EE4511
Renewable Generation & Smart Grid

Topic 3: Hydro, Ocean, Biofuel and Geothermal Energy

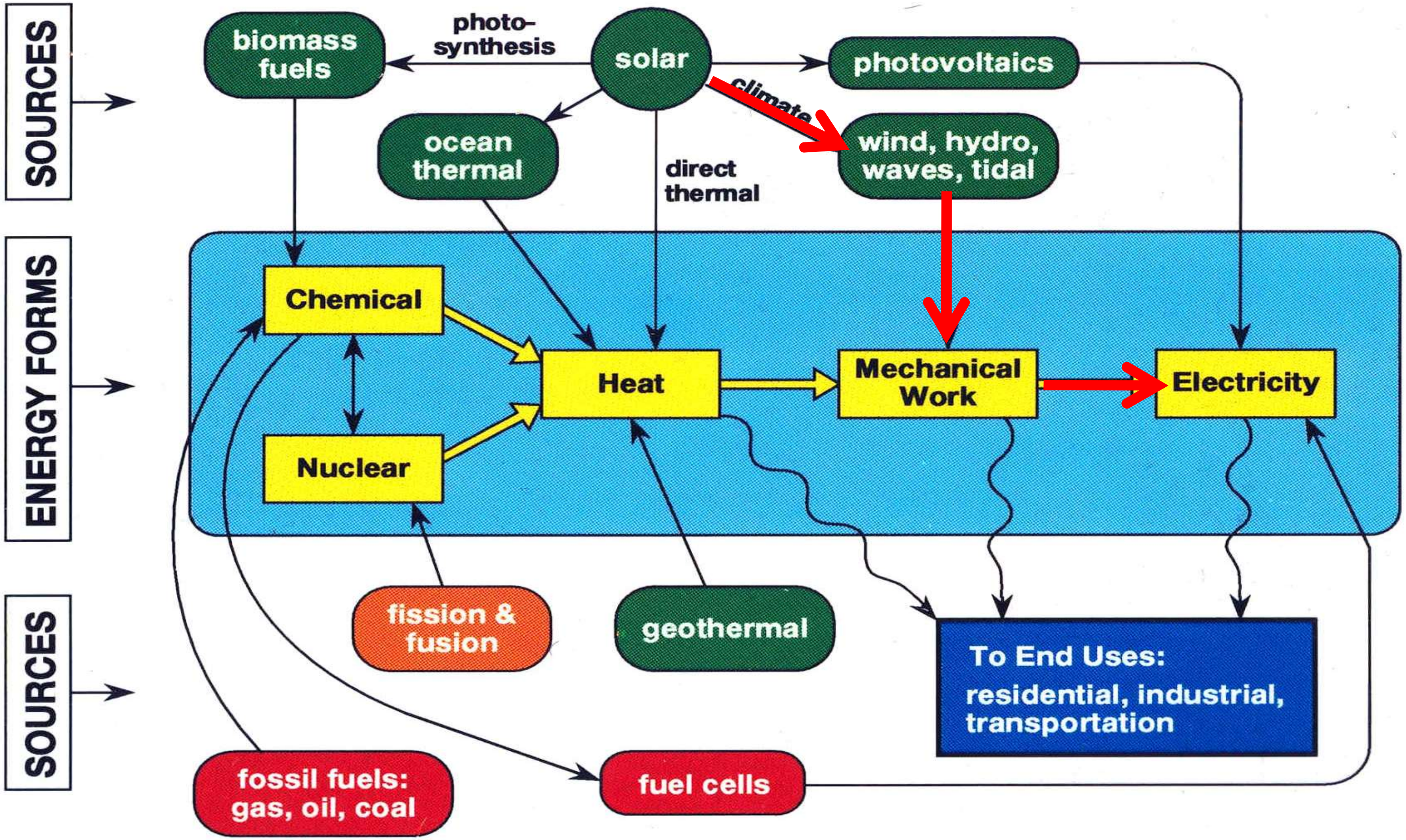
National University of Singapore

Learning outcomes:

- Understand how energy can be harnessed from water, biomass and geothermal sources
- Understand main types of systems
- Discuss advantages, limitations, issues, and trends

Hydropower Generation

ENERGY SOURCES AND CONVERSION PROCESSES



Introduction: Hydro Electricity

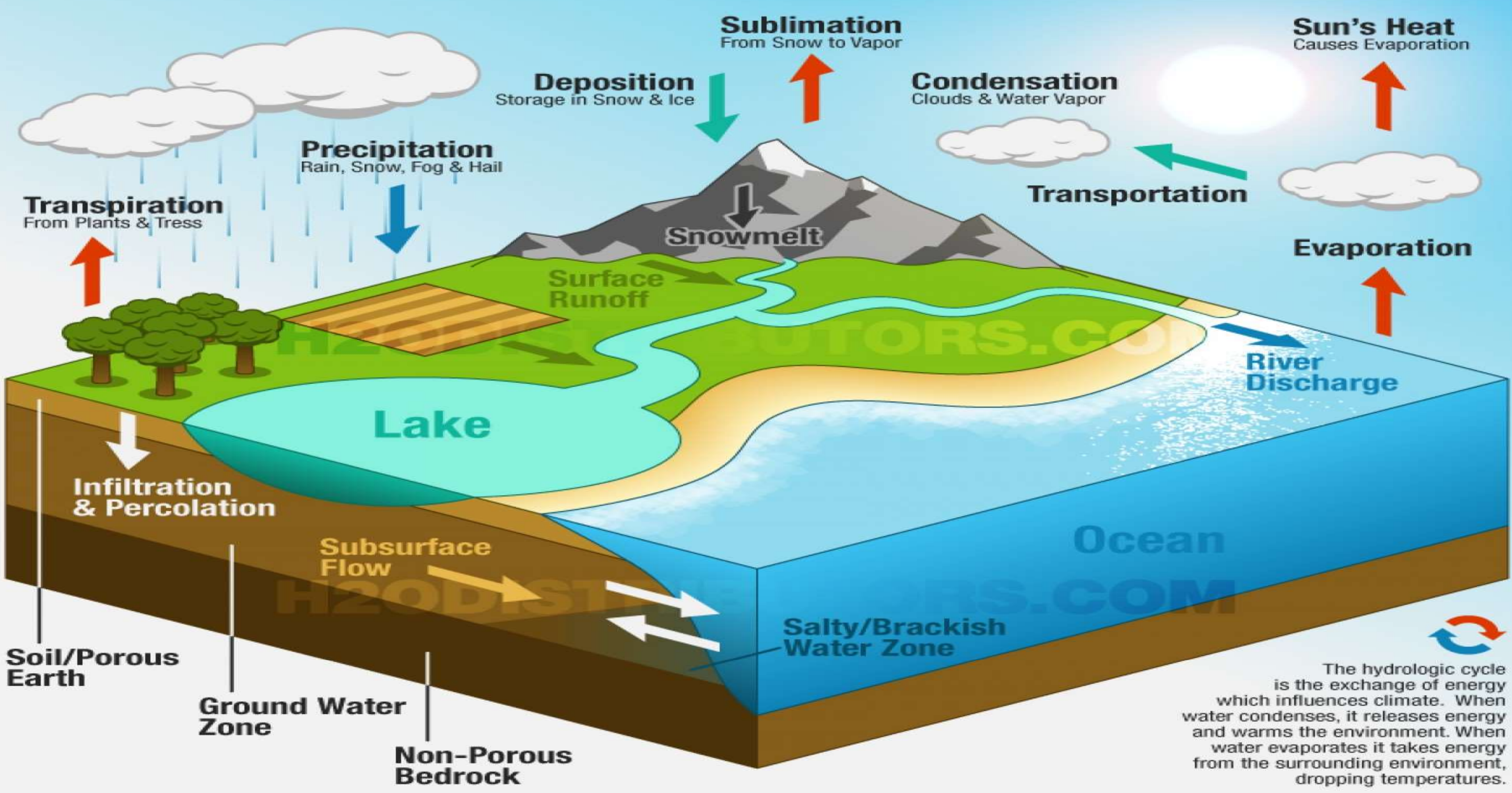
- Power obtained from rivers, precipitation or oceans
- One of the most widely used renewable source of energy for generating electricity on large scale basis
- 17% of global electricity demand is met by hydro-electric power.
- Total global installed capacity is over 1170 GW
- Have a long life (100 to 125 years) as they operate at atmospheric temperature

Hydrologic Cycle

The Hydrologic Cycle (also called the Water Cycle) is the continuous movement of water in the air, on the surface of and below the Earth.

Human activities that alter the water cycle:

- Alteration of Atmosphere
- Construction of Dams
- Deforestation and Afforestation
- Water Abstraction from Rivers
- Agriculture
- Industry
- Urbanization



The hydrologic cycle is the exchange of energy which influences climate. When water condenses, it releases energy and warms the environment. When water evaporates it takes energy from the surrounding environment, dropping temperatures.

http://www1.eere.energy.gov/windandhydro/hydro_how.html

Process Definitions:

Condensation
The transformation of water vapor to liquid water droplets in the air, creating clouds and fog.

Deposition
Also known as desublimation, is a thermodynamic process, a phase transition in which gas (vapor) transforms into solid (ice).

Evaporation
The transformation of water from liquid to gas phases as it moves from the ground or bodies of water into the overlying atmosphere.

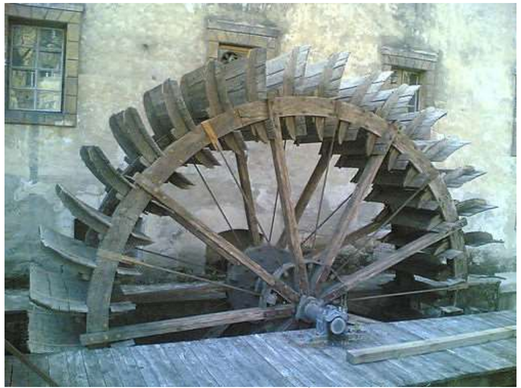
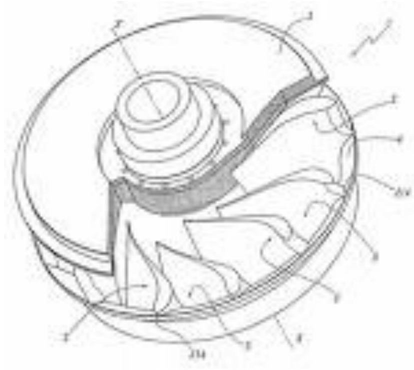
Percolation
Water flows horizontally through the soil and rocks under the influence of gravity.

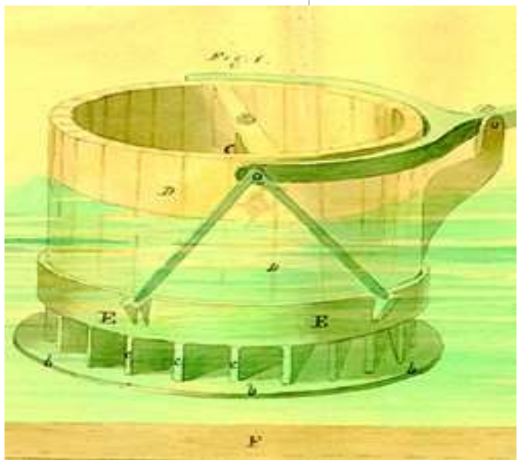
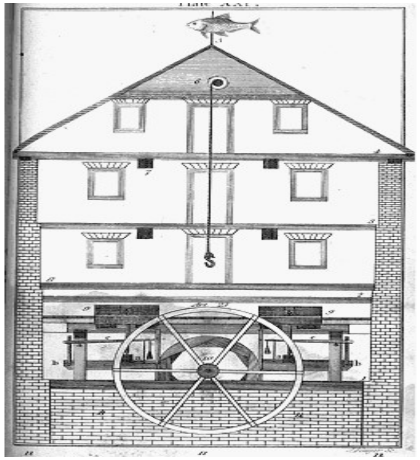
Precipitation
Condensed water vapor that falls to the Earth's surface. Most precipitation occurs as rain, but also includes snow, hail, fog drip, graupel, and sleet.

Sublimation
The state change directly from solid water (snow or ice) to water vapor.

Transpiration
The release of water vapor from plants and soil into the air. Water vapor is a gas that cannot be seen.

Harnessing Water Power

- Humans have used the power of moving water for more than 2,000 years
- Greek, Roman, and Chinese used water mills for mechanical work, e.g. grinding grains.
- In late 1700s, Oliver Evans (American) designed a mill that combined gears, shafts and conveyors –> power source for saw mills and textile mills

Source: www.eia.gov

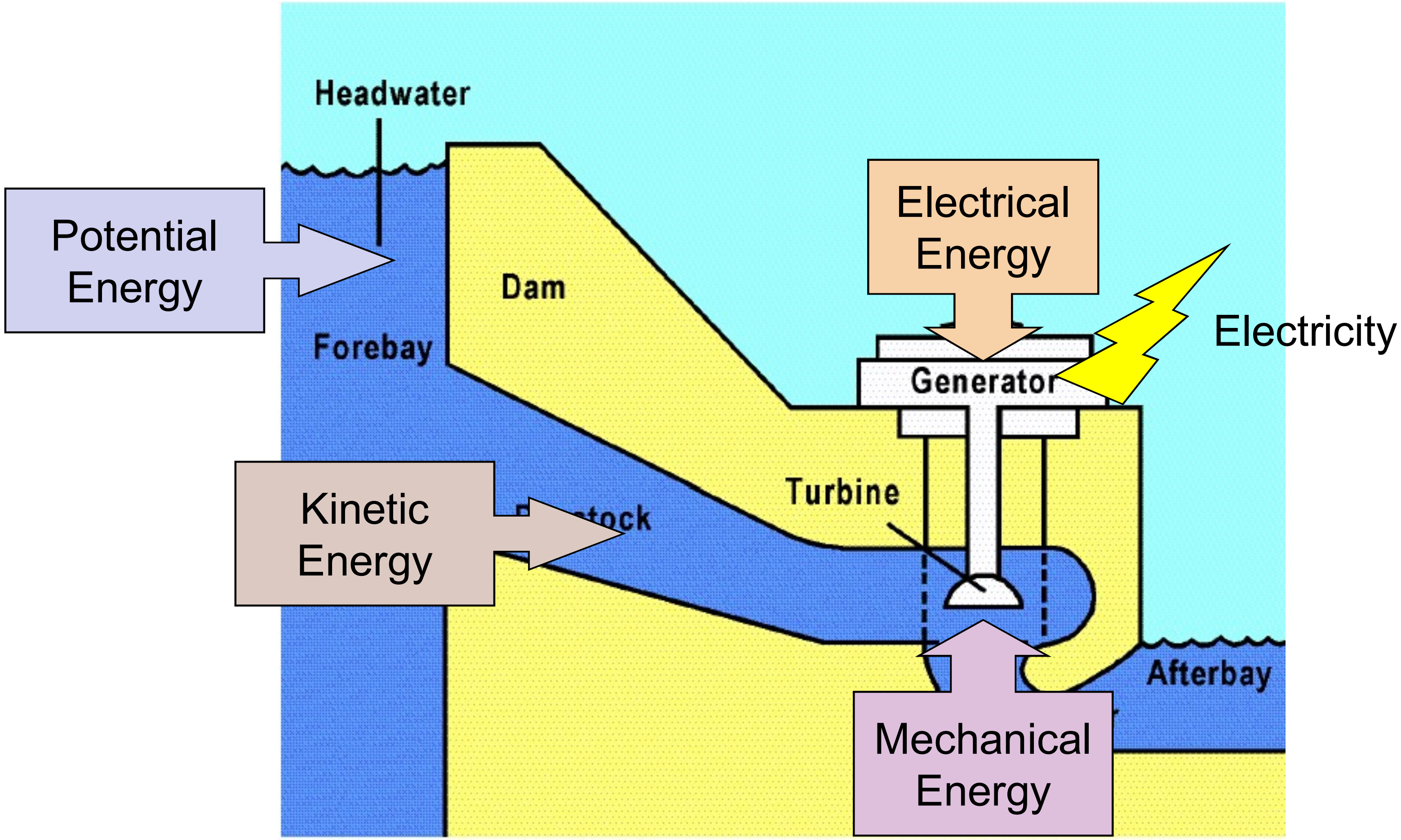
World's First Hydropower Plant

1880: The Grand Rapids Electric Light and Power Company used a water turbine to generate enough electricity to power 16 lights.

1882: World's first hydroelectric power plant began operation on the Fox River in Appleton, WI

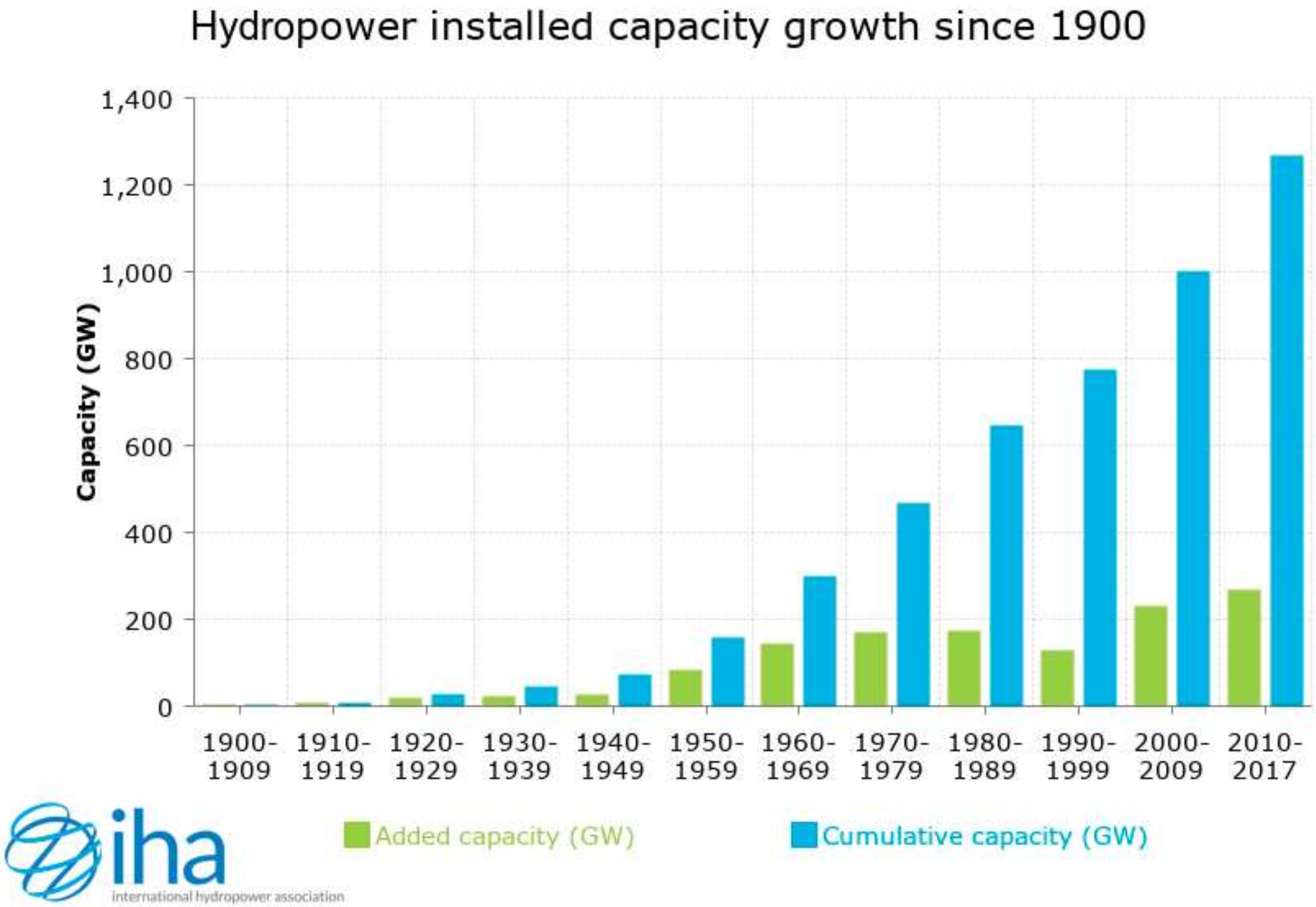
Source: www.eia.gov

Hydropower to Electric Power



- Environmentally speaking, it's relatively clean
- Has the ability to supply large amounts of electricity quite consistently.
- The technology is simple, and well understood
- Once built, dams and generators last a very long time.

Growth of Hydropower



World’s Largest Dams

Power plant	Installed capacity (MW)
Three Gorges Dam (China)	22,500
Itaipu Dam (Brazil/Paraguay)	14,000
Xiluodu Dam (China)	12,600
Belo Monte Dam (Brazil)	11,000
Guri Dam—Simón Bolívar hydroelectric power station (Venezuela)	10,240
Tucurui Dam (Brazil)	8,550
Grand Coulee Dam (USA)	6,810
Sajano-Schuschenskaja GES (Russia)	6,400
Longtan Dam (China)	6,300
Xiangjiaba Dam (China)	6,000
Krasnoyarsk Hydroelectric Dam (Russia)	6,000
Nuozhadu Dam (China)	5,850
Robert-Bourassa hydroelectric power station (Canada)	5,620
Churchill Falls hydroelectric power station (Canada)	5,430
Jingping II Hydropower Station (China)	4,800

China

Source: Introduction to Hydro Energy Systems, Springer Book

Three Gorges Dam (China)

- Cost $37 Billion to build
- World's largest hydroelectric dam
- Took 16 years of construction

Data of Three Gorges Dam Hydropower Station	
Year of beginning of construction	1994
Installed power	22,500 MW
Number of turbines	34
Type of turbines	Francis
Total water reservoir capacity	40 km^3
Rated power per unit	700 MW ($\times$32), 50 MW ($\times$2)
Length of dam	2,300 m
Maximum height of dam	185 m
Produced electricity (2009)	$\approx$80 TWh

"Hydroelectricity," Wikipedia.org

Itaipú Dam (Brazil & Paraguay)

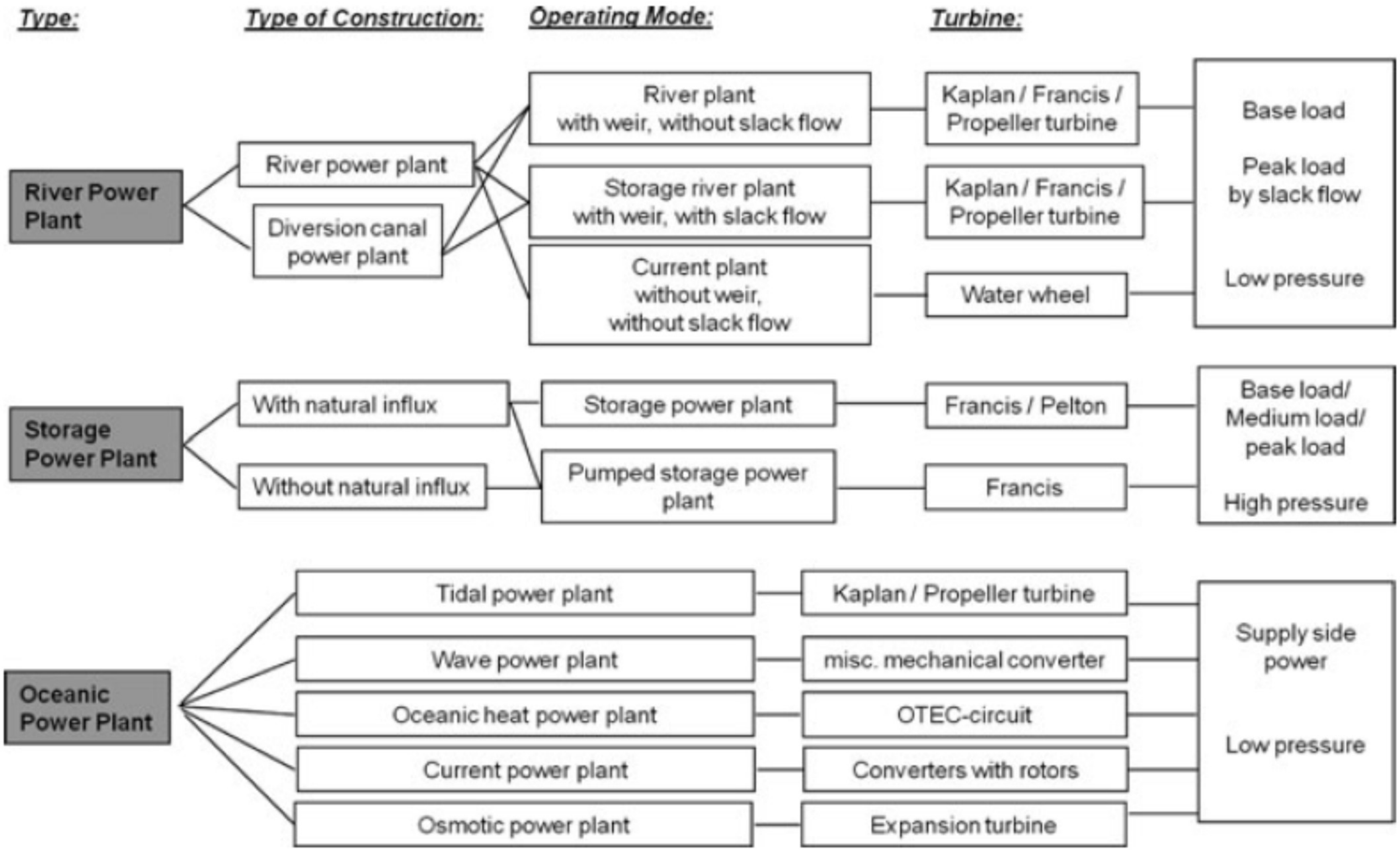
- Second largest hydropower plant in the world
- supplies a significant portion of the electrical demand of Brazil and almost the total Paraguayan demand

"Hydroelectricity," Wikipedia.org

Data of ITAIPU Hydropower Station

Year of beginning of construction	1975
Installed power	14000 MW
Number of turbines	20
Type of turbines	Francis
Rated water flow per unit	645 m^3/s
Rated power per unit	715 MW
Number of poles (50 Hz/60 Hz)	66/78
Length of main dam	610 m
Maximum height of main dam	196 m
Produced electricity (2007)	$\approx$90 TWh

Overview of Hydropower Plants



Source: Introduction to Hydro Energy Systems, Springer Book

Types of hydro-power systems

Reservoir-based

Micro-hydro

- Typically Run-of-the-river (no reservoirs)

https://www.energy.gov/eere/water/types-hydropower-plants

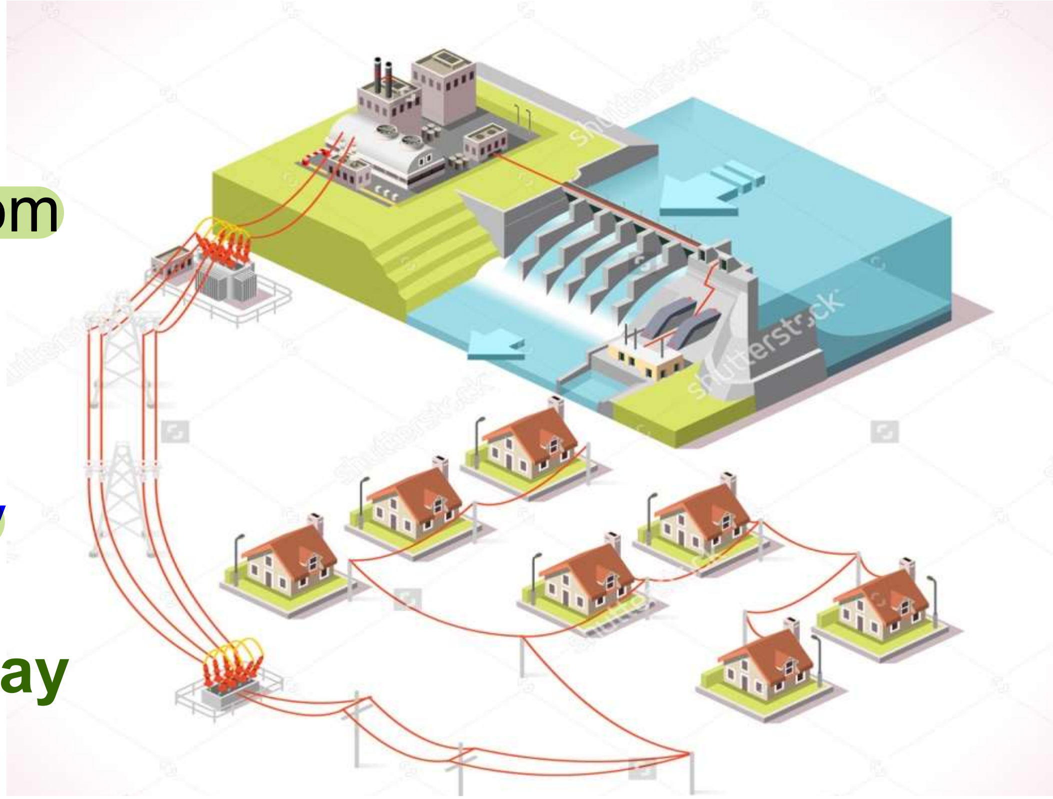
Essential Features of a Hydro Power Plant

Essential Features Of A Water Power Plant

- **Catchment area** – area behind the dam, where water is collected from rain and streams
- **Reservoir** – storage area where the water collected from the catchment area is stored behind a dam. The level of water surface in the reservoir is called Head water level
- **Dam and intake house** – Stores all incoming water and regulates the out going flow of water.

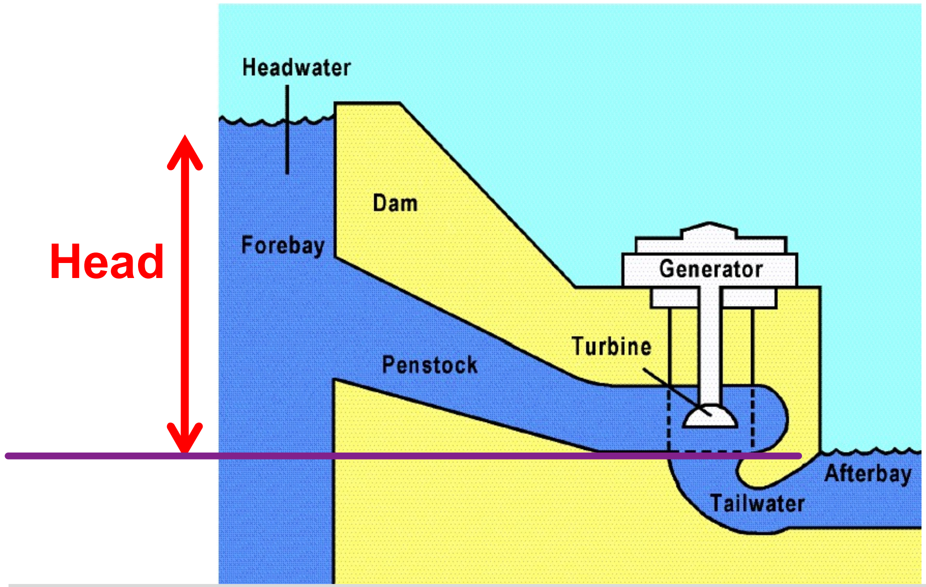
Essential Features Of A Water Power Plant

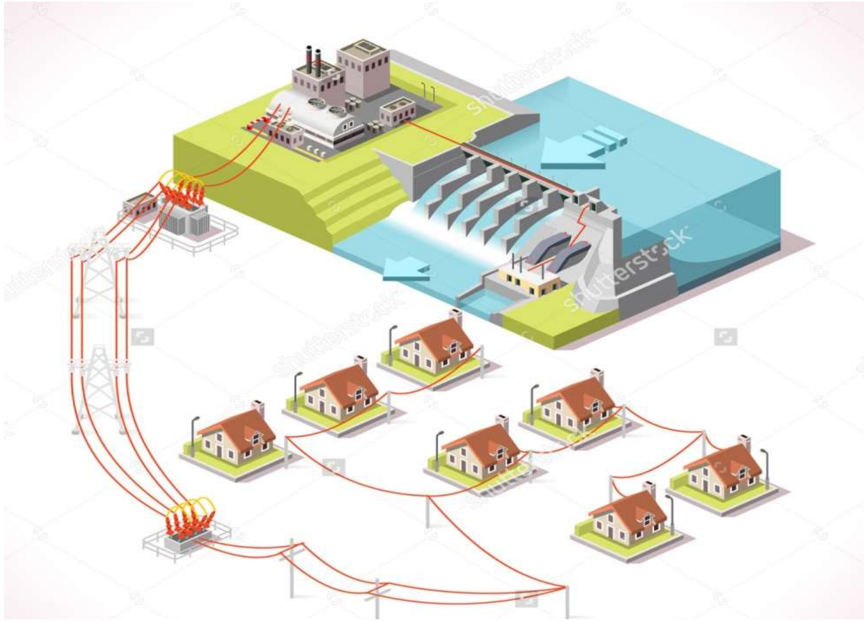
- **Dam and intake house** – Stores all incoming water and regulates the out going flow of water.
- **Water way** - passages through which the water is conveyed to the turbines from the dam
- **Power house** - a building which houses the turbines, generators and the auxiliary plant
- **Tail race or outlet water way**



Terminology

- Head
  - Water must fall from a higher elevation to a lower one to release its stored energy.
  - The difference between these elevations (the water levels in the forebay and the tailbay) is called **head**





Dams: three categories

high-head (800 or more feet)

medium-head (100 to 800 feet)

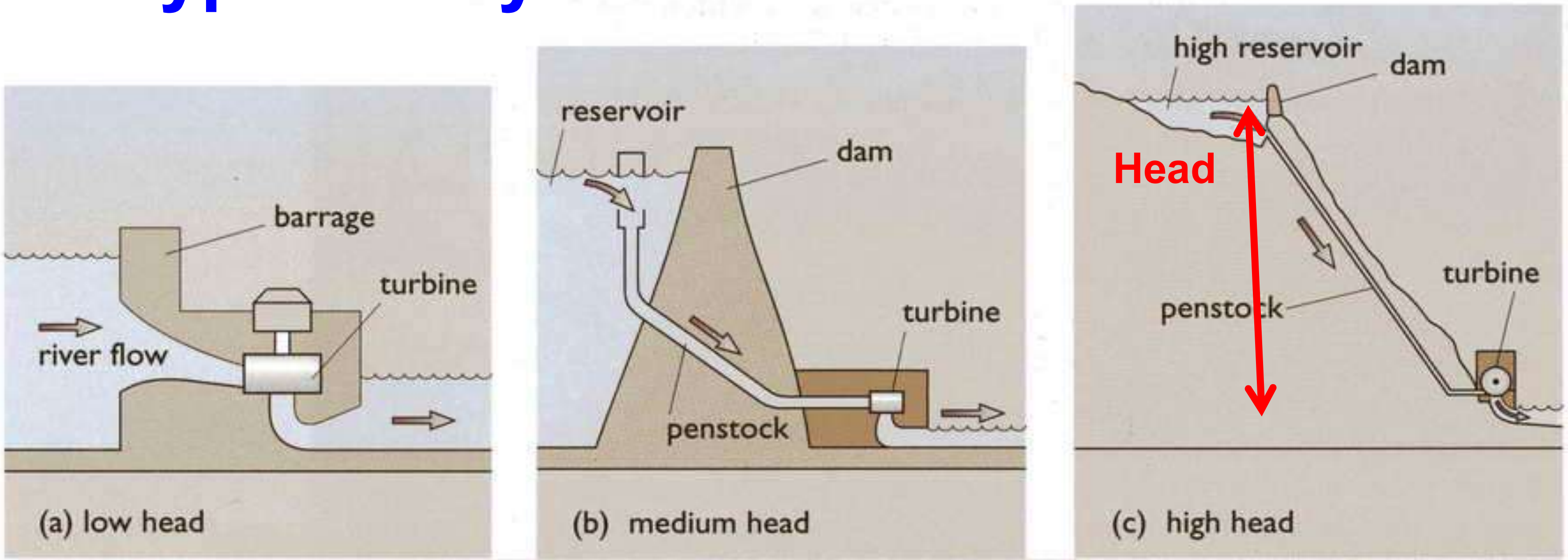
low-head (less than 100 feet)

Power is proportional to the product of *head x flow*

P ∝ (Head x Flow)

http://www.wapa.gov/crsp/info/harhydro.htm

Types of Hydroelectric Installations



Large-hydro: More than 100 MW feeding into HV electricity grid

Medium-hydro: 15 - 100 MW usually feeding HV grid

Small-hydro: 1 - 15 MW - usually feeding into a grid

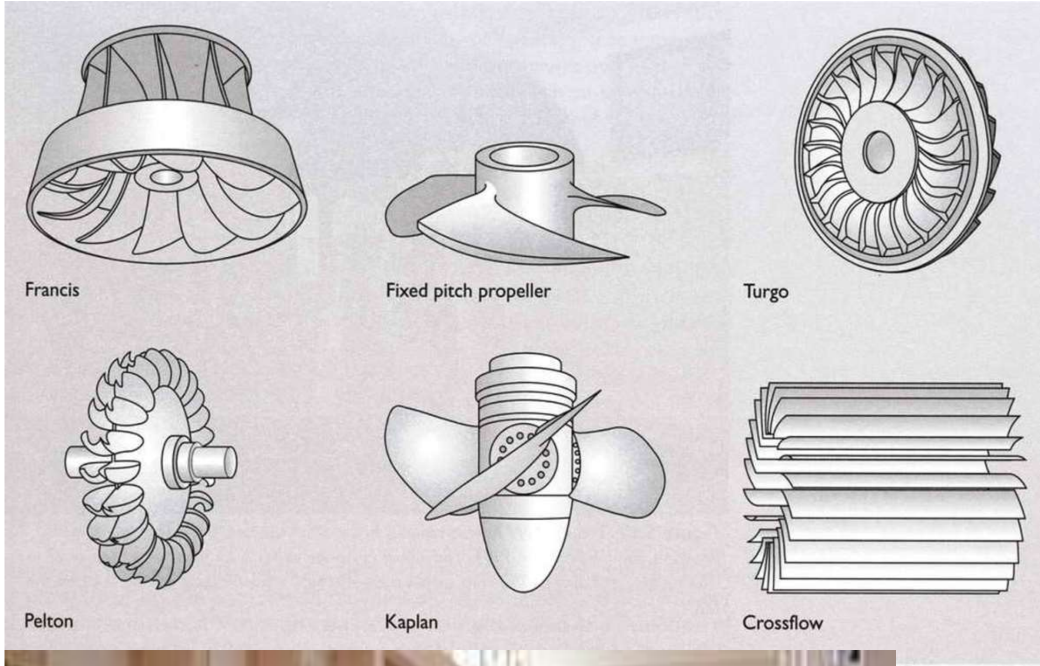
Mini-hydro : Above 100 kW, but below 1 MW; Either stand alone schemes or feeding into the medium-voltage grid

Micro-hydro : From 5kW up to 100 kW ; Usually provide power for a small community or rural industry in remote areas away from the grid.

Boyle, *Renewable Energy*, 2nd edition, Oxford University Press, 2003

Main Types of Hydropower Turbines

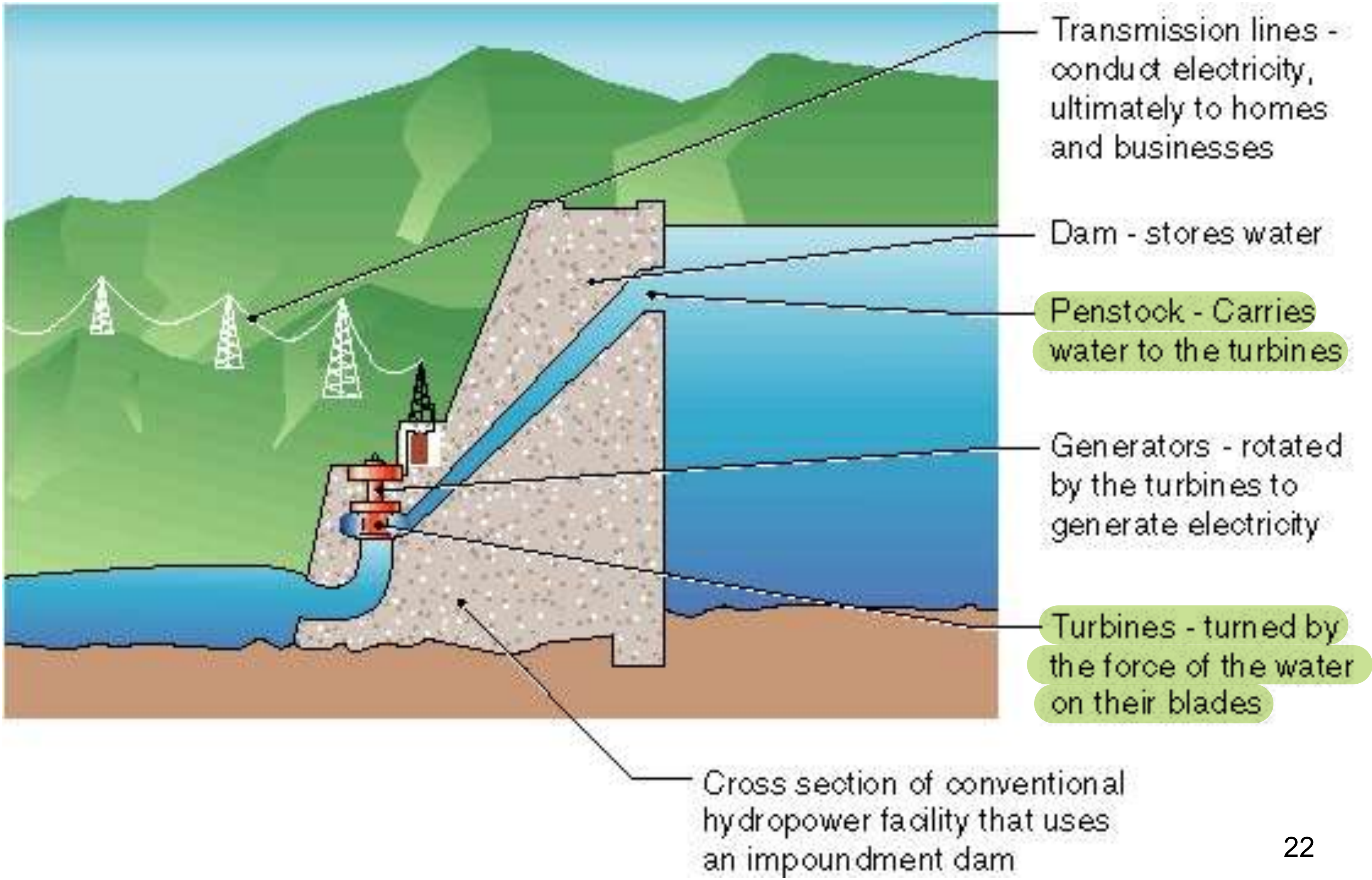
Turbine types:



Turbine room:

Source: www.eia.gov

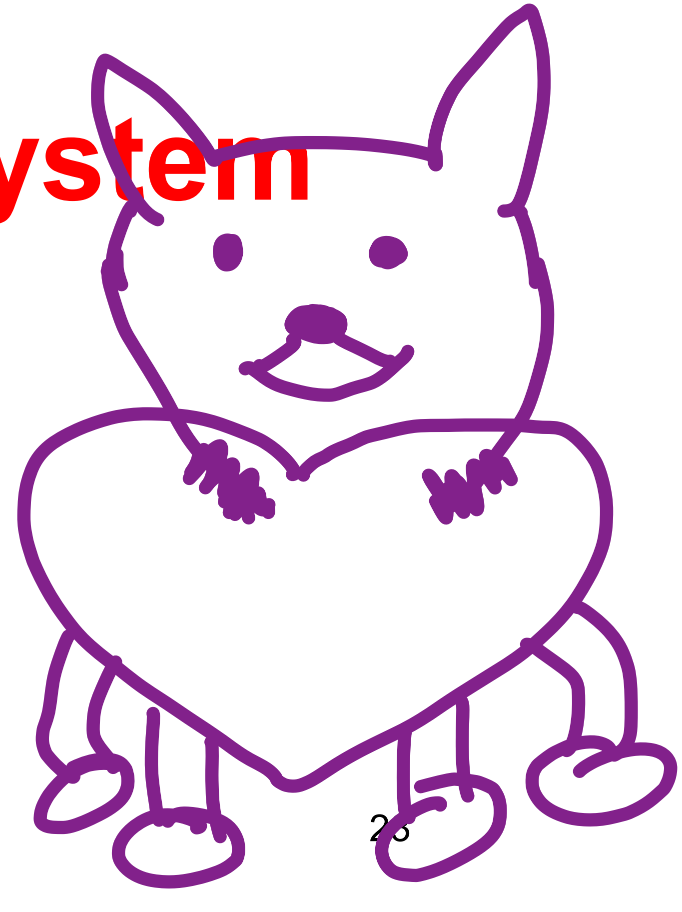
Reservoir-based Hydroelectric System



http://www1.eere.energy.gov/windandhydro/hydro_plant_types.html

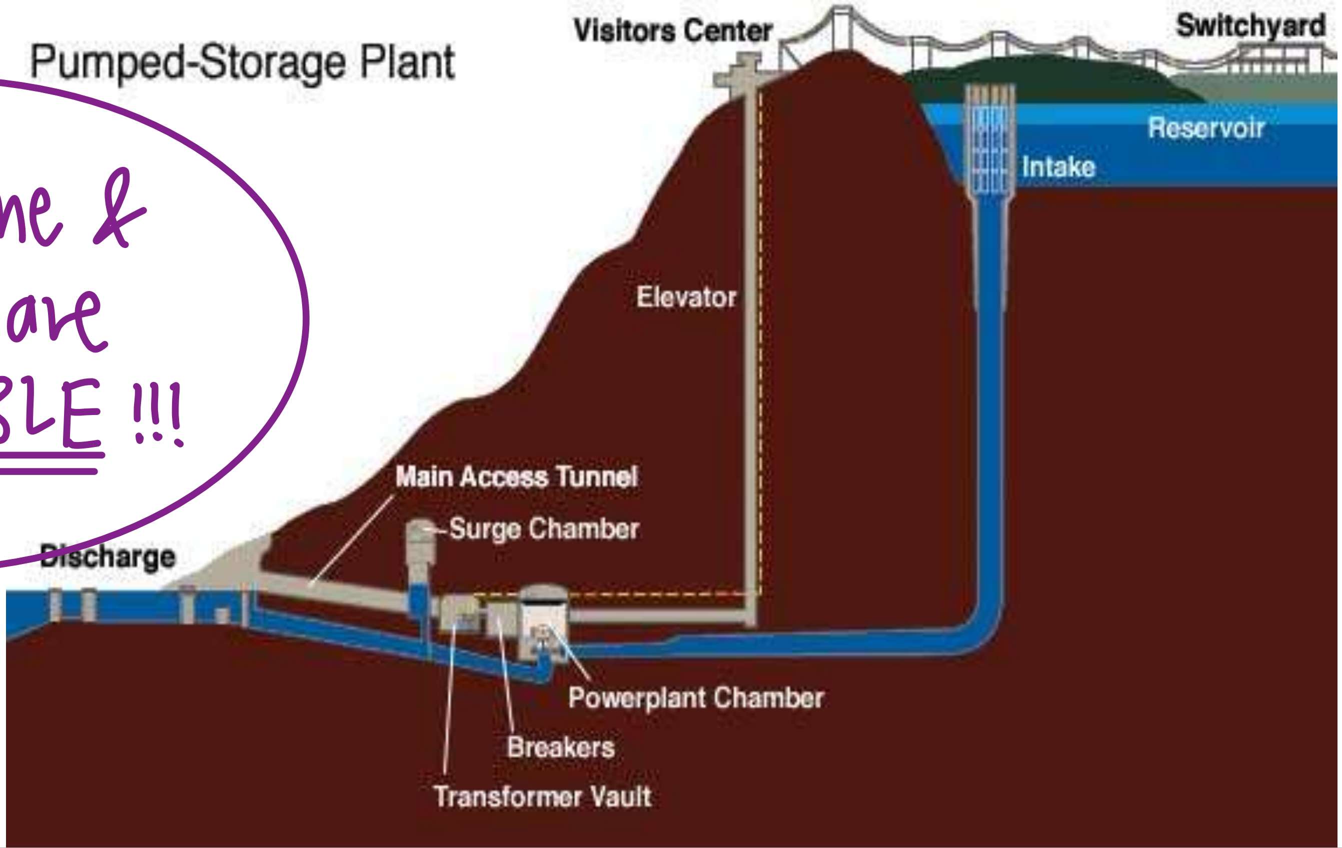
Pumped Storage System

Pumped Storage System




Bork!
wagg-

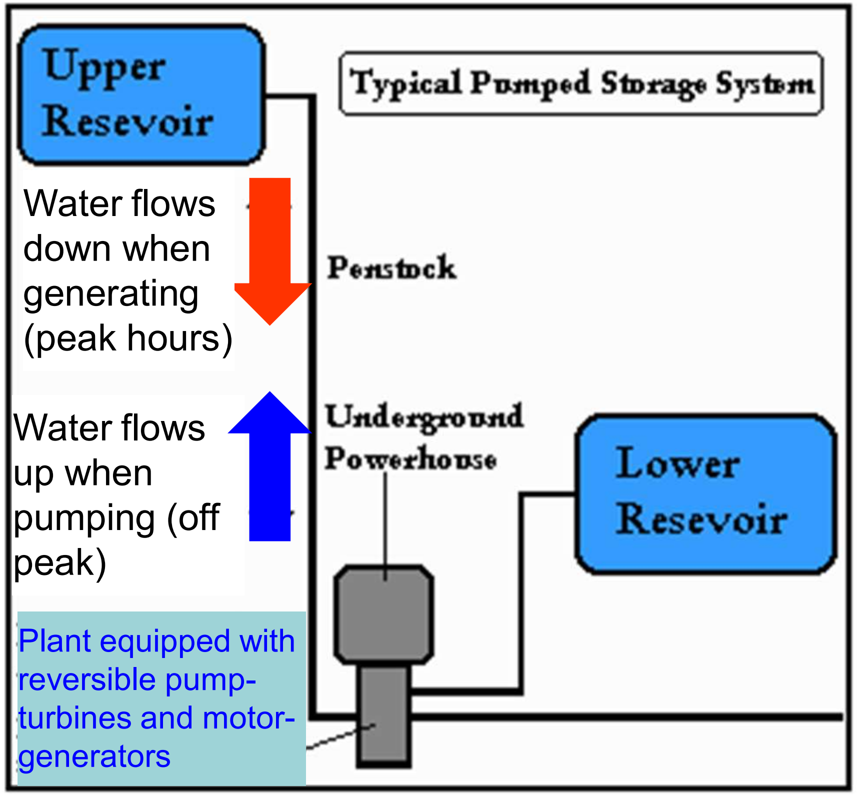
Pumped Storage System



BOTH turbine & generator are REVERSIBLE !!!

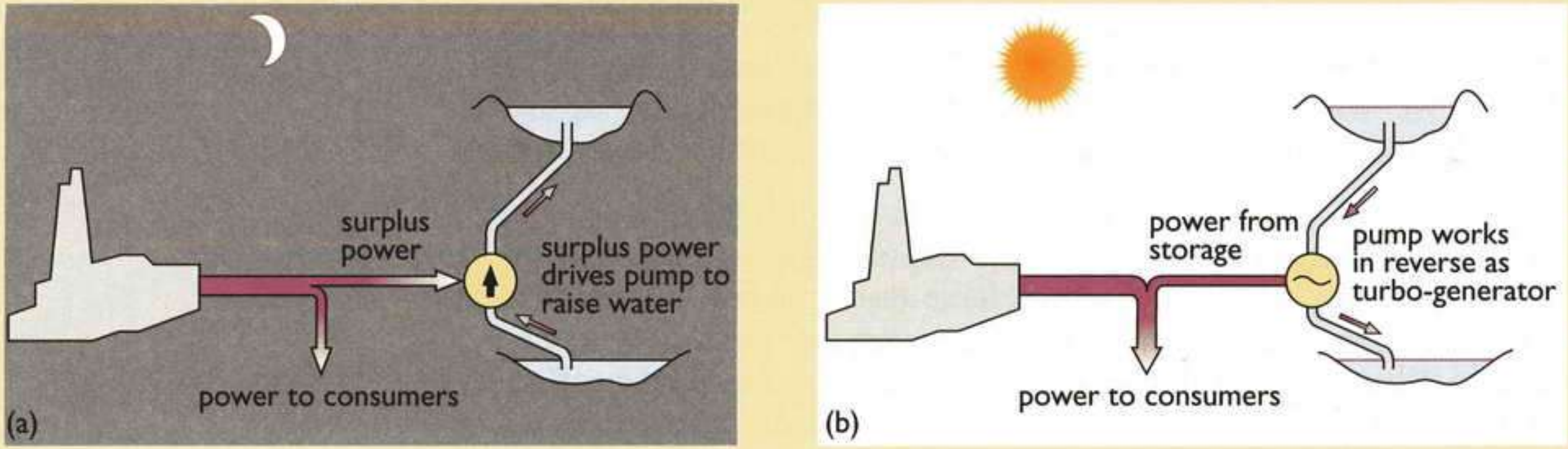
- In order to meet the fluctuating electricity demands, pumped hydro storage facilities can be used to store electrical potential when demand is low and help supply electricity when demand is peaking.
- **The efficiency of this system is typically between 70% and 85%, making it one of the most economical and efficient methods for storing energy.**

Pumped Storage System



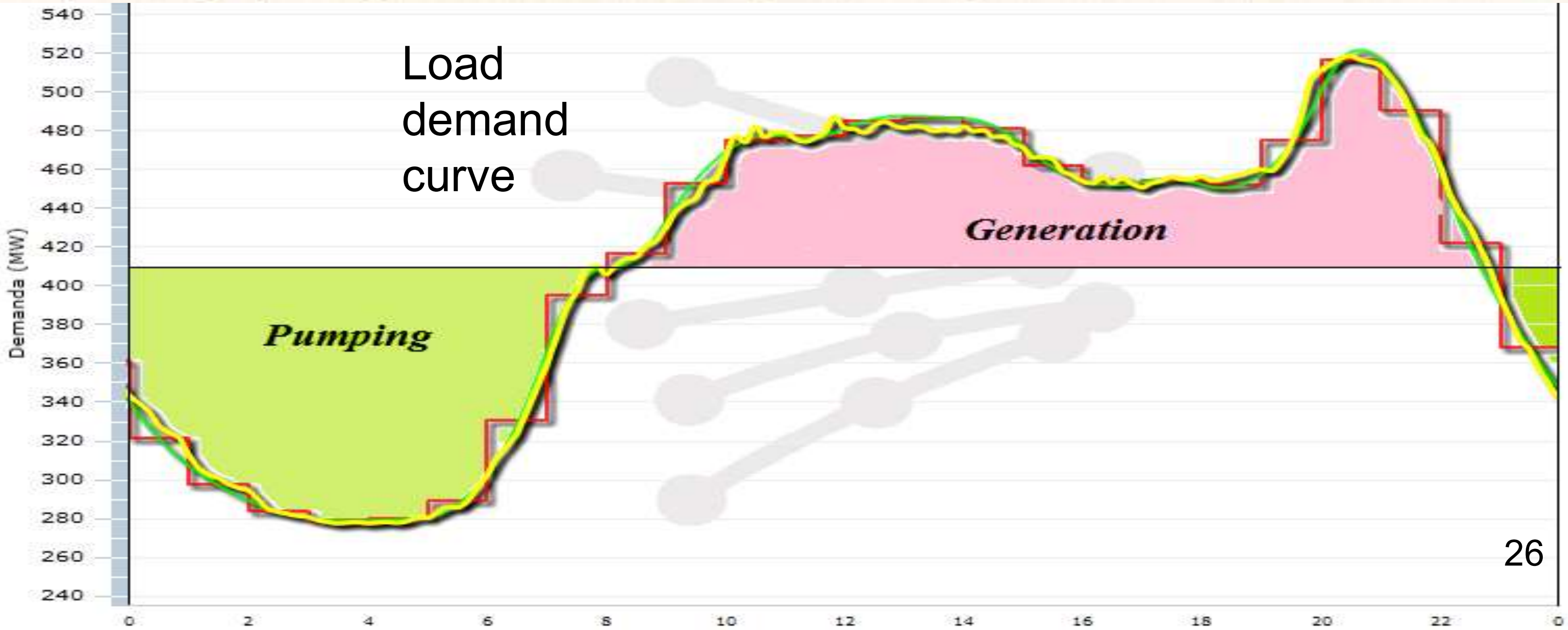
Global pumped hydro capacity is 160 GW, and growing rapidly

Pumped Storage System

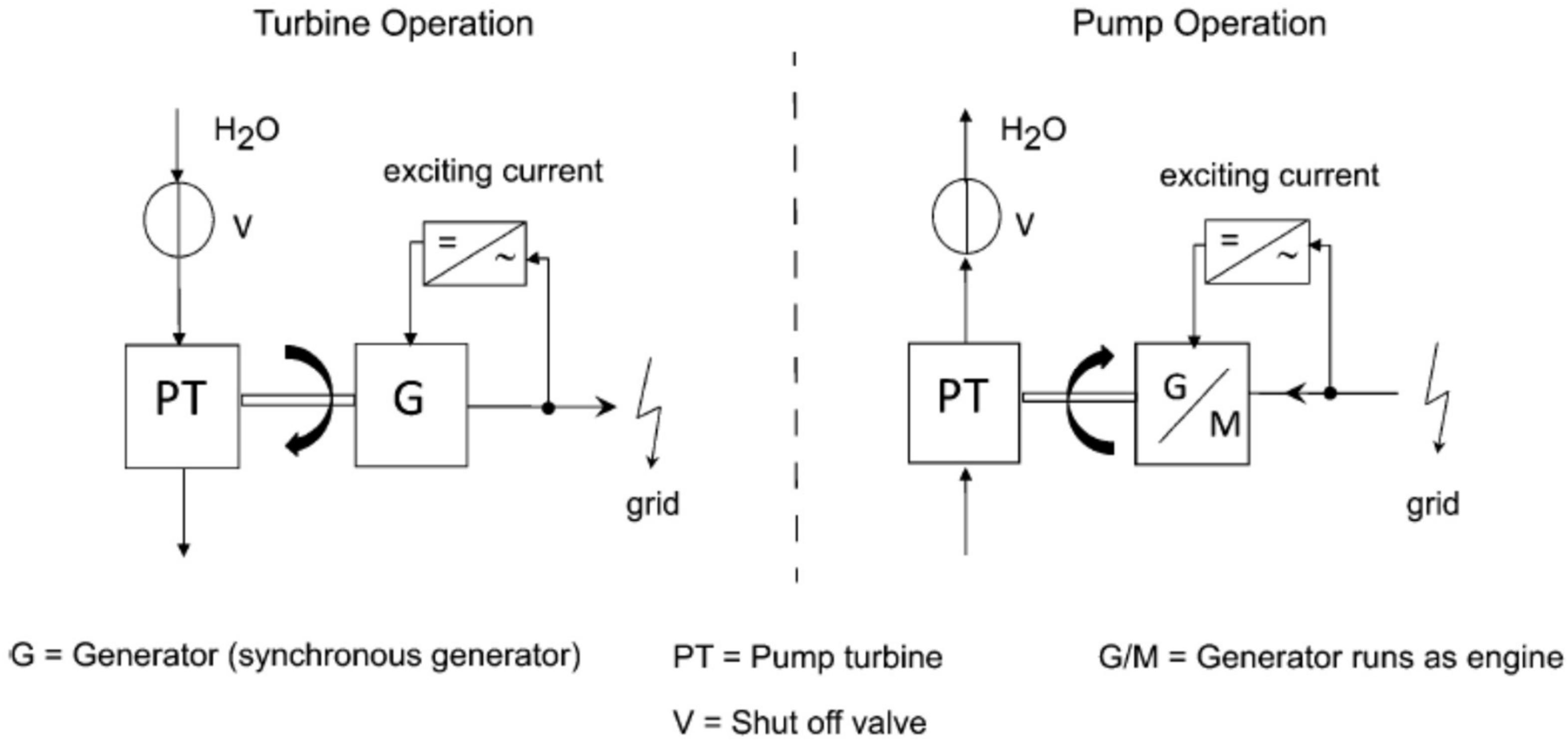


Boyle, *Renewable Energy,* 2nd edition, Oxford University Press, 2003

Figure 5.27 Pumped storage system: (a) at time of low demand; (b) at time of high demand



Pumped Storage System



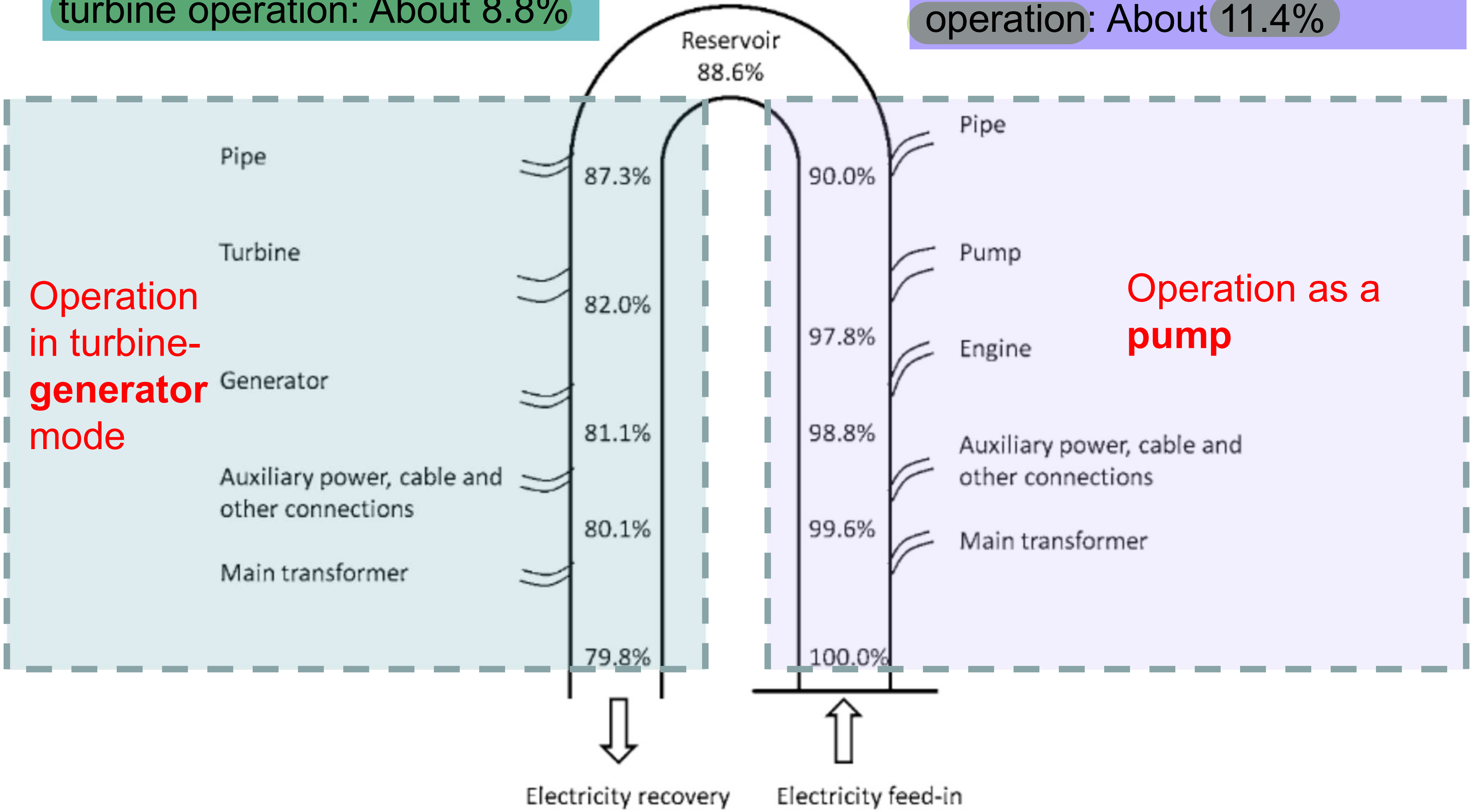
- When demand is low and electricity is cheap, the plant uses energy to pump water from the lower reservoir to the upper reservoir.
- When demand is high and electricity is more expensive, water from the upper reservoir is released back into the lower reservoir through the same system of pipes, this time the turbines acting as they would in a traditional hydroelectric plant and generating electricity.
- Once the facility is operational it can quickly respond to changing energy demands.

Source: Introduction to Hydro Energy Systems, Springer Book

Energy Balance in a Pumped Storage Plant

Total power loss during turbine operation: About 8.8%

Total power loss during pump operation: About 11.4%



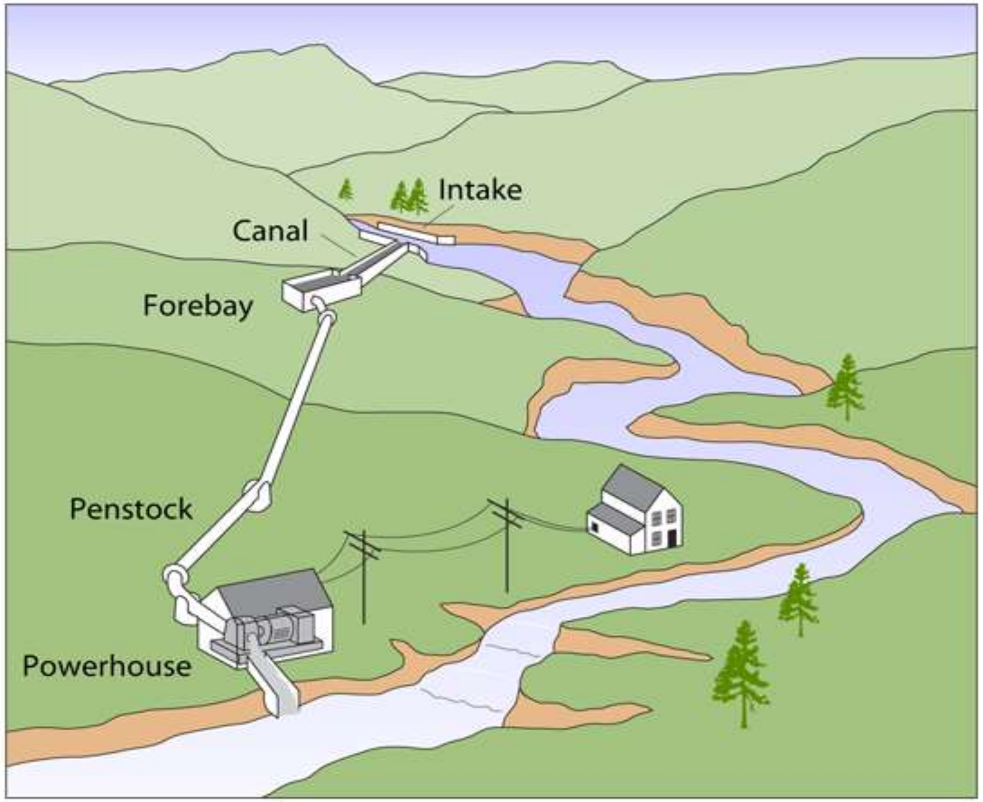
Source: Introduction to Hydro Energy Systems, Springer Book

Micro Hydropower Systems

↳ the future!!!

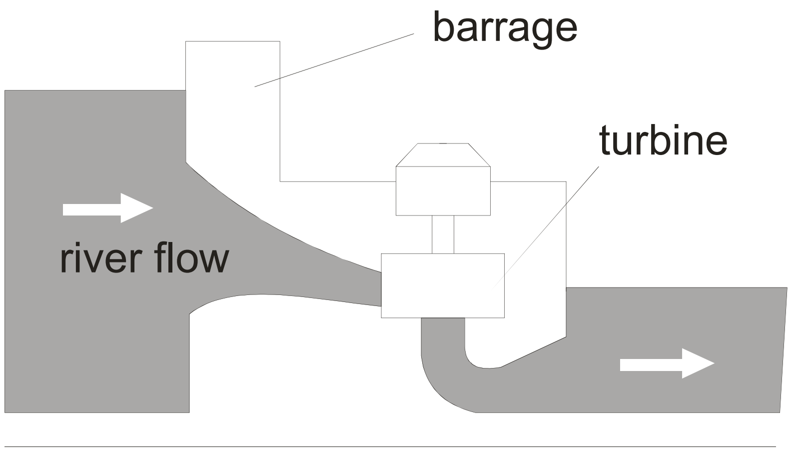
Micro Hydropower Systems

- Micro hydro systems typically produce up to 100 kW of electricity using the natural flow of water.
- Very useful for isolated homes or small communities
- May be connected to electric power grid
- Provide an economical source of energy without the purchase of fuel



In this microhydropower system, water is diverted into the pen-stock. Some generators can be placed directly into the stream.

Source: DOE

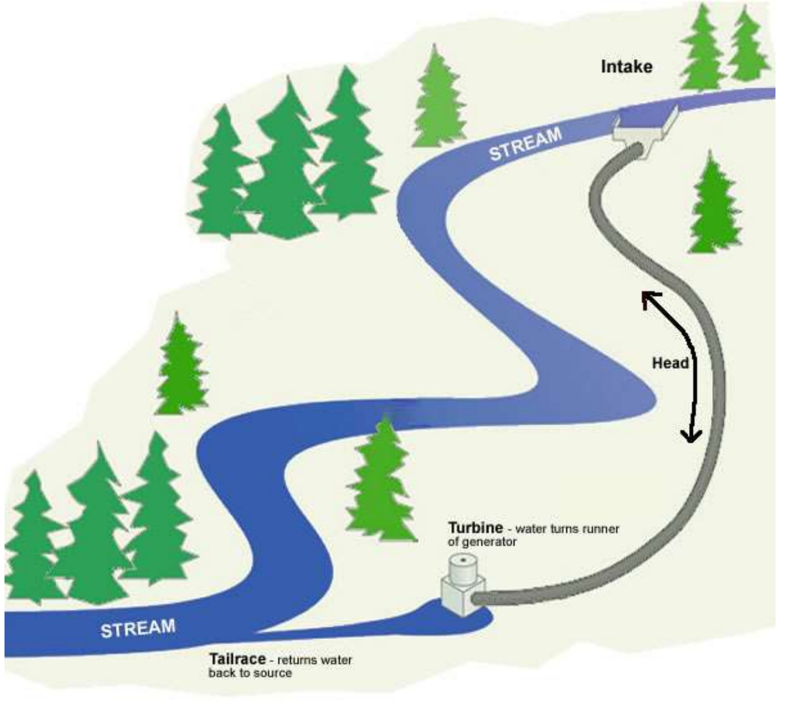


Source: Ramage (1996, *Renewable Energy, Power for a Sustainable Future*, Oxford University Press, Oxford, 183-226)

Micro Hydropower Systems

Advantages:

- Minimal environmental impact
- Large reservoirs are not needed



Disadvantages:

- Uneven electricity generation due to changing river flow
- No storage
- Availability of suitable sites

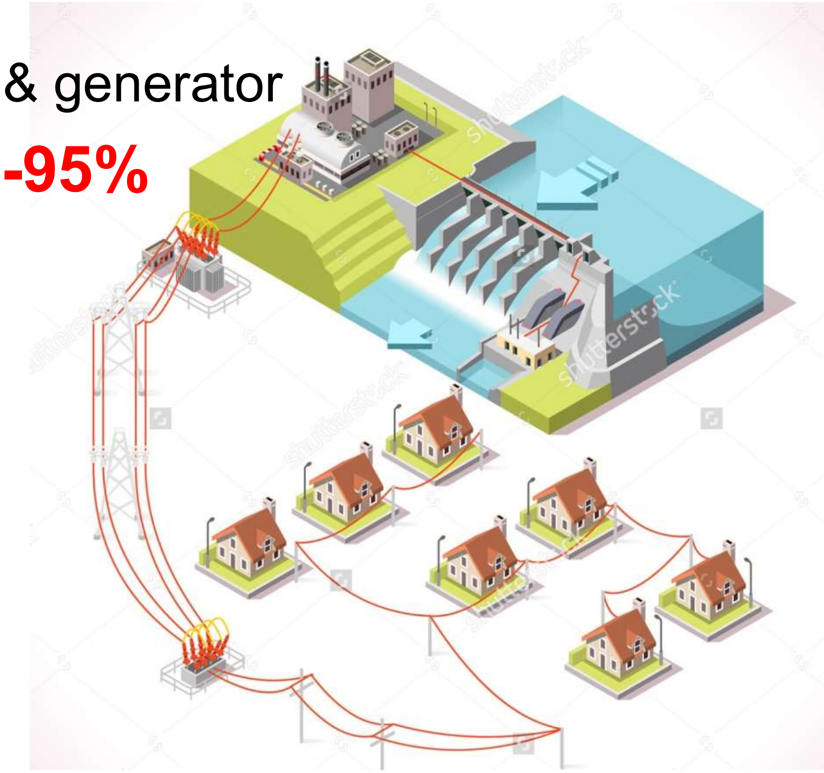
Efficiency of Hydropower Plants

Efficiency of Hydropower Plants

- **Hydropower is very efficient**

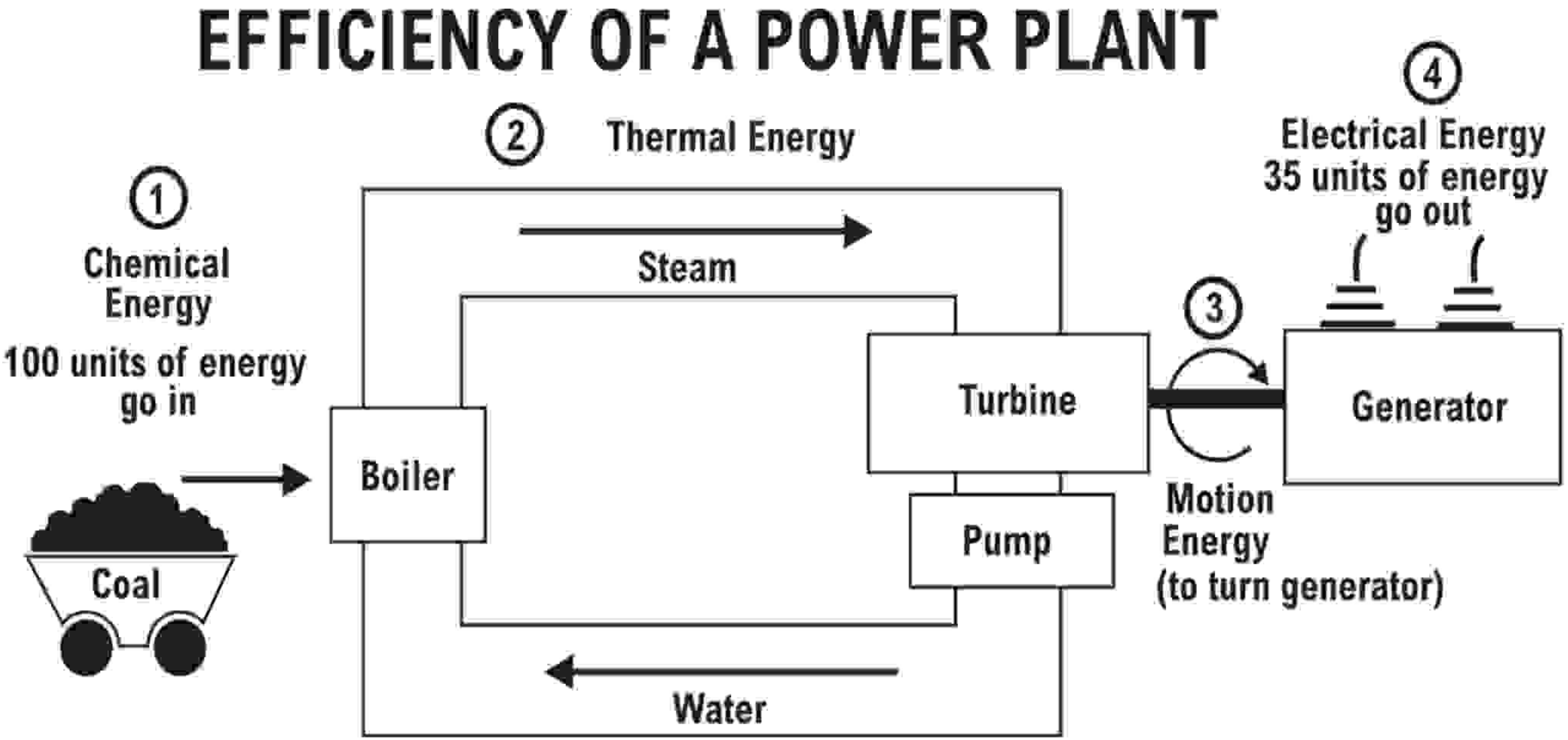
$$\text{Efficiency} = \frac{\text{(electrical power delivered to the “busbar”)}}{\text{(potential energy of head water)}}$$

- **Typical losses are due to**
  - Frictional drag and turbulence of flow
  - Friction and magnetic losses in turbine & generator
- **Overall efficiency ranges from 75-95%**



Boyle, *Renewable Energy,* 2nd edition, Oxford University Press, 2003

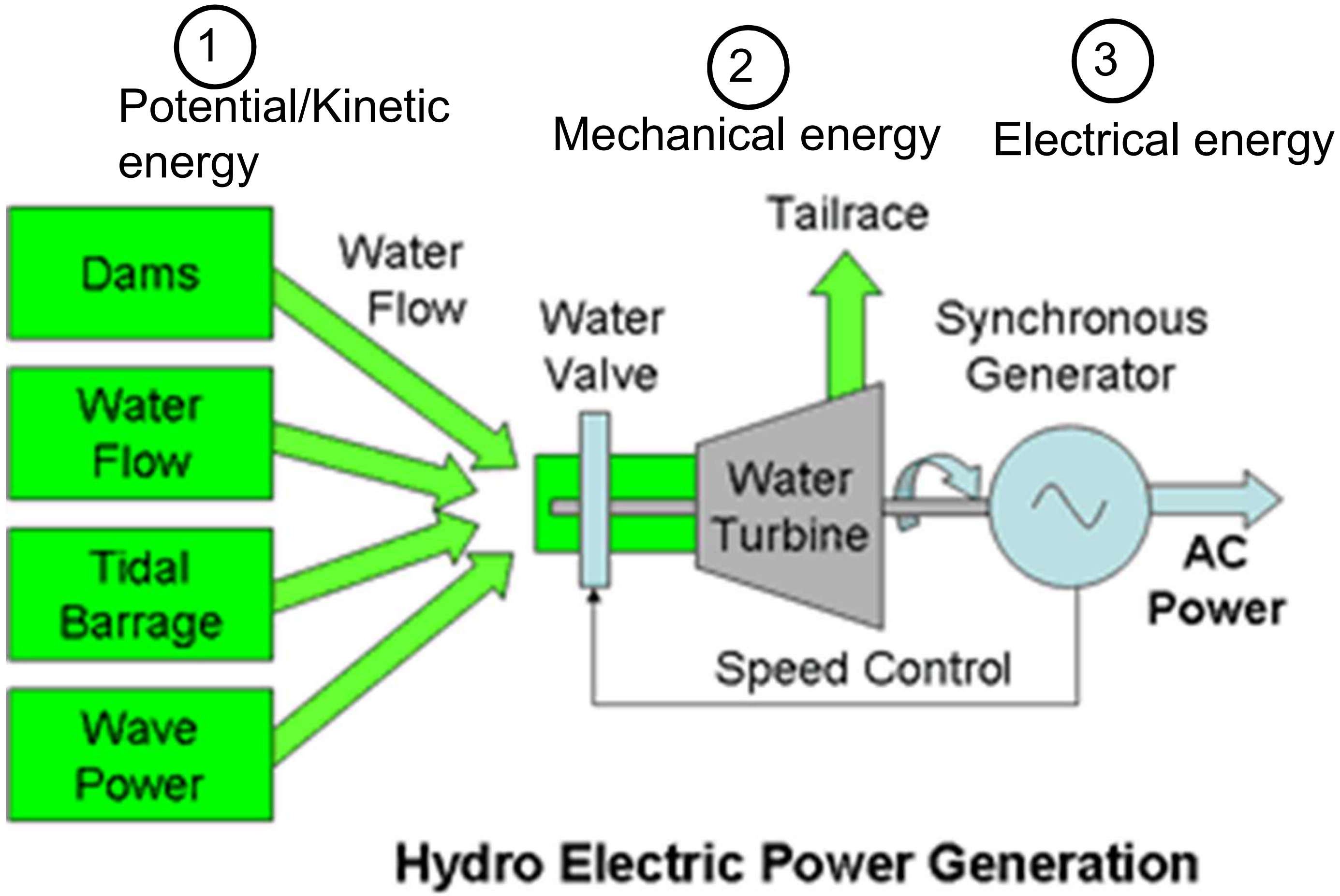
Power Plant Efficiency: Thermal vs Hydro power plant



Most thermal power plants are about 35% efficient. For every 100 units of energy that go into a plant, 65 units are lost as one form of energy is converted into other forms. Most of the lost energy is in the form of heat from friction and heat that escapes the system. Thirty-five units are left to do usable work.

Source: www.eia.gov

Power Plant Efficiency: Thermal vs Hydro power plant



For every 100 units of energy that go into the plant, about 5-15 are lost

Source: www.eia.gov

Power Plant Efficiency: Thermal vs Hydro power plant

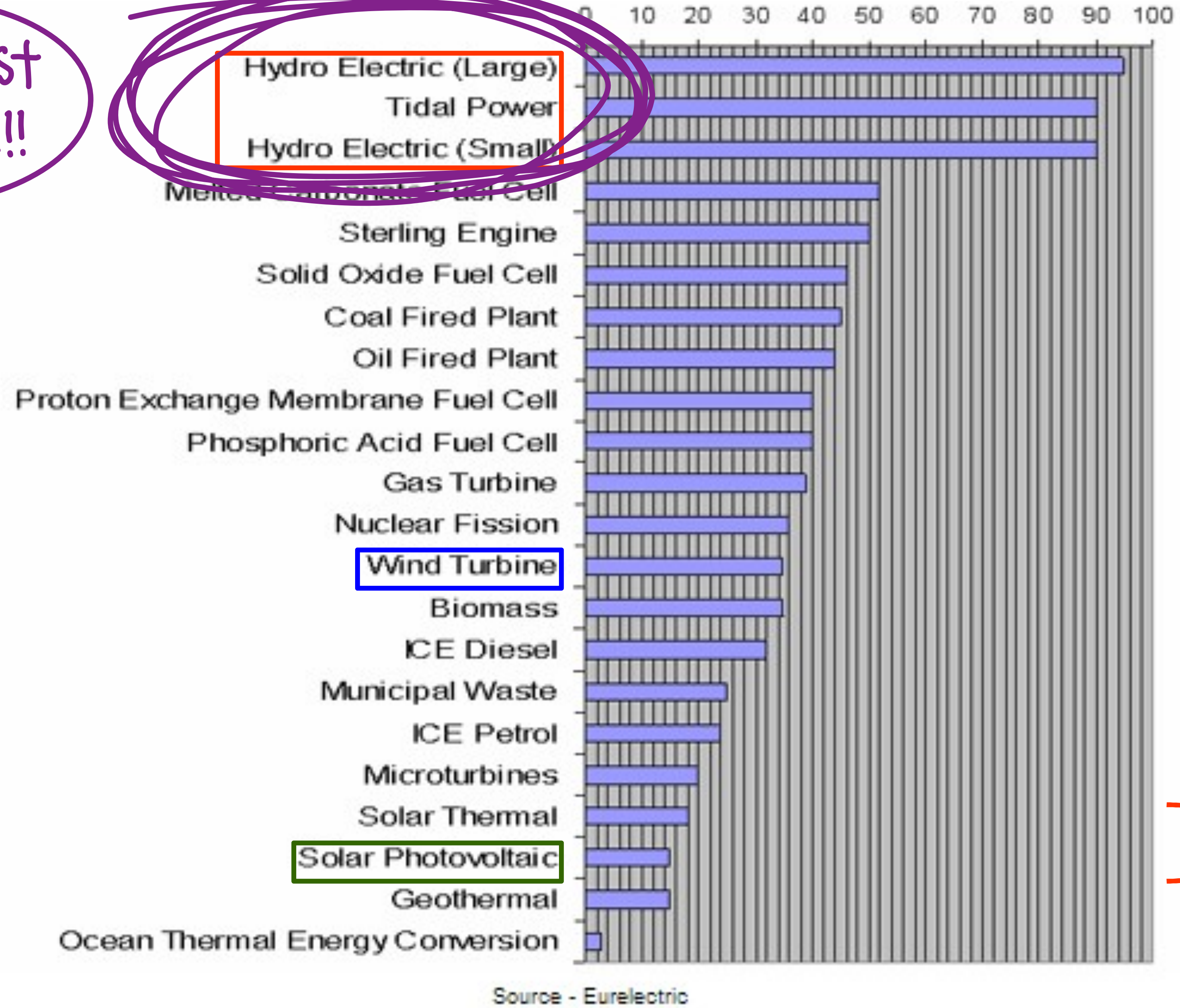
- Coal power plant : 35%
- Large hydro power 95%

HYDRO : 95% efficient

Source: www.eia.gov

Electricity Generation Efficiency: Comparison

Hydro most efficient!!!

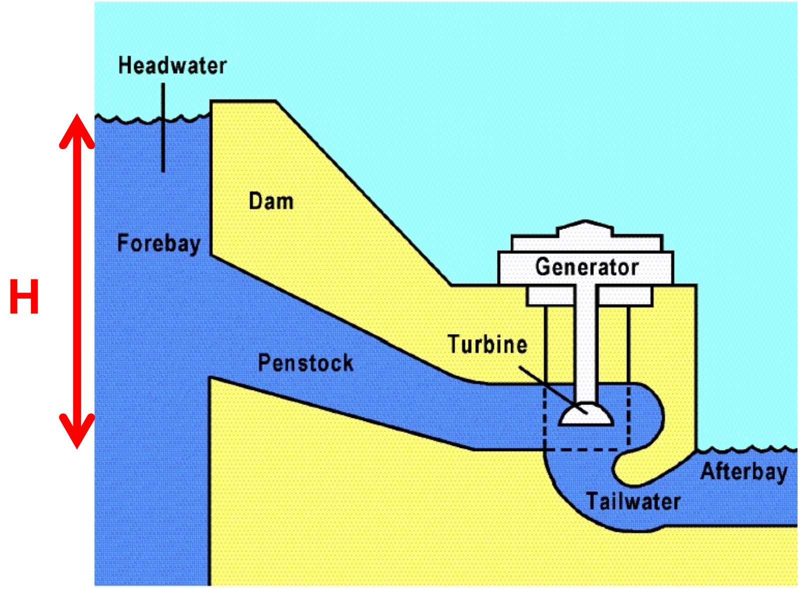


Power Produced by a Hydropower Plant

Hydropower Calculations

$$\boxed{P = g \times \eta \times Q \times H}$$

$$P \cong 10 \times \eta \times Q \times H$$



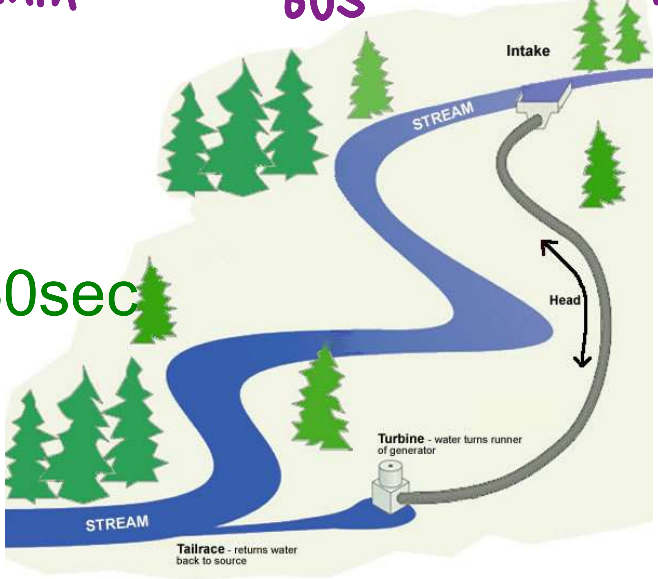
- P = power in kilowatts (kW)
- g = gravitational acceleration (9.81 m/s^2)
- η = turbo-generator efficiency ($0<n<1$)
- Q = quantity of water flowing (m^3/sec)
- H = effective head (m)

Boyle, *Renewable Energy*, 2nd edition, Oxford University Press, 2003

Example 1

Consider a mountain stream with an effective head of 25 m and a flow rate of 600 liters (ℓ) per minute. How much power could a hydro plant generate at this location? Assume plant efficiency (η) of 83%.

$\frac{600\,\ell}{1\,\text{min}} = \frac{600/1000\,m^3}{60\,s} = 0.01\,m^3/s$



- H = 25 m
- $Q = 600\ \ell/\text{min} \times 1\ m^3/1000\ \ell \times 1\ \text{min}/60\text{sec}$

  $= 0.01\ m^3/\text{sec}$

  $\eta = 0.83$

- $P \cong 10\eta QH = 10(0.83)(0.01)(25) = 2.075$ kW

  $P \cong 2.1$ kW

Boyle, *Renewable Energy*, 2nd edition, Oxford University Press, 2003

Example 2

How much energy (E) will the hydro plant generate each year?

- $E = P \times t$

  $= 2.1$ kW × 24 hrs/day × 365 days/yr

  $= 18{,}396$ kWh annually

About how many people will this energy support (assume approximately 3,000 kWh / person)?

- People = $E \div 3000$

  $= 18396/3000 = 6.13$

- The generated power will meet the electricity demands of about 6 people

Boyle, *Renewable Energy,* 2nd edition, Oxford University Press, 2003

Example 3

Consider a second site with an effective head of 100 m and a flow rate of 6,000 cubic meters per second (about that of Niagara Falls). Answer the same questions.

- $P \cong 10\eta QH$ = 10(0.83)(6000)(100)

  $\cong$ 4.98 million kW = 4.98 GW

- $E = P \times t$

  = $4.98GW$ × 24 hrs/day × 365 days/yr

  = 43,625 GWh = 43.6 TWh (terrawatt hours)

- People = E ÷ 3000

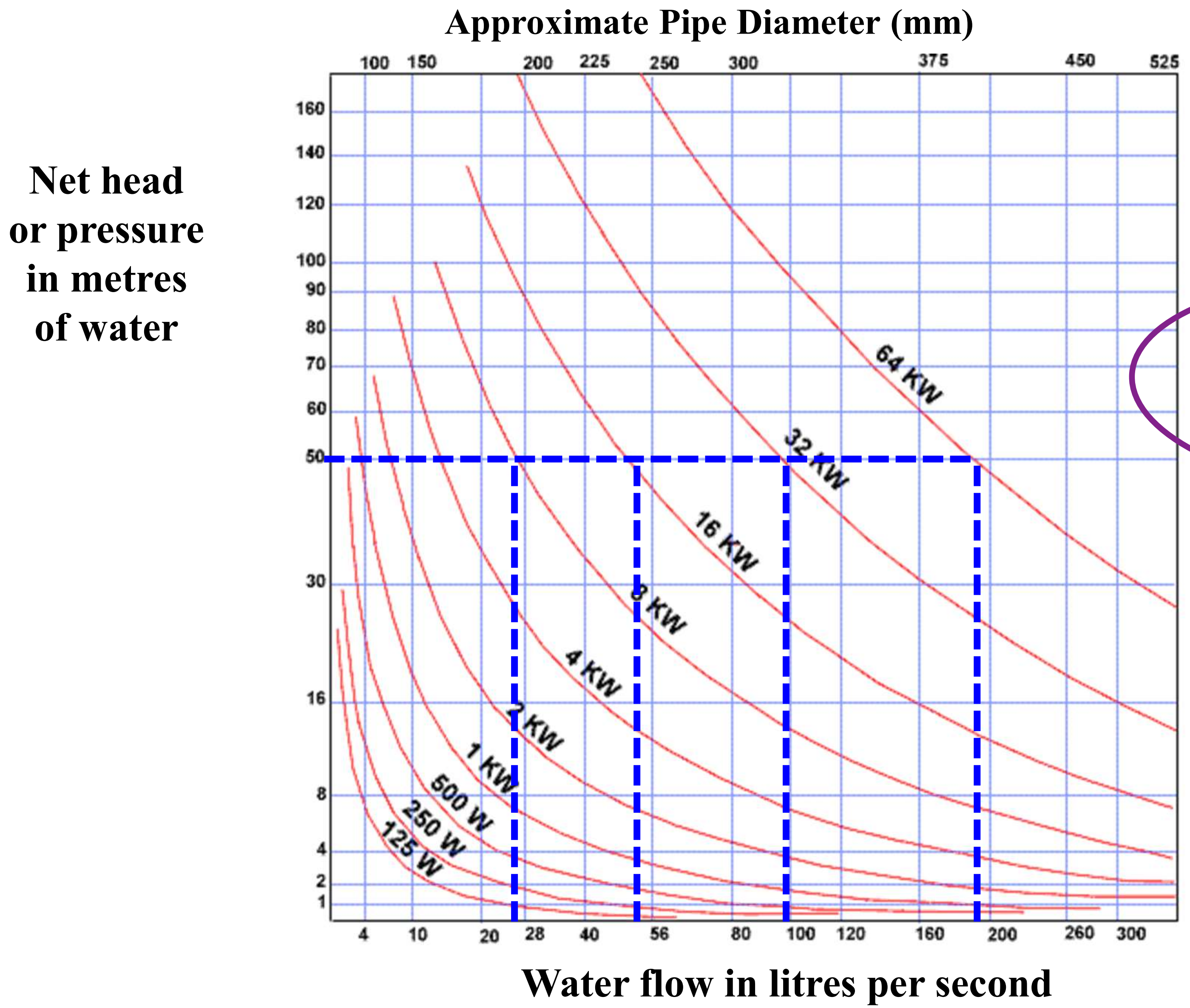
  = 43.6 TWh / 3,000 kWh

  = 1.45 million people

(This assumes maximum power production 24x7)

Boyle, *Renewable Energy*, 2nd edition, Oxford University Press, 2003

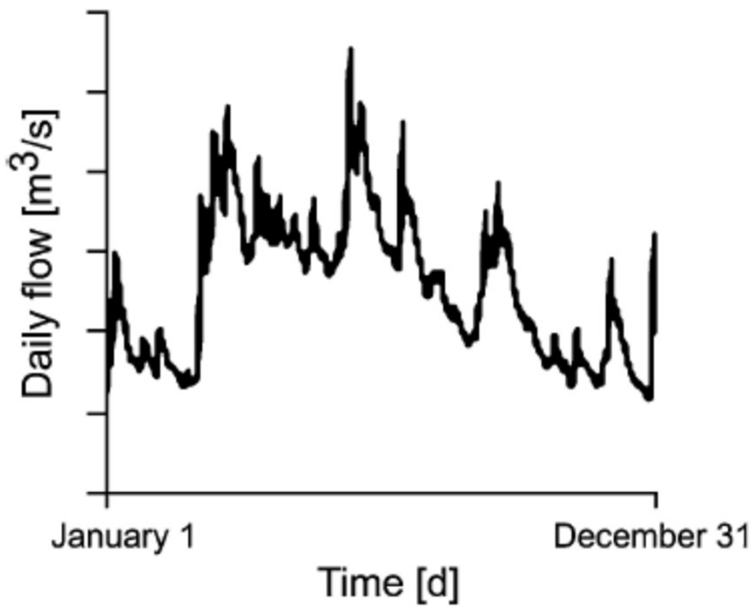
Practical Considerations: Power vs. Head and Flow



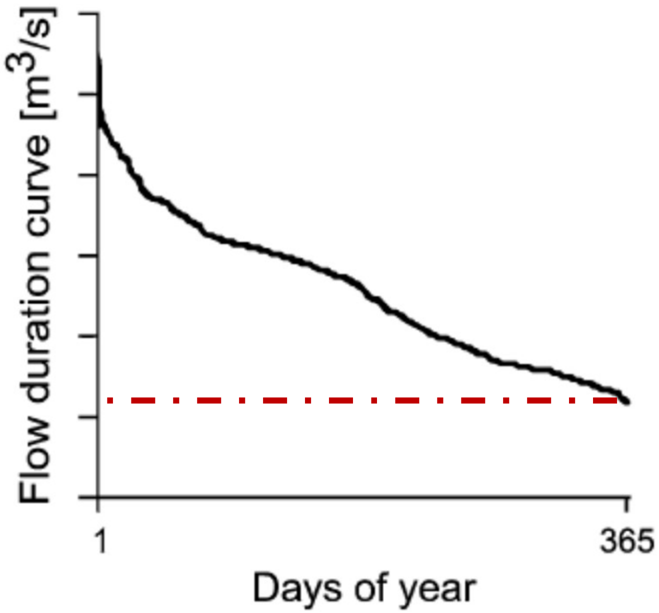
$P \propto (Q \times H)$

Practical Considerations : Expected average availability of water

Hydrograph



Average flow duration curve

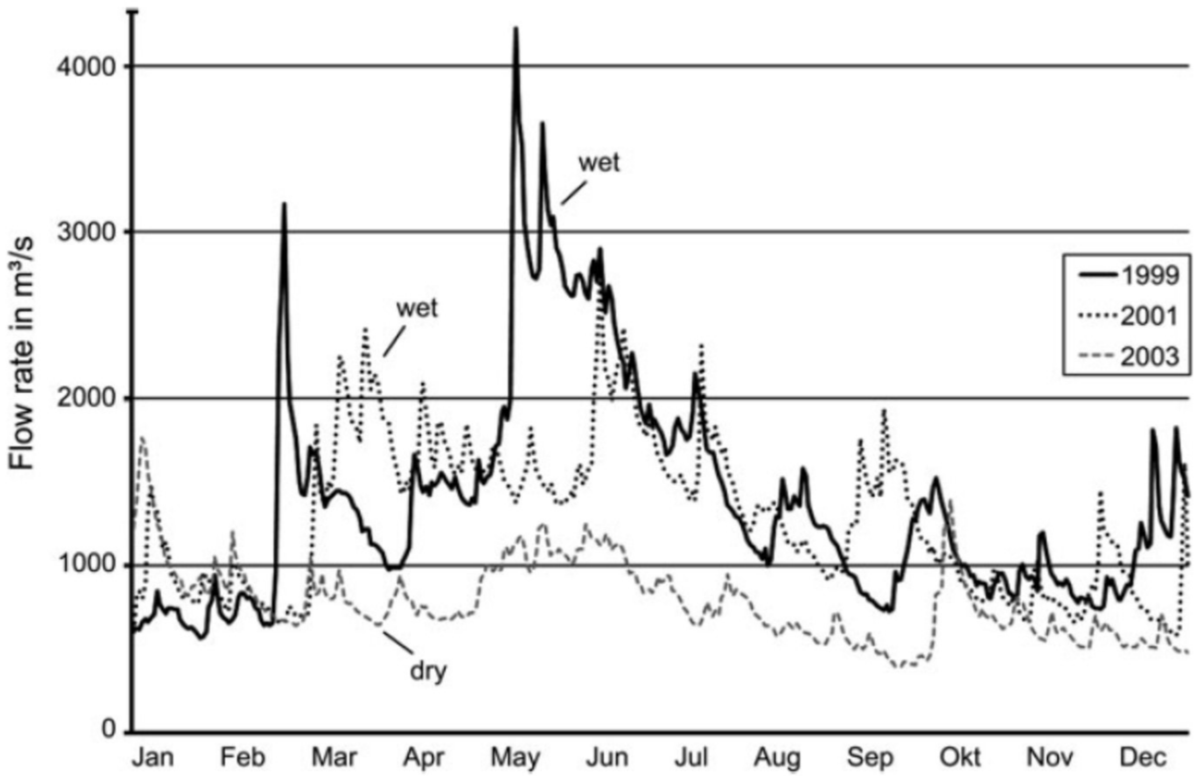


When deciding on a location for a hydropower plant, it is necessary to know the average expected supply of water available for power generation.

Source: Introduction to Hydro Energy Systems, Springer Book

Practical Considerations : Expected average availability of water

- Historical data of previous decades is used
- Still there is unpredictability about annual average volume of water being available



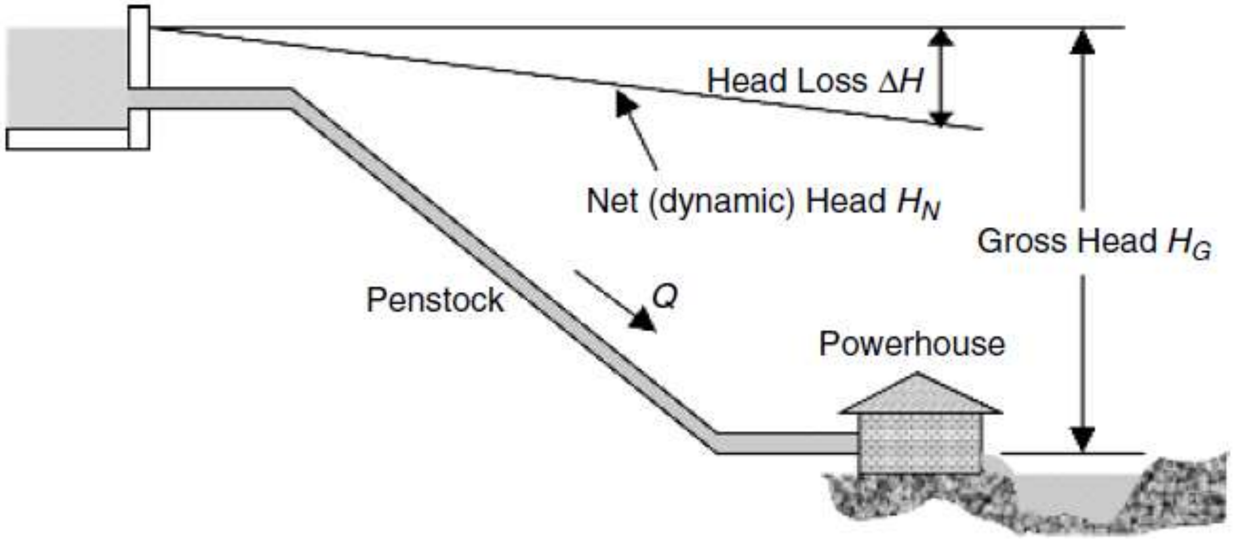
Hydrograph of the Rhine River in Germany of two selected "Wet" years (1999 and 2001) and one "Dry" year (2003)

In the light of this example, how much sense does it make to construct a power plant based on the average water supply?

Source: Introduction to Hydro Energy Systems, Springer Book

Low-head hydro-electric system

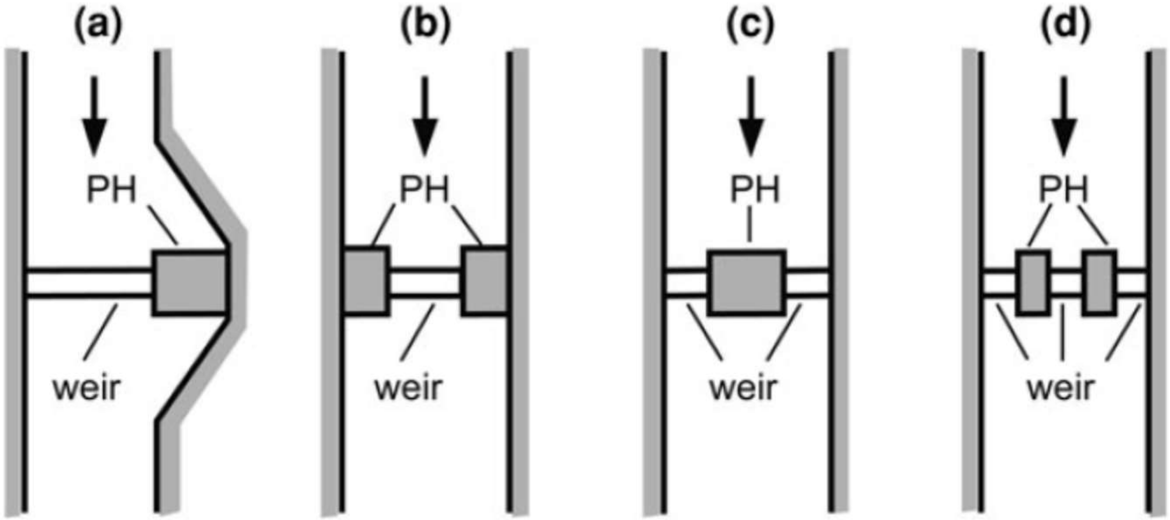
- Pipe losses result in decreased power available for the turbine
- Net head = Gross head – Loss of head due to pipe losses
- Larger diameter pipes will cause smaller pipe losses, but cost more



Refer to Section 4.5 in GM Master's Book

Practical Considerations: Locating the power house and Weir

Depending on the topographic situation at the river-site where a hydropower plant is planned, there are several possibilities to locate the power house, in low-head hydropower systems



Source: Introduction to Hydro Energy Systems, Springer Book

What is the minimum head and flow required?

For a commercially viable site: atleast 25 kW power output.
For a low-head micro hydropower system we need;
Minimum gross head: 2 metres
An average flow rate of 2.07 m^3/s.

- To put this in context this would be a small river, which is approximately 7 metres wide and around 1 metre deep in the middle.

For a site with 25 metres head;
A much lower average flow rate of 0.166 m^3/s is needed

- E.g. A large stream of 2 – 3 metres width and around 40 cm deep in the middle.

If the head drops to 1.5 metres it isn’t normally possible to get any kind of return on investment.

$\frac{800\ \ell}{1\text{min}} = \frac{800/1000\ m^3}{60s} = 0.0133\ m^3/s$

Example 4

Gross head = 35m

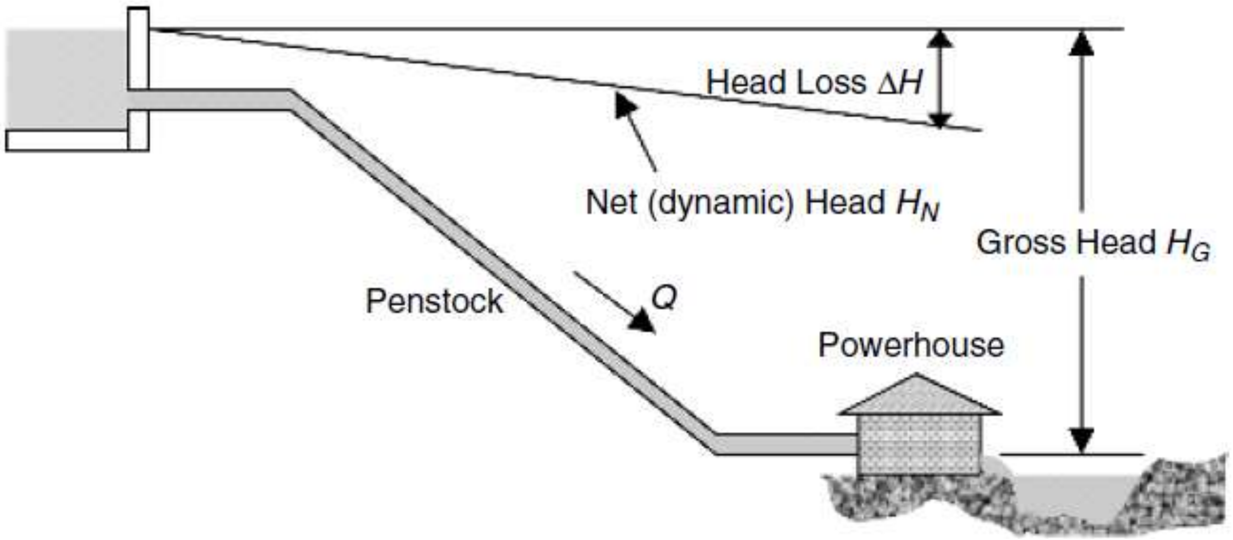
Suppose 800 litres per minute of water is taken from a mountain creek and delivered through 300 meters of 3-inch diameter pipe to a turbine 35 meters lower than the source.

Estimate the power delivered by the turbine generator if the pipe loses 5% head due to frictional losses.

Assume the turbine-generator efficiency to be 90%.

- Pipe loses 5 m of head for every 100 m of length
- The loss of head due to friction = 5% of 300 = 15 m
- Net head available for the turbine:

  Net head = Gross head – friction head = 35-15 = 20 m

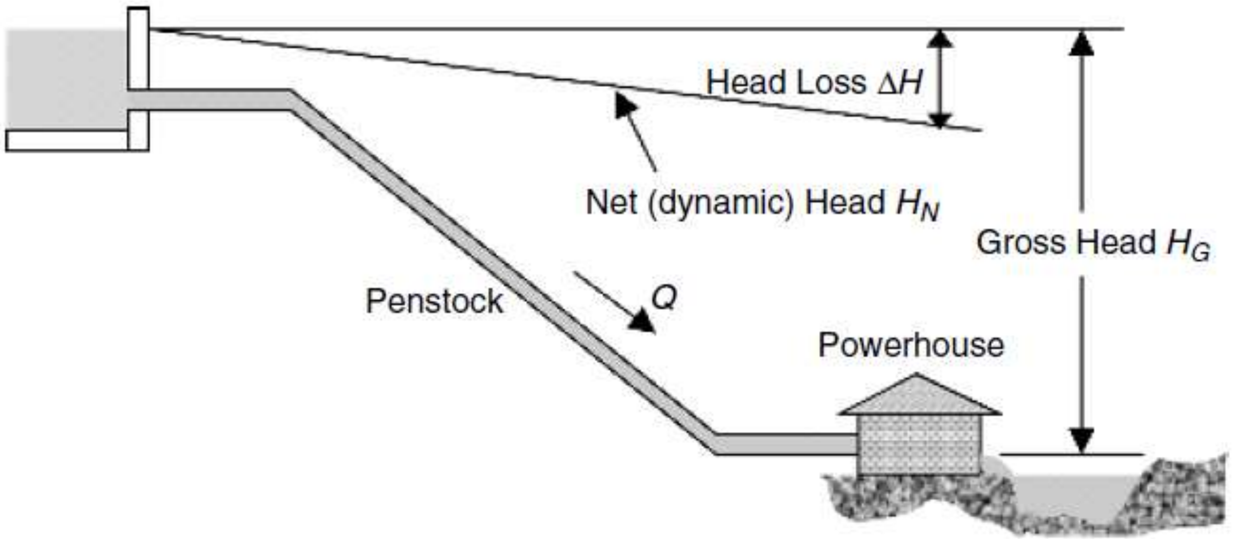


Example 4

- $Q = 800\ \ell/\text{min} \times 1\ \text{m}^3/1000\ \ell \times 1\ \text{min}/60\text{sec}$
  $= 0.01333\ \text{m}^3/\text{sec}$

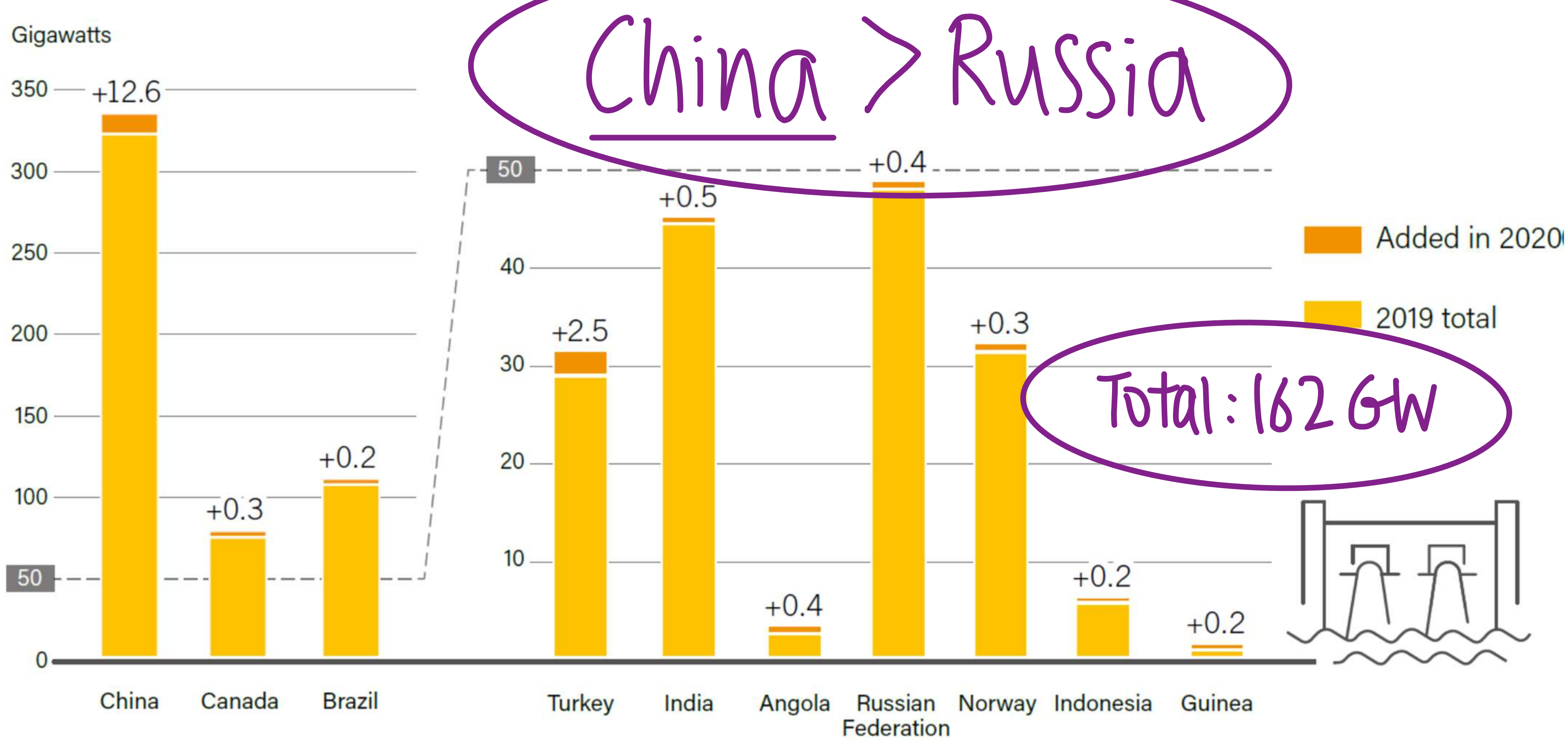
$\eta\ = 0.9$

$P \cong 10\eta QH$
$= 10(0.9)(0.01333)(20)$
$= 2.4\ \text{kW}$



Hydro Power Trends and Current Status

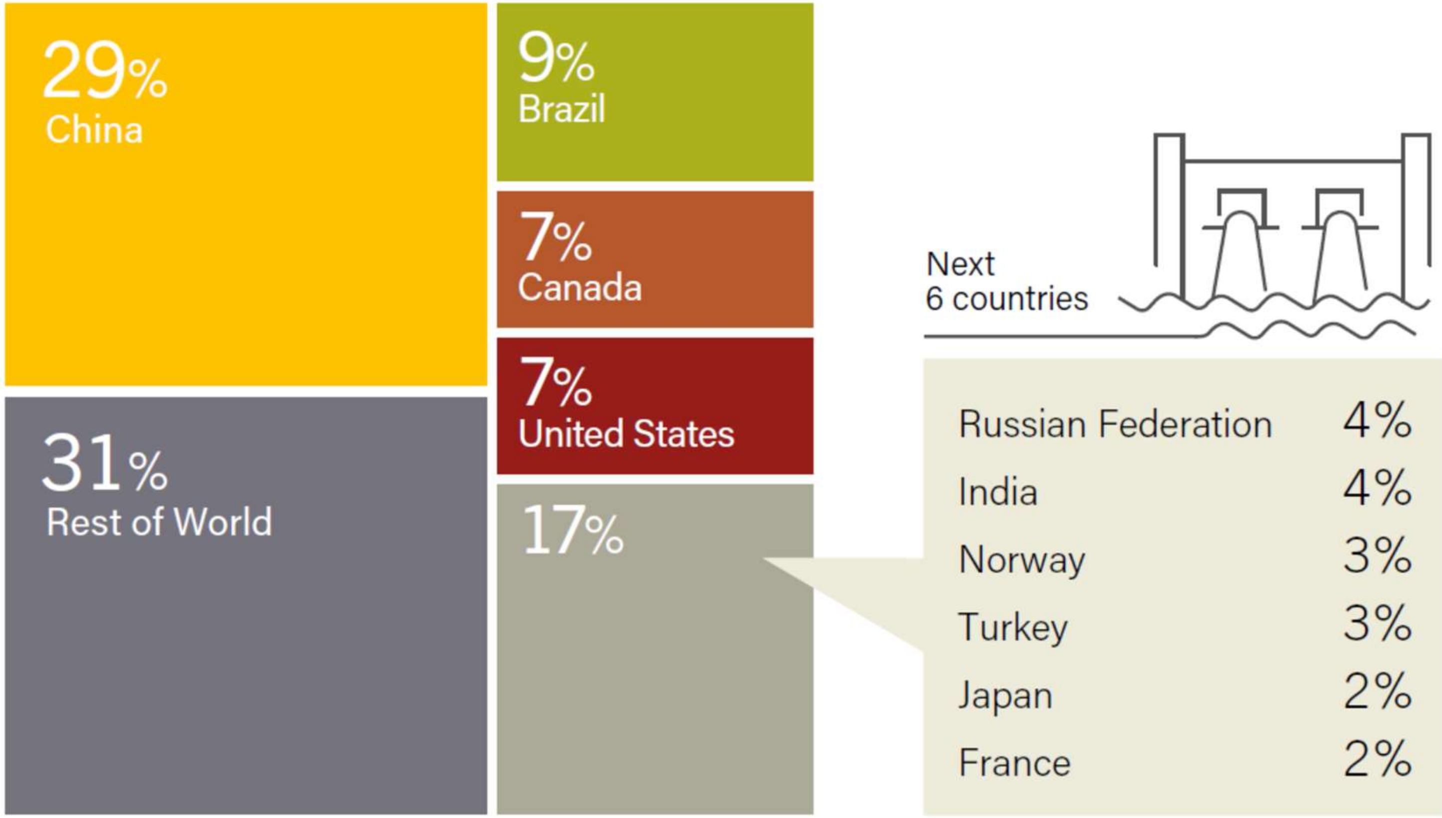
Hydro Power Capacity in the World, 2021



- China added 12.6 GW of new capacity in 2020 alone
- Pump storage capacity grew to 162 GW
- China is the leading country in terms of hydroelectricity generation, capacity and number of new developments

Source: REN21's Renewables 2021 Global Status Report

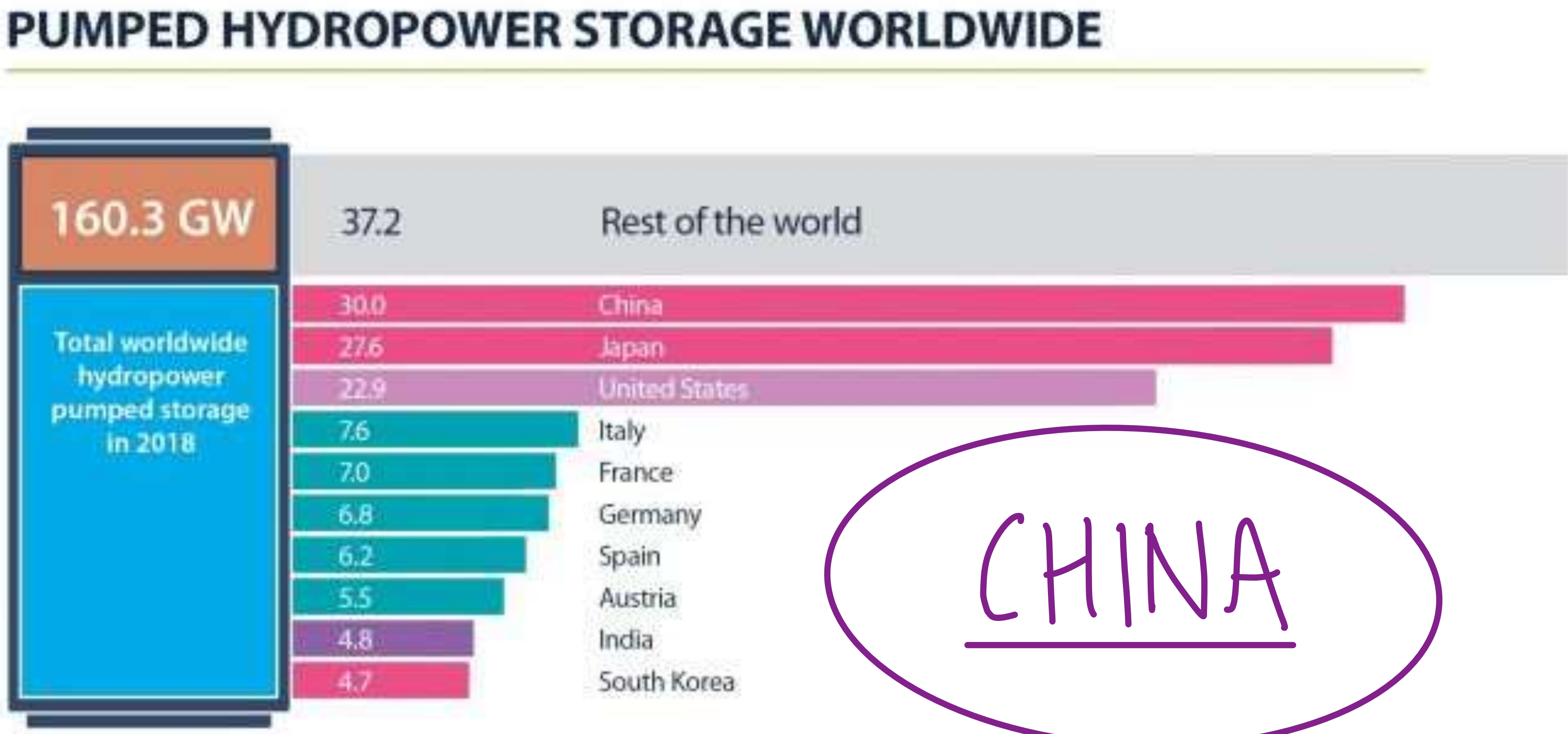
World Trends in Hydropower



Hydroelectricity accounted for roughly 17 percent of global electricity generation, almost all produced by the world's 45,000-plus large dams.

Source: REN21's Renewables 2021 Global Status Report

Total Installed Capacity of Pumped Storage Systems Worldwide



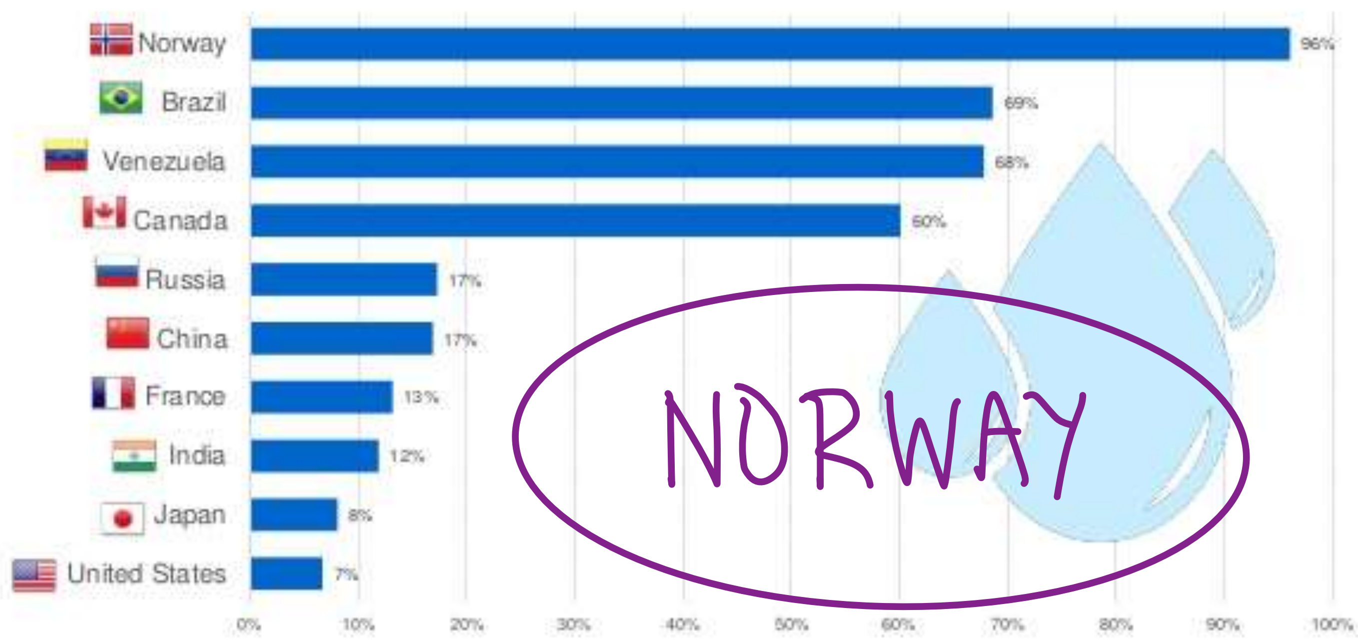
CHINA

Source: 2019 Hydropower Status Report

Share of Electricity from Hydropower

Percentage of hydropower in Top 10 countries (2014)

Norway leads, with almost all electricity generated from hydro resources



Source: IHA 2015 Hydropower Status Report
IEA October 2015 Monthly Electricity Statistics

Hydroelectric Power Systems: Advantages

Source: www.eia.gov

- Renewable Energy
- Clean Energy Source
- Generally Available As Needed
- Provides Recreational Opportunities
- Water Supply and Flood Control

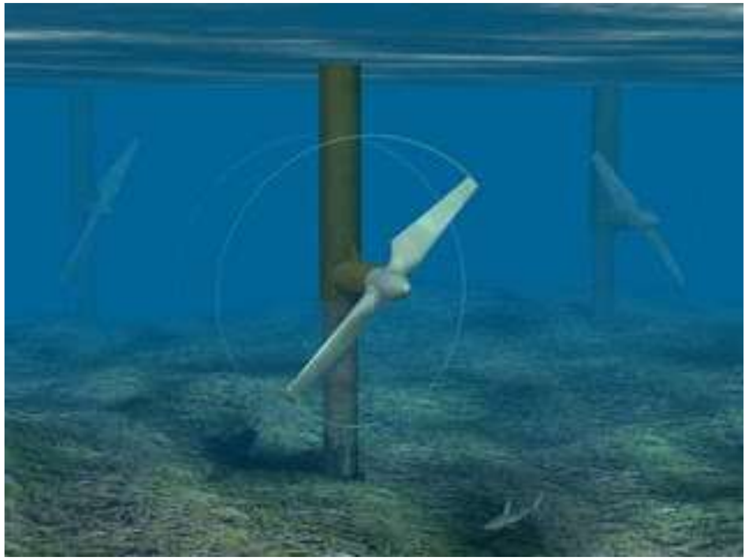
Hydroelectric Systems - Issues and Trends

- The optimum locations for major dams have already been exploited around the world
- Large dams are currently under attack by some who feel that they should be breached to “restore the natural river flows” and “to let the river run free”
  - This lack of dams often led to massive floods and loss of life in the past
- Further large installations are unlikely, although many small stream systems are still being developed
- The reservoir behind large impoundment dams can generate GHG due to decomposition of plant material

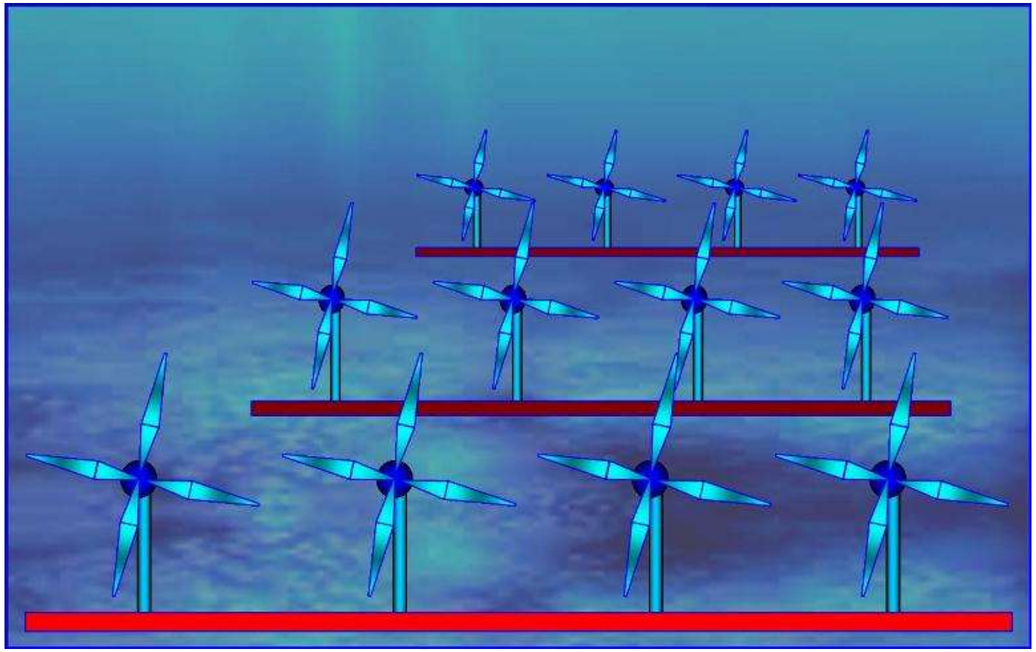
Is there a way around this whole issue of building Dams?

Dam-less Hydropower plants

A typical damless hydro turbine



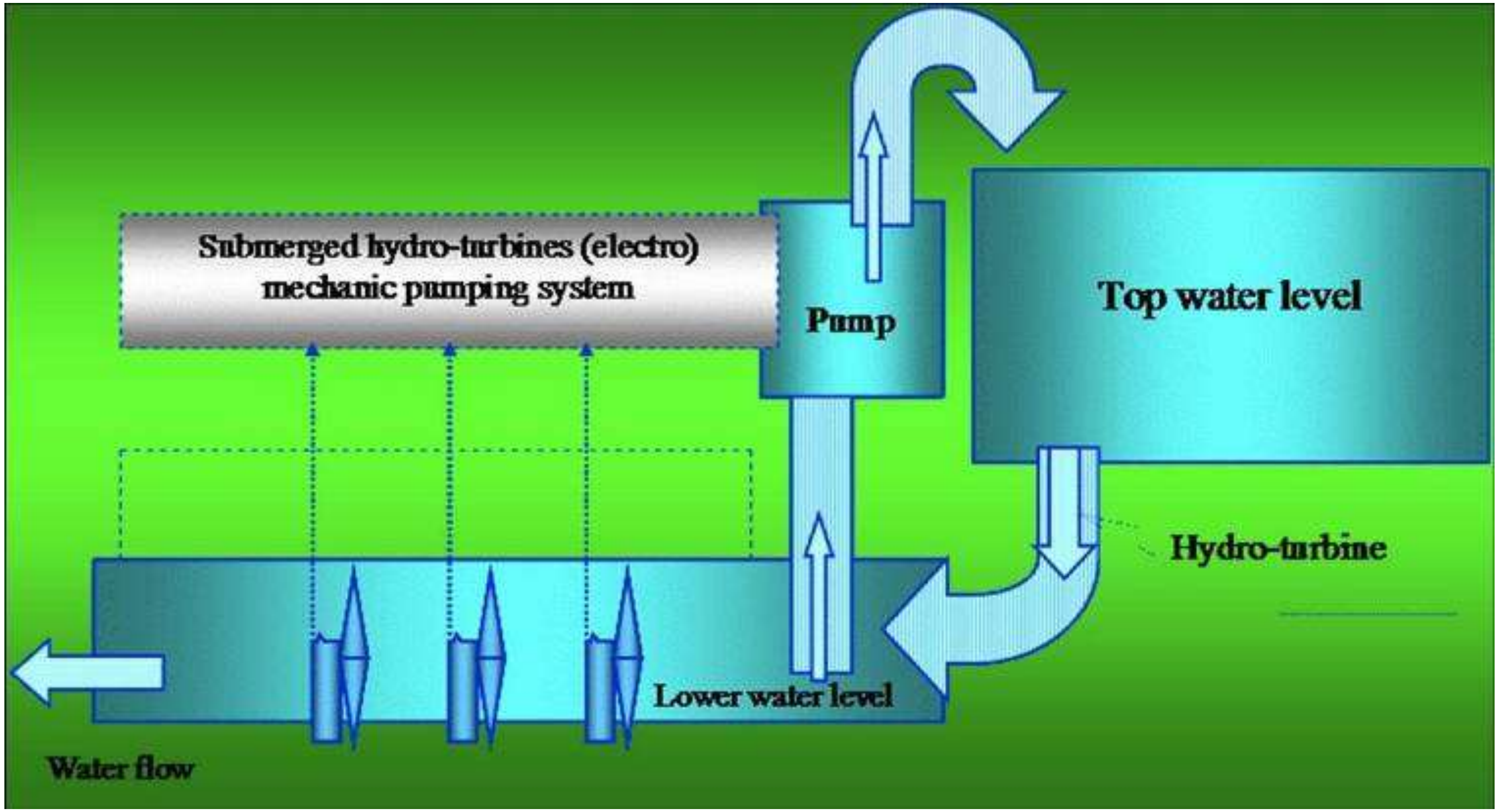
Cascaded damless hydropower plants with submerged hydro turbines



- Damless hydropower does not need a dam to create pressure
- Uses natural flow of the river or tide to produce electricity
- Such turbines are low head installations
- Very minimal environmental impact
  - **The developers of damless hydropower also claim that the blades turn slow enough to allow fish to escape**

Dam-less Hydropower plants

Combined dam-less hydropower plants for pumped storage and electrical power productions



Example: One such 1 MW hydropower system can lift about 10 m^3 of water every second into a storage pool having height of 10 meters.
Hence, Water stored in the storage pool > 860000 m^3 per day.
With five such systems, we can generate 20 MW for 6 hours

Hydroelectric Systems - Conclusion

- Hydropower is an efficient, predictable, and affordable source of energy that produces no greenhouse gases and already generates a fifth of the world's electricity
- **Best renewable energy source for large scale power generation**
- Starts easily and quickly
- Power output can be changed rapidly, and hence complements large thermal plants (coal and nuclear), which are most efficient in serving base power loads.
- **Pumped storage system provides excellent storage option**
- The majority of logical hydropower sites were developed long ago.
- Africa has only 7% hydro potential developed
- Small hydropower on the scale of remote home energy is still developing
- Environmental effects should be taken into consideration when designing a hydroelectric system

Ocean Energy

Ocean energy

- Ocean energy refers to any energy harnessed from the ocean by means of :
  - ocean **waves**
  - **tidal** range (rise and fall), tidal streams
  - ocean (permanent) **currents**
  - **temperature gradients** and salinity gradients.
- Tidal stream and wave power are the main focus of development efforts
- The industry is now moving from small-scale pilot projects towards semi-permanent commercial ocean energy installations.
- Total world capacity is approximately 535 MW

535MW

Overview of Ocean Energy

- Ocean energy is replenished by the sun and through tidal influences of the moon's gravitational forces
- Near-surface winds induce **wave** action and cause wind-blown currents at about 3% of the wind speed
- **Tides** cause strong currents into and out of coastal basins and rivers → tides: 2 times a day
- Ocean surface heating by some 70% of the incoming sunlight adds to the surface water **thermal** energy, causing expansion and flow
- **Wind** energy is stronger over the ocean due to less drag, although technically, only seabreezes are from ocean energy

Tidal Energy

How Does It Work?

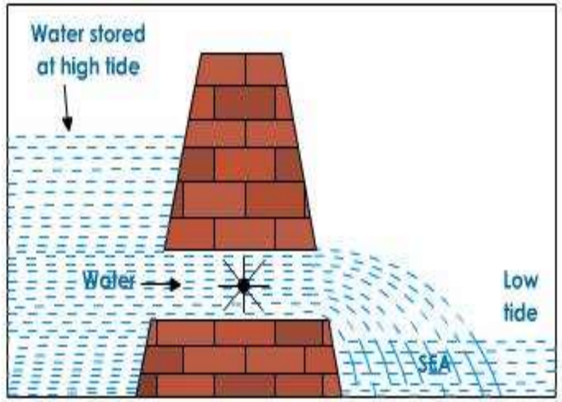
The movement of water by tides pushes or pulls a turbine to generate electricity

- Barrages
- Lagoons
- Undersea/ Offshore

Tidal Barrage

Tidal Energy

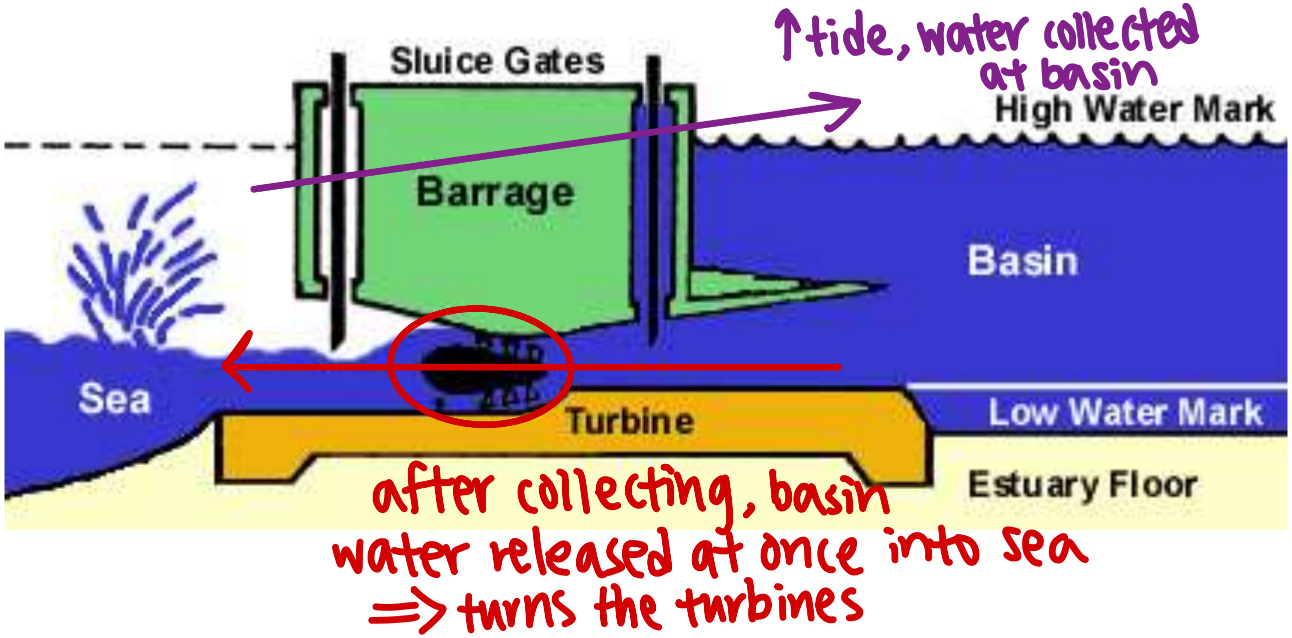
- Tides are produced by gravitational forces of the moon and sun and the Earth's rotation
- Existing and possible sites:
  - France: La Rance river estuary 240 MW station
  - S Korea: 254 MW Sihwa plant
  - UK: Swansea Bay (320 MW project awaiting approval)
  - Canada: Passamaquoddy Bay in the Bay of Fundy;
    - Truro Bay site operational.
  - California: high potential along the northern coast
- Environmental, economic, and aesthetic aspects have delayed implementation



At low tide, stored water flows out from reservoir into sea and turns the turbine

Tidal Energy: Barrage

Current flow converted to rotary motion by tidal current



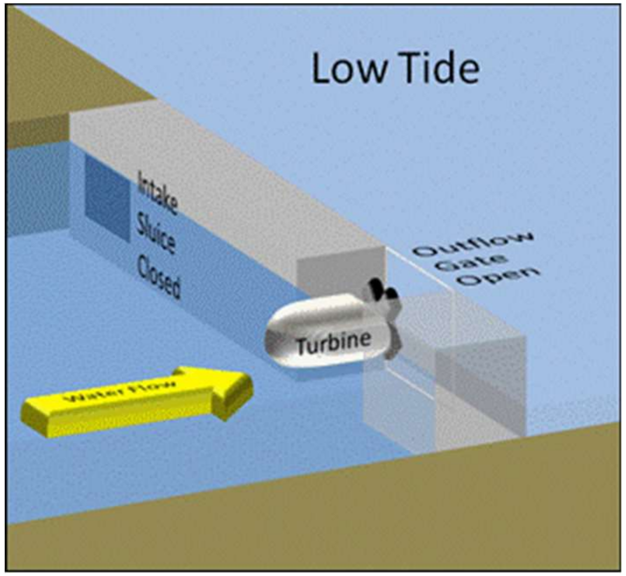
Barrages: Dam like structure that captures tidal energy entering or exiting an area

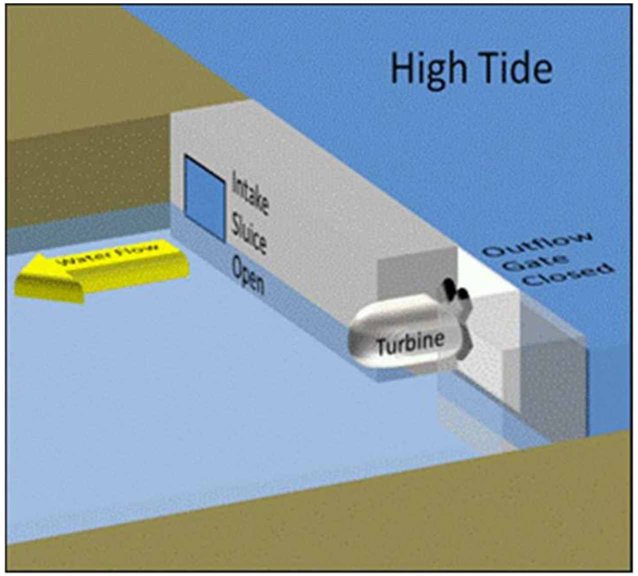
- Gates control water movement
- Used to spin a turbine
- Can be installed in a Bay, River, or Estuary

Tidal Energy: Lagoons

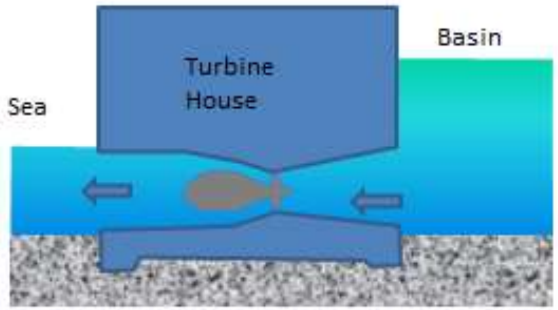
- Built structure that contains turbines
- Closes off a tidal area similar to a harbour
- Tides can flow through turbines four times a day at high tide and low tide

↳ similar to barrage, but turbine works both direction ⇒ 2× the Pgen!

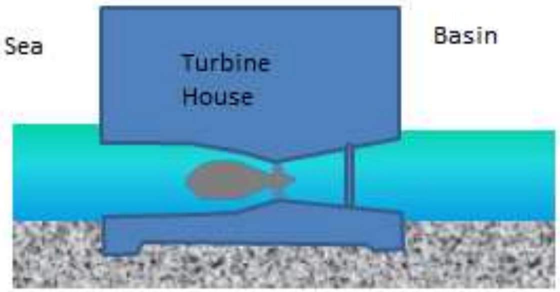




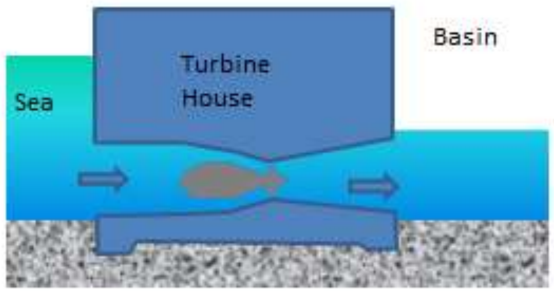
Tidal Energy (continued)



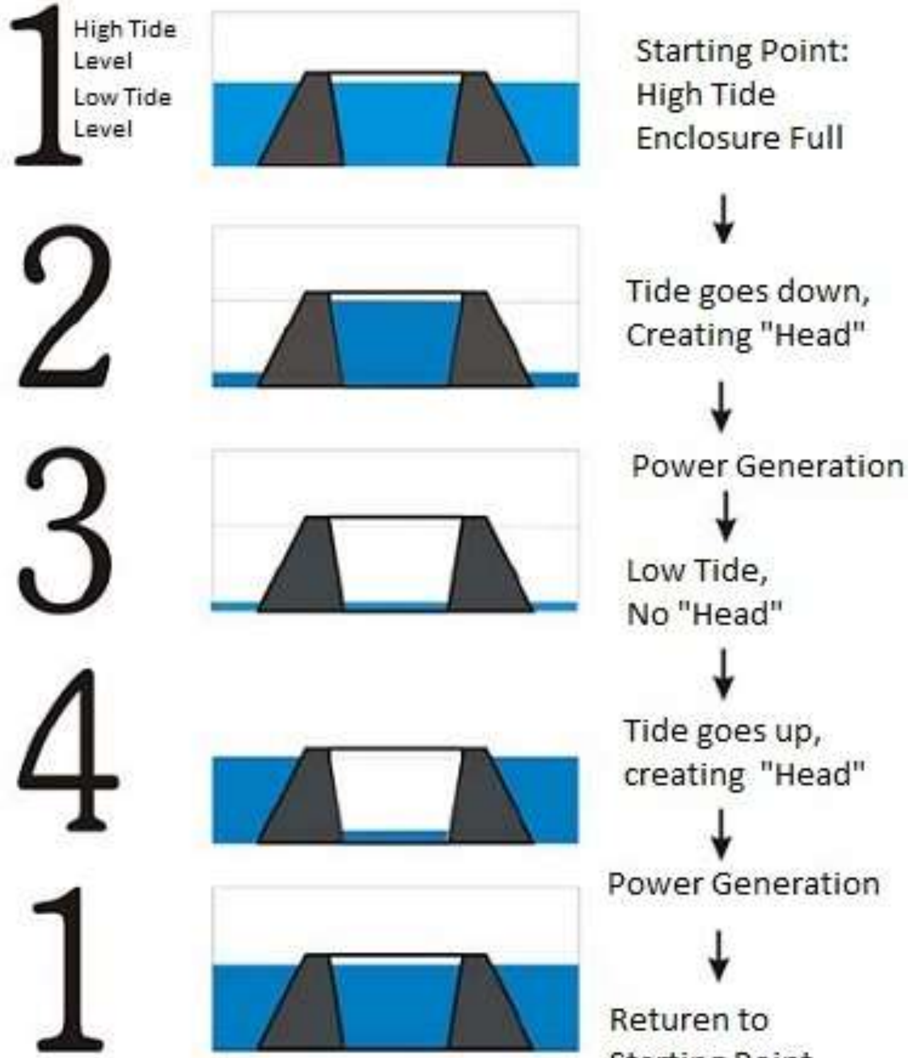
Generating on the ebb tide



Holding Period at Low or High Water



Generating on the flood tide



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

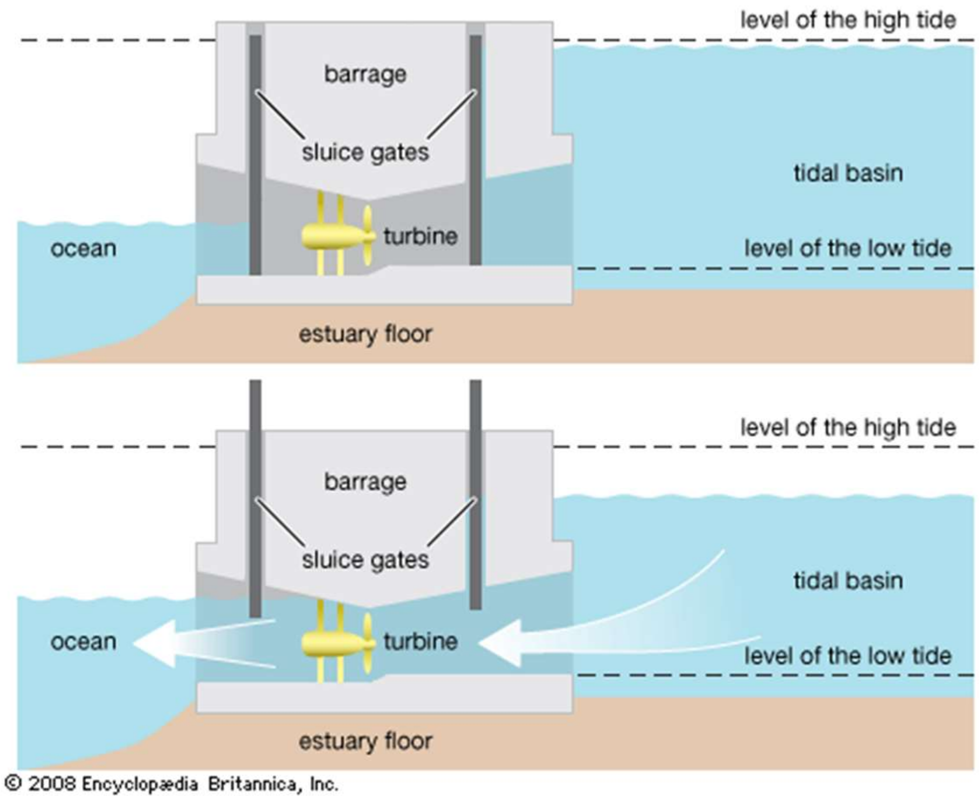
https://www.youtube.com/watch?v=m7ImT4CdcPo

Tidal Barrage in France

World's first commercial tidal power plant is the Rance Tidal Barrage in France

Tidal Water Turbines

- Turbines placed across The Rance River, France
  - 240 MW plant with 24, 10 MW turbines operated since 1966
  - Average head is 8m
  - Consists of a 330m long dam and a $22 km^2$ basin
  - Storage pumping contributes 1.7% to energy level
  - **Produces electricity cheaper than oil, coal, or nuclear plants in France**

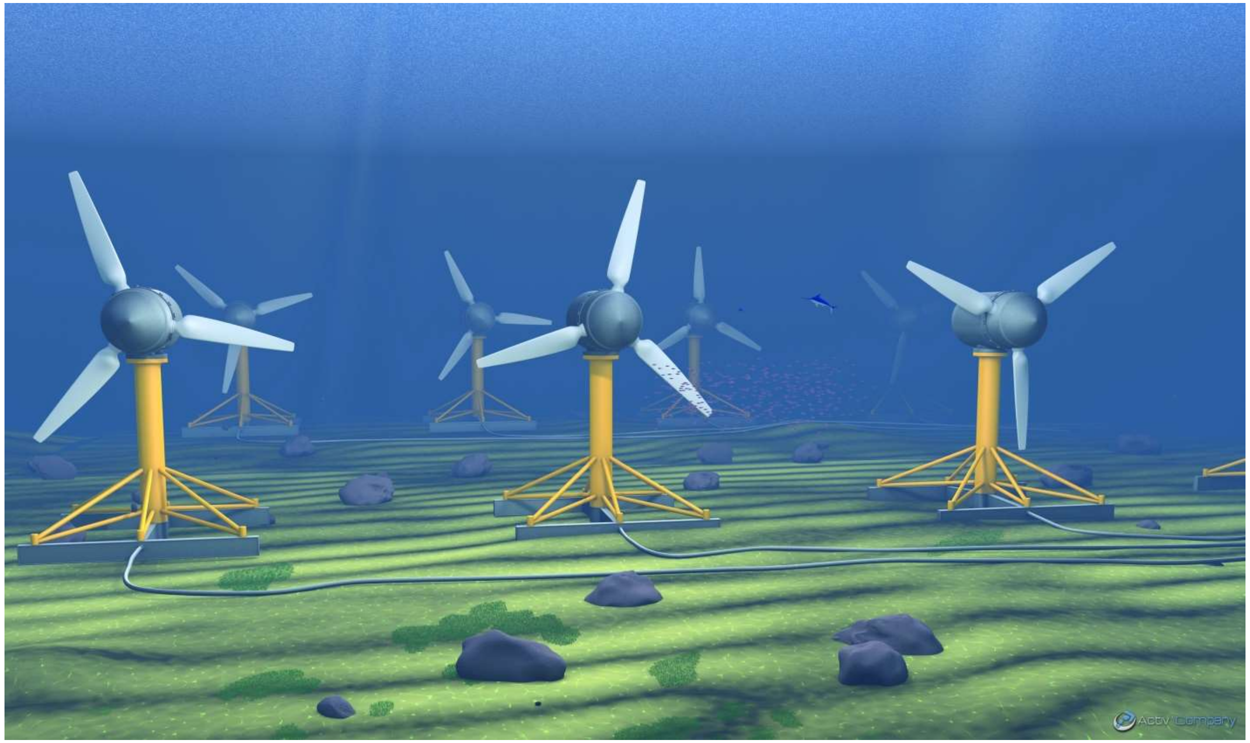


Undersea/ Offshore Tidal Turbines

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

$\hookrightarrow \rho_{sea} = 1025\ kg/m^3$

- Newest form of tidal energy
- Underwater "Wind Farms"
- Estimated power production from a 30m turbine is 13.5 MW (enough for roughly 13,000 high use American homes)
- Only small scale creations at this point



https://www.youtube.com/watch?gl=SG&hl=en-GB&v=lzc9-V9DSew

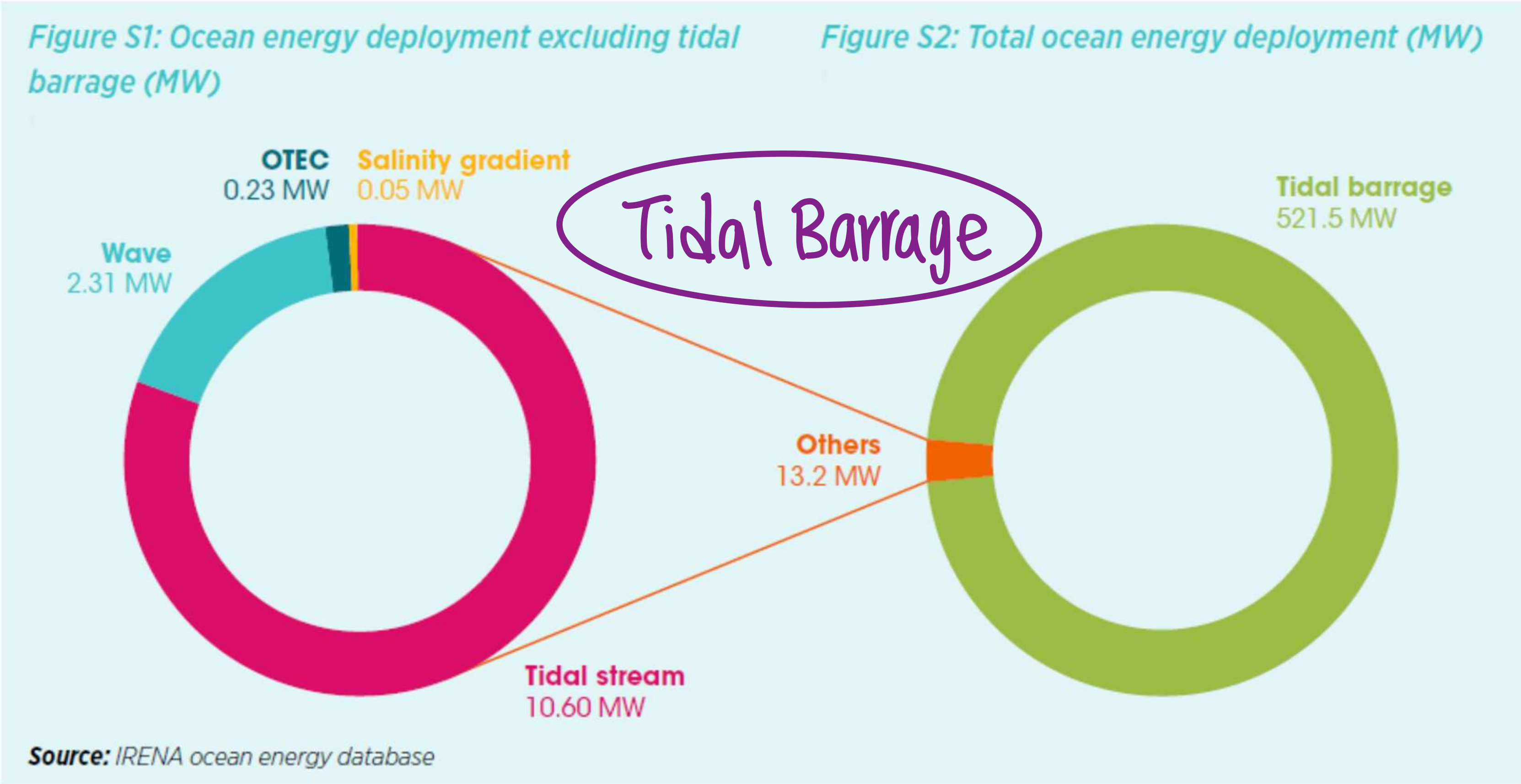
World's Largest Tidal Energy Project in Scotland

- MeyGen project – 400 MW (planned full capacity)
- The first power to the national grid delivered in 2016
- When fully completed, will power nearly 175,000 homes through network of turbines on seabed off coast of Caithness, Scotland

https://www.youtube.com/watch?v=D-OVU2RGNDo
Alstom project

Source: The Guardian newspaper, UK

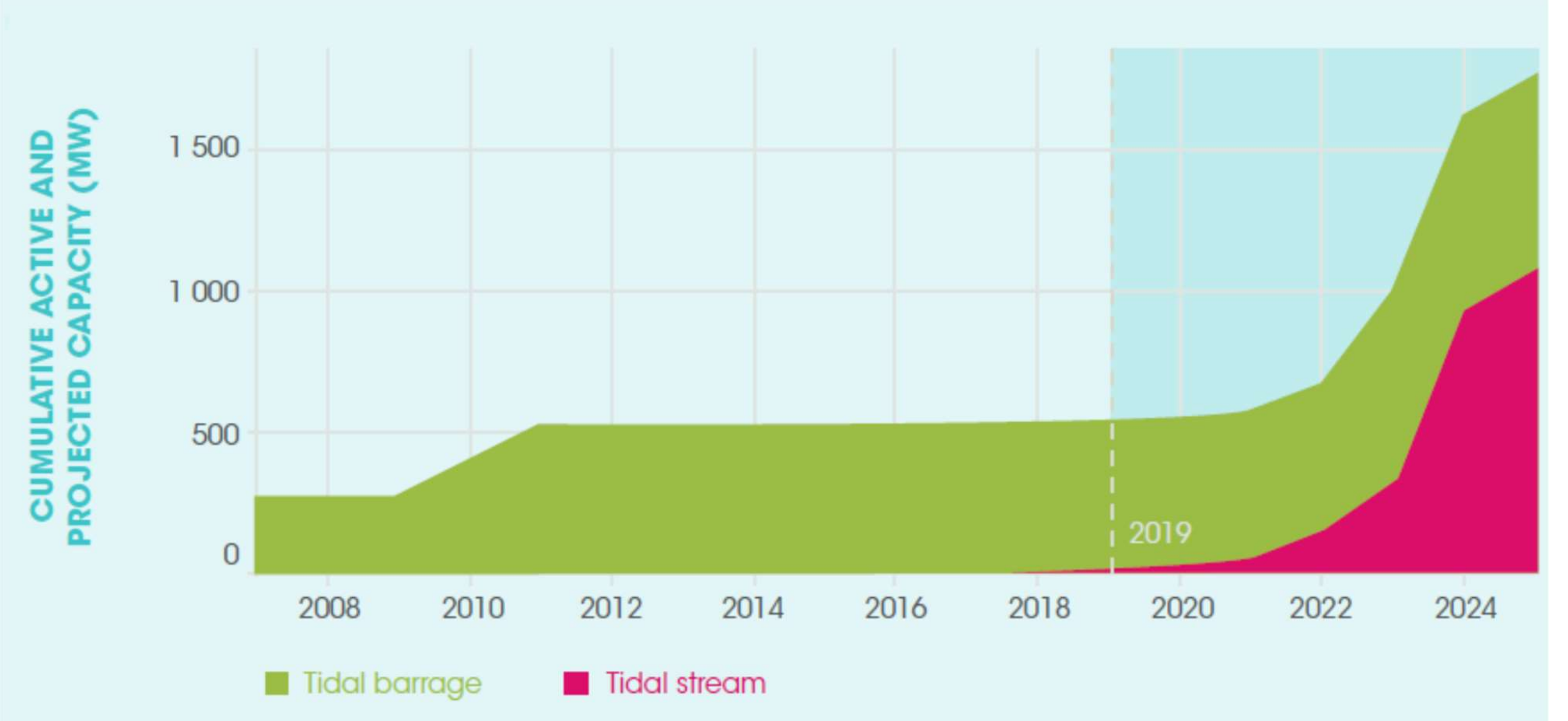
Ocean Power: Current status



- More than 98% of the total combined capacity that is operational is Tidal Barrage
- New projects based on Tidal Stream and Wave energy are being developed dynamically

Ocean Power: Current status

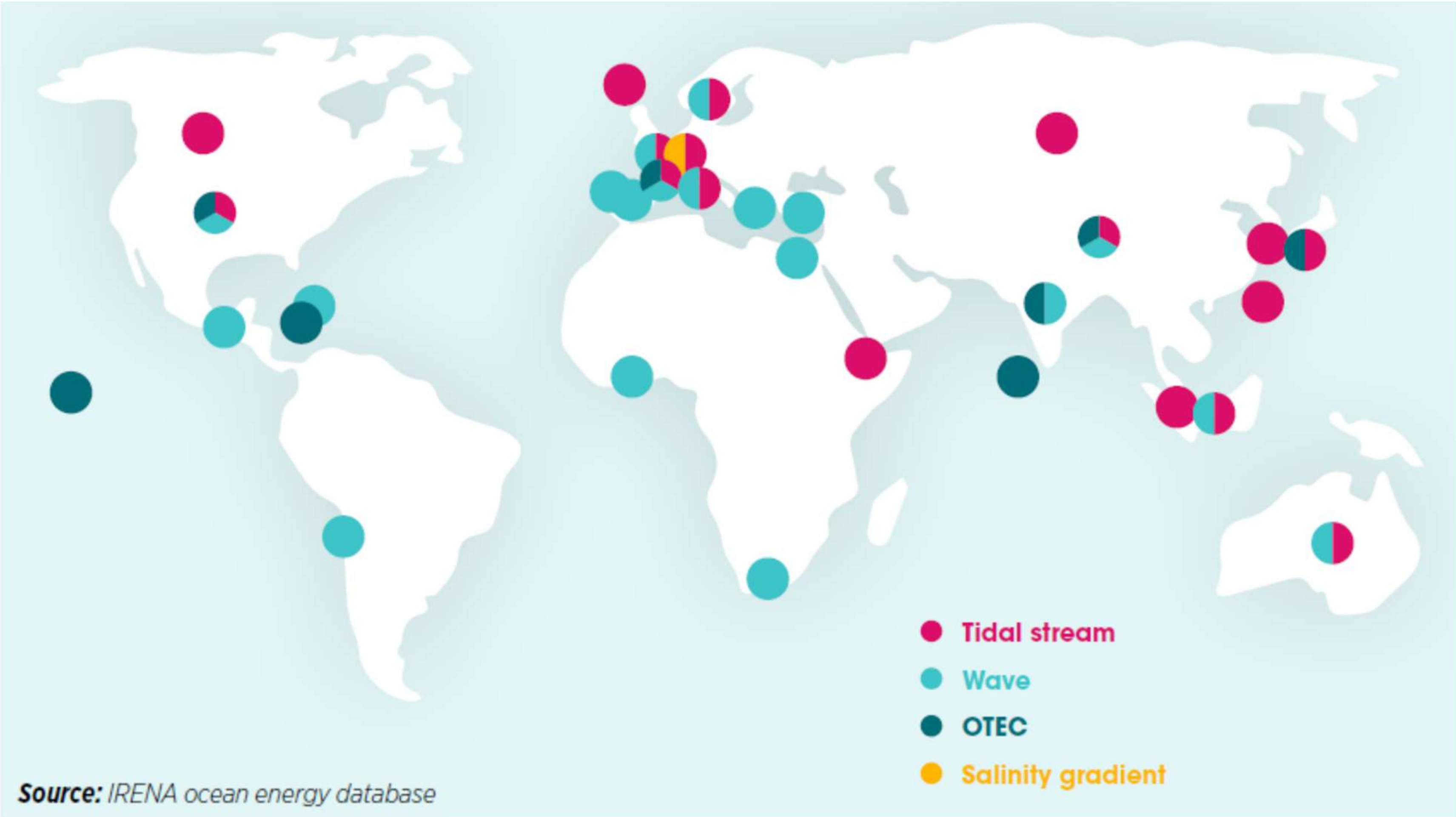
- The installed capacity of tidal stream and barrage are expected to grow much faster in the near future
- Many large-scale tidal farms are being planned, mostly in the UK



Source: *IRENA ocean energy database*

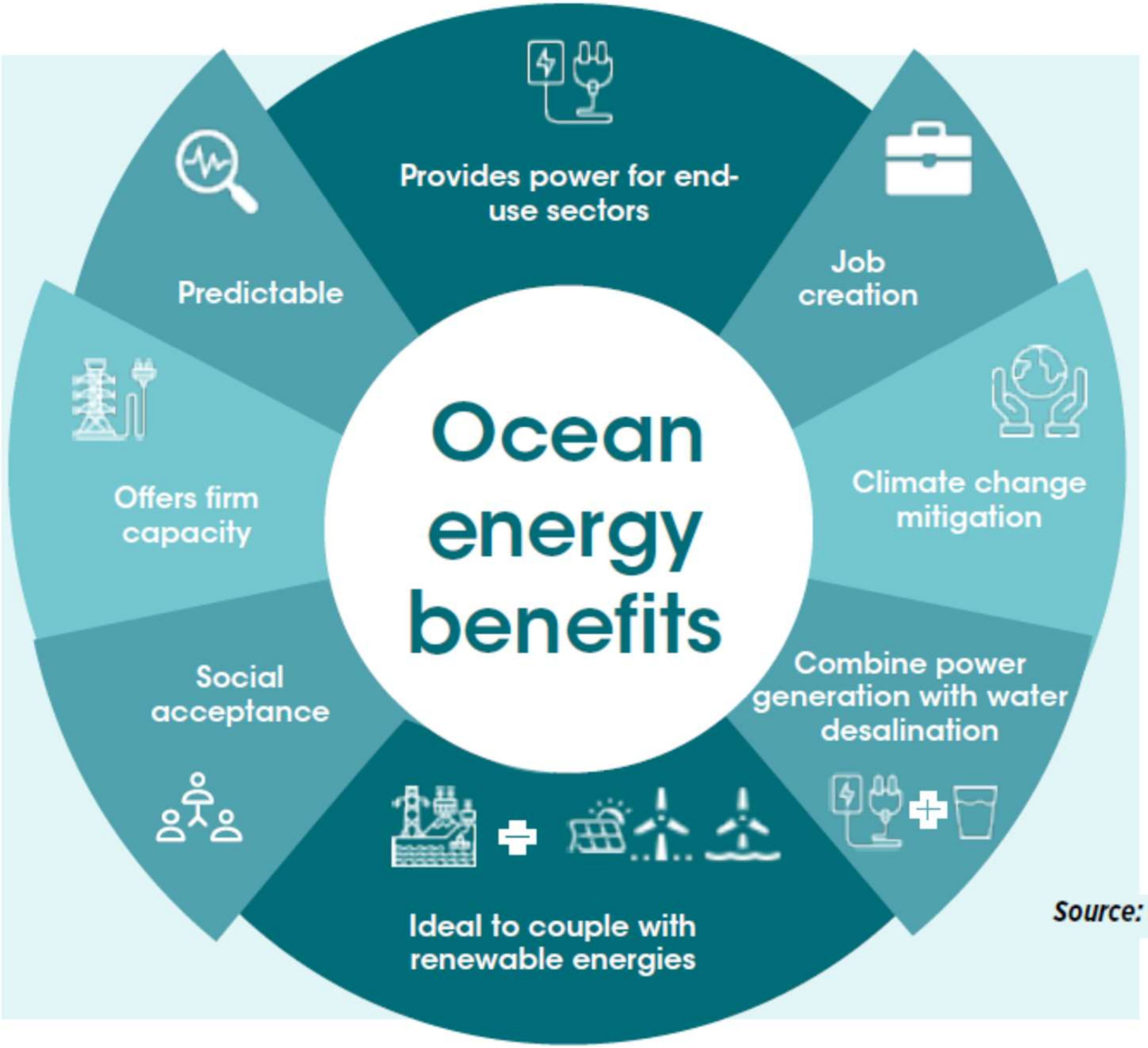
Ocean Power: Current status

- Global distribution of Ocean energy activity



Key Benefits of Ocean Energy

- Ocean energy can bring key technological and socio-economic benefits, in addition to mitigating climate change



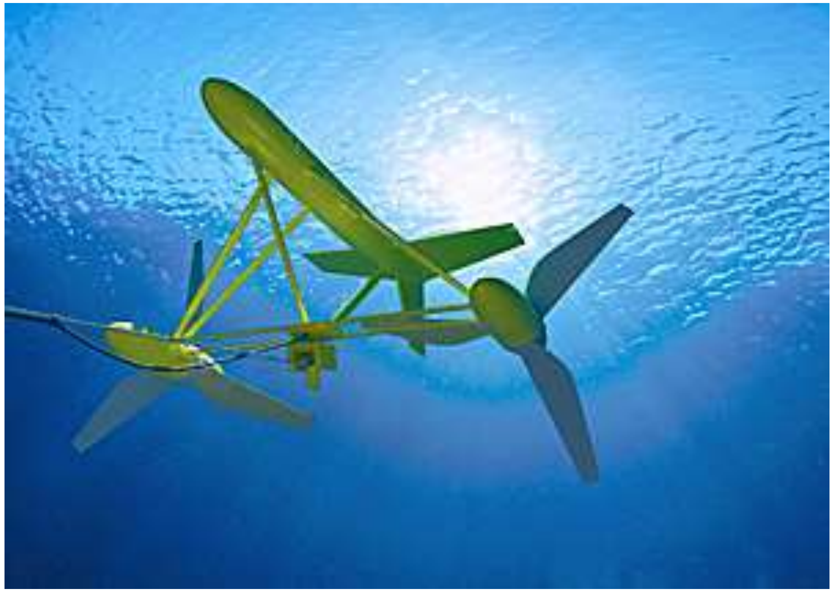
Source: *IRENA ocean energy database*

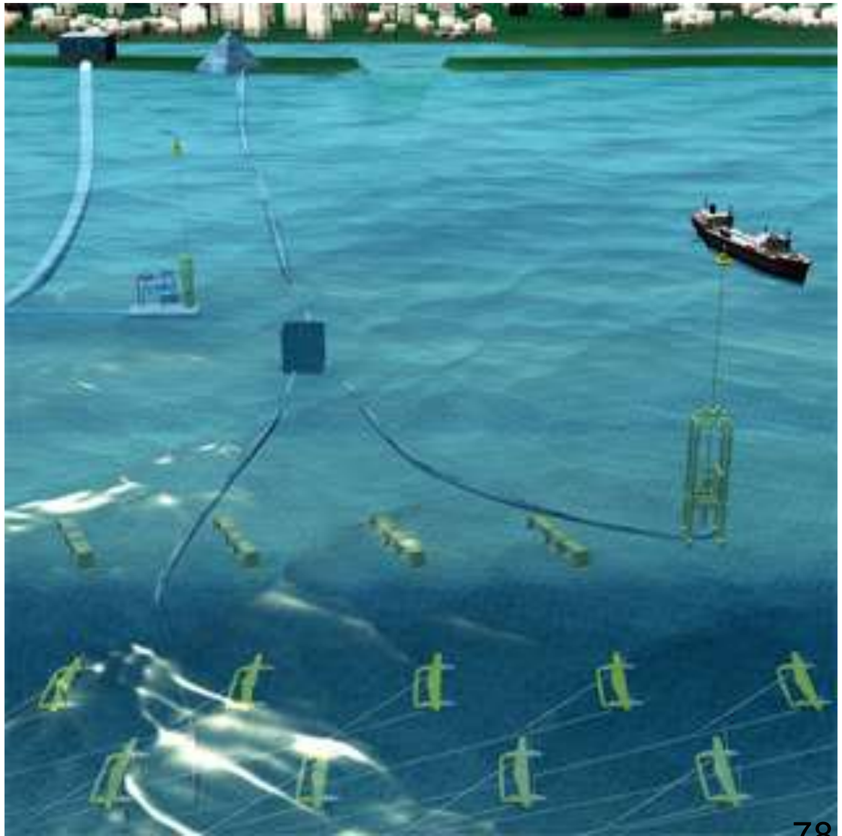
Ocean Power: Current status

- Ocean power represents the smallest portion of the renewable energy market, with most projects focused on relatively smallscale demonstration and pilot projects of less than 1 MW
- Total installed capacity: 535 MW
- Most of the projects are in Europe, and particularly off the shores of Scotland, where several arrays of tidal turbines were being deployed.
- The EU aims to install 40 GW of ocean power capacity by 2050
- **The resource potential of ocean energy is enormous, but it remains largely untapped**

Ocean Power Systems

- **The Gulf Stream contains an enormous amount of energy that can be converted into electricity**
- Gulf Stream Turbines has developed a turbine system it says could produce electricity continuously from the ocean current running from the Gulf of Mexico and up the US Atlantic Coast

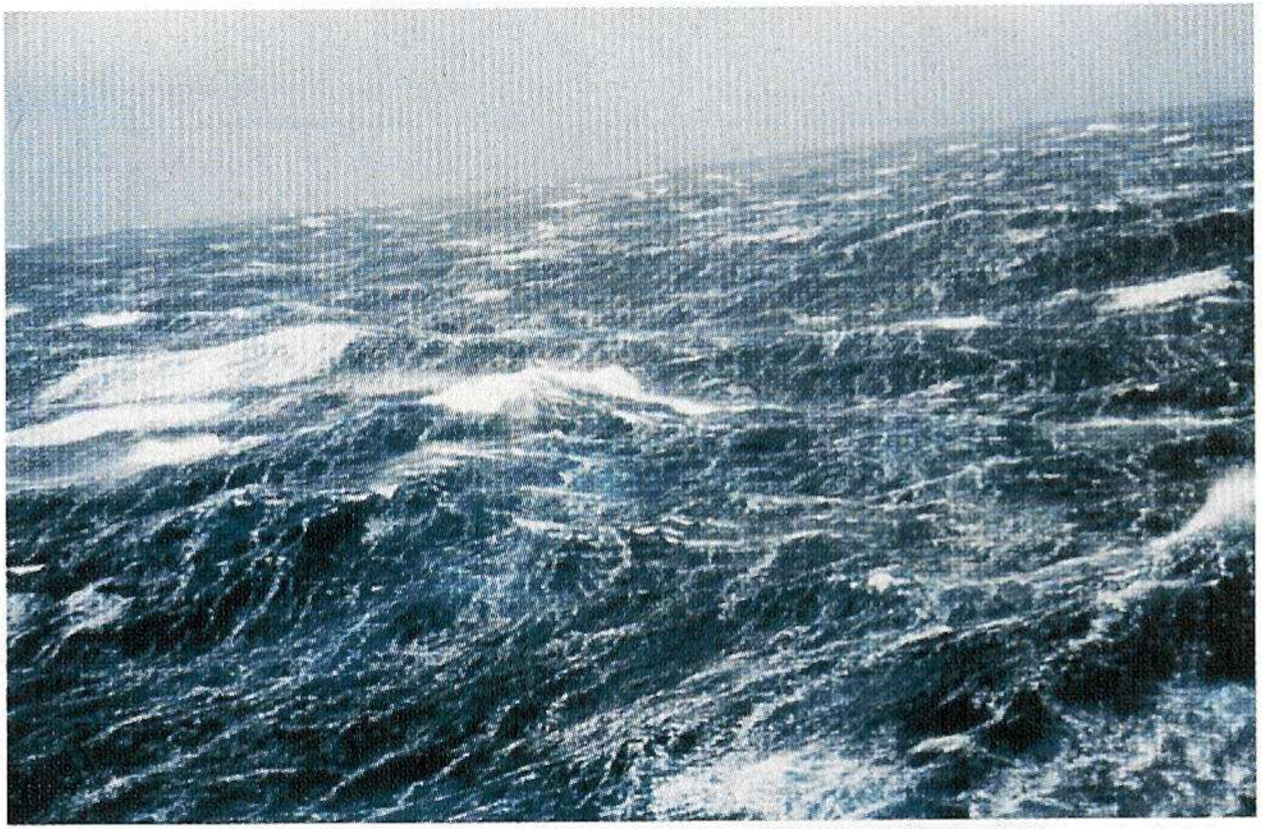




Converts energy from ocean currents into electricity

http://www.brighterenergy.org/6846/news/marine-hydro/gulf-stream-turbine-inventors-seek-investors/

Wave Energy



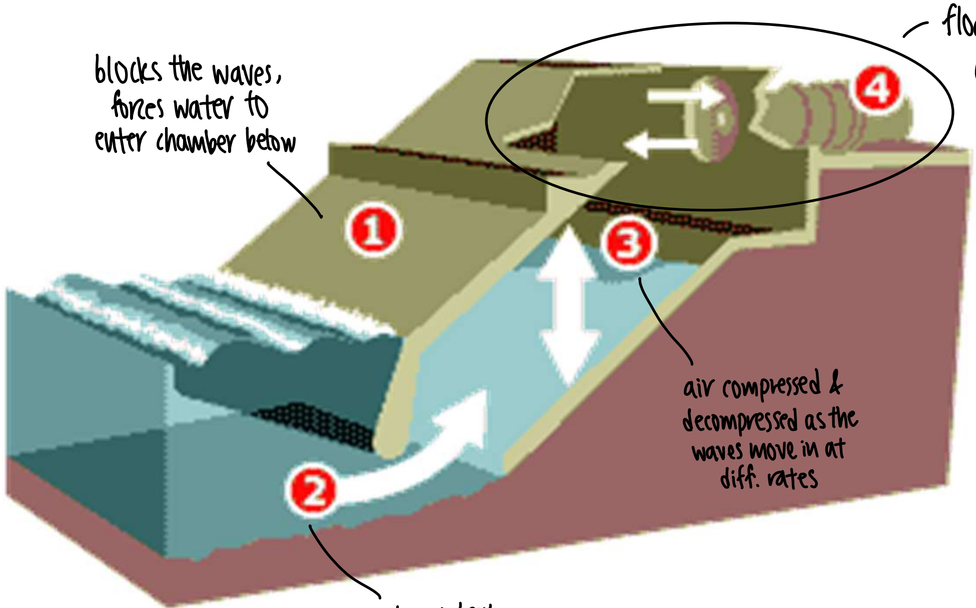
The proper conditions for current turbines call for concentrated tides at a minimum of 4 knots. Faster currents are even better.

Wave Energy

- Change of water level by tide or wave can move or raise a float, producing linear motion from sinusoidal motion
- Water current can turn a turbine to yield rotational mechanical energy to drive a pump or generator
    1. The wave capture chamber is set in a rigid structure like a cliff face - or in a tower built on the sea-bed..
    2. Wave power forces water into the chamber
    3. Air is alternately compressed and decompressed in the OWC
    4. Compressed air forces the turbine to turn

float moves up & down, causing turbine to turn
↳ linear → rotational motion

blocks the waves, forces water to enter chamber below

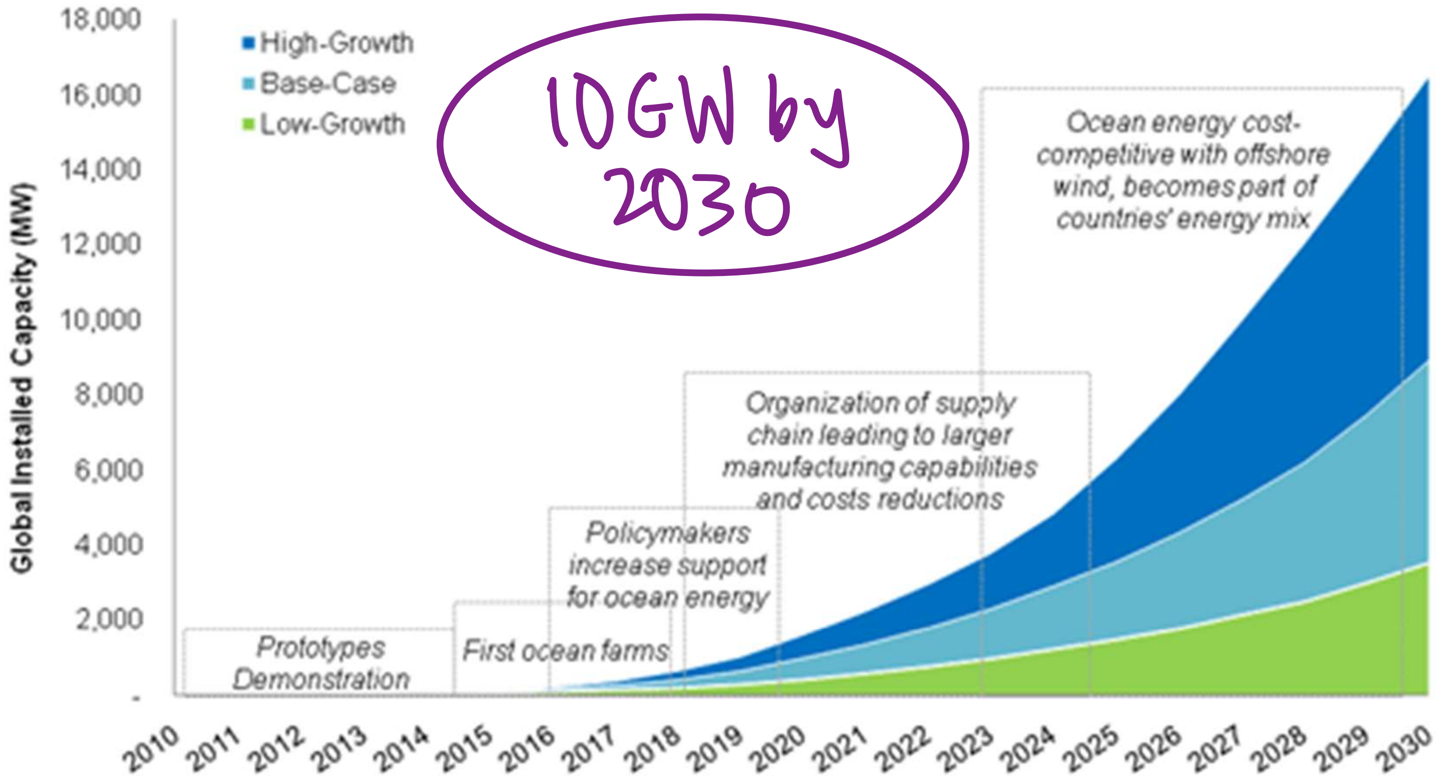


air compressed & decompressed as the waves move in at diff. rates

water enters chamber here

https://www.youtube.com/watch?v=7ZN5CthZhvg

Global Ocean Energy Forecast



Global ocean energy capacity is expected to reach nearly 10 GW by 2030

(Source: Energy trends research)

2020 . 535MW → 2030 : 10GW

Global Ocean Energy – Current Status

Tidal and wave power are the main focus of development efforts.

Advancements have been mainly concentrated in Europe

Although the potential of ocean power is enormous, the technologies are still in the early states of development

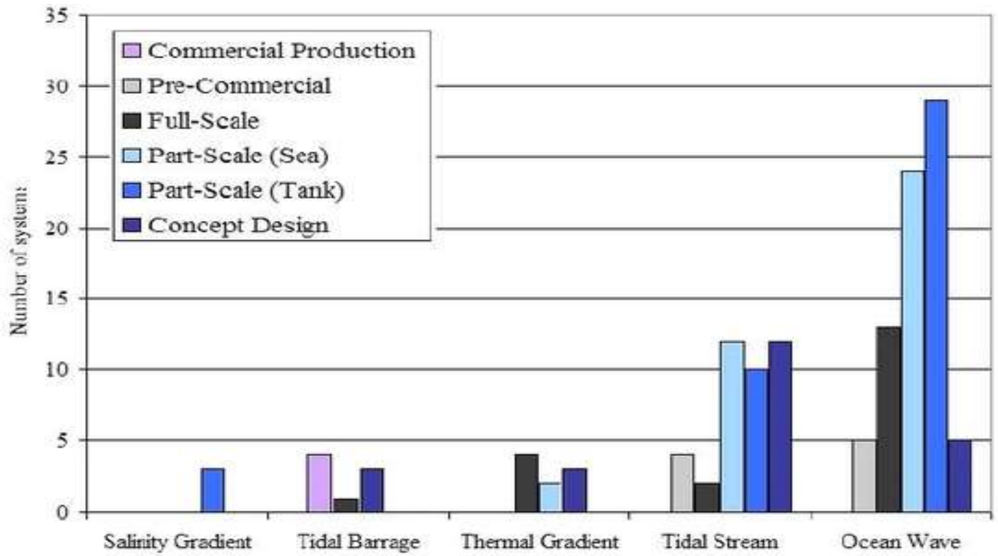


Figure 2: Ocean energy technologies at different stages of development (source: [2])

Ocean Energy Overview: Status

current fav:

* FUTURE *

	Tidal Barrage	Tidal Stream	Wave	Thermal Gradient
				
Energy source	• Tidal range (using conventional hydro technology)	• Tidal currents • Ocean currents	• Ocean waves	• Temperature gradient between the sea surface and deepwater
Example technologies	• Ebb generation • Flood generation	• Horizontal Axis • Ducted Rotor • Vertical Axis • Hydrofoil	• Attenuator • Oscillating Water Column (OWC) • Point Absorber • Overtopping	• Different Ocean Thermal Energy Conversion (OTEC) processes
Maturity of installed devices	• Mature: plants in operation	• Pre-commercial: full-scale proto-types (~1MW)	• Testing: part-scale proto-types (<1MW)[1]	• Demonstration: first small-scale devices (<250kW)
Exploitation potential	• Environmental concerns limit further exploitation (~300 TWh/a[2])	• Emerging exploitation, sites under development (~800 TWh/a)	• Mid-term potential (~8,000 TWh/a, economically viable)	• Long-term potential (~10,000 TWh/a[2])

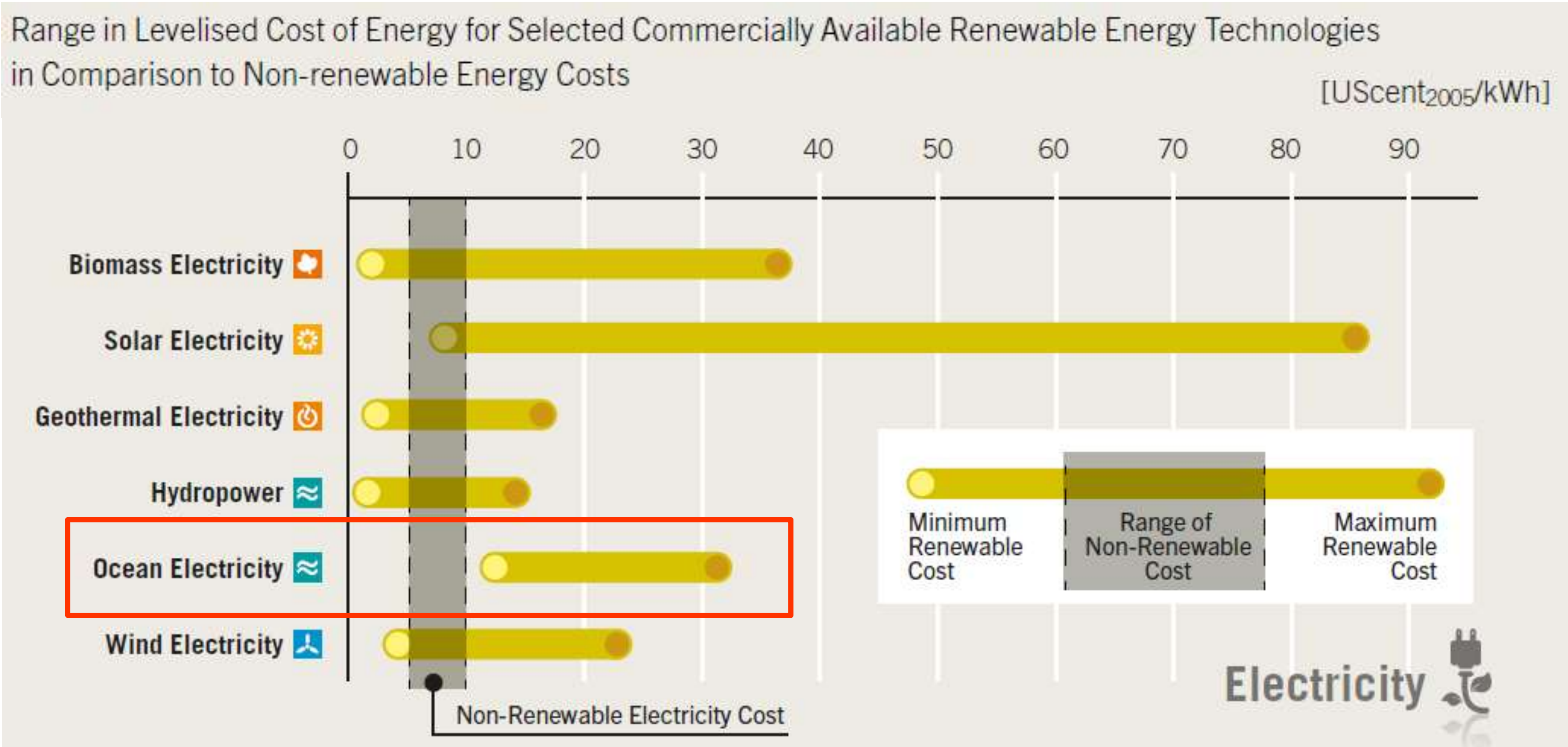
Source: IHS Emerging Energy Research (2010), Siemens

1) OWC commercially available, 2)

Ocean Energy Overview: Status

- Ocean energy is still at an early stage of development and can be compared to the state of the wind industry in the early 1980
- There are currently numerous designs available with a correspondingly low standardisation rate.
- Commercial ocean energy capacity was roughly 535 MW by the end of 2020.
- The tidal power facility in the north of France is the largest in terms of installed capacity; small-scale projects have been deployed in the United States and Portugal.
- Tidal power devices have evolved to a level where they exhibit considerable predictability in performance.
- Wave energy is still at a technology development stage
- Ocean energy is seeing measured but steady progress.

Levelised Cost of Electricity from Renewables



Ocean only slightly more $ $ than fossil fuels

Source: REN21's Renewables 2018 Global Status Report

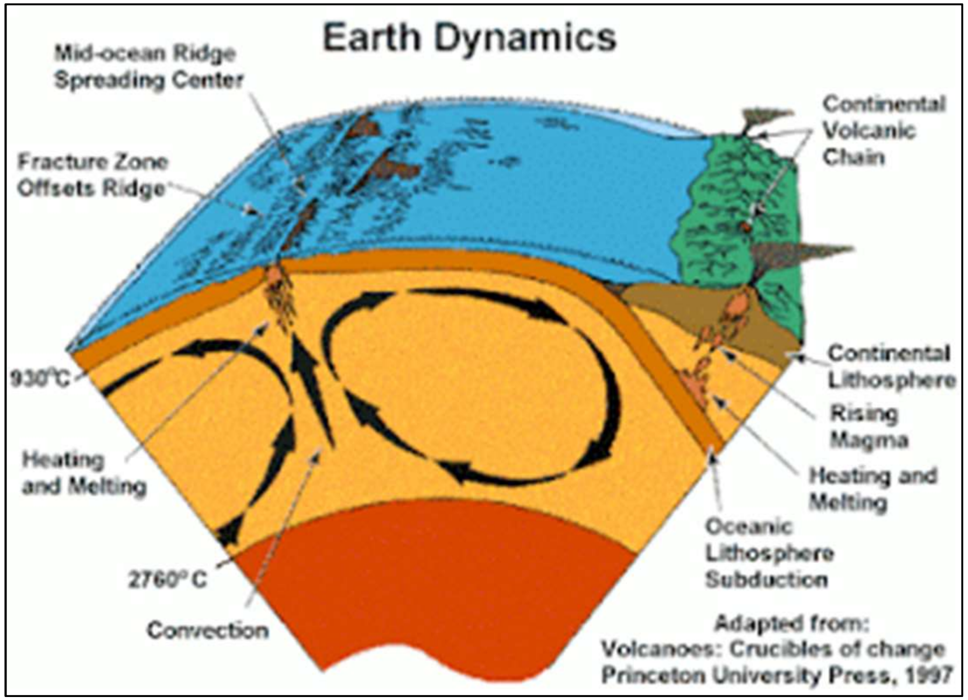
Ocean Energy: Summary

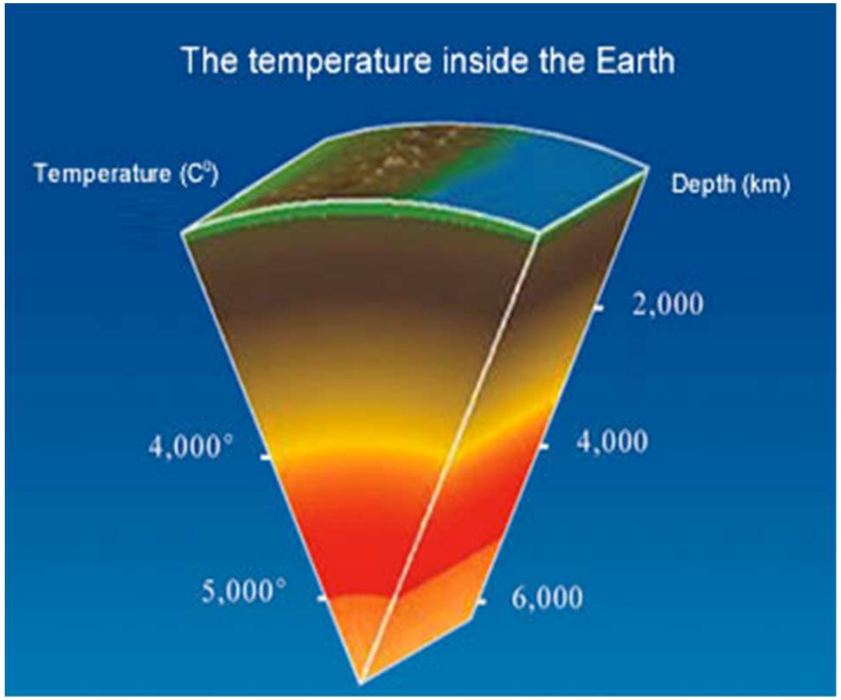
- The **tidal** gravitational forces of the ocean can provide a major energy source
- **Wave** action adds to the extractable surface energy, but is less than tidal energy
- Major **ocean currents** (like the Gulf Stream) may be exploited to extract energy with strong underwater rotors similar to wind turbines

Geothermal Energy

What is Geothermal Energy?

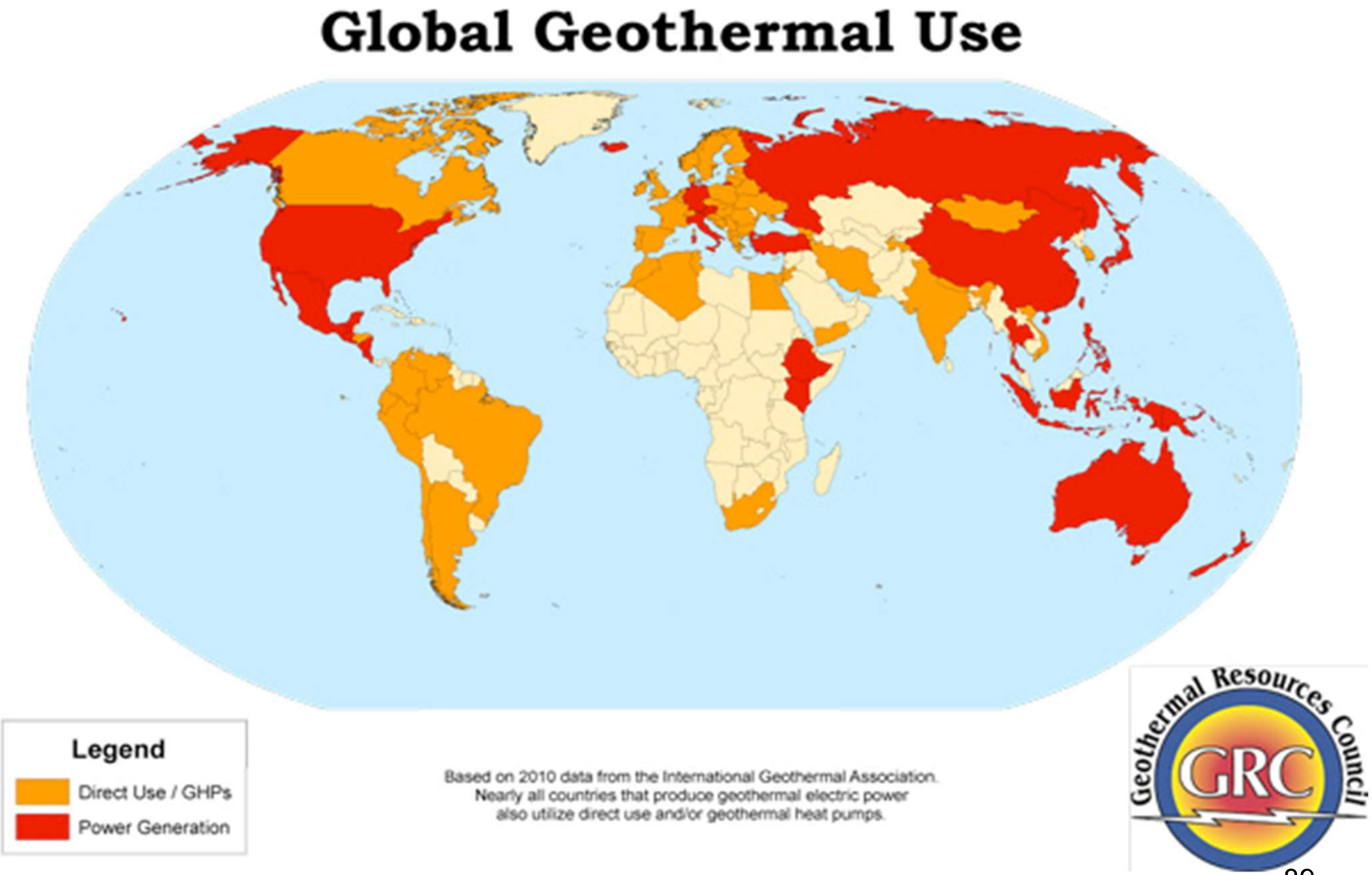
Geothermal energy is the thermal energy contained in the rock and fluid (that fills the fractures and pores within the rock) in the earth's crust.



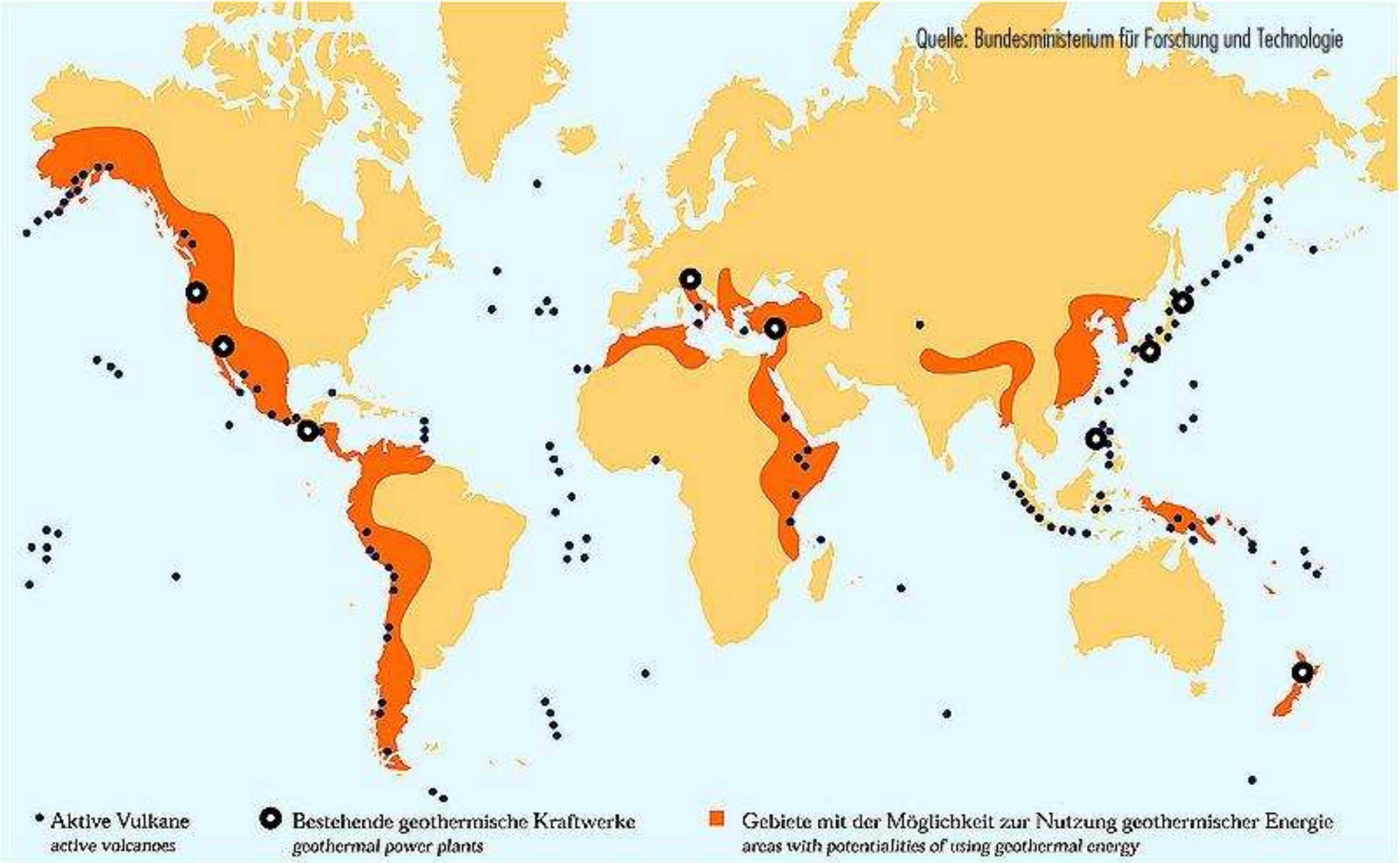


http://www.worldbank.org/html/fpd/energy/geothermal/technology.htm

Geothermal profile of Earth

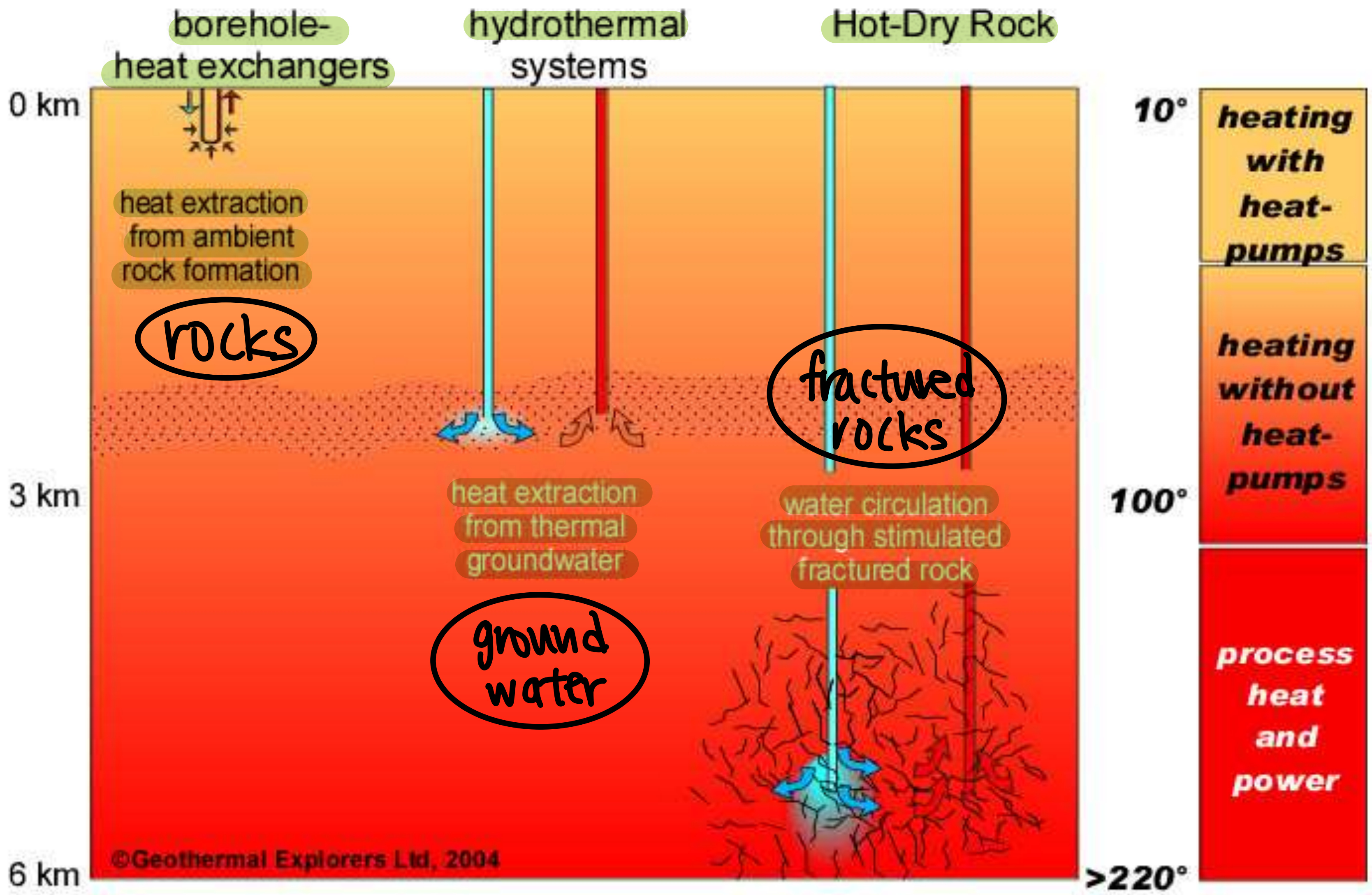


Currently active / potential geothermal plants location



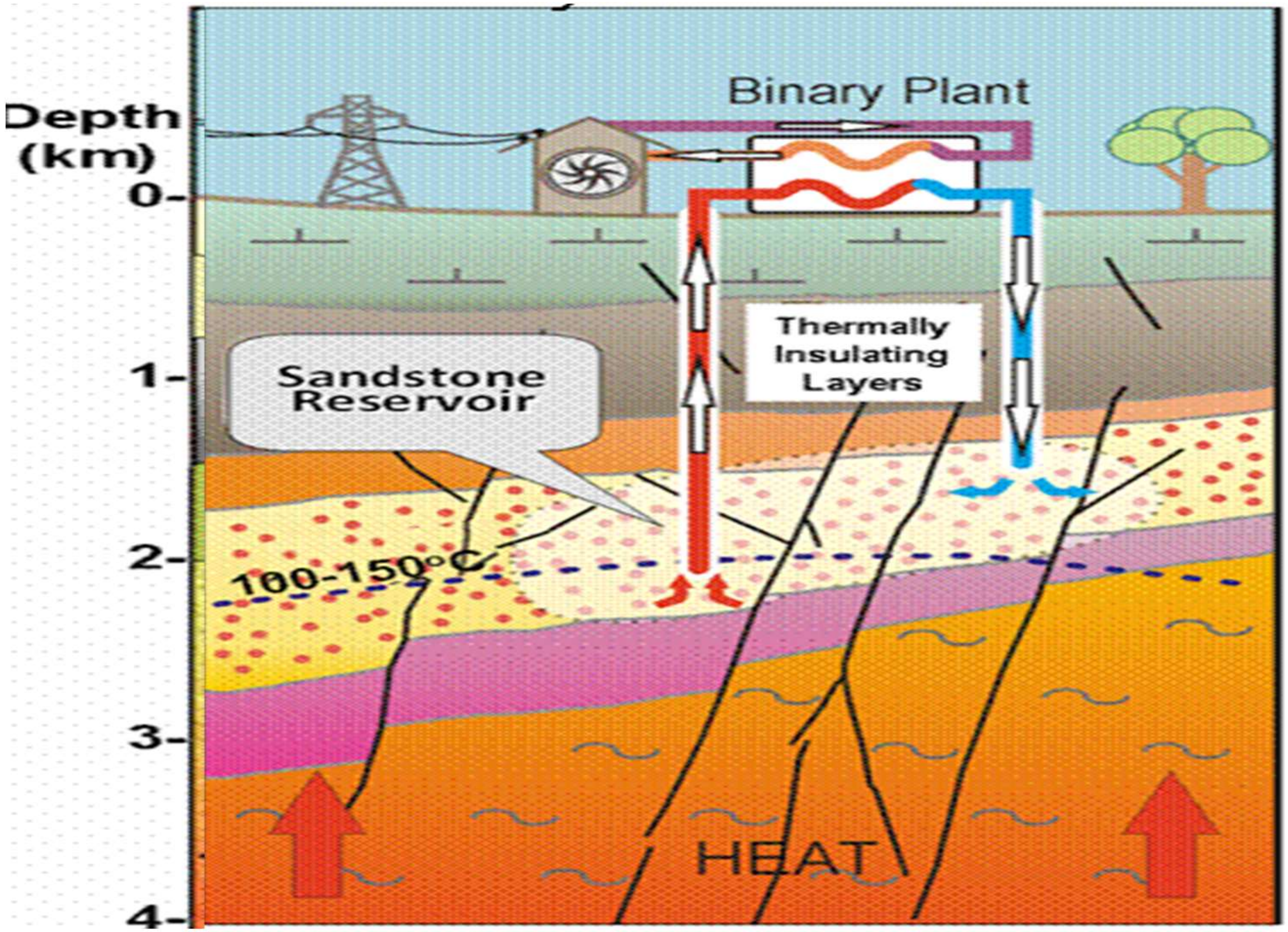
Source : http://www.deutsches-museum.de/ausstell/dauer/umwelt/img/geothe.jpg

Classification of Geothermal resources



https://www.worldbank.org/en/results/2020/11/10/the-global-geothermal-development-plan-mitigating-upstream-cost-and-risk groundwater

Hydrothermal Systems

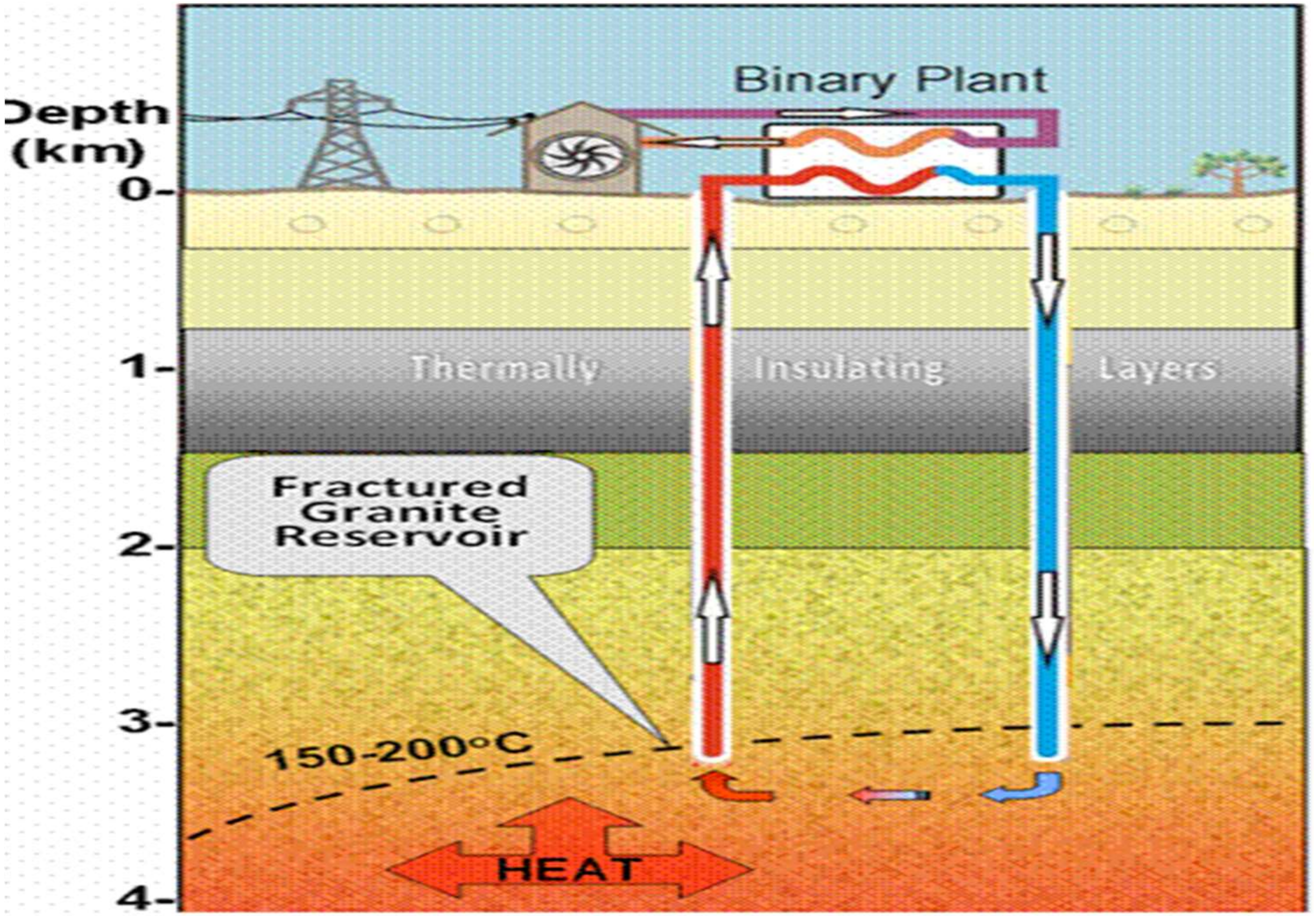


- Hot sedimentary aquifers
- Relatively lower depth 1-3 km
- Convective heat transfer
- Temperature range between 75-150 degree Centigrade

http://cleanenergyaus.com.au/technology.htm

↗ fractured rocks

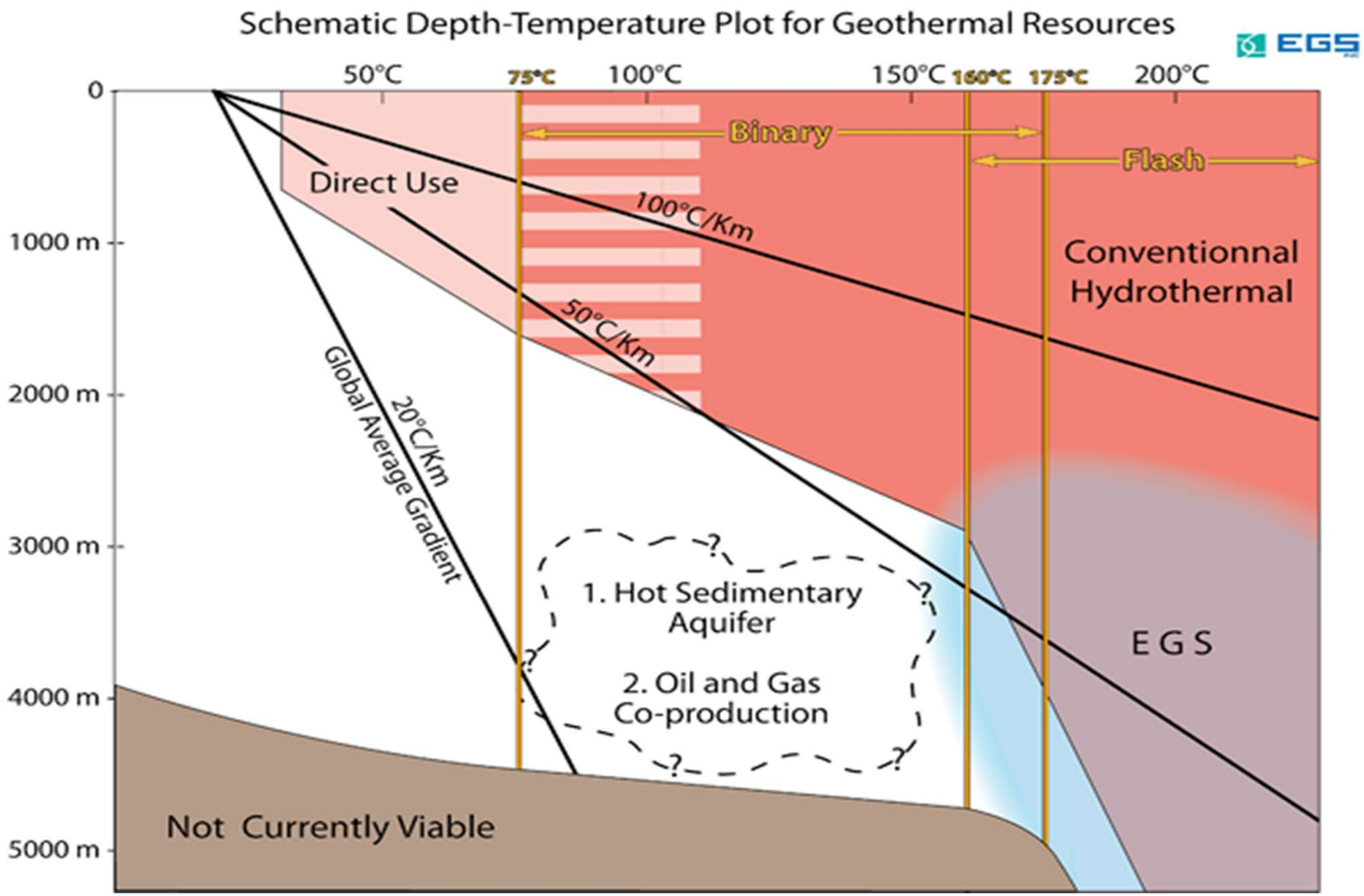
Hot dry rock Geothermal Systems



- Water is injected into the fissures in the granite reservoir
- Depth between 1-4 km
- Convective heat transfer as well as heat generation from the fissures
- Temperature range between 100-200 degree Centigrade

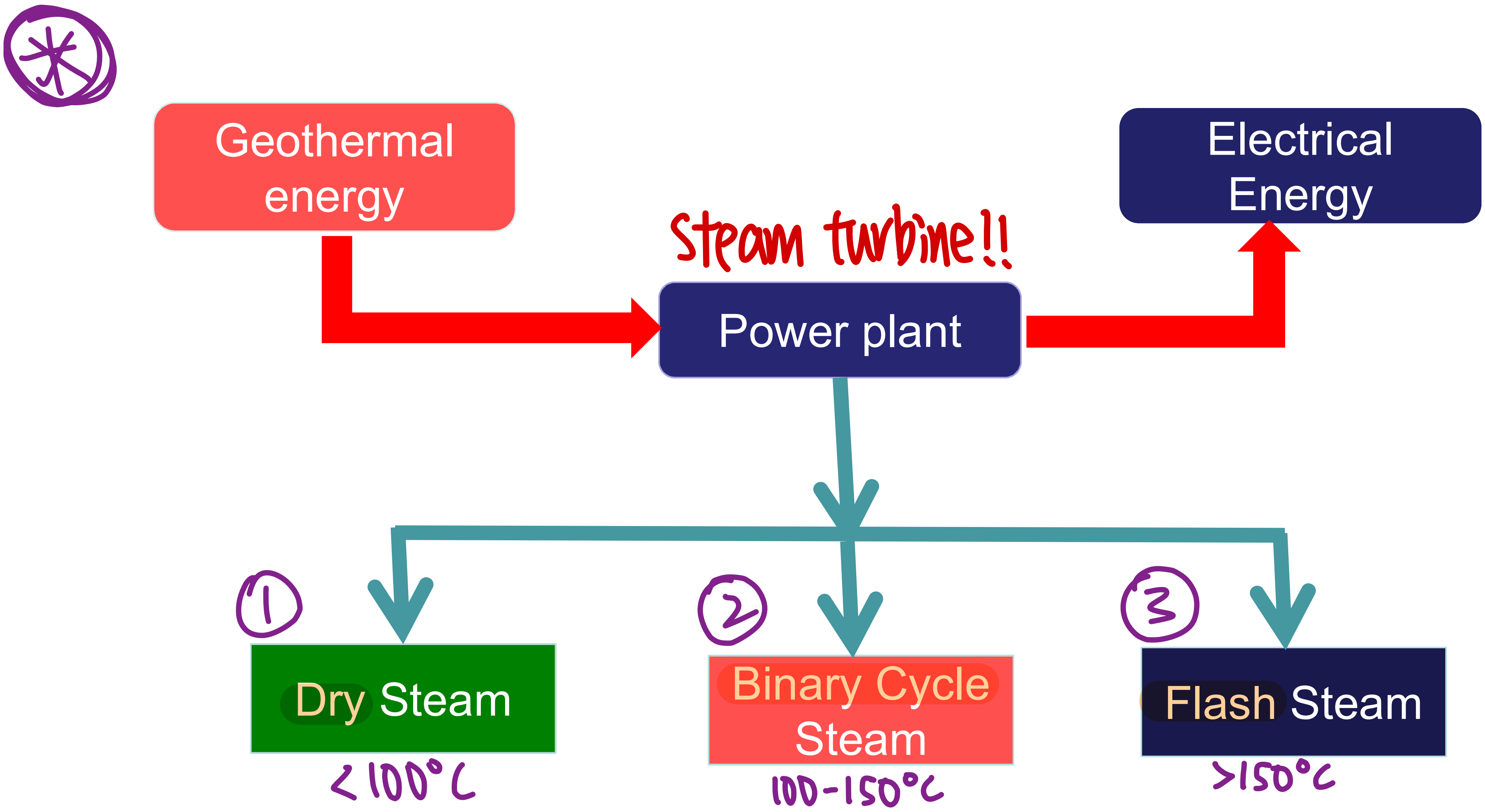
http://cleanenergyaus.com.au/technology.htm

Geothermal to usable energy conversion



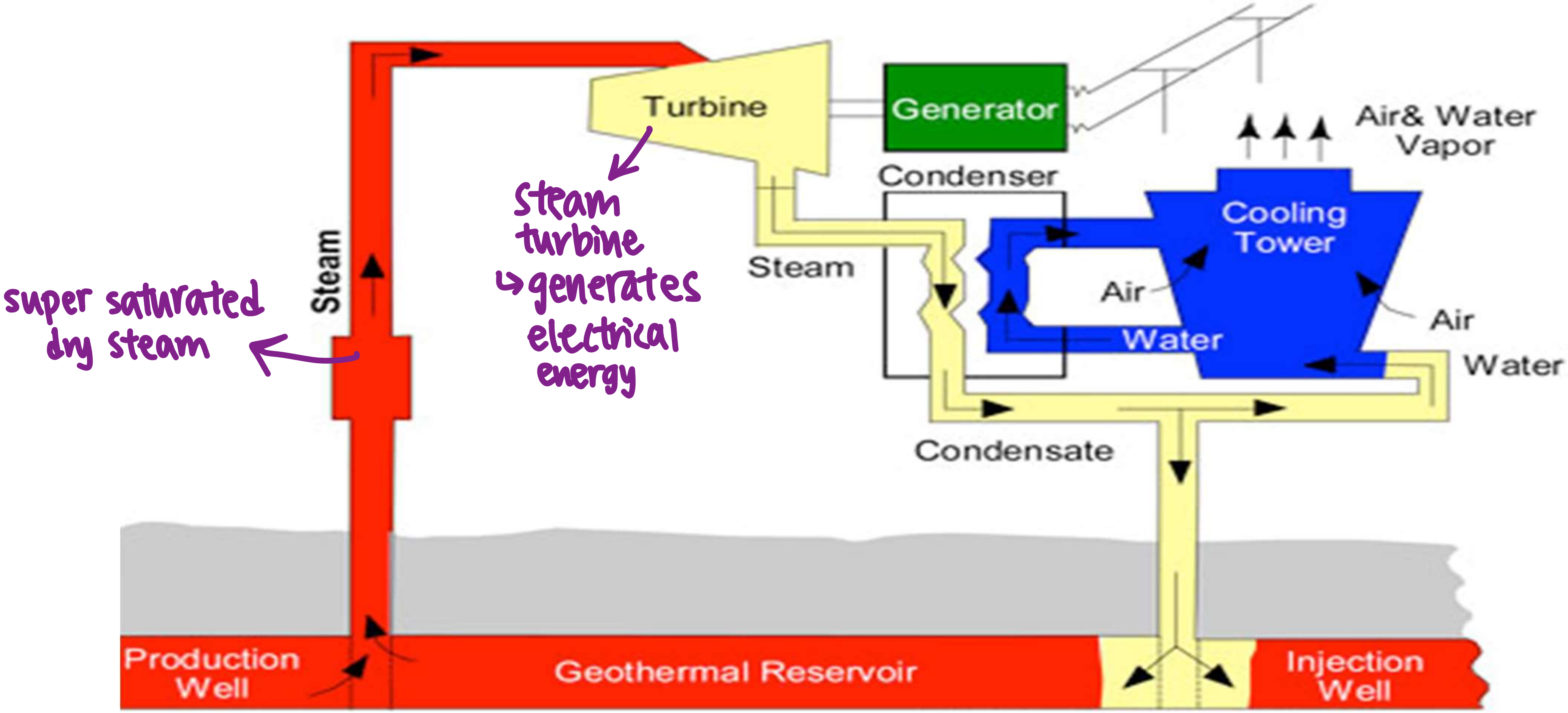
Source: http://cleanenergyaus.com.au/technology.htm

Power plants based on Geothermal System



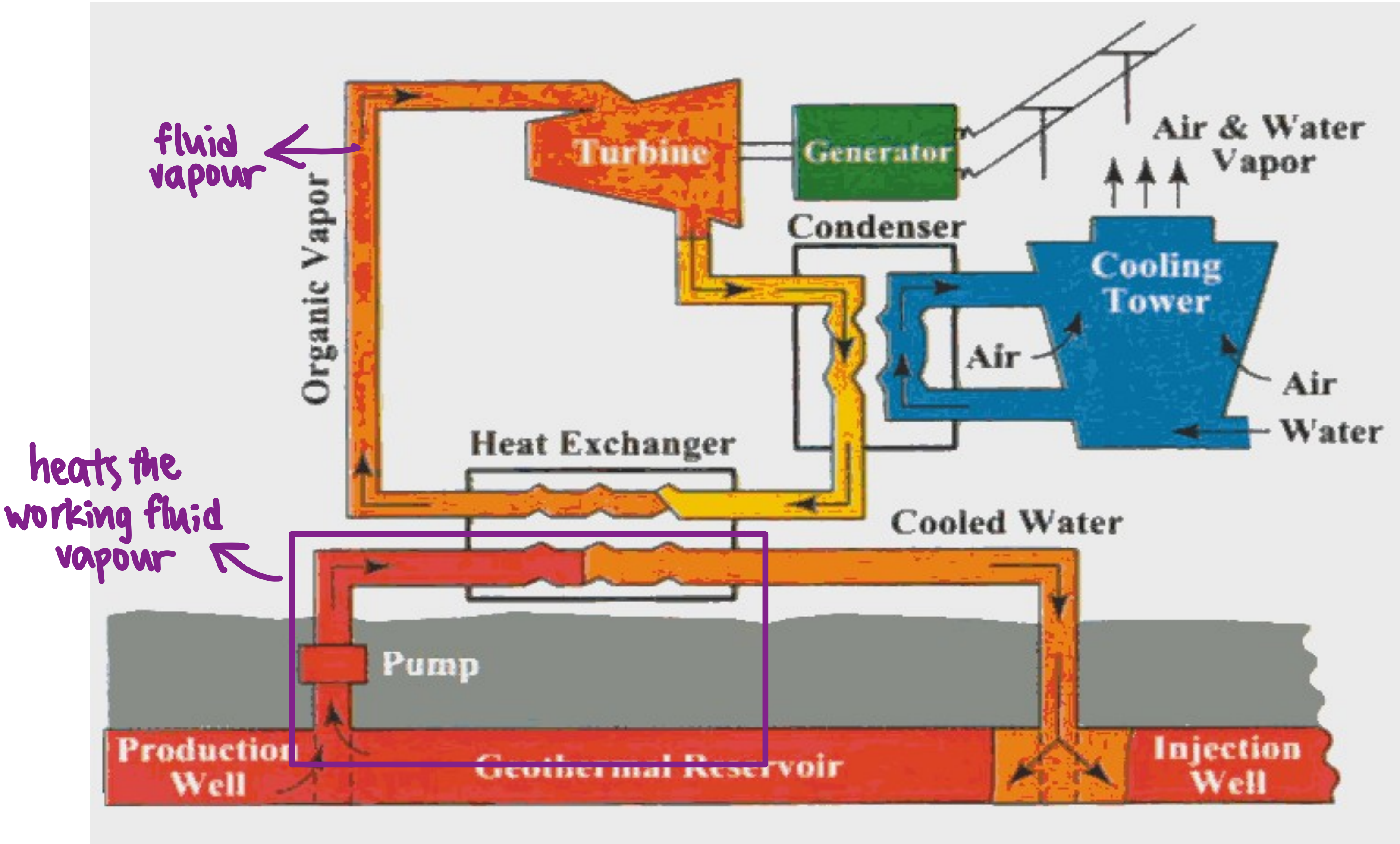
https://www.youtube.com/watch?v=mCRDf7QxjDk

Dry steam Power plant



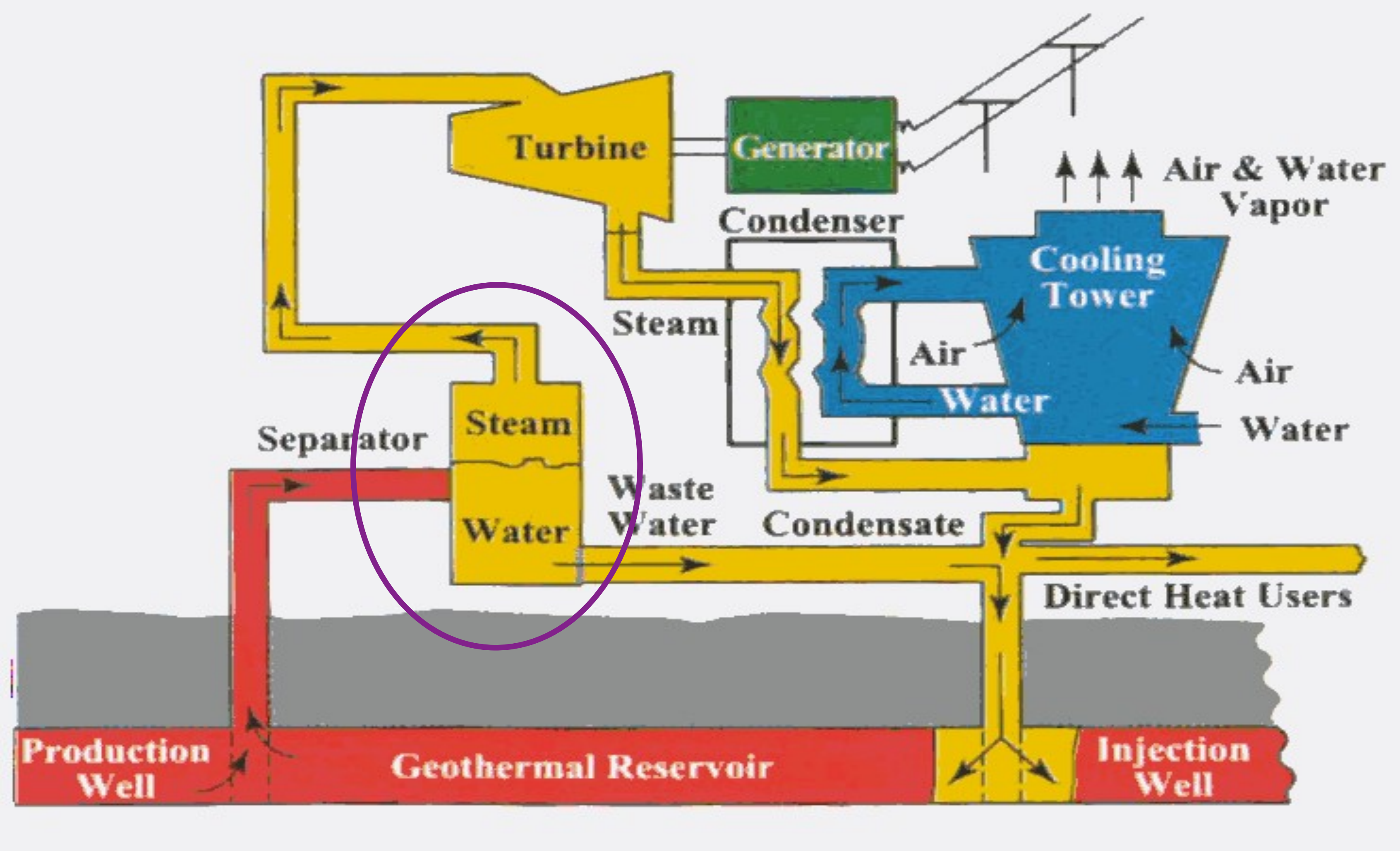
- Super saturated dry steam (Hydrothermal fluid) is directly sent to the turbines
- One of the oldest method of geothermal power generation
- *Extremely rare to find dry steam*

Binary Cycle Power plant



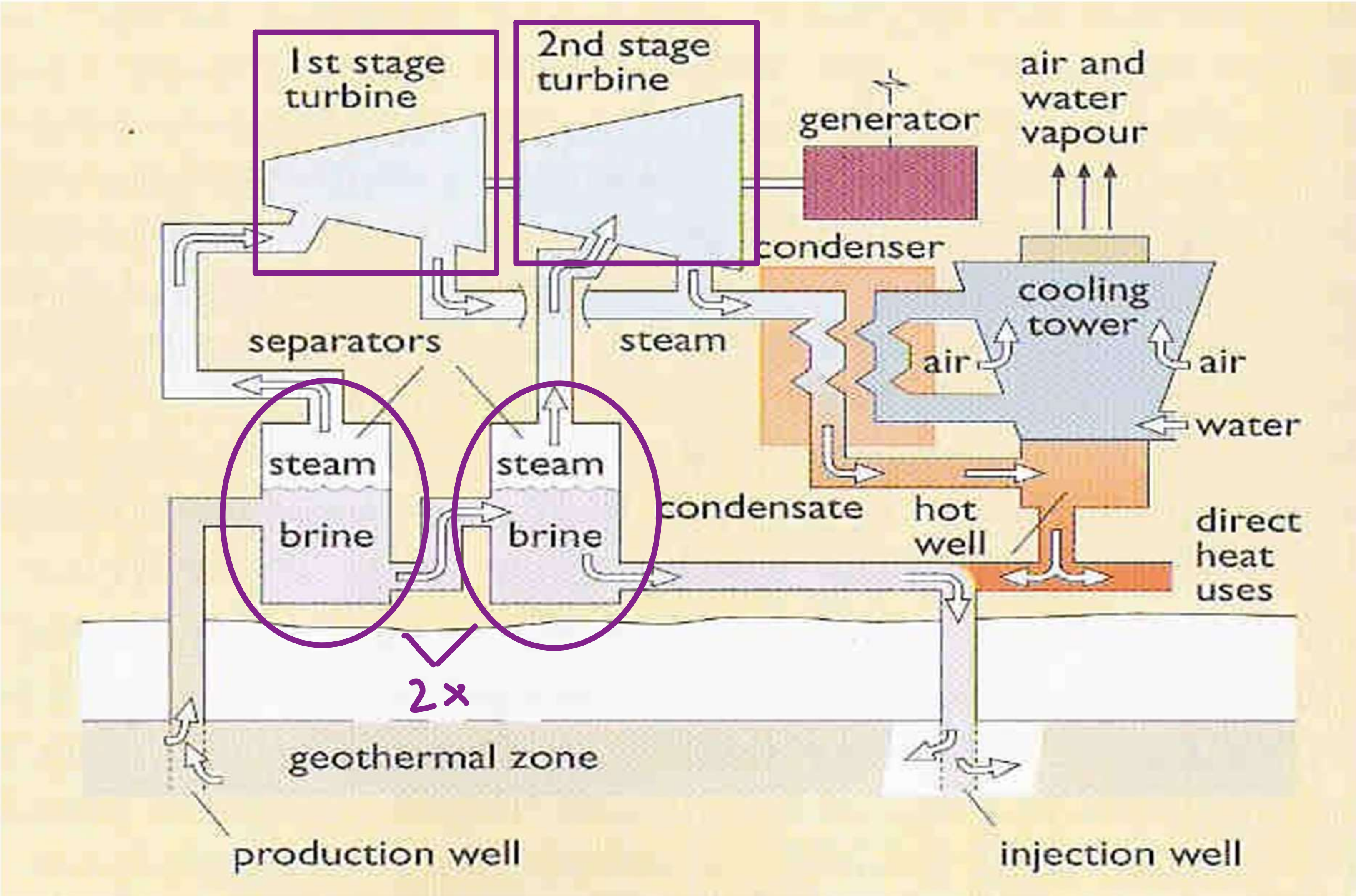
- Used when geothermal resource temperatures are in the range of 100-150°C
- This fluid heats, through a heat exchanger, a secondary working fluid which vaporises at a lower temperature than water.
- Working fluid vapour turns the turbine and circulates in a closed-loop circuit .

Flash steam Power plant



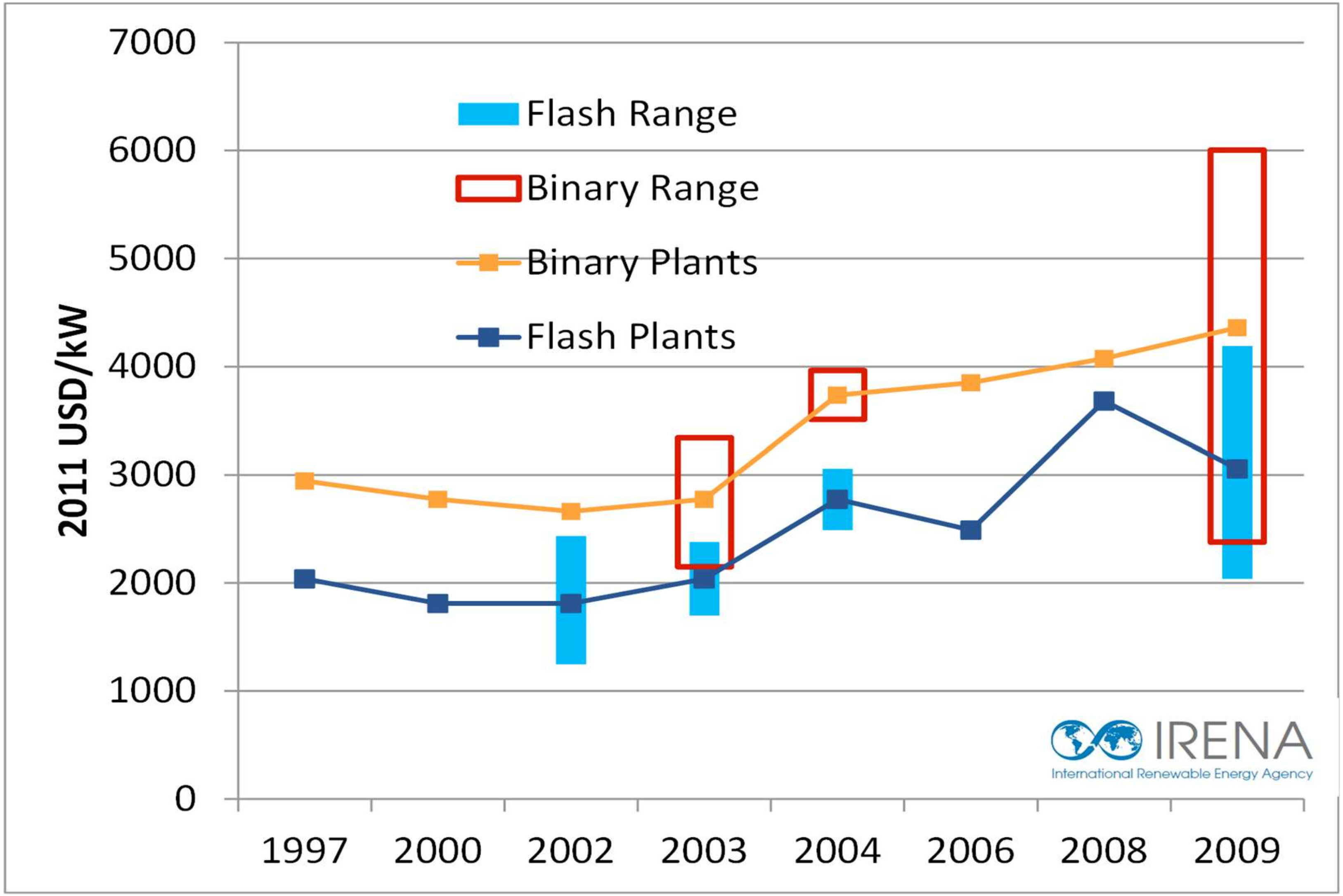
- Used when geothermal resource temperatures are above 150^{o}C
- Some reservoirs yield steam directly, while the majority produce water from which steam is separated and fed to a turbine engine connected to a generator

Double flash steam Power plant



- Improved heat capture and reuse

Cost of production



- Cost of production of geothermal by flash plants is much cheaper as the efficiency of the power plant is much higher and tends to provide better utilization of the heat generated

Environmental impact

Estimated Emission Levels by Pollutant and Energy Source of Power Plants

[lbs/MWh]	Dry Steam	Flash	Binary	Natural Gas	Coal
CO_2	59.82	396.3	-	861.1	2200
CH_4	0.0000	0.0000	-	0.0168	0.2523
$PM_{2.5}$	-	-	-	0.1100	0.5900
PM_{10}	-	-	-	0.1200	0.7200
SO_2	0.0002	0.3500	-	0.0043	18.75
N_2O	0.0000	0.0000	-	0.0017	0.0367

Source: Climate Registry 2012, EIA 2013e, EPA 2009, EPA 2011, NRC 2010

Other environmental Impacts

- Water quality is affected
- Emission of Sulpher can cause production of Sulphuric acid on mixing with water
- Life cycle global warming emissions

Source: http://www.climatetechwiki.org/technology/geoth
http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/environmental-impacts-geothermal-energy.html#.VNuA7HbHOkQ

Top 10 Largest Geothermal power plants

Rank	Station	Country	Capacity (MW)
1.	The Geysers	United States	1,808
2.	Cerro Prieto	Mexico	958
3.	Larderello	Italy	769
4.	Hellisheiði	Iceland	303
5.	Olkaria	Kenya	260
6.	Darajat	Indonesia	255
7.	Malitbog	Philippines	233
8.	Wayang Windu	Indonesia	227
9.	Kamojang	Indonesia	203
10.	US Navy	United States	240

Installed geothermal electric capacity

highest capacity

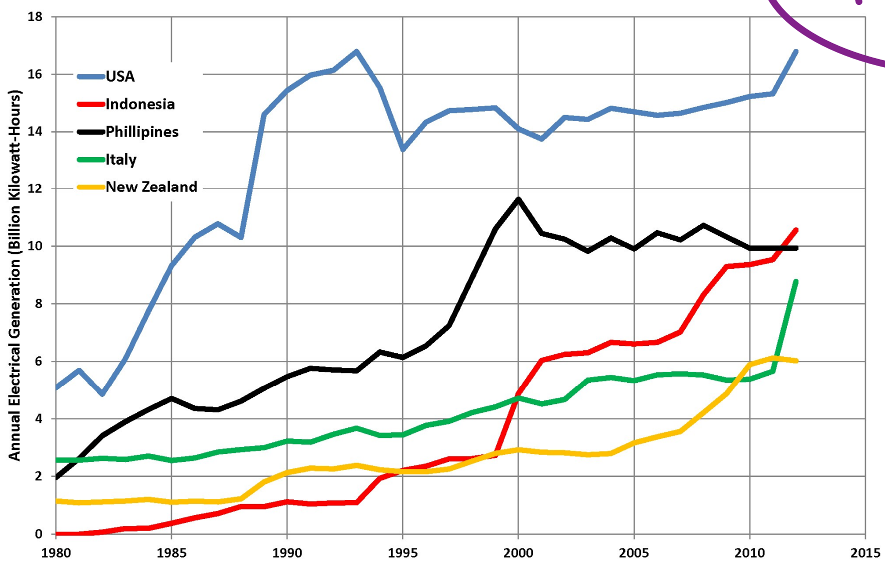
USA

Country	Capacity (MW) in 2015	% of National Production
USA	3450	0.3
Philippines	1870	27.0
Indonesia	1340	3.7
Mexico	1017	3.0
New Zealand	1005	14.5
Italy	916	1.5
Iceland	665	30.0
Kenya	594	51.0

highest % of national production

KENYA

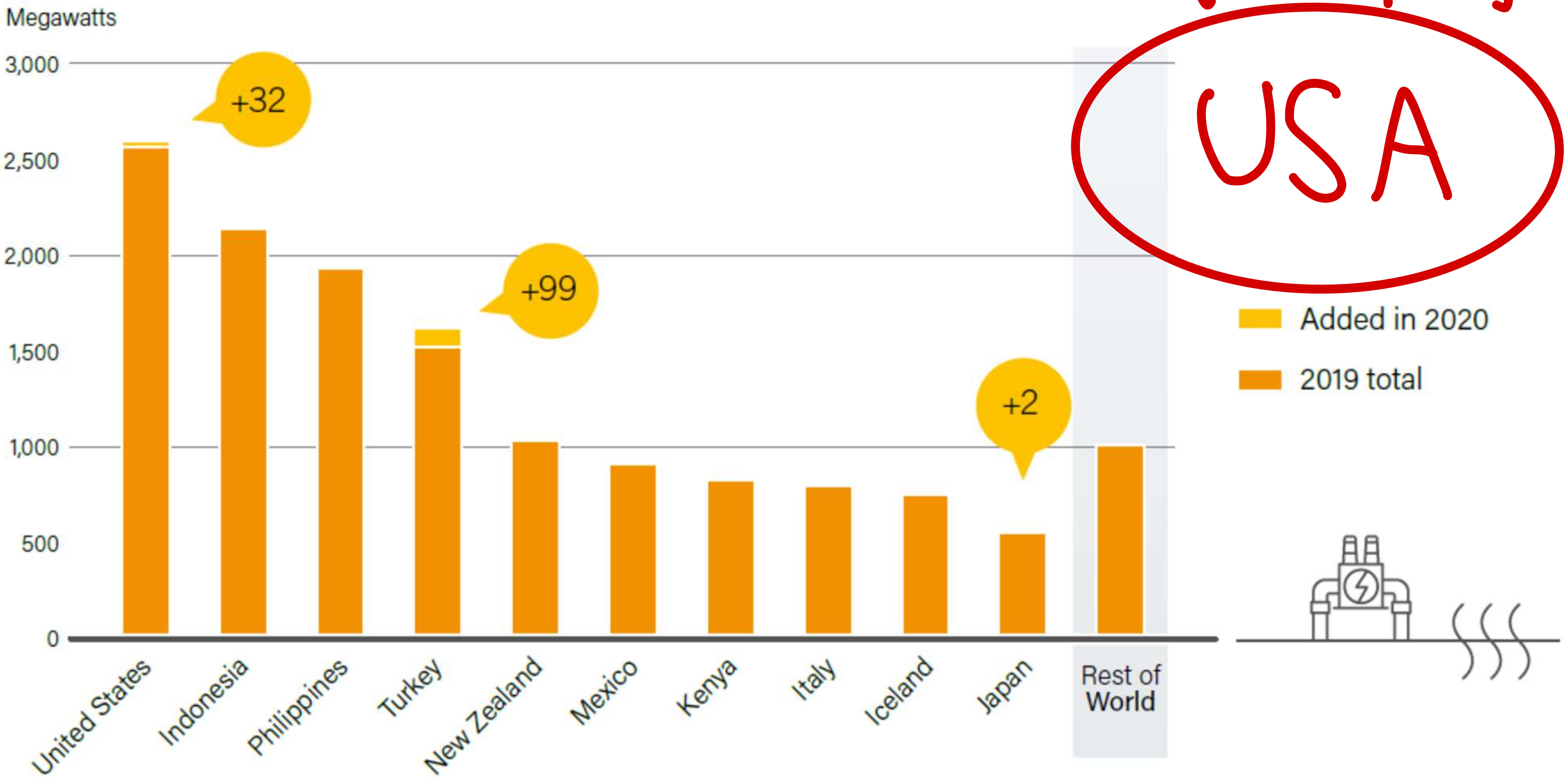
Trends in top 5 geothermal power producing countries



Geothermal power plants – Installed capacity across countries

highest capacity

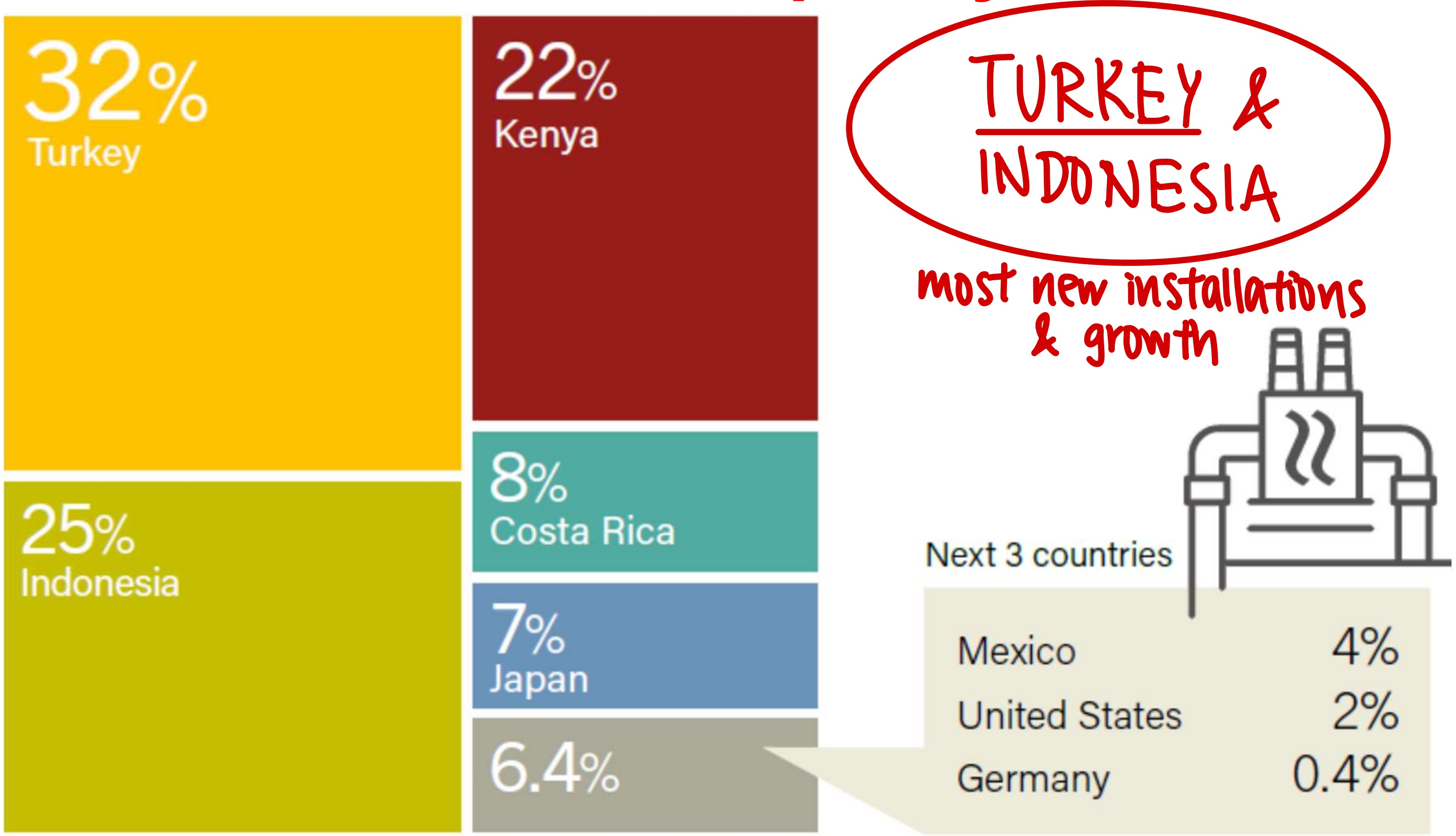
USA



United States remains the global leader for installed geothermal power capacity, despite little growth in recent years

Source: REN21's Renewables 2021 Global Status Report

Geothermal Power Capacity Additions, 2019



- Turkey and Indonesia remained the leaders for new installations and accounted for about two-thirds of the new capacity installed.
- Turkey has developed most of its geothermal capacity in just six years, with more than 1 GW added between 2014 and 2019

Source: REN21's Renewables 2020 Global Status Report

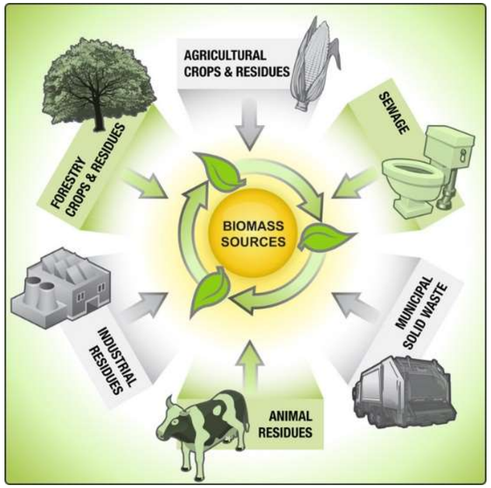
Geothermal Energy - Advantages

- Useful minerals, such as zinc and silica, can be extracted from underground water.
- In large plants the cost is 4-8 cents per kWh – same as conventional energy sources.
- Geothermal plants can be online 100%-90% of the time. Coal plants can only be online 75% of the time and nuclear plants can only be online 65% of the time.
- Flash and Dry Steam Power Plants emit considerably less CO2 than fossil fuel plants, no nitrogen oxides and little SO_2.
- Binary and Hot Dry Rock plants have no gaseous emission at all.
- Geothermal plants do not require a lot of land, 400m^2 can produce 1 GWh of energy over 30 years.

Geothermal energy - Disadvantages

- Brine can salinate soil if the water is not injected back into the reserve after the heat is extracted.
- Extracting large amounts of water can cause land subsidence, and this can lead to an **increase in seismic activity**. To prevent this the cooled water must be injected back into the reserve in order to keep the water pressure constant underground.
- Power plants that do not inject the cooled water back into the ground can release H_2S, the “rotten eggs” gas. This gas can cause problems if large quantities escape because inhaling too much is fatal.
- There is the fear of noise pollution during the drilling of wells.

Biomass to Energy

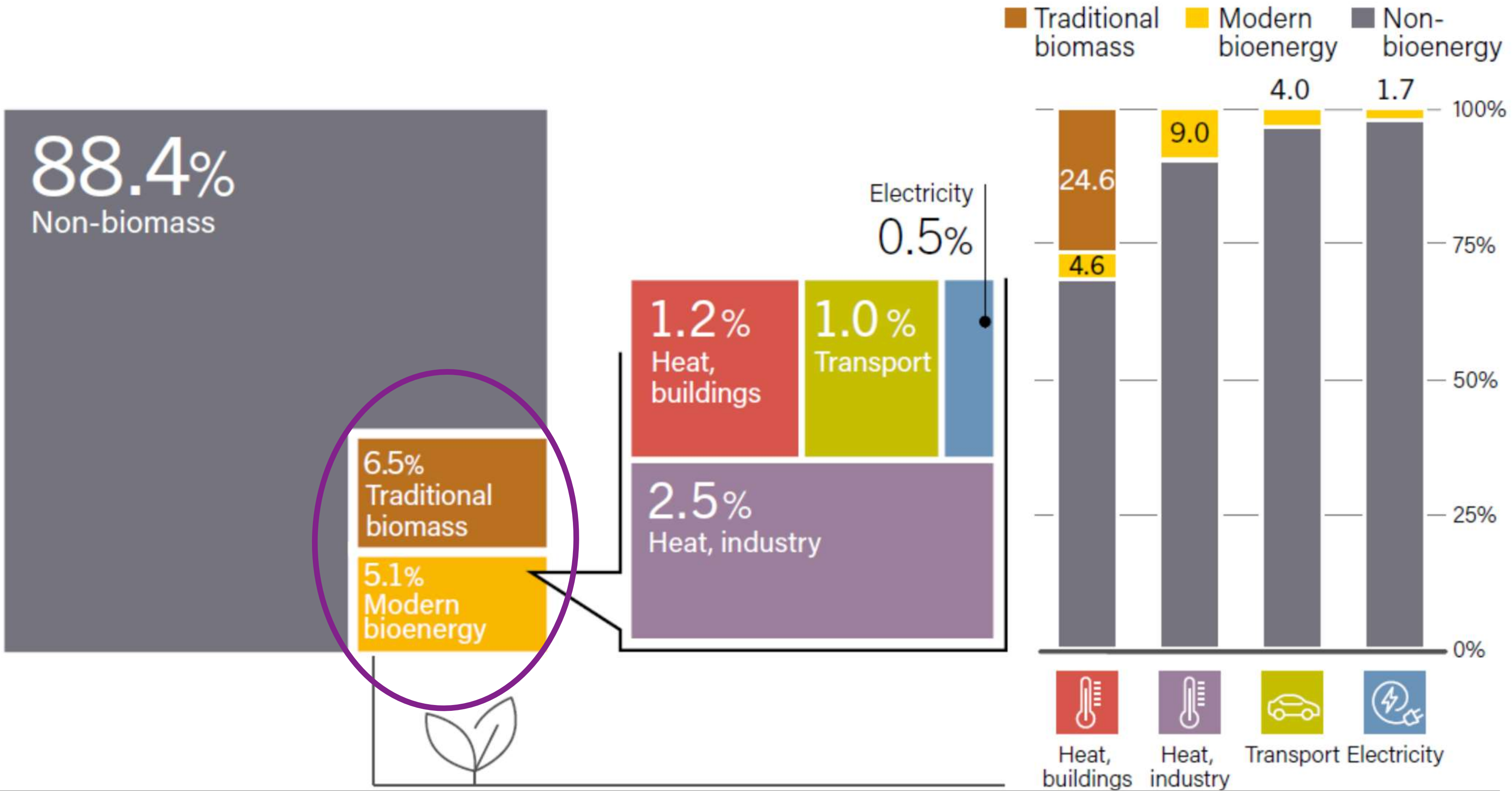


Biomass Energy

- There are many pathways by which biomass feedstocks can be converted into useful renewable energy.
- A broad range of wastes, residues and crops grown for energy purposes can be used
  - directly as fuels for heating and cooling or
  - for electricity production, or
  - they can be converted into gaseous or liquid fuels for transport or
  - as replacements for petrochemicals
- Many bioenergy technologies and conversion processes are now well-established and fully commercial

Biomass Energy

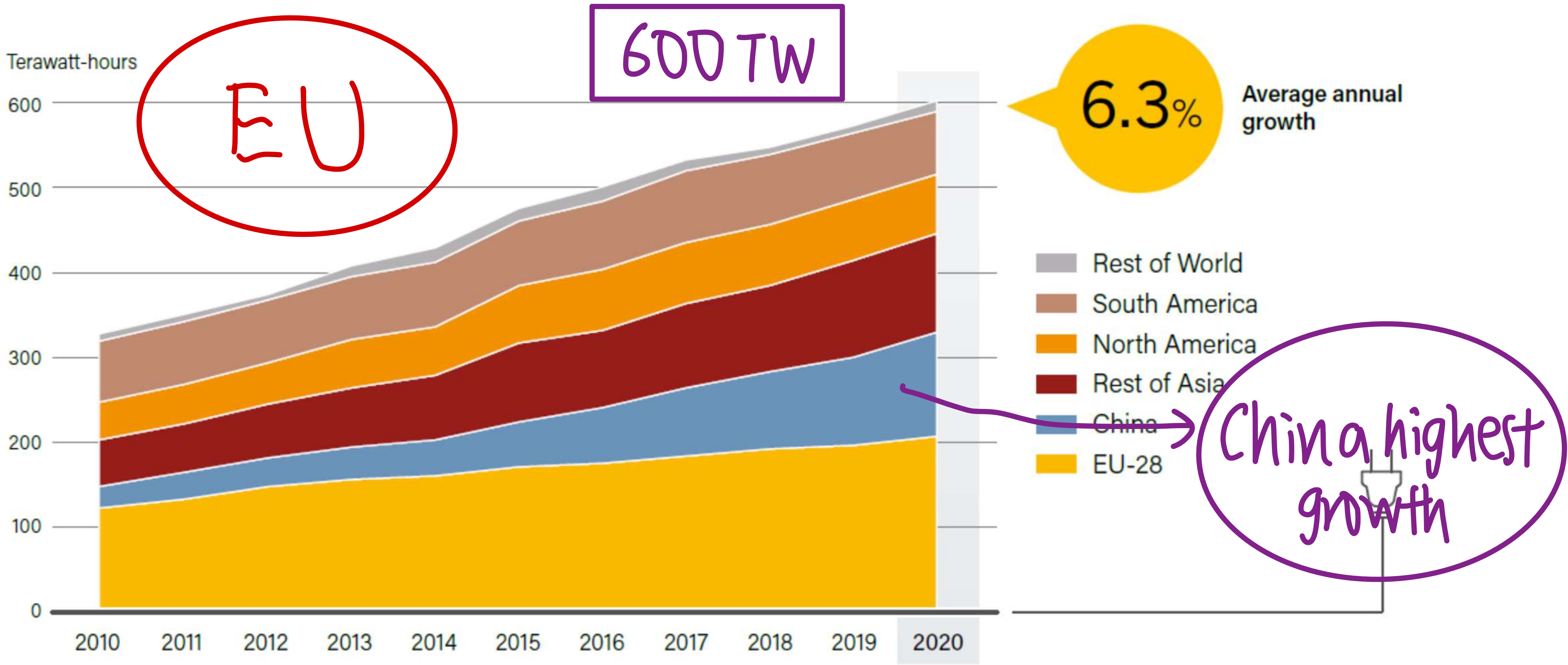
- Share of bioenergy in total final energy consumption



- Biomass provides energy for heating in industry and buildings, transport and energy production.
- The amount of biomass used for heating has been growing steadily

Source: REN21's Renewables 2021 Global Status Report

Global Biomass Power Generation

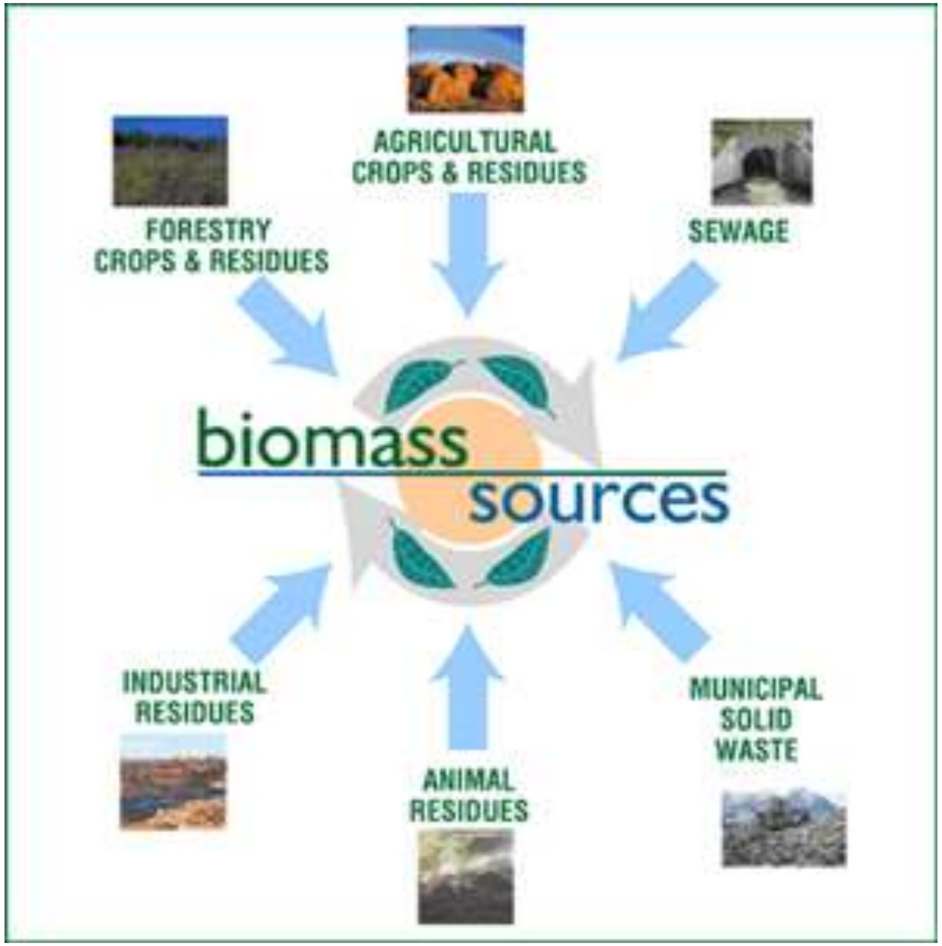


- Global bio-power capacity increased 6.3% in 2020, led by China
- Total bioelectricity generation rose to 600 TWh in 2020
- The EU remained the largest generator by region stimulated by the Renewable Energy Directive.

Source: REN21's Renewables 2021 Global Status Report

What is Bio-mass?

Biomass is biological material derived from living, or recently living organisms. In the context of biomass for energy this is often used to mean plant based material, but biomass can equally apply to both animal and vegetable derived material.

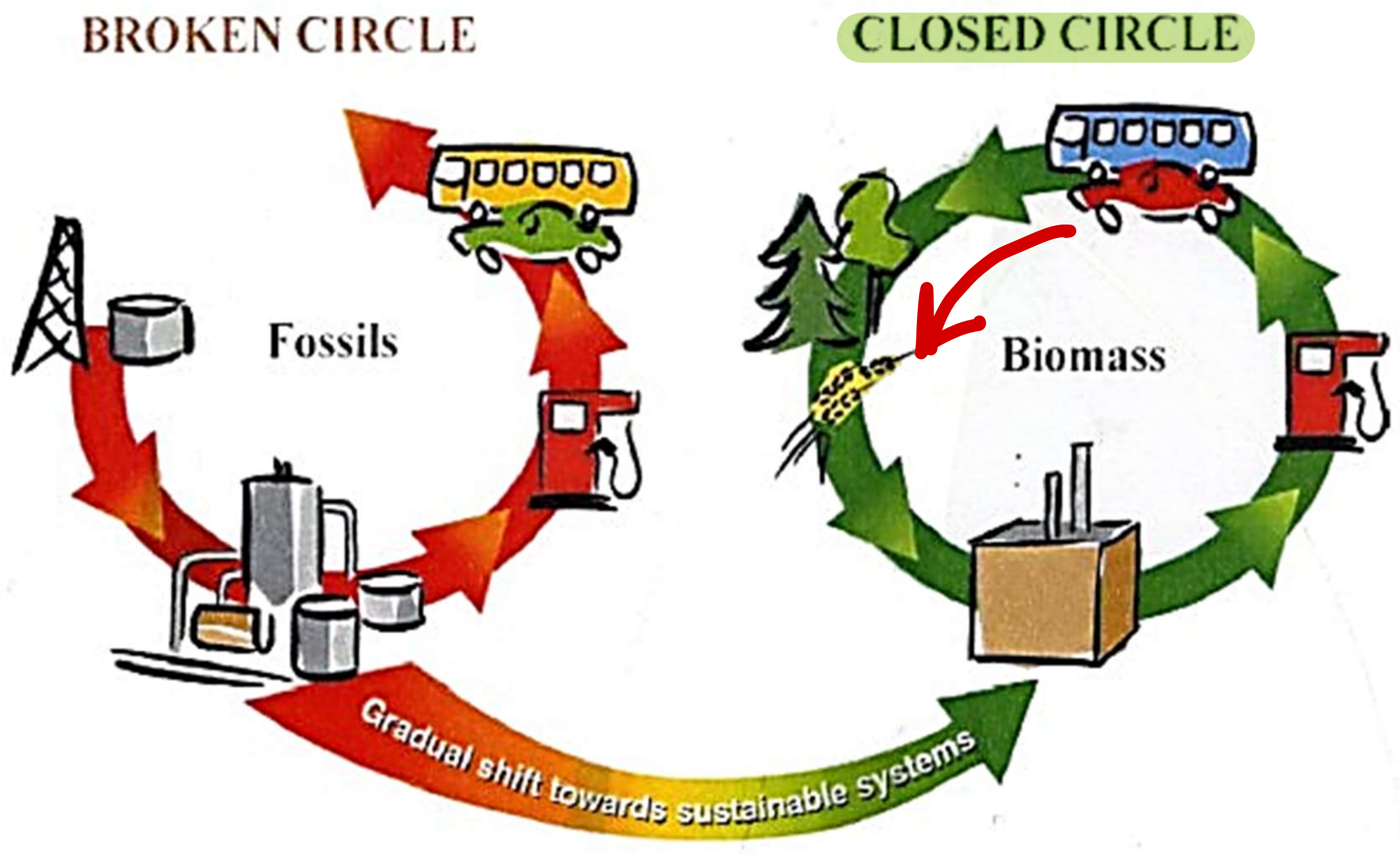


Chemical Composition of Biomass

- Biomass = Organic molecules of H_2
  + atoms of O_2
  + Nitrogen
  + Alkali, Alkaline earth
  + heavy metals

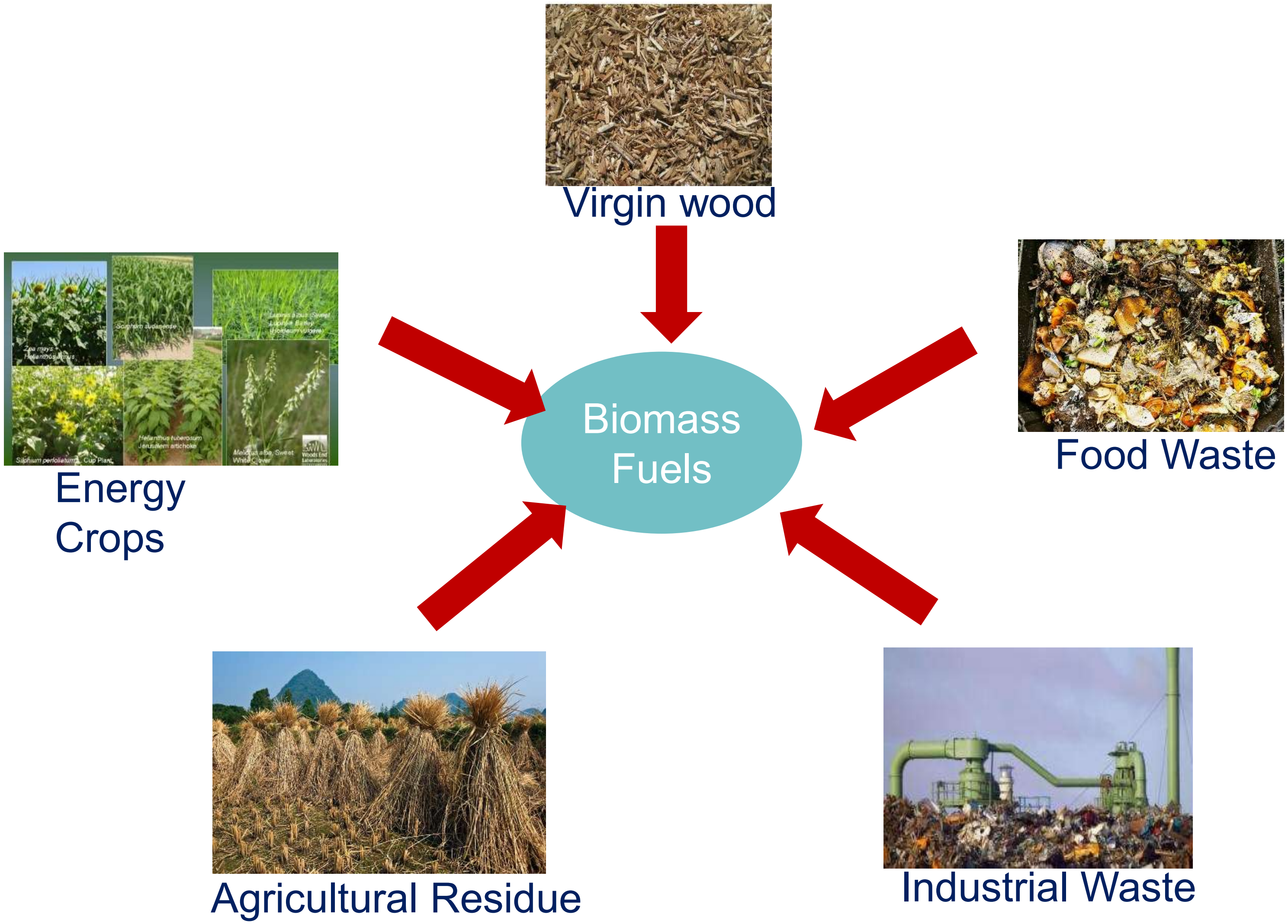
- The metals are often found in functional molecules such as the porphyrins which include chlorophyll which contains magnesium.

Difference between Biomass and Fossil Fuel



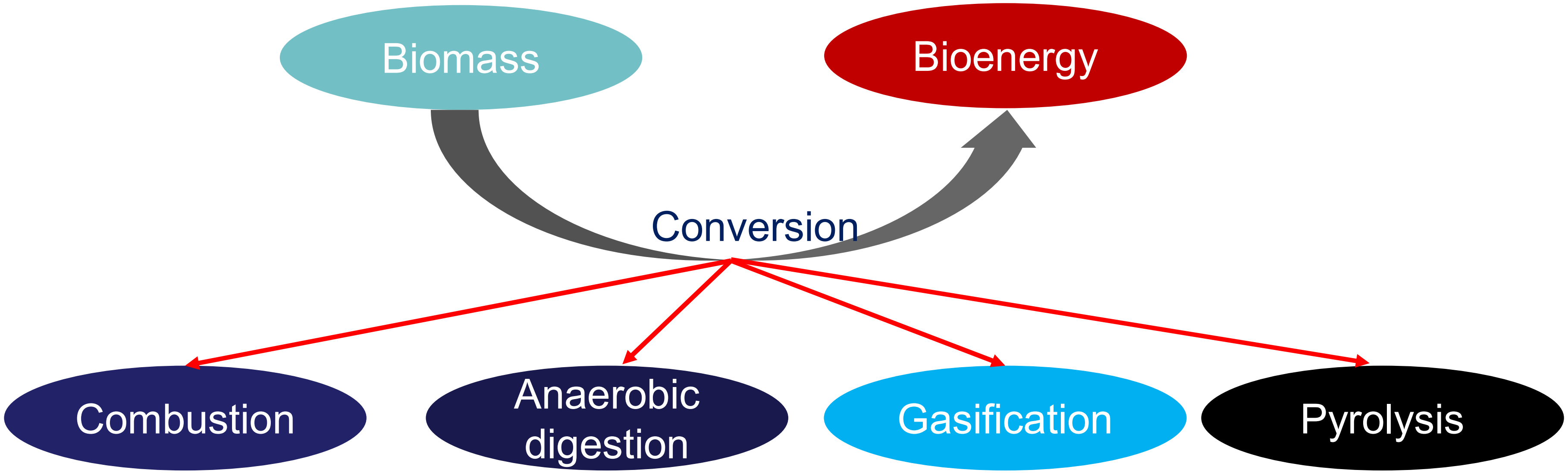
Source : http://www.slideshare.net/chemistryaddict/kaw-energy-andenergyconversions

Biomass Fuels

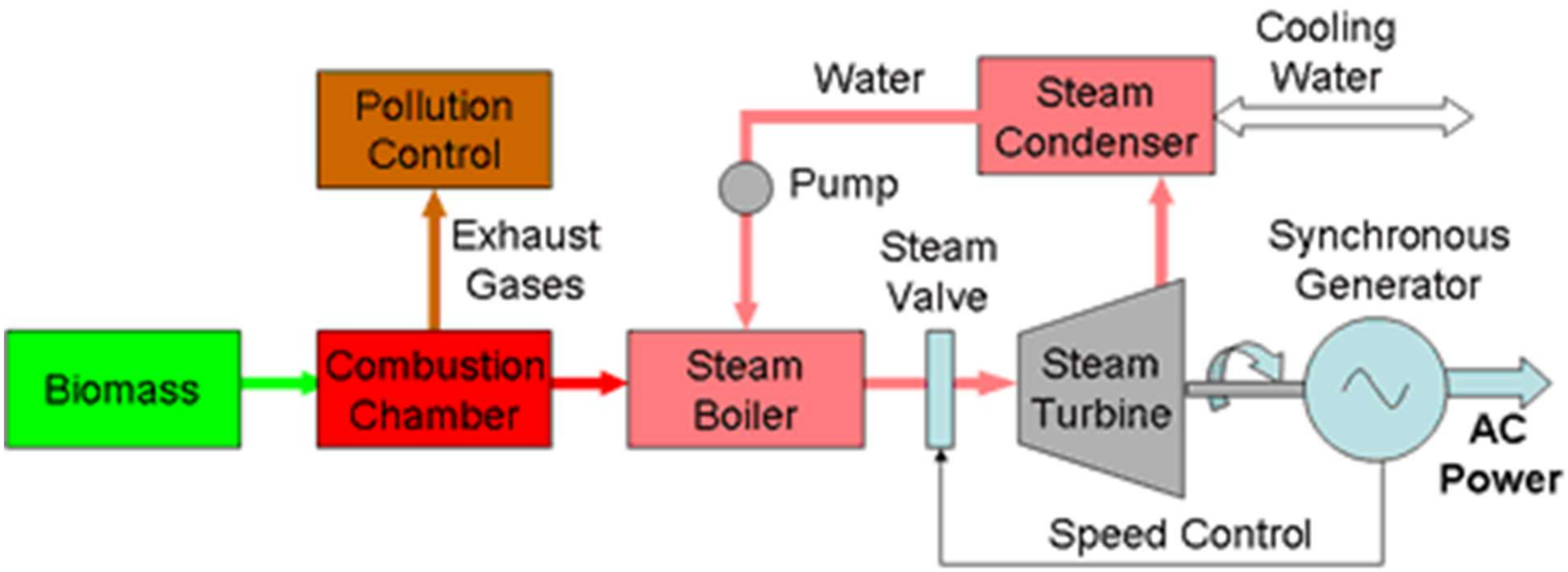


Bioenergy

Bioenergy is energy derived from biomass which includes biological material such as plants and animals, wood, waste, (hydrogen) gas, and alcohol fuels. In essence bioenergy is the utilization of solar energy that has been bound up in biomass during the process of photosynthesis. It is a **renewable energy source**



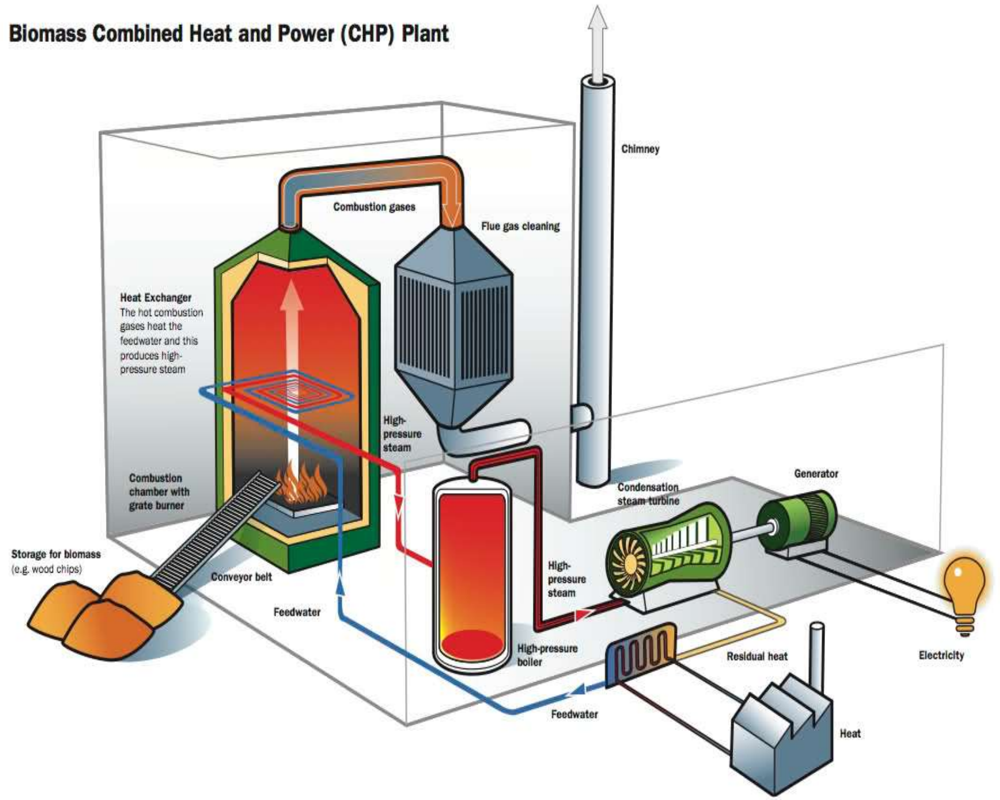
General Scheme of a Biomass power plant

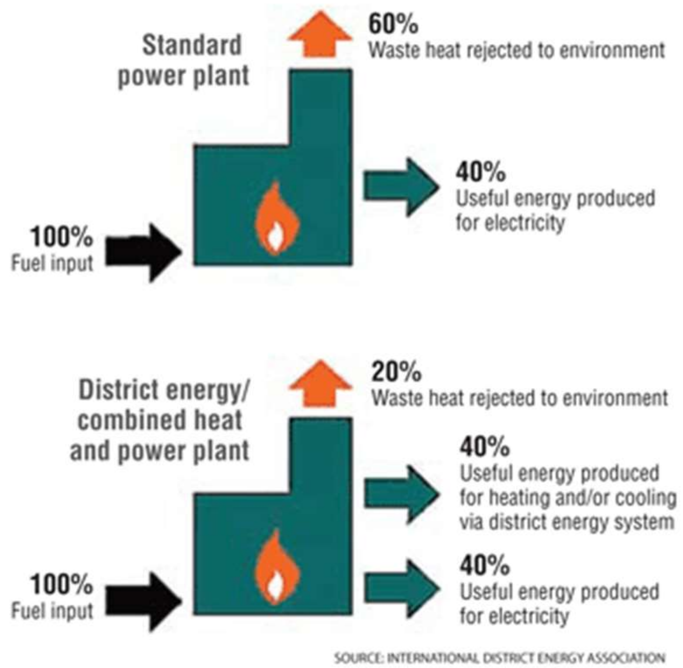


Electricity Generation Powered by Biomass

- Biomass power is carbon neutral electricity generated from renewable organic waste that would otherwise be dumped in landfills, openly burned, or left as fodder for forest fires.
- In biomass power plants, the organic waste is burned to produce steam that runs a turbine to make electricity

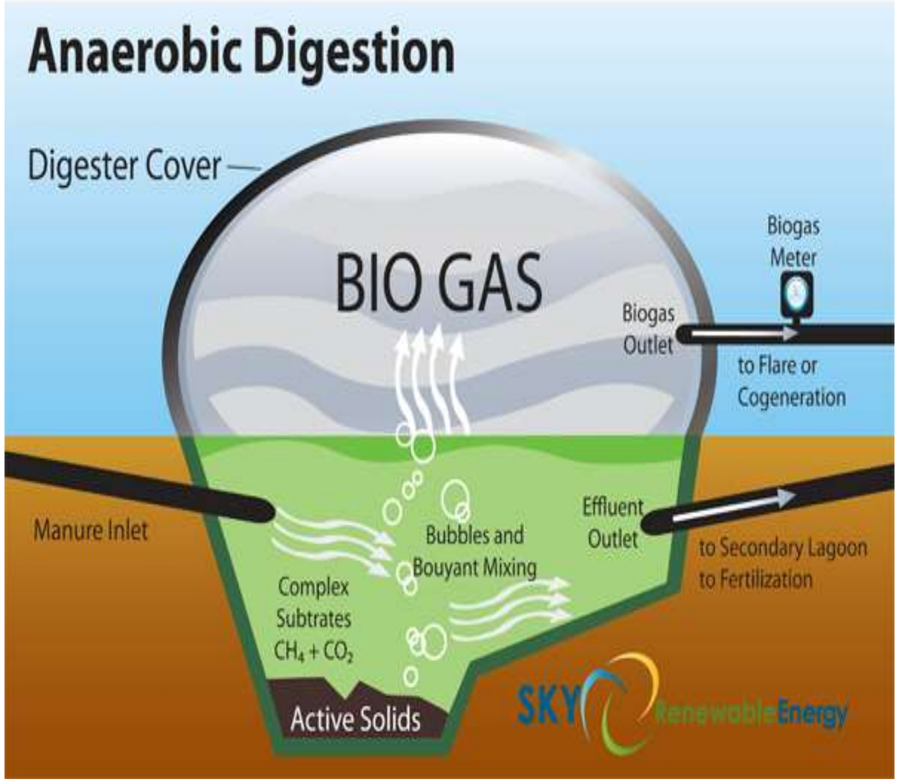
Biomass Combined Heat and Power Plant - CHP

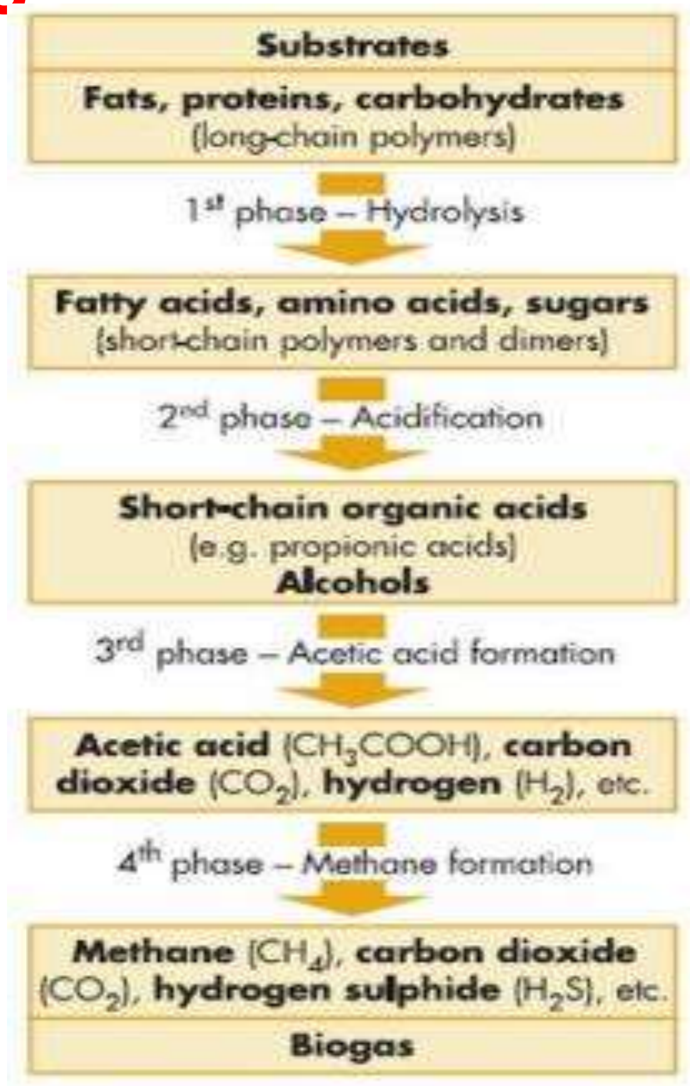




- Dual benefit by producing electricity and also heating solution
- Primary component is usually wood chips
- Wetness of the chips determine the efficiency

What is Anaerobic digestion?

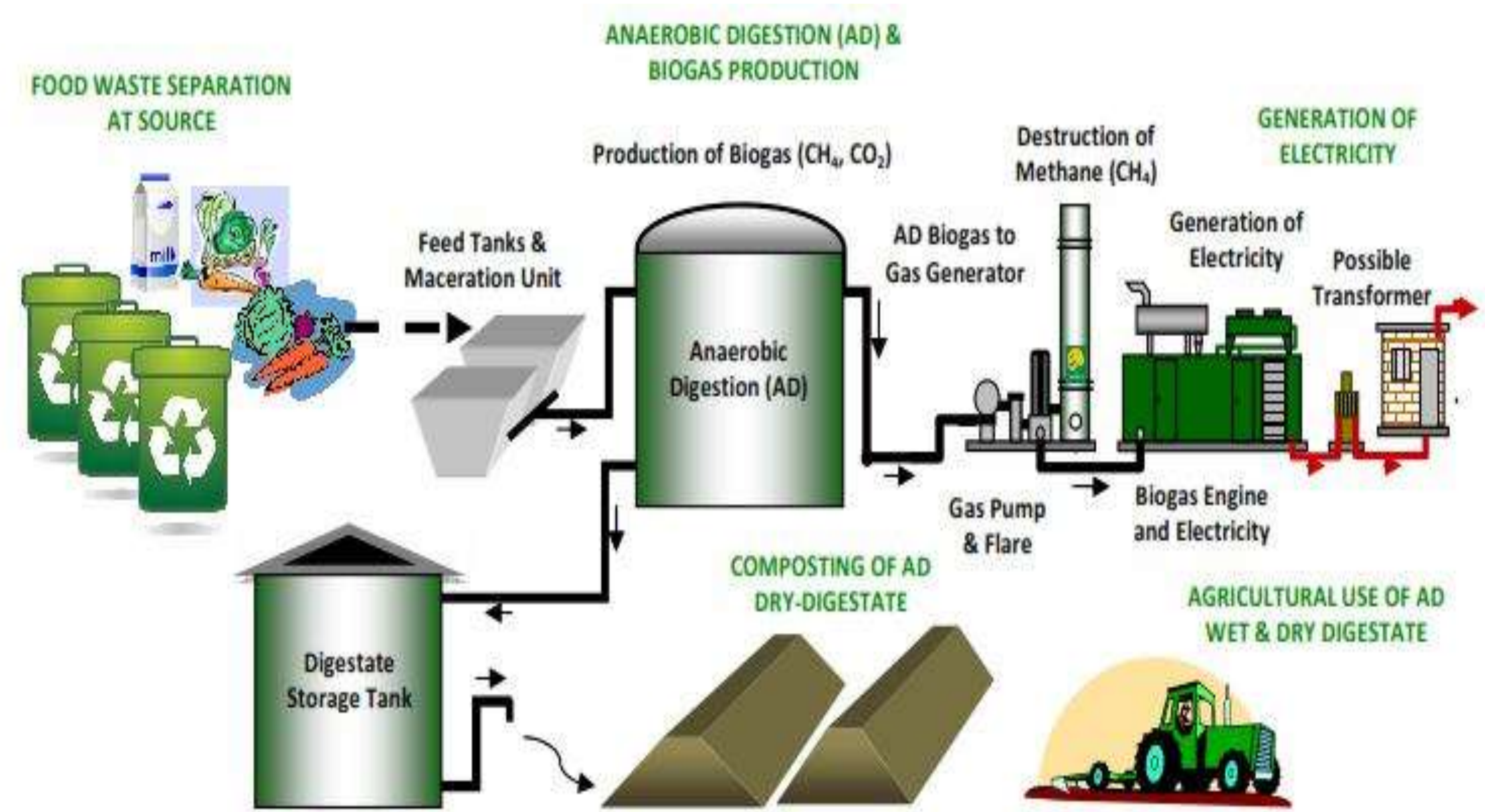




- The process of producing combustible gas from organic material is called anaerobic digestion
- Temperature is a critical parameter in anaerobic digestion
- Typical ranges : 32 and 45 C for Mesophilic and 50 and 65 C for thermophilic

Source : www.seai.ie/Renewables/Bioenergy/Bioenergy_Technologies/Anaerobic_Digestion/

Anaerobic digestion biomass power plant



- Reduction of pollution due to nitrogen stripping
- Sustainable management of organic waste
- Renewable alternative to fossil fuel

Source : http://www.greeneridea.com

$C + H_2O \xrightarrow{\Delta} CO + H_2$ $C + 2H_2O \xrightarrow{\Delta} CO_2 + 2H_2$

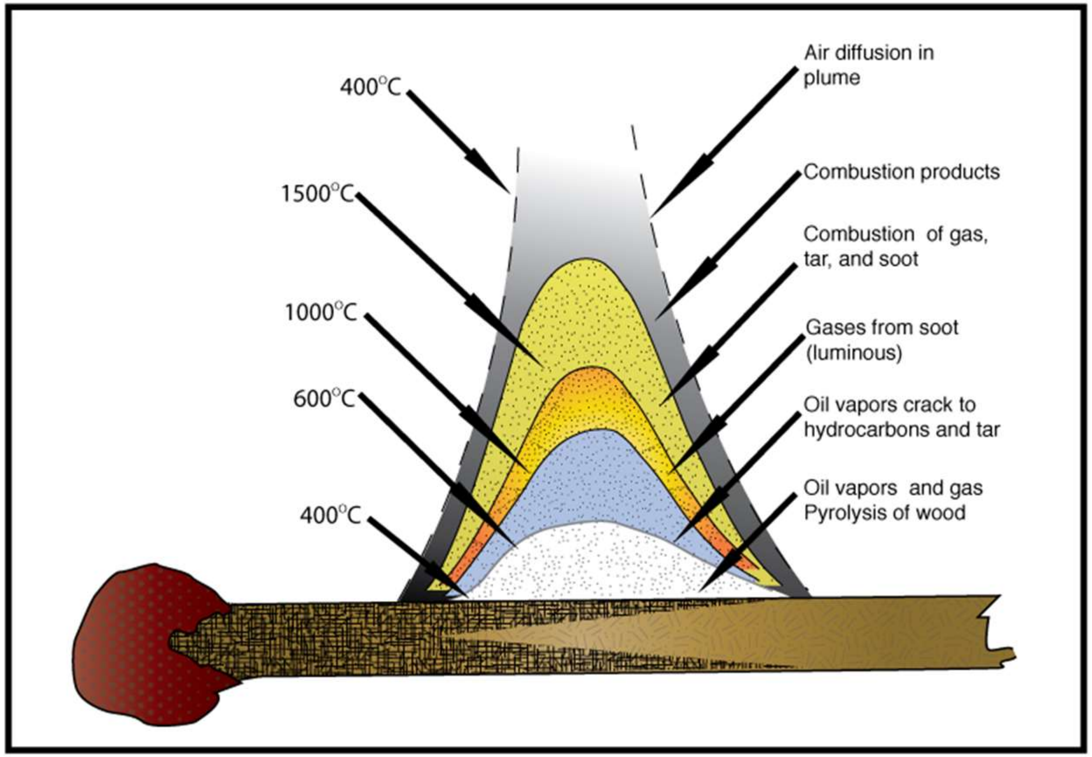
What is Gasification?

Gasification is a partial oxidation process whereby a carbon source such as coal, natural gas or biomass, is broken down into carbon monoxide (CO) and hydrogen (H_2), plus carbon dioxide (CO_2) and possibly hydrocarbon molecules such as methane (CH_4) in an reduced oxygen environment.

↳ breaking down of carbon

W O_2

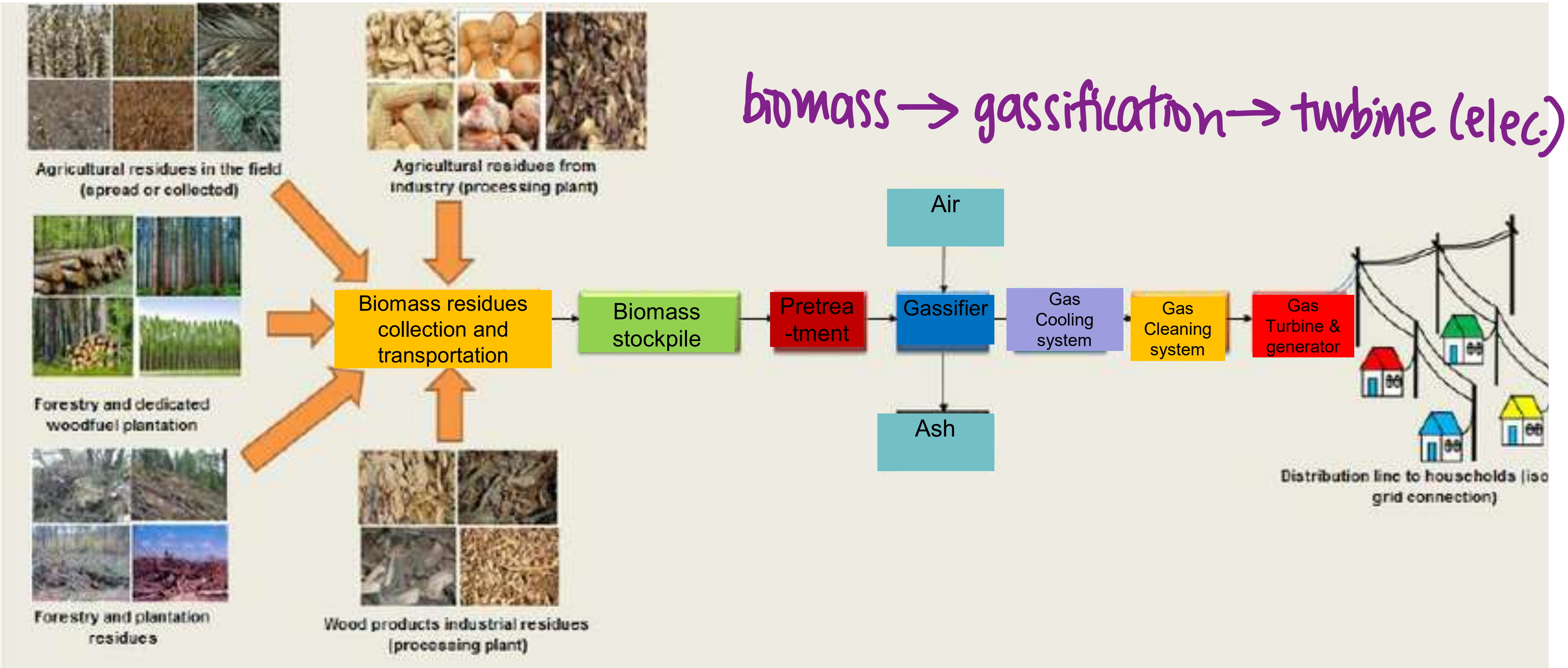
Pyrolysis, Gasification and Combustion in a Flaming Match



Adapted from Tom Reed

*Source :*https://www.allpowerlabs.com/intro.

Gasifier based power plant: From Biomass to Electricity



- The above plant uses downdraft gasifier for generation of electricity.
- After the gasifier, the energy conversion process is similar to the regular conventional fossil fuel power plants where steam produced turns a turbine and generates electricity

What is Pyrolysis?

Biomass pyrolysis is defined as the **thermal decomposition of biomass** in the **absence** of an oxidizing agent (air/oxygen) and occurs at temperatures in the range of 400 to 800ºC.

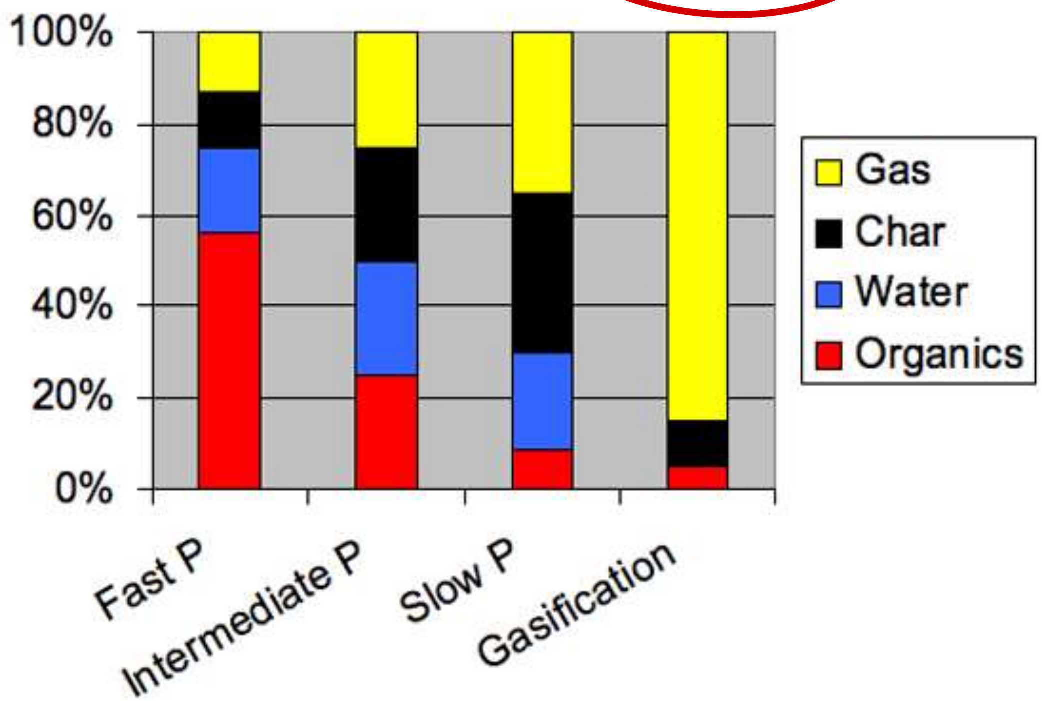
↳ similar to gassification, but no O_2

NO O_2

Biomass

Pyrolysis ↓

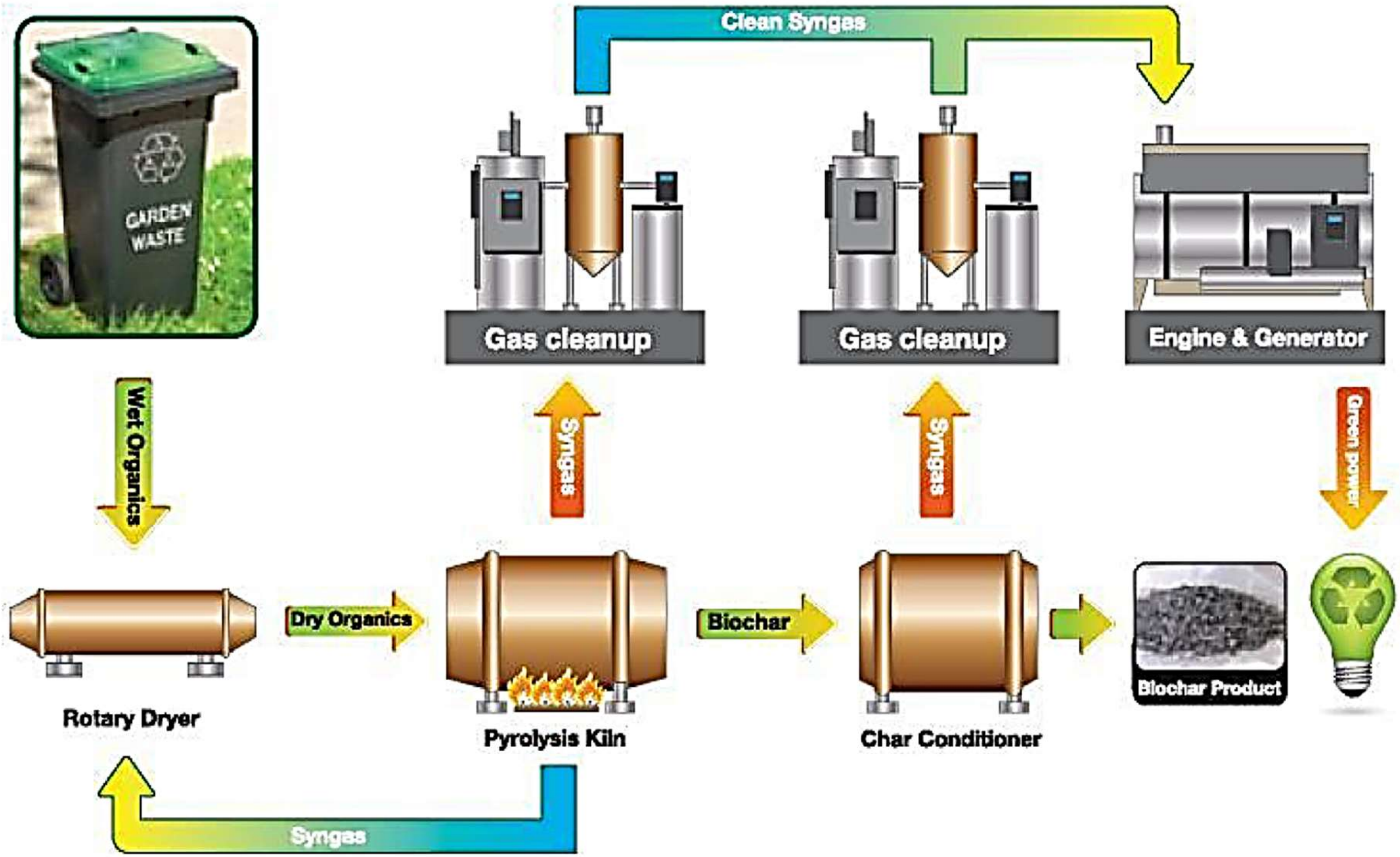
Carbon monoxide
+
Carbon dioxide
+
Methane
+
Hydrogen
+
Higher Hydrocarbons



Based on temperature used Pyrolysis is classified as Fast, Intermediate and Slow Pyrolysis

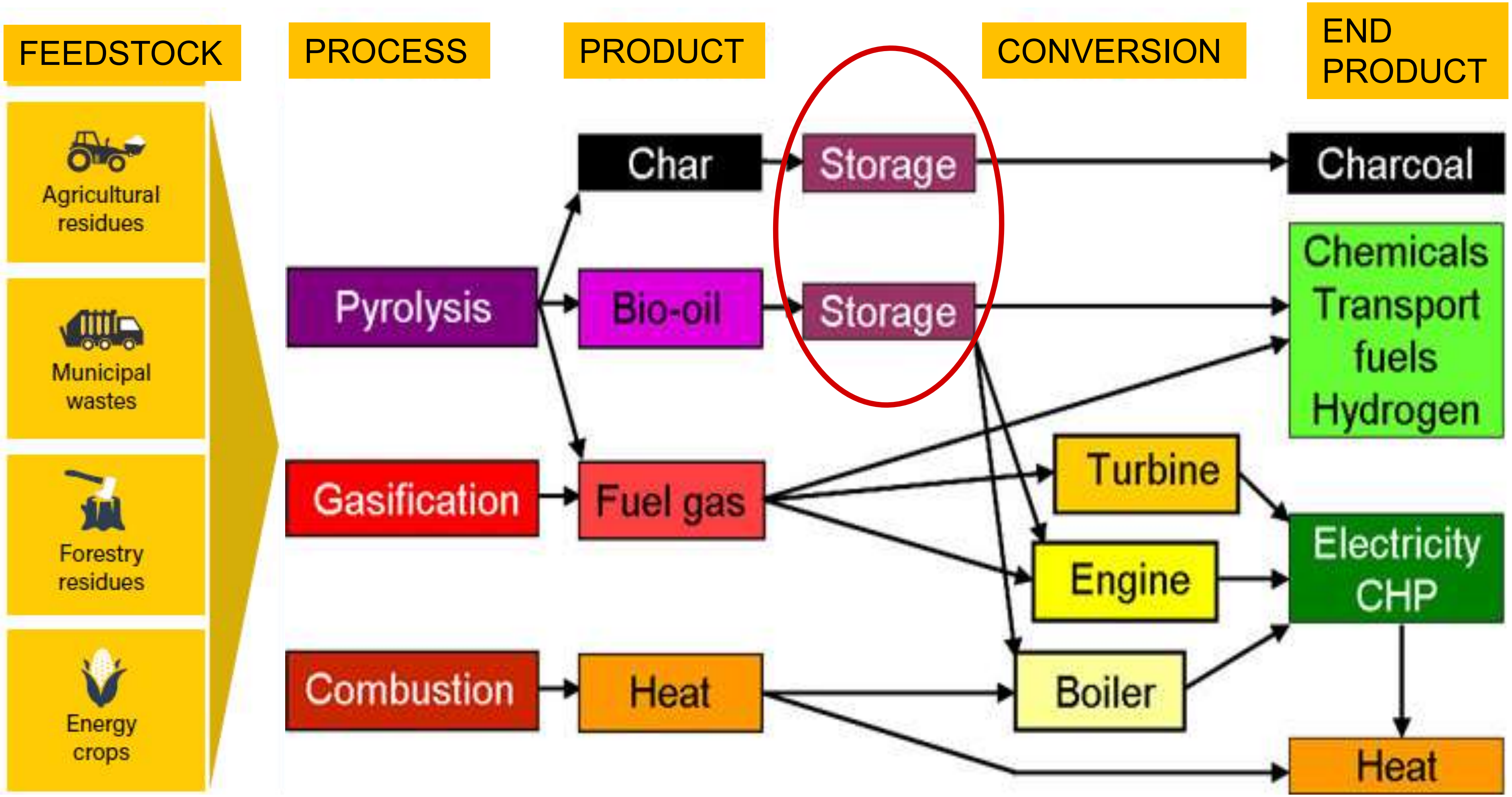
Source : http://www.copybook.com/environmental/conversion_and_resource_evaluation_ltd/articles/biomass-pyrolysis-and-gasification-processes-and-

Pyrolysis based biomass power plant



WAG LIMITED

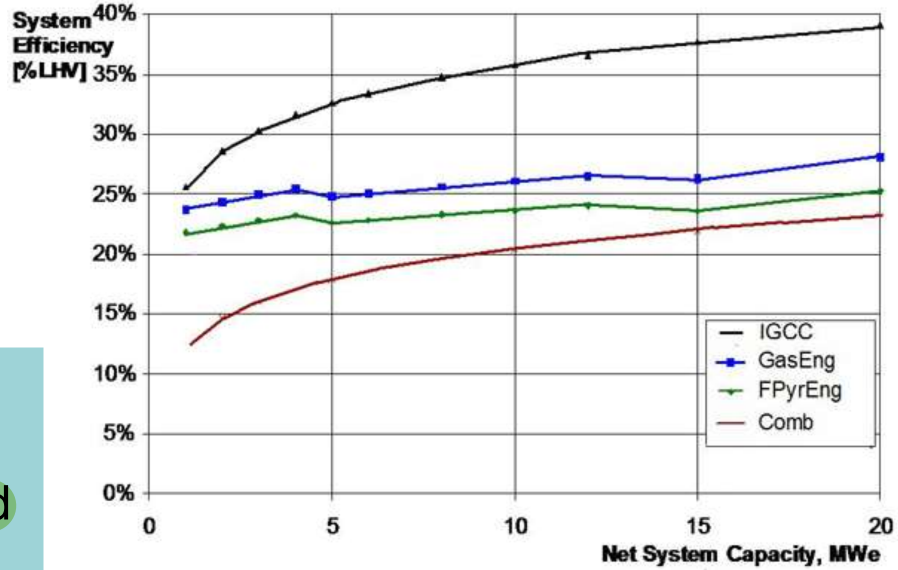
Conversion Pathways to Advanced Biofuels



Bioenergy requires a more complex supply chain than other renewable technologies, given the many potential feedstocks and conversion processes for bioenergy and the need to collect, process and convert biomass raw materials to fuels.

Biomass efficiency and trends

Integrated gasification combined cycle (IGCC) power plants have the highest efficiency

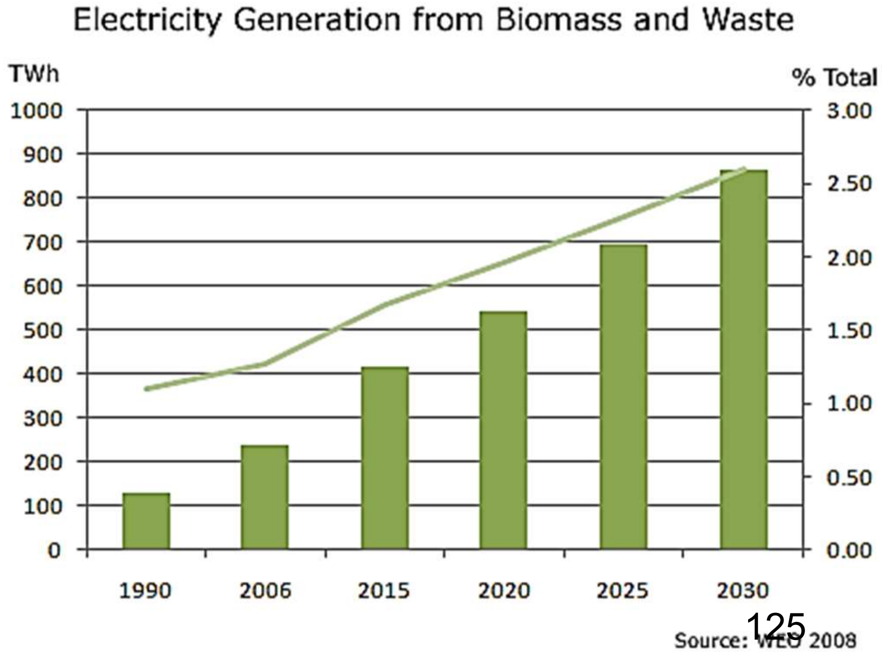


Biomass power is expected to see steady growth as:

(a) biomass power generation can be used for base load, dispatchable power, or cogeneration;

(b) biomass fuel is abundant in many parts of the world;

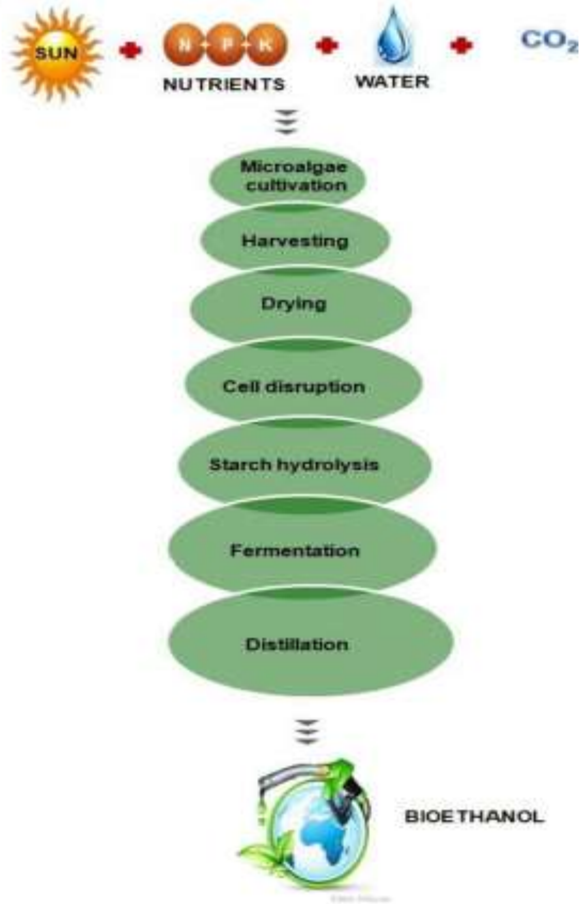
(c) cost of generating electricity from biomass material is relatively low compared with the costs of generating from other renewable energy sources such as geothermal, PV, fuel cell, and microturbine sources



Source :
http://www.copybook.com/environmental/conversion_and_resource_evaluation_ltd/articles/biomass-pyrolysis-and-gasification-processes-and-differences
http://www.wbdg.org/resources/biomasselectric.php

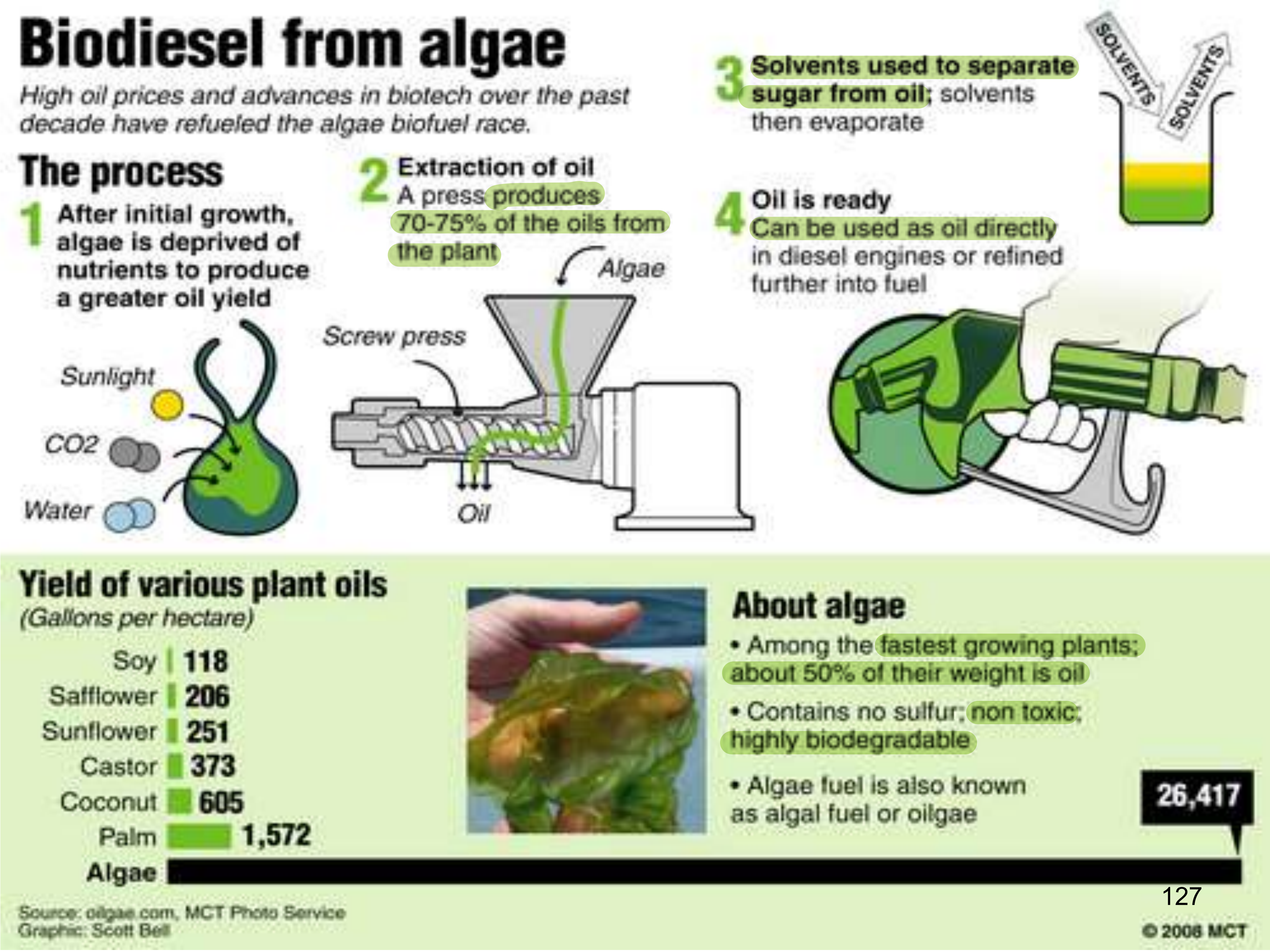
Algae - Third Generation Biofuels

Algae fuel



http://www.youtube.com/watch?v=n9_-ZguuhBw

https://www.youtube.com/watch?v=IxyvVkeW7Nk


Biodiesel from algae
High oil prices and advances in biotech over the past decade have refueled the algae biofuel race.
The process
1 After initial growth, algae is deprived of nutrients to produce a greater oil yield
Sunlight
CO2
Water
2 Extraction of oil
A press produces 70-75% of the oils from the plant
Algae
Screw press
Oil
3 Solvents used to separate sugar from oil; solvents then evaporate
SOLVENTS
SOLVENTS
4 Oil is ready
Can be used as oil directly in diesel engines or refined further into fuel
Yield of various plant oils
(Gallons per hectare)
Soy 118
Safflower 206
Sunflower 251
Castor 373
Coconut 605
Palm 1,572
Algae 26,417
About algae
• Among the fastest growing plants; about 50% of their weight is oil
• Contains no sulfur; non toxic; highly biodegradable
• Algae fuel is also known as algal fuel or oilgae
Source: oilgae.com, MCT Photo Service
Graphic: Scott Bell
© 2008 MCT

Biomass Energy - Issues

- Increase in demand of fuel crops may lead to a lower food quality and diversity, threatening the supply of food
- Higher food prices will threaten food security, specially in the poor regions
- Water availability for human consumption will be threatenned:
  - Producing one gallon of corn ethanol requires the consumption of 170 gallons of water
  - Producing one gallon of soybean-based biodiesel requires the consumption of 900 gallons of water.

FOOD

INCREASED COMPETITION

LIMITED NATURAL RESOURCES

CROPS

BIOFUELS

Conclusion : Biofuels

- Biofuels are environmentally friendly and sustainable
- Advanced biofuels use non food crops as feedstocks and have higher energy content
- Biodiesel fuels are **directly usable** in petroleum diesel engines
- **The technology required for the widespread implementation of biofuels is already available**
- Biofuels may offer advantages over fossil fuels, but the magnitude of these advantages depends on how a biofuel crop is grown and converted into a usable fuel

Conclusion: Renewable Generation Sources

Hydropower > Solar PV > Wind > Bio fuel > Geothermal

		2019	2020
INVESTMENT			
New investment (annual) in renewable power and fuels[1]	billion USD	298.4	**303.5**
POWER			
Renewable power capacity (including hydropower)	GW	2,581	**2,838**
Renewable power capacity (not including hydropower)	GW	1,430	**1,668**
Hydropower capacity[2]	GW	1,150	**1,170**
Solar PV capacity[3]	GW	621	**760**
Wind power capacity	GW	650	**743**
Bio-power capacity	GW	137	**145**
Geothermal power capacity	GW	14.0	**14.1**
Concentrating solar thermal power (CSP) capacity	GW	6.1	**6.2**
Ocean power capacity	GW	0.5	**0.5**

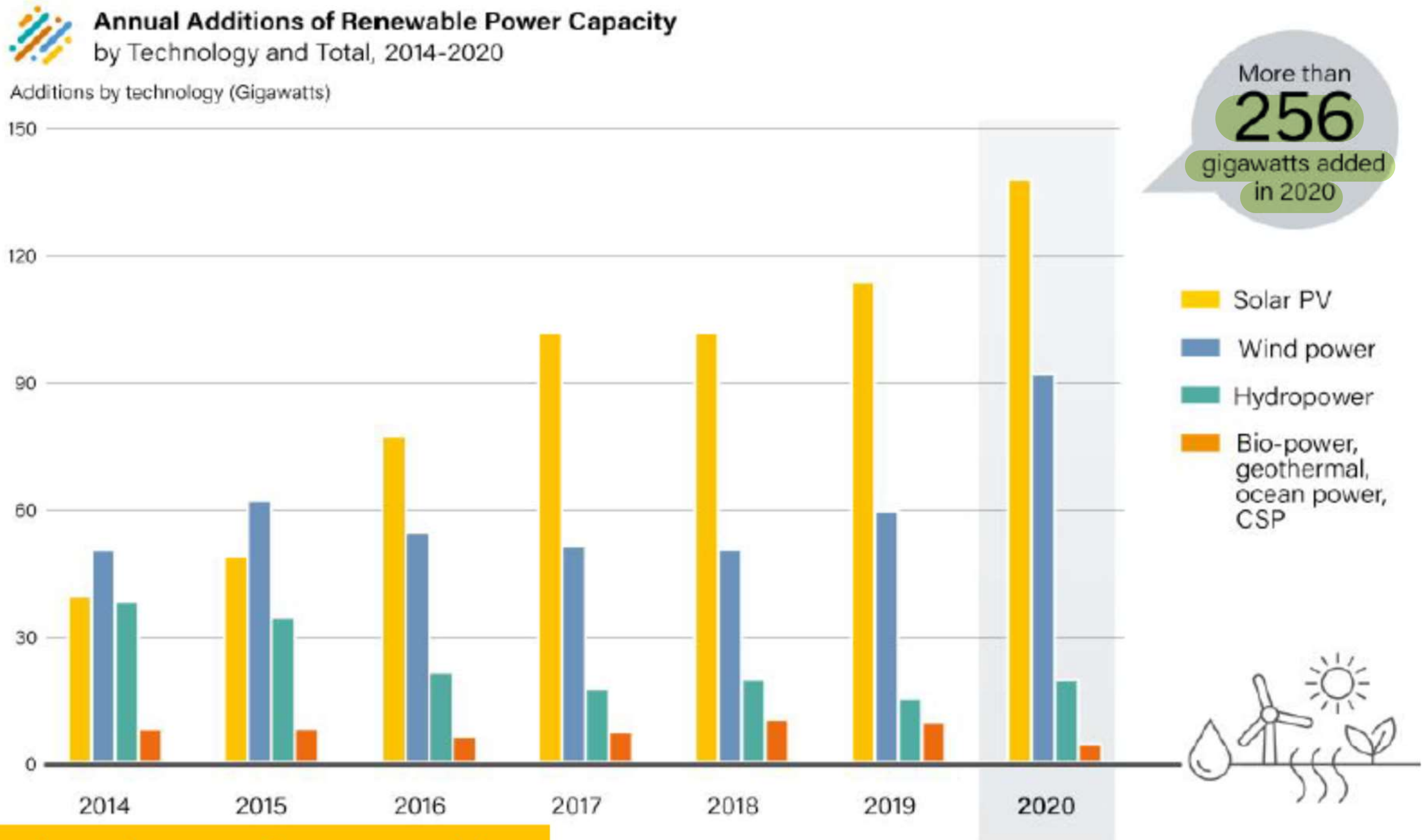
- Total global capacity grew 8.4% in 2019 (mostly wind and solar energy)
- More than 90 countries have more than 1 GW of installed renewable power capacity

Source: REN21's Renewables 2020 Global Status Report

Conclusion: Renewable Generation Sources

- In developing and emerging economies, distributed renewable energy systems continued to play an important role in connecting households in remote areas to electricity services. An estimated 5% of the population in Africa and 2% of the population in Asia has access to electricity through off-grid solar PV systems
- Renewable energy now accounts for around one-third of total installed power generation capacity worldwide
- The World Bank Group announced a target of investing USD 200 billion over five years starting in 2021 to support 35 gigawatts (GW) of renewable energy and enabling infrastructure

Conclusion: Renewable Generation Sources

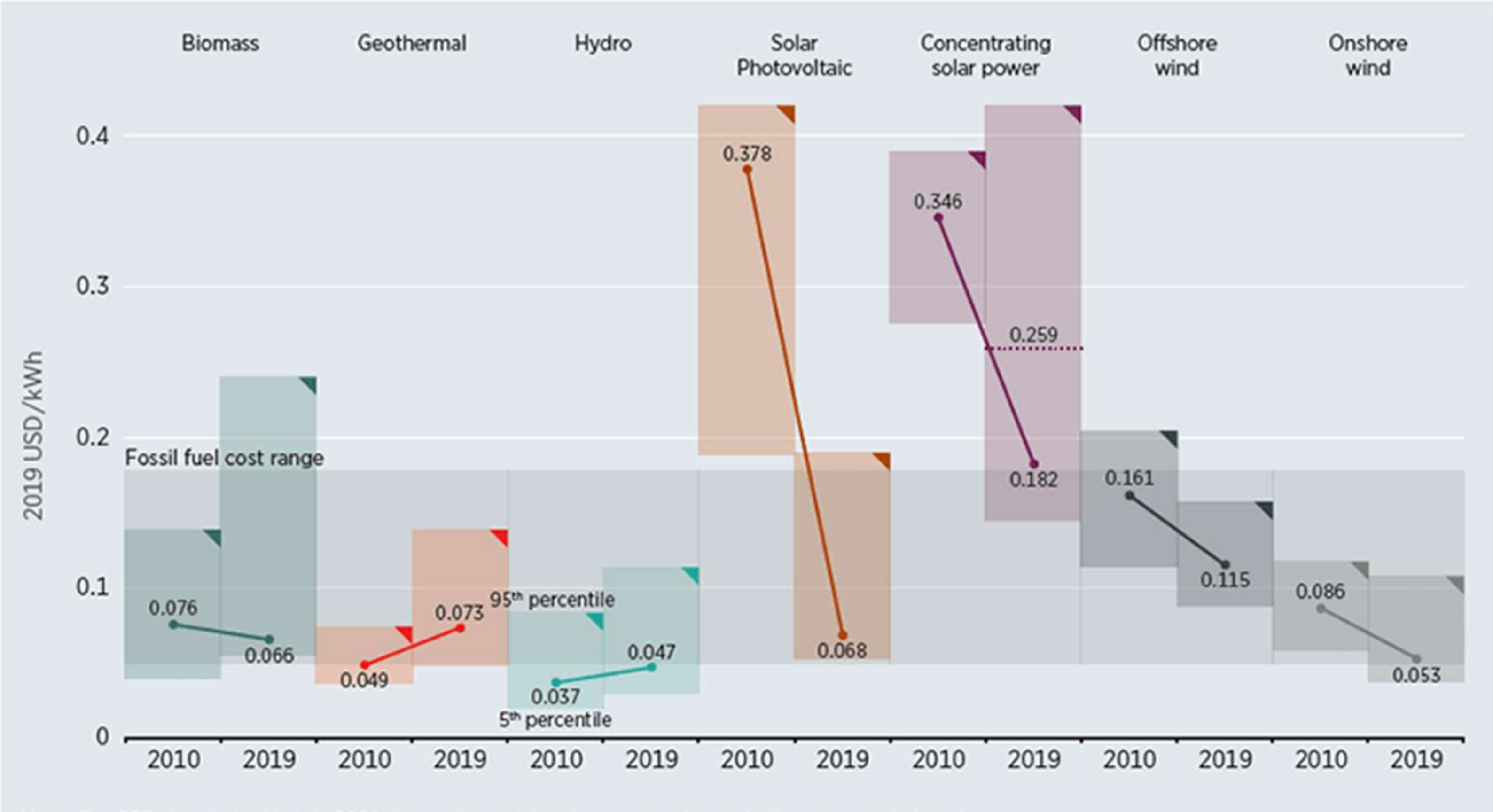


The share of renewables in electricity generation is **rising in many countries around the world.**

→ Renewable energy is now **more than 33%** of global installed power generating capacity

Source: REN21's Renewables 2021 Global Status Report

Conclusion: Renewable Generation Sources



- Renewable power is increasingly cost-competitive compared to conventional fossil fuel-fired power plants.
- Electricity generated from new wind and solar photovoltaics (PV) plants has become more economical than power from fossil fuel fired plants in many places

Source: ARENA Global Status Report

Conclusion: What is needed to advance energy transition?

- → **Set ambitious targets** globally, across regions, countries and sectors
- → Create the right, sustainable **market conditions**
- → **Accelerate investment** in renewable power, while also establishing new (and strengthening existing) policies for renewables in heating, cooling and transport
- → Encourage **sector integration** among the power, heating and cooling, and transport sectors
- → **Align** regional, national and sub-national policies, and **support cities** in their actions
- → Enact integrated policies that enforce **energy efficiency** measures while promoting the uptake of renewable energy
- → Support local job creation and a **just transition**
- → **Build social acceptance** and increase public buy-in