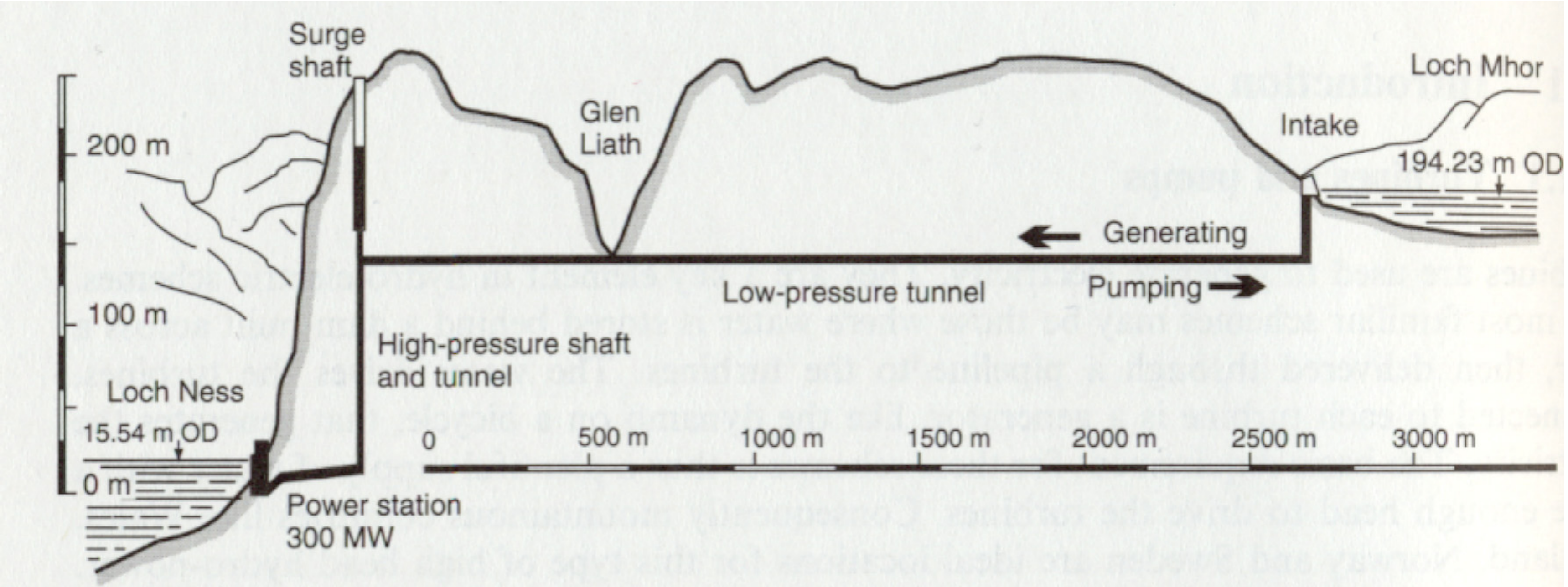
$$P = \eta \, \gamma \, Q \, h_T$$

the efficiency η accounts for head losses inside the turbine, mechanical friction and the efficiency of the generator.
Notice the difference between this equation and that of the power required to drive a pump.

Traditional hydropower (with storage and long diversion)

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

Type: traditional, consumptive use (for the environment)



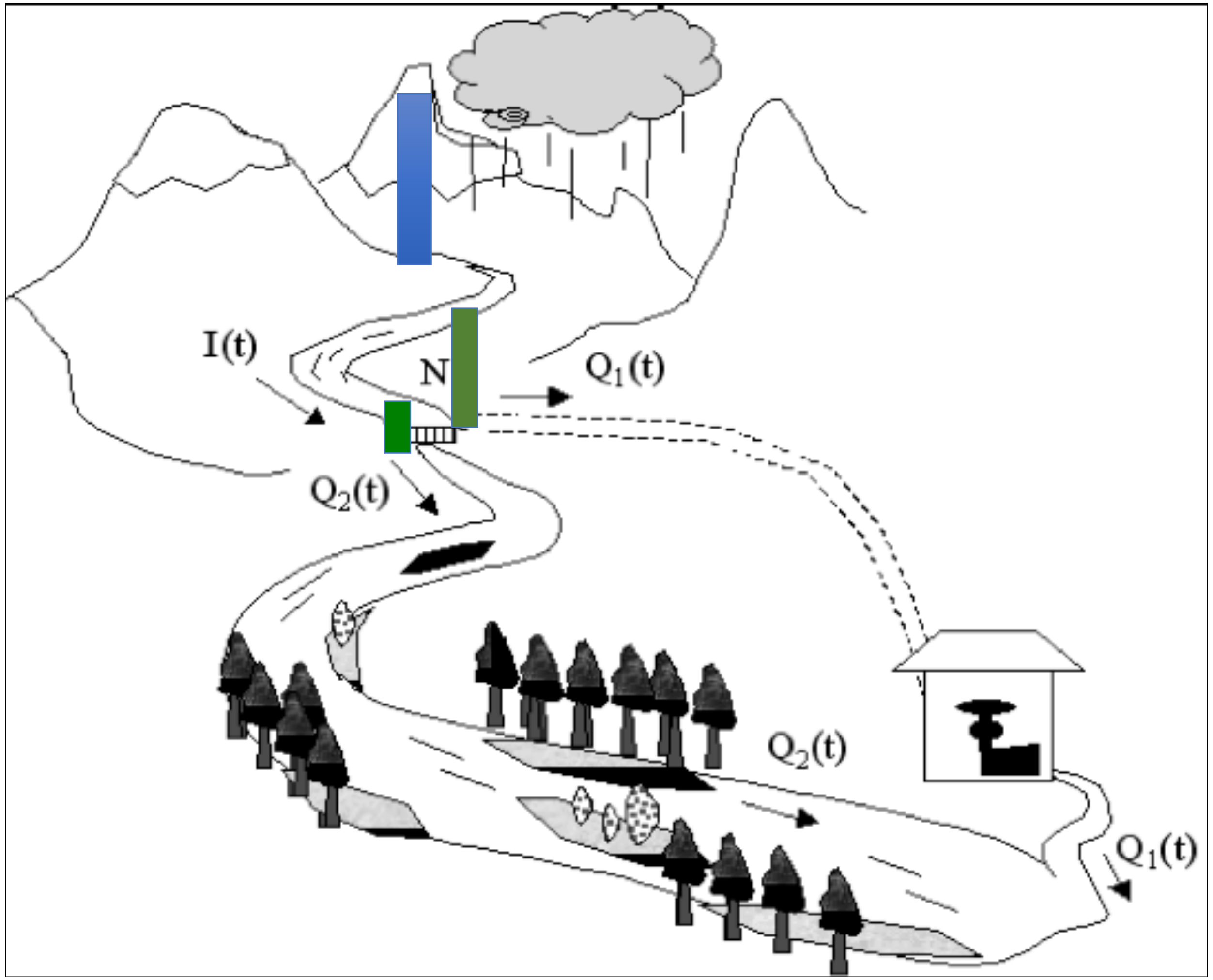
- Potential energy = mgH
- Power = rate of work = mgH/T
- m/T = mass flow rate = rQ
- P = rQgH

- This is the theoretical power of the *water*
- To get electricity generated need to multiply by the efficiency of the pipes, of generating machineries, etc. say 0.8

Minihydropower

Small (or Mini)-hydropower (with diversion)

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES



Type: <10MW; traditional, consumptive use (for the impounded riverine ecosystem)

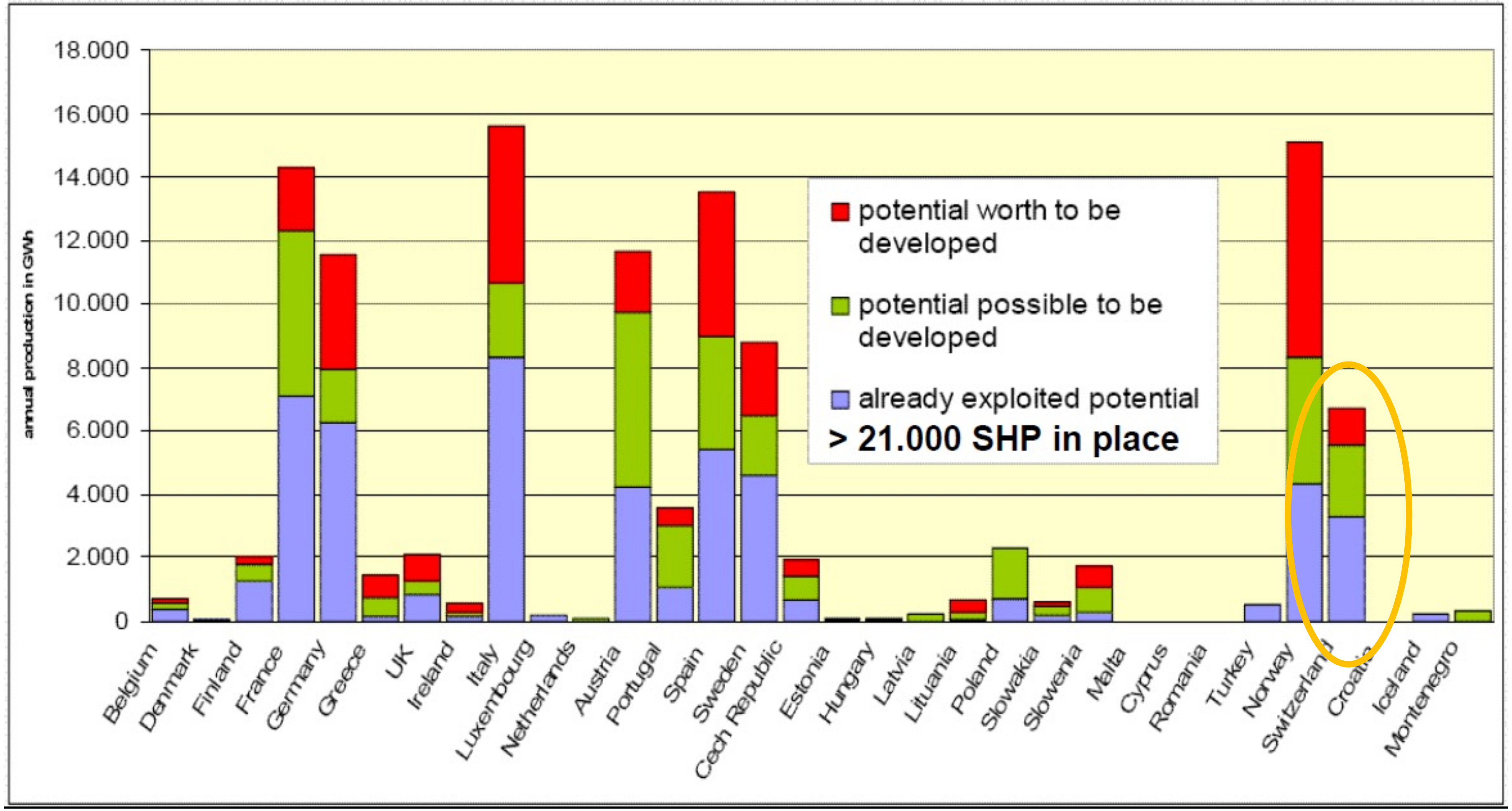
$I(t) = Q_1(t) + Q_2(t)$

$Q_1(t)$ is generically determined by hydropower design and the redistribution policy at the node (possible competition)

Policies for residual flow left to the environment, $Q_2(t)$

- Minimal flow;
- Proportional to inflow, $I(t)$;
- Non-proportional to inflow, $I(t)$

Mini-hydropower: existing and potential for Europe



Choosing a sustainable Environmental flow release policy will become the mo and the more important!

Source: ESHA, 2010

Horizon 2050: 1.4 TW;
1300 – 1500 NEW Mini-hydropower

Environmental issues of impoundment by dam and diversions

• Transport of sediment along the river is altered. Erosion in the downstream part of the river (countermeasure: release of flow and sediment from the bottom gates).

• Alteration of fish migration (countermeasure: fish ladder).

• Alteration of hydrologic cycle because of lake evaporation. Salinization of water especially in tropical or equatorial zones (high ET).

•Alteration of the natural flow regime in the downstream section of the river (countermeasure: release of minimum flow or more advance sequence of releases).

•Alteration of the natural flow regime and onset of peak releases (Hydropeaking → fish stranding)

•Alteration of water temperature (usually colder → thermopeaking).

•The lake can increase incidence of diseases related to water like malaria, schistosomiasis and cholera.

•Resettlement of people.

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