Turbines II: Hydro and Wind

GEOS 24705/ ENST 24705

Cheapness and reliability make hydro the generation technology of choice of developing countries

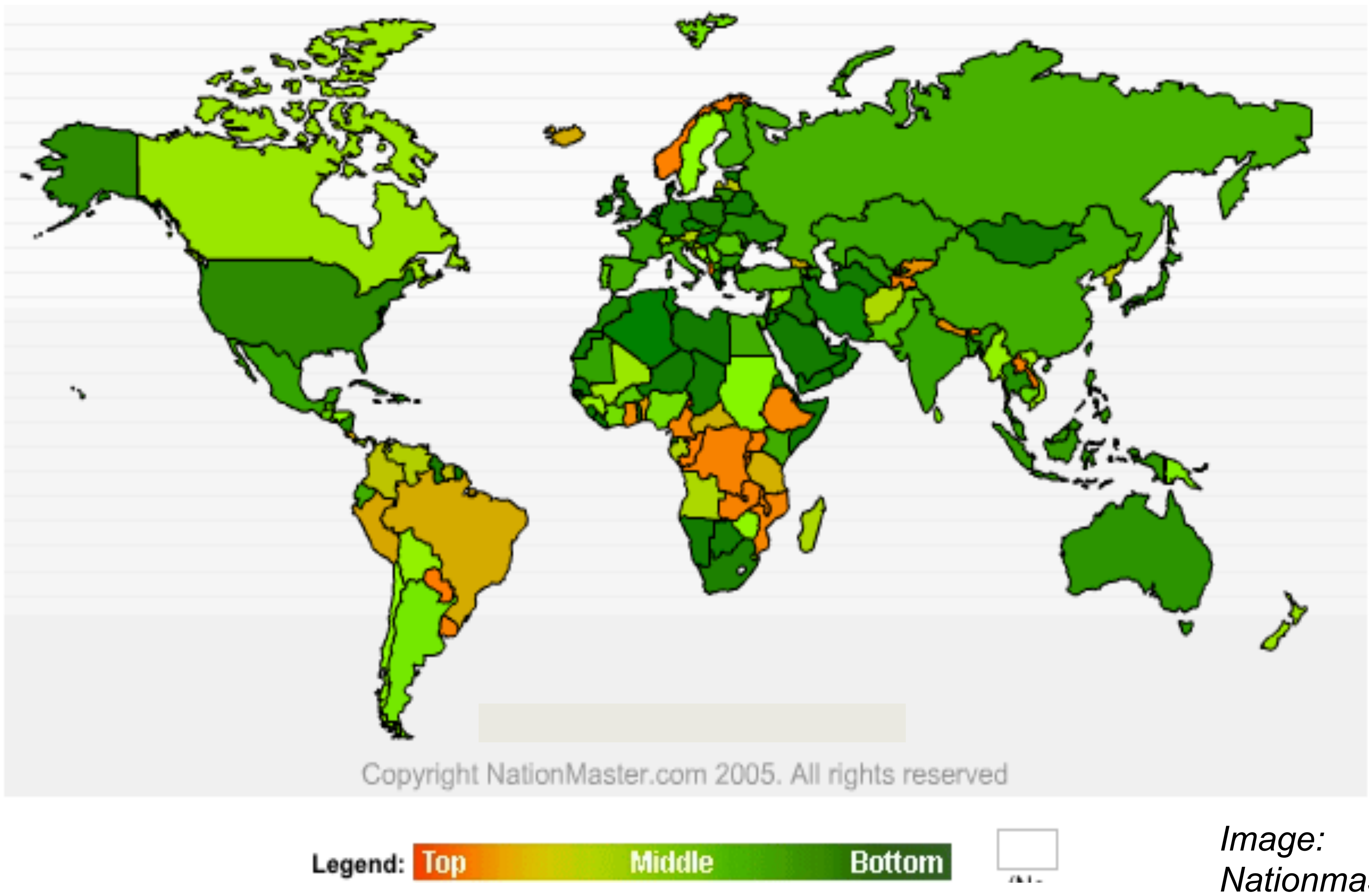


Image: Nationmaster.com, 2005

Cheapness and reliability make hydro the generation technology of choice of developing countries

Hydro as fraction of electricity generation:

U.S.	~ 7%
World	~ 15%
18 countries	> 95%

in Africa: Congo Brazzaville, Zambia, Burundi, Uganda, Congo DRC, Rwanda, Ethiopia, Cameroon, Mozambique, Malawi, Ghana

in Asia: Bhutan, Laos, Tajikistan

In Latin America: Paraguay, Uruguay

In Europe: Norway, Albania

Data: Nationmaster. com, 2005

Developed countries also use as much hydro as possible

....use more of their hydro potential than developing countries.

Developing countries just don't have much else.)

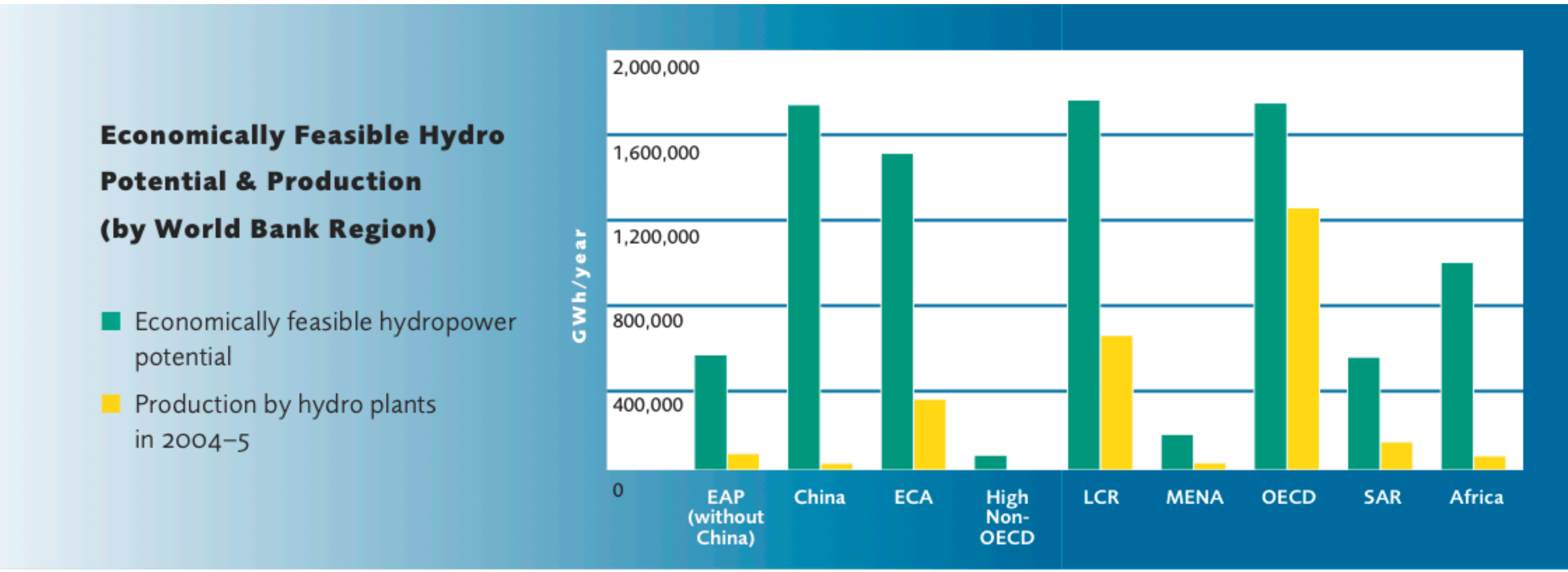


Image: "Directions in Hydropower", The World Bank Group, 2009. Figure: based on International Journal on Hydropower and Dams, World Atlas 2006 and various national statistics.

Pros and cons of dam hydro

Cons

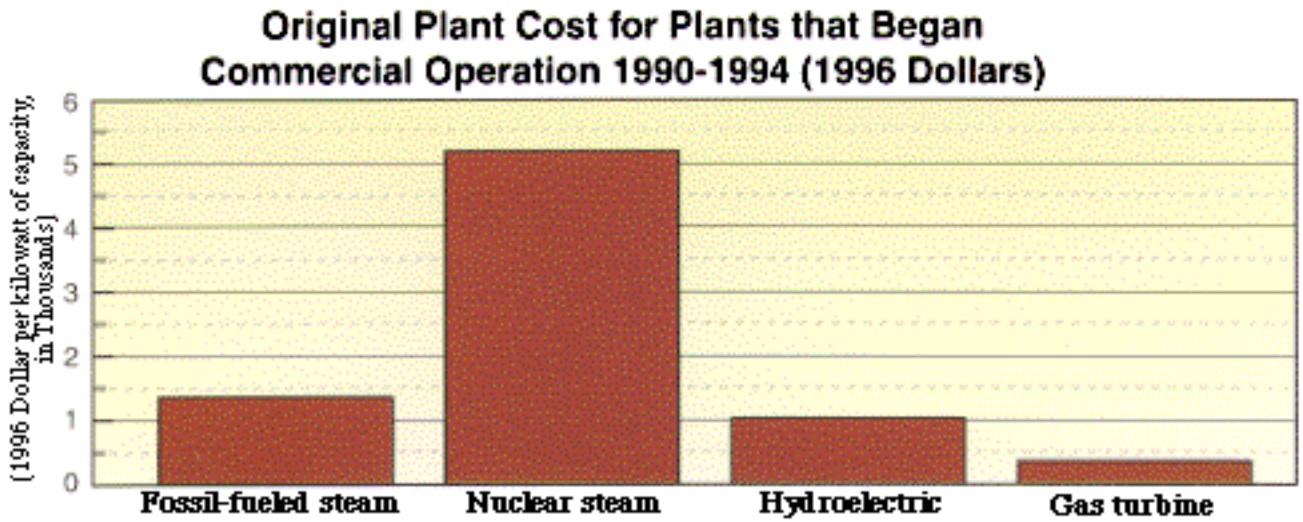
- Environmentally destructive
- Increases evaporation – reduces downstream flow
- Capacity not ultimately great enough to meet all world's energy needs

Pros

- Low maintenance over long life
- .. and zero fuel cost..
- … means in long term is extremely cheap and simple
- CO_2-free
- Infinitely schedulable – fast turn-on
- Provides storage when not needed...
- ...therefore reliable (compared to wind, solar)

Hydro has long life, low capital and operating costs

$1/W in best case, but some hydro projects can go to $3/W… still, very low build and the fuel is then free



Long-term hydro operating costs are lower than for any other form of electrical generation. *(Note that gas fuel costs are lower now; this figure is old).*

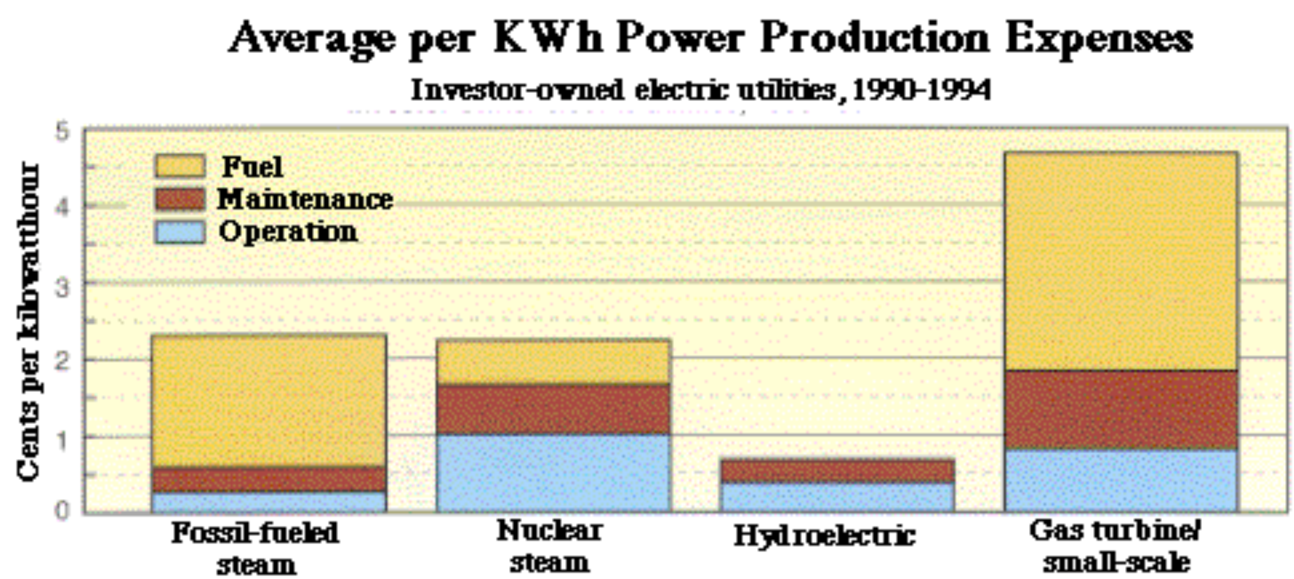


Image: from inseda.org. Data source and copyright unknown.

Energy density and turbine/pump efficiency makes hydro a useful form of energy storage

Use electricity to drive pump to water uphill to store energy

Release water through a turbine to generate electricity

Uses:

- Storing energy from intermittent sources
- Buy low, sell high: arbitraging electricity prices

Image: source unknown, copyright unknown

Why dam a river to get energy from its flow?

run-of-river

vs.

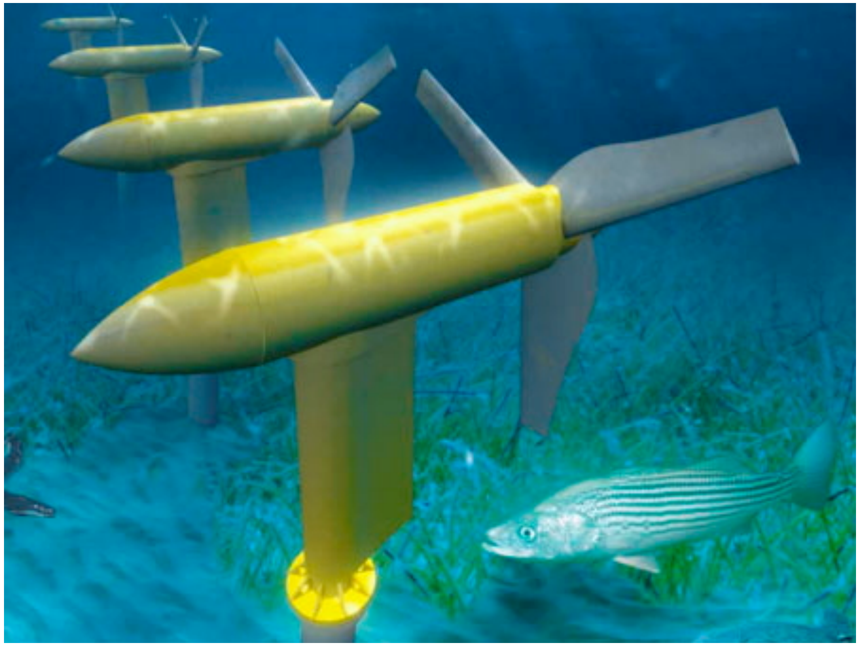
dam

If the point is just to get kinetic energy from the river's flow, why do you need a dam at all?

Less environmentally damaging if you didn't dam…

Photo: L. PapaKaster Photography

Why dam a river to get energy from its flow?



run-of-river vs. **dam**

If the point is just to get kinetic energy from the river's flow, why do you need a dam at all?

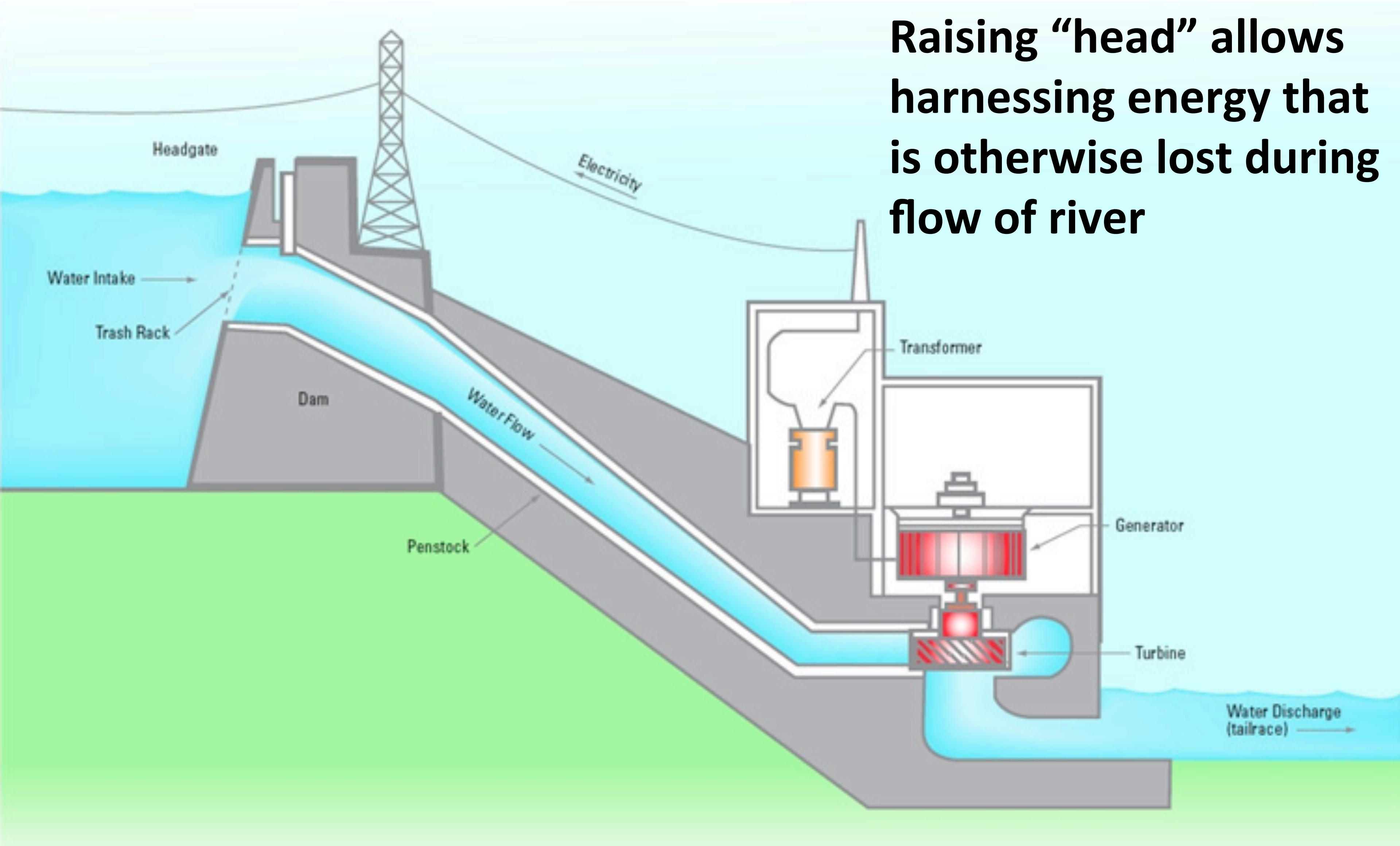
Less environmentally damaging if you didn't dam…

Photo: L. PapaKaster Photography

Where does the potential energy of an undammed river go?

Dam increases extractable energy

Raising "head" allows harnessing energy that is otherwise lost during flow of river



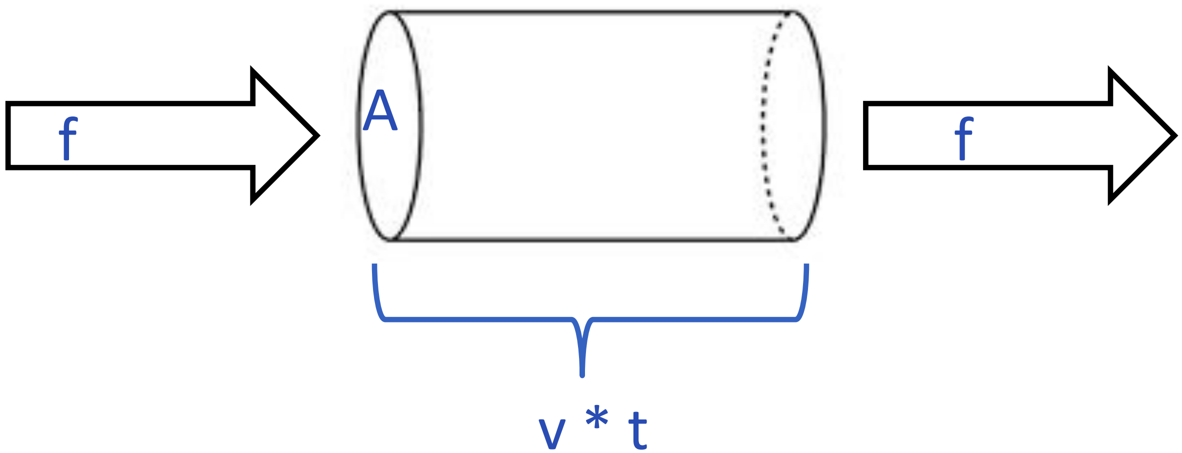
Water is guided to the turbine via a "penstock" that controls flow and pressure

Image: Xeneca Corp.

Power in a flow

Power = (energy/mass) * (mass/time)

= (energy/mass) * (mass/volume) * (volume/time)



$$\text{Power} = \varepsilon \cdot \rho \cdot A \cdot v$$

where ε = (energy/mass), ρ = density, and $A \cdot v$ is the (volume/time)

Energy/mass in a flow: Bernoulli's equation

$$\text{Energy/mass} = \tfrac{1}{2} v^2 + g\,h + p/\rho$$

kinetic   gravitational   pressure gradient

Can swap energy back and forth between these terms.

This form is for **incompressible** fluids only..
Assumes no change in volume or temperature.

Gases are **compressible** - heat on adiabatic compression, cool on adiabatic expansion. Need to add in a term for the thermal energy ("internal energy") of the gas, since energy swaps into and out of heat in gas.

Energy in a flow: wind power *(kinetic term)*

$$\text{Energy/mass} = \tfrac{1}{2} v^2 + g\,h + p/\rho$$

kinetic — gravitational — pressure gradient

Power = energy/mass * mass/volume * volume/time

Flow f = mass/time

$$P = \varepsilon \cdot \rho \cdot A \cdot v$$

energy density is kinetic term: $\varepsilon = \tfrac{1}{2} v^2$

$$P = \tfrac{1}{2} \rho A v^3$$

Energy in a flow: dam hydro *(pot. energy term)*

Energy/mass = $\frac{1}{2} v^2$ + $g\,h$ + p/ρ

kinetic   gravitational   pressure gradient

Power = energy/mass * mass/volume * volume/time

Flow f = mass/time

$$P = \varepsilon \cdot \rho \cdot A \cdot v$$

energy density is pot. energy term: $\varepsilon = gh$

$$P = g\,h\,\rho \cdot (A \cdot v)$$

Energy in a flow: dam hydro *(recover in pressure term)*

$$\text{Energy/mass} = \tfrac{1}{2} v^2 + g\,h + p/\rho$$

kinetic — gravitational — pressure gradient

Power = energy/mass * mass/volume * volume/time

Flow f = mass/time

$$P = \varepsilon \cdot \rho \cdot A \cdot v$$

energy density is pressure term: $\varepsilon = p/\rho$

$$P = p \cdot (A \cdot v)$$

3 main dam hydro turbine designs

choice governed by flow rate and pressure

Pelton (1870s)

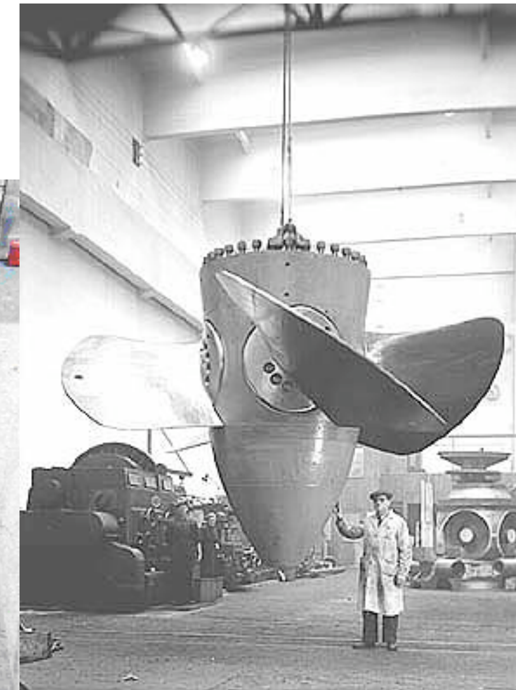
High head, low flow

Impulse turbine used with dam

Francis (1848)

Medium head, all but highest flows

Pure reaction turbine



Kaplan (1922)

Low head, all flows

Pure reaction turbine

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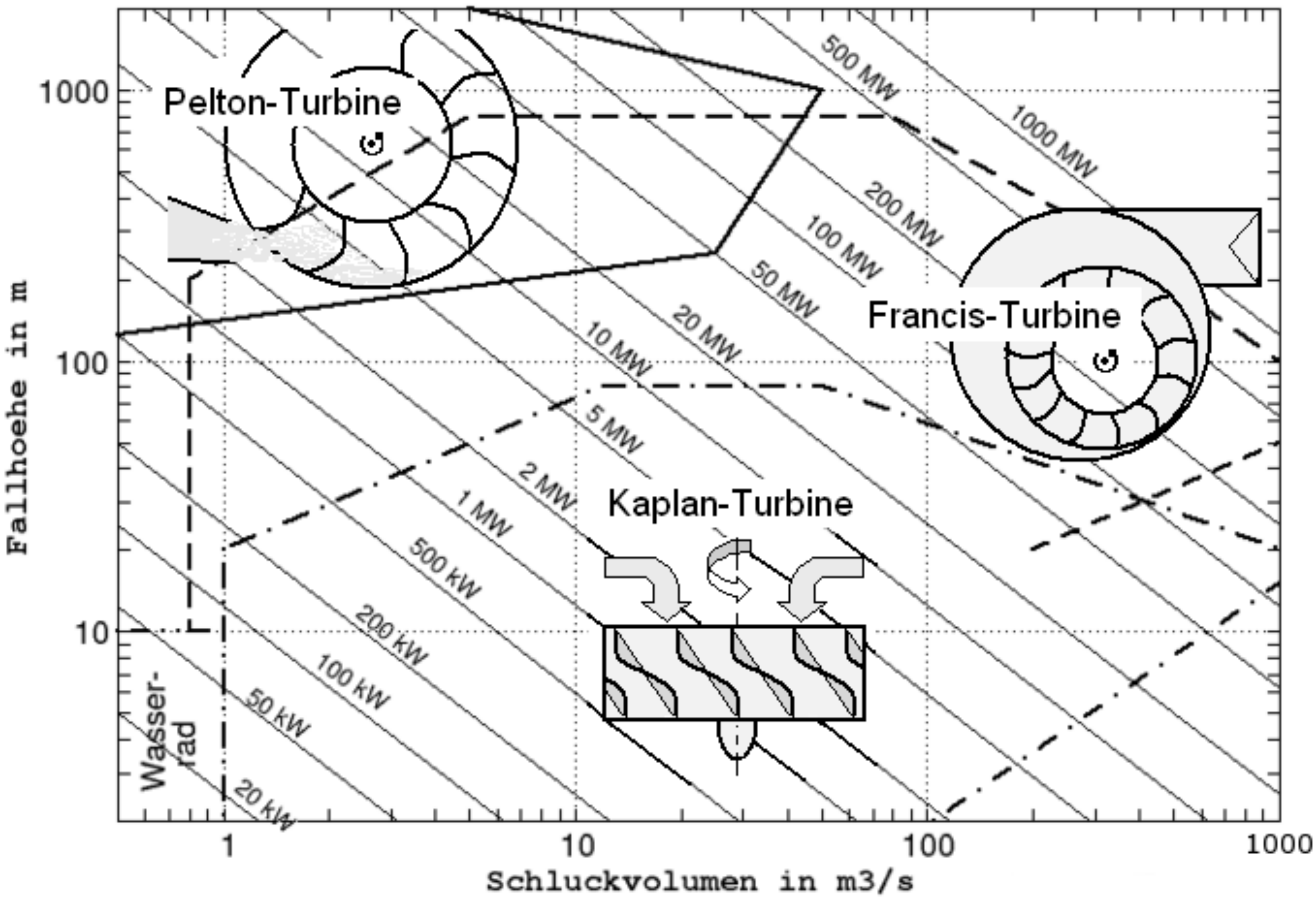
3 main dam hydro turbine designs

choice governed by flow rate and pressure



1. Francis turbine: *reaction turbine*
(medium head: 10 - 500 m)
Hydro getting bigger…over 800 MW max

Efficiency already near max – but larger scale lowers cost

Francis turbine runner from Three Gorges Dam project, China (700 MW)

Runner is only small part of turbine assembly

Inlet spiral is even larger

Francis turbine intake spiral from Grand Coulee Dam