UNIVERSITÀ DEGLI STUDI DI TRIESTE

Adapt your future. Let's talk about climate change

October 4, 2022

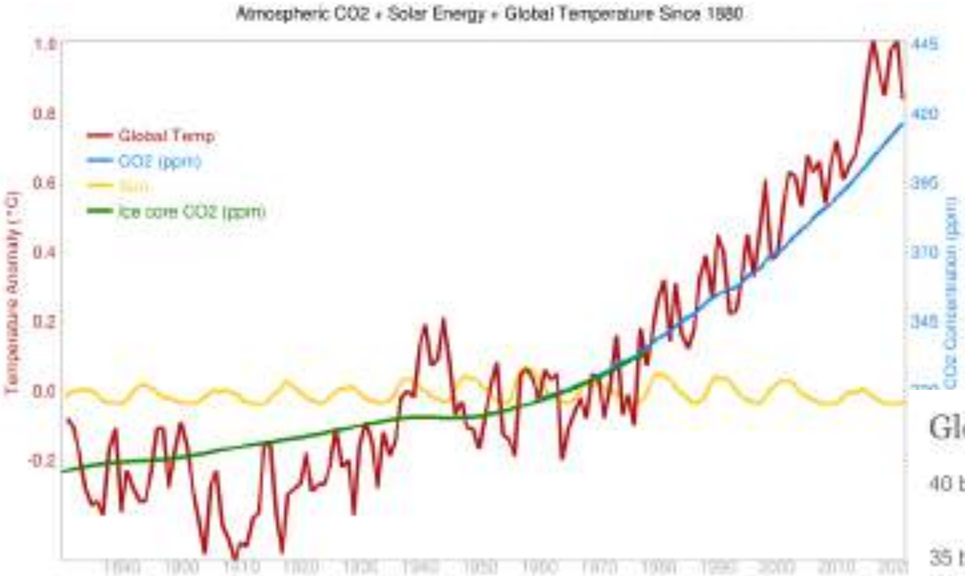
Technologies for the energy transition

Prof. Mauro Reini

reini@units.it

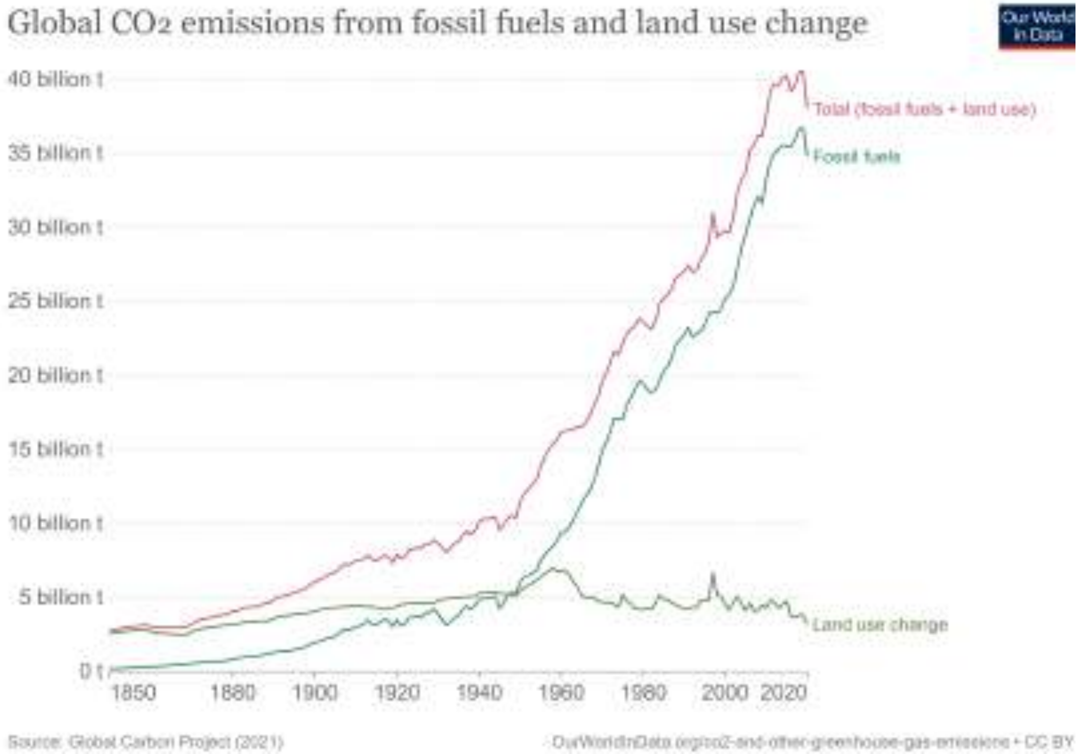
Introduction

- The links among climate warming, decarbonization and climate adaptation



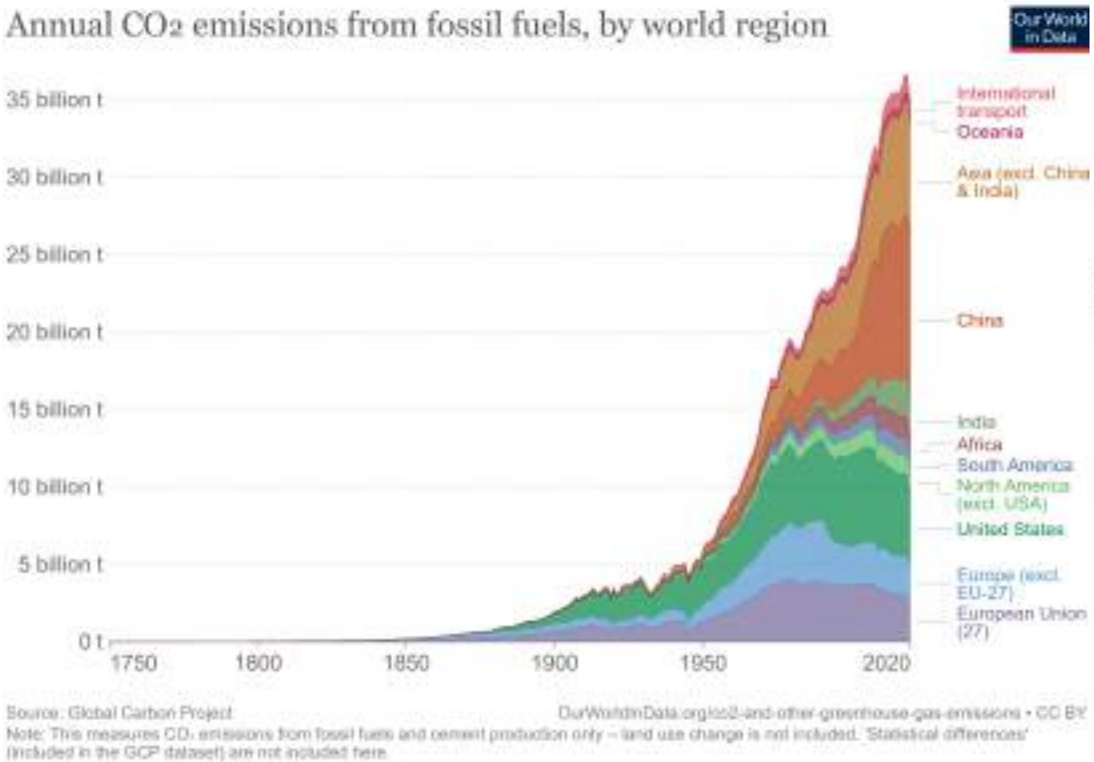
The increment of CO_2 concentration in the atmosphere is the main cause of climate warming, much evident after the middle of the past century.

Emissions from fossil fuels combustion (in engines, power plants, and industrial process) are the main cause of the rising CO_2 concentration in the atmosphere, and therefore of climate warming.

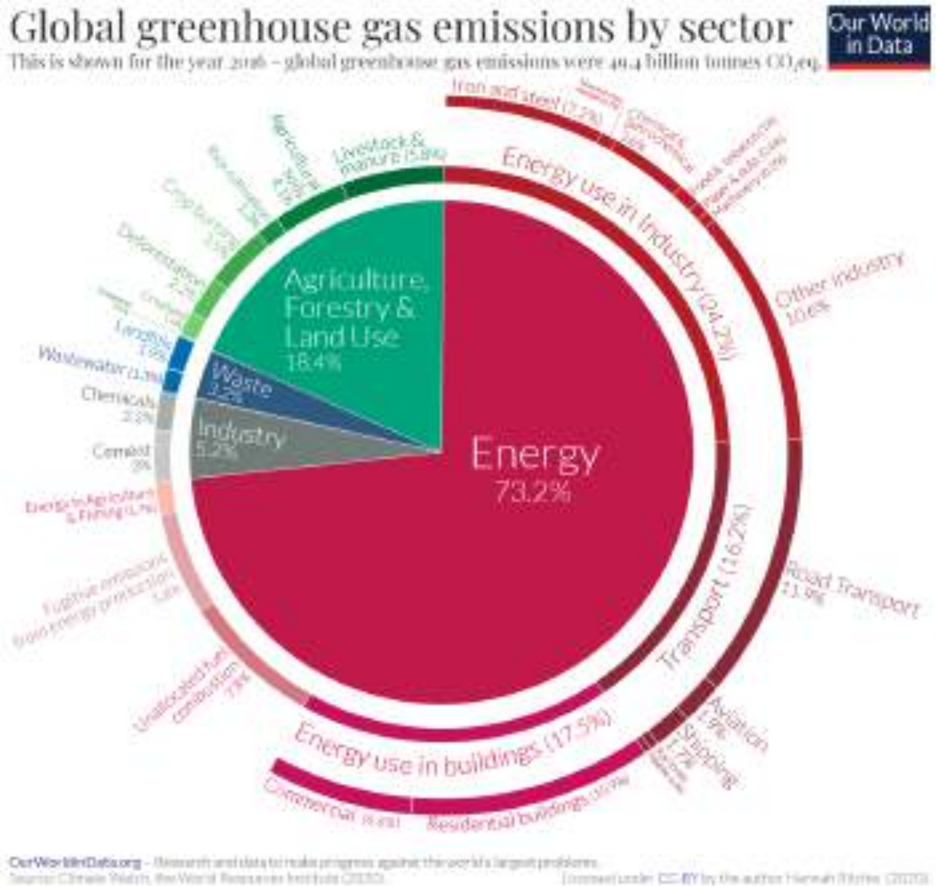


Introduction

- The links among climate warming, decarbonization and climate adaptation



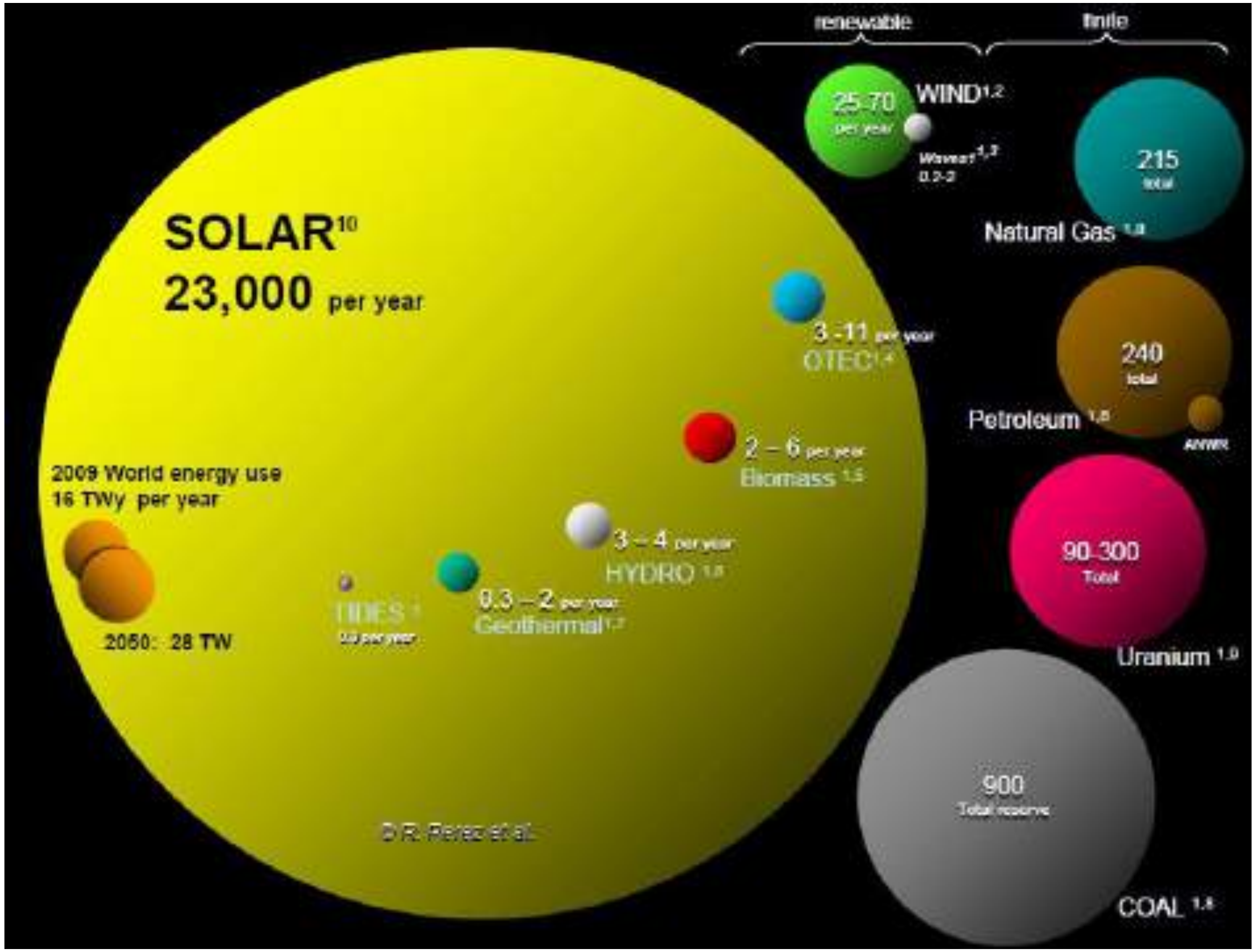
Decarbonization is the main strategy to reduce climate warming and allow us an easier adaptation to future climate conditions.



Decarbonization implies the production of a huge amount of energy (for industry, transport, and buildings) without the usage of fossil fuels (natural gas, oil and coal).

Technologies for RES conversion

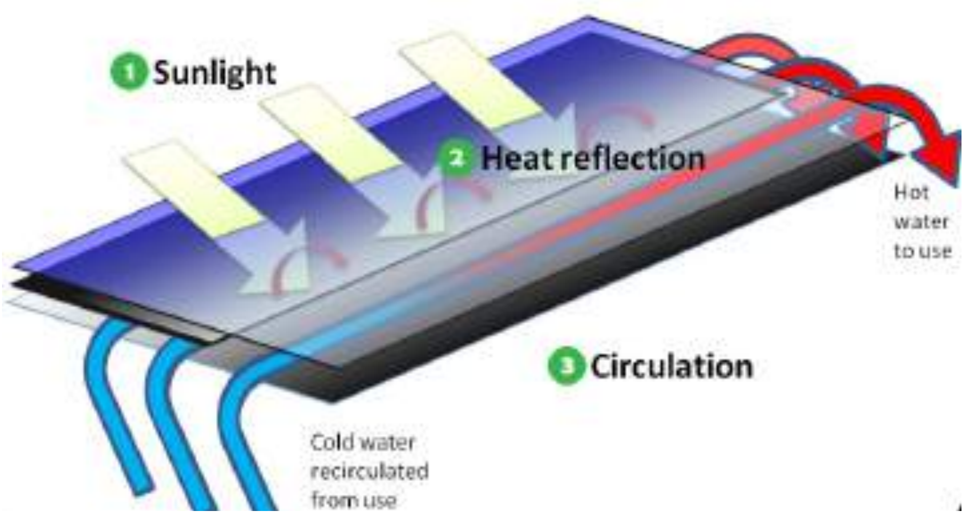
- Solar
- Wind
- Hydro
- Geo
- some recent opportunities under development:
    - deep geothermal
    - wave energy

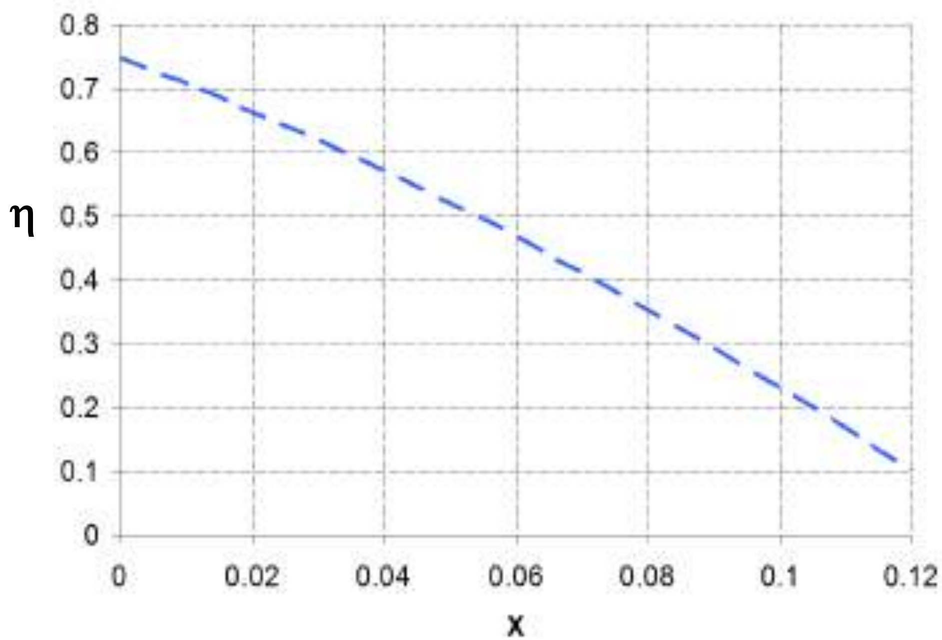


Technologies for RES conversion: Solar thermal

Flate-plate solar collectors are among the simplest solutions

1. **Sunlight:** Sunlight travels through the glass and hits the dark material inside the collector, which heats up.
2. **Heat reflection:** A clear glass or plastic casing traps heat that would otherwise radiate out.
3. **Circulation:** Cold water or another fluid circulates through the collector, absorbing heat.
4. **Losses**: Some heat is lost because radiation cannot be completely eliminated. In addition, convection and conduction allow heat to leave the hot collector and reach the colder surrounding air (T°).
5. **Efficiency** (η): It depends on the temperature difference between the hot collector and the colder air (T°). X is this difference divided by the solar irradiance.

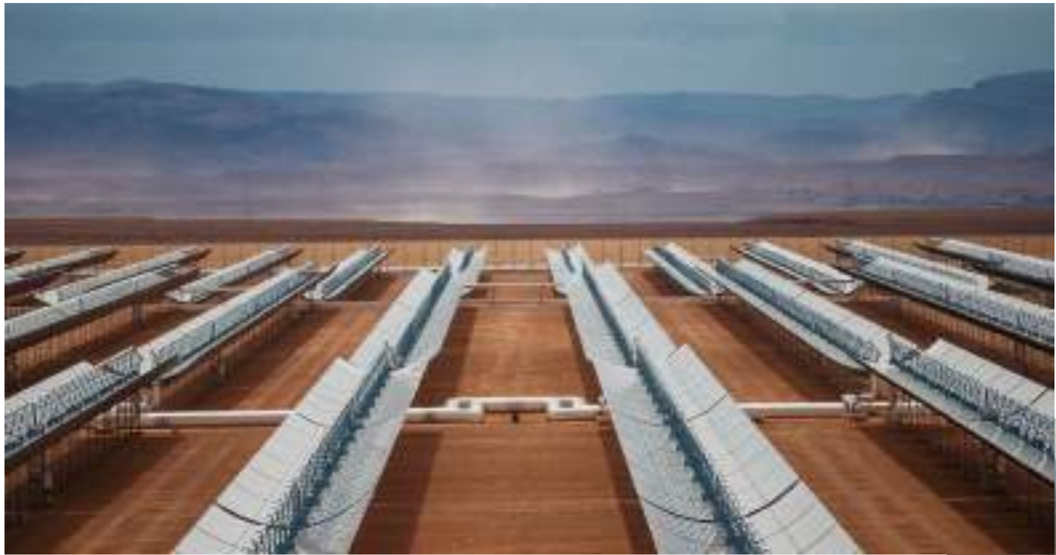




The higher the temperature required by users, the lower the efficiency of the solar collector!

Technologies for RES conversion: Solar thermal

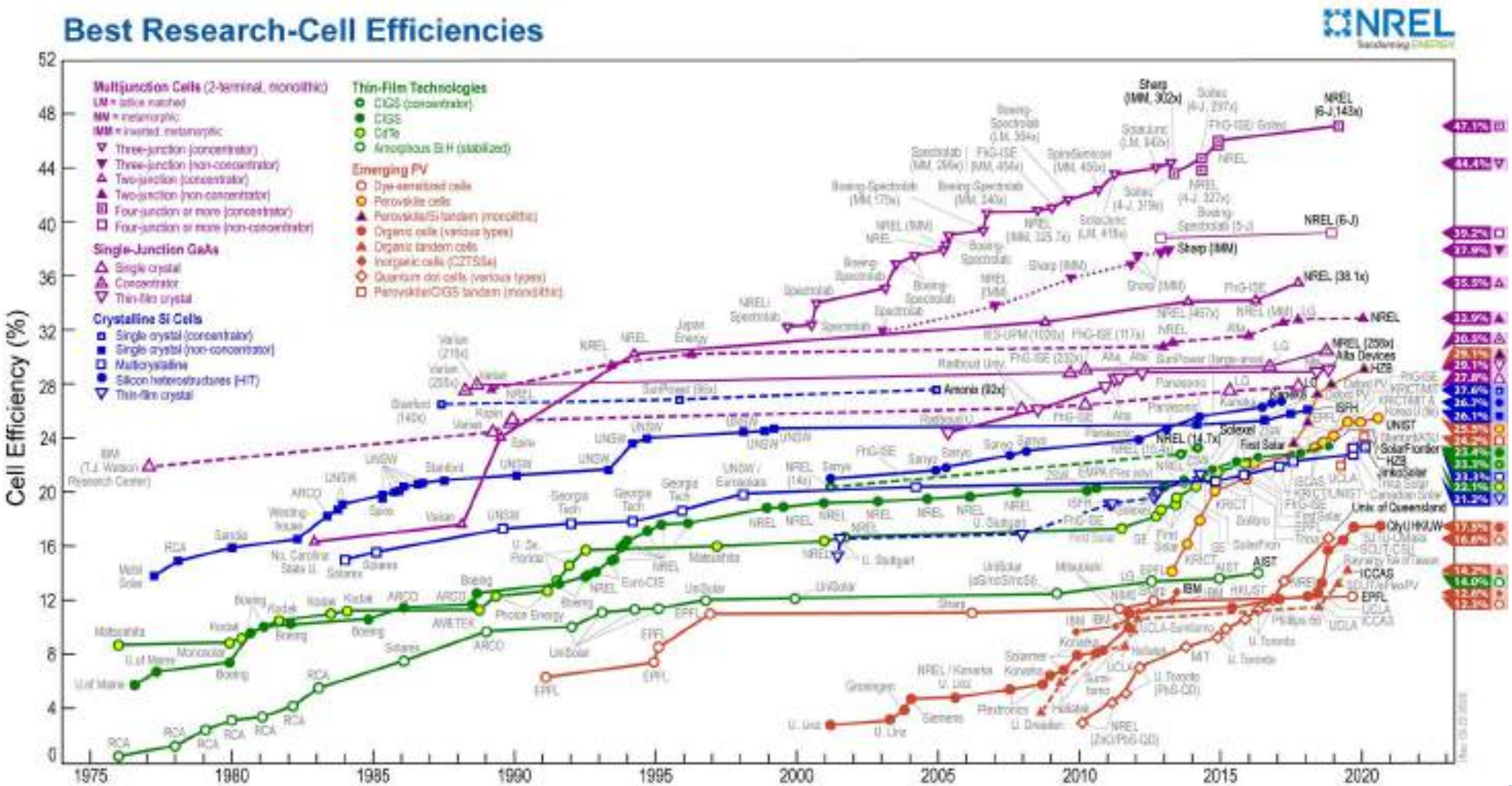
- The physical phenomenon governing heat-trapping and heat losses are qualitatively the same for all kinds of solar thermal collectors.
- Very hight temperatures can be obtained by introducing Solar CONCENTRATION technology.



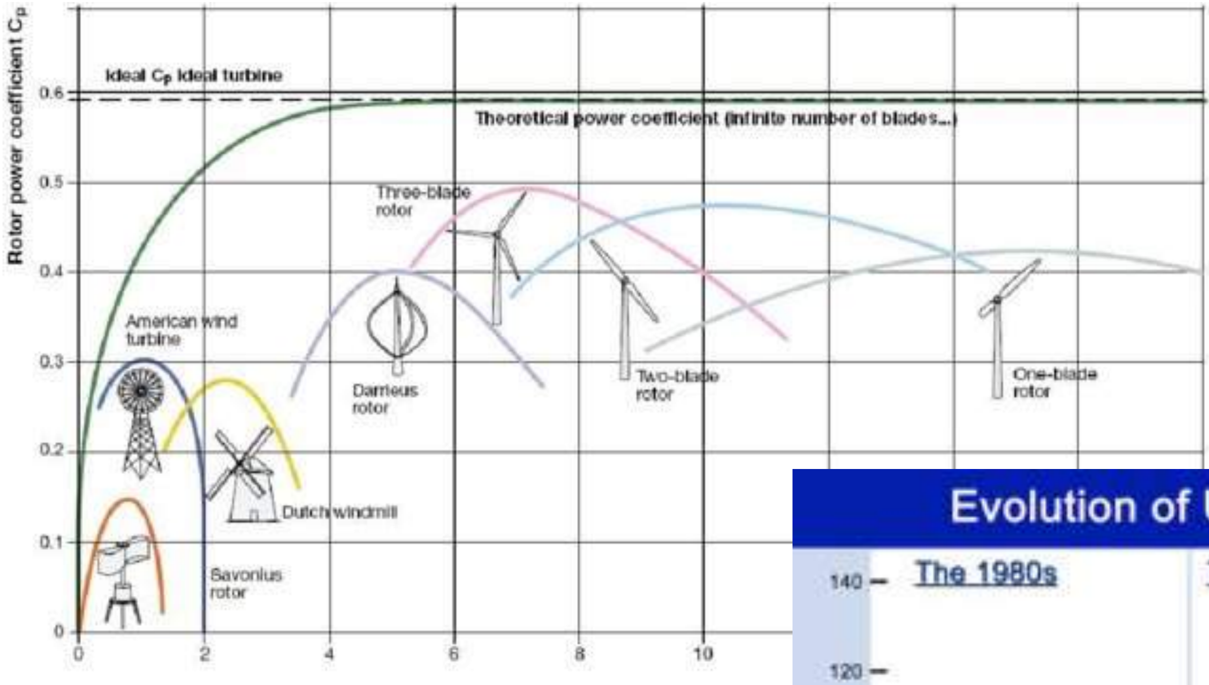
This kind of technology is necessary for feeding a thermal power plant, and it will be required for replacing fossil fuels in high-temperature industrial processes!

Technologies for RES conversion: Solar PV

- Solar PV is the most popular technology for RES conversion. The huge effort toward high-efficiency and low-cost solar cells is evident from the famous NREL diagram.
- Losses in cell connection, panel wiring, and power conditioning (to produce AC from DC) have to be considered for evaluating Power plant efficiency: 23.3% → 18-20%!



Technologies for RES conversion: Wind

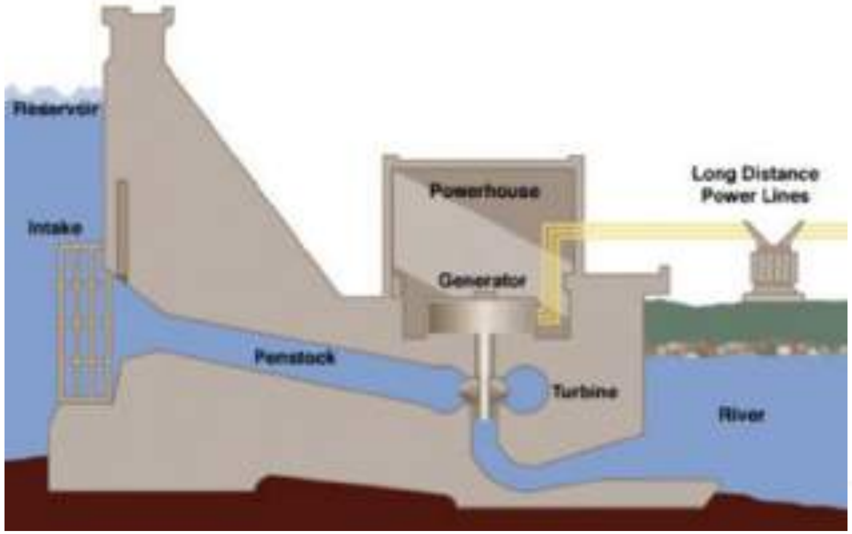


Modern wind turbines have an «efficiency» (power coefficient) as high as 50%: very good!

The technological trend is toward:

- Few blades (2, or 3),
- Large diameter (150 m, or more!),
- Offshore location,
- Making up wide farms.

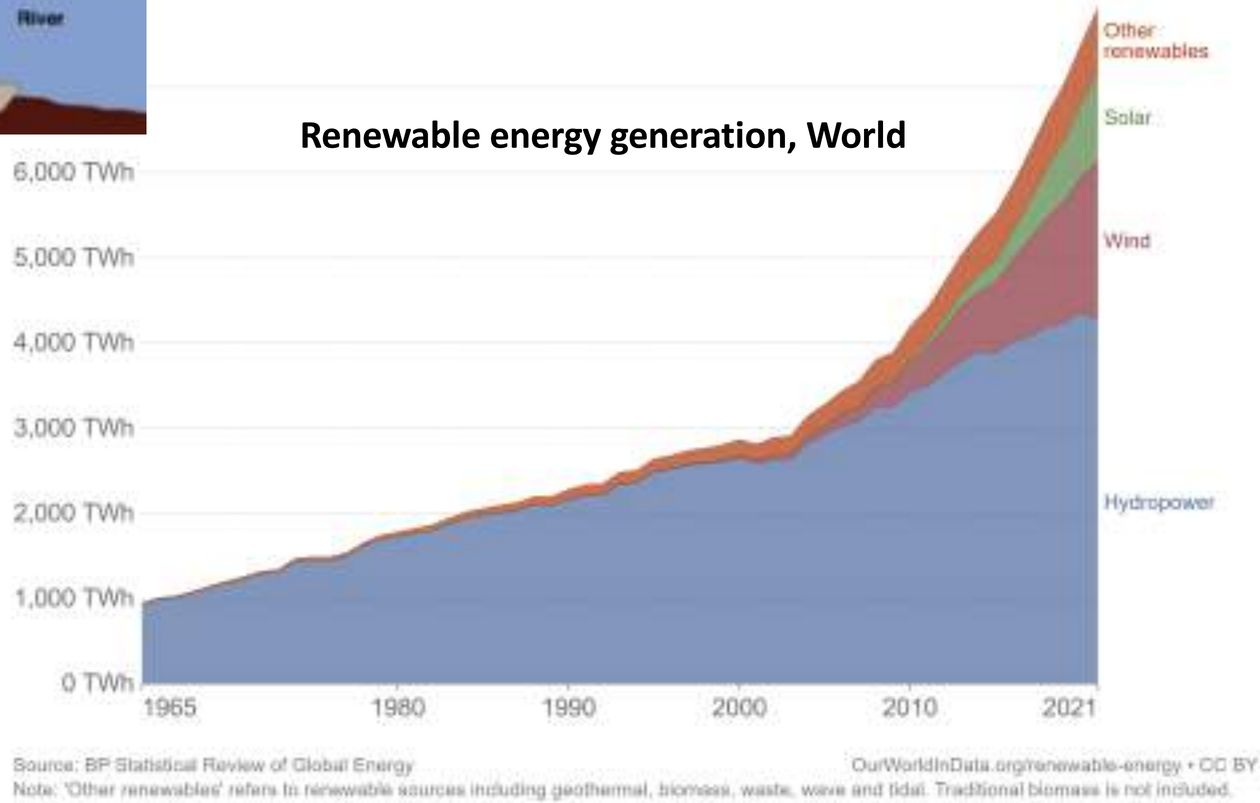
Technologies for RES conversion: Hydro



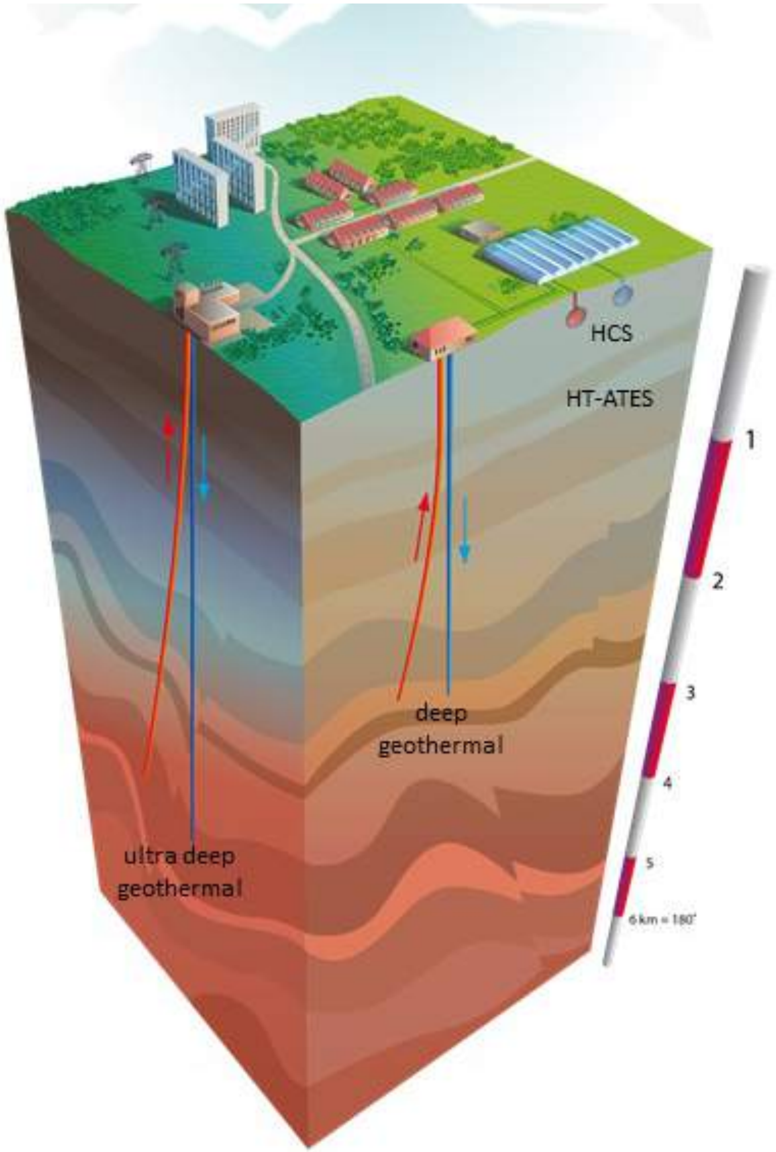
Hydropower is the oldest industrial technology for RES conversion:

- The source is in form of potential energy, allowing for very high efficiency.

- New, big Hydro power plants could be built only by blocking the course of a river and converting a valley into an artificial lake.
- Even if CO_2 emissions are about zero, the environmental impact of this kind of plant may be very big.



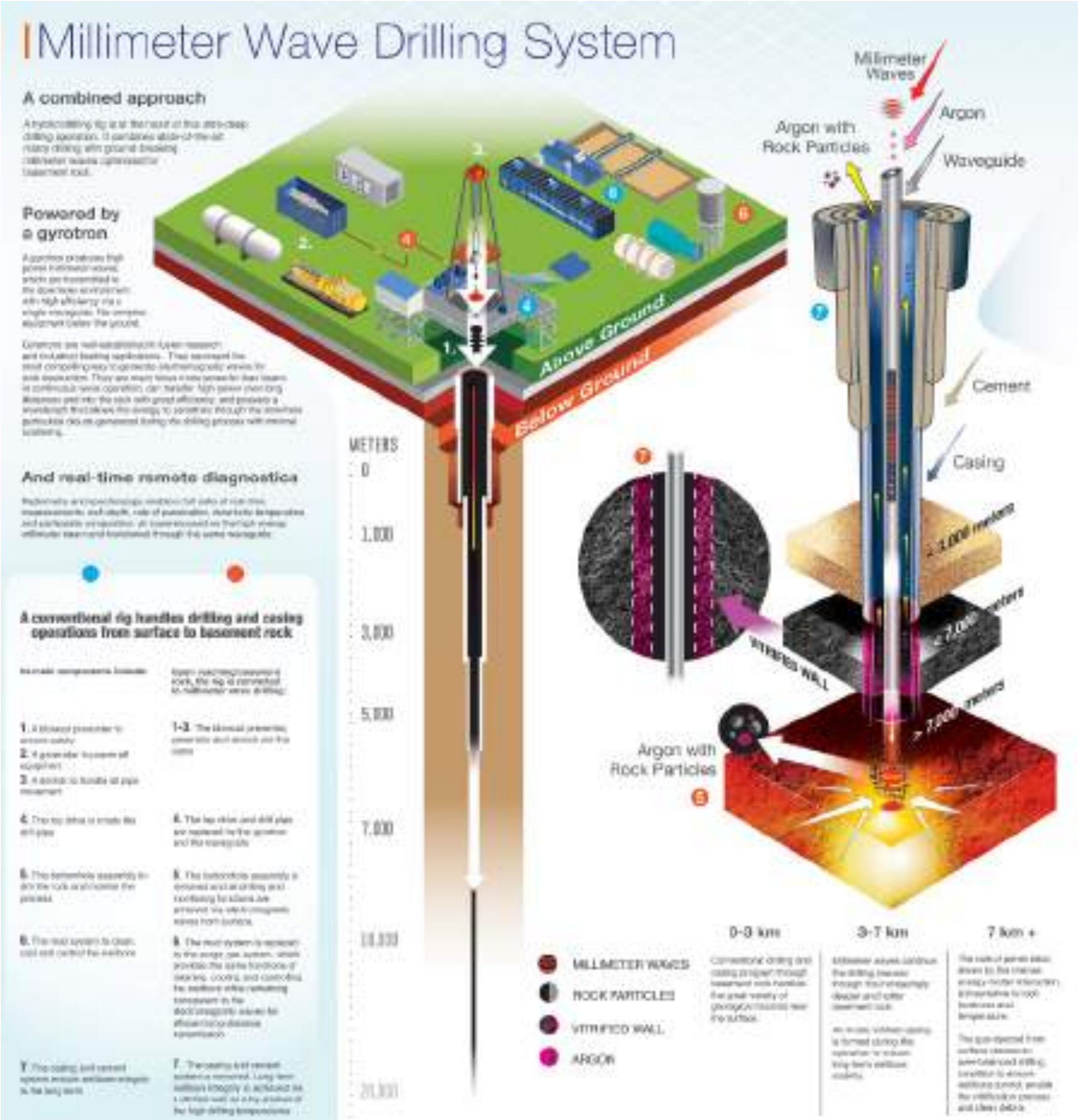
Technologies for RES conversion: Geo



The internal heat of the Heart is a big RES

- Unfortunately, only low-temperature energy (20°-120° C) is generally available at a depth of hundred meters.
- Very few sites have a source of hot water or steam.
- Recently, drilling technologies derived from oil extraction, allow water to be injected at a depth of 1000-2000 m, extracting heat at a temperature of about 100°-200°C and even more.

Technologies for RES conversion: Ultra-deep Geothermal



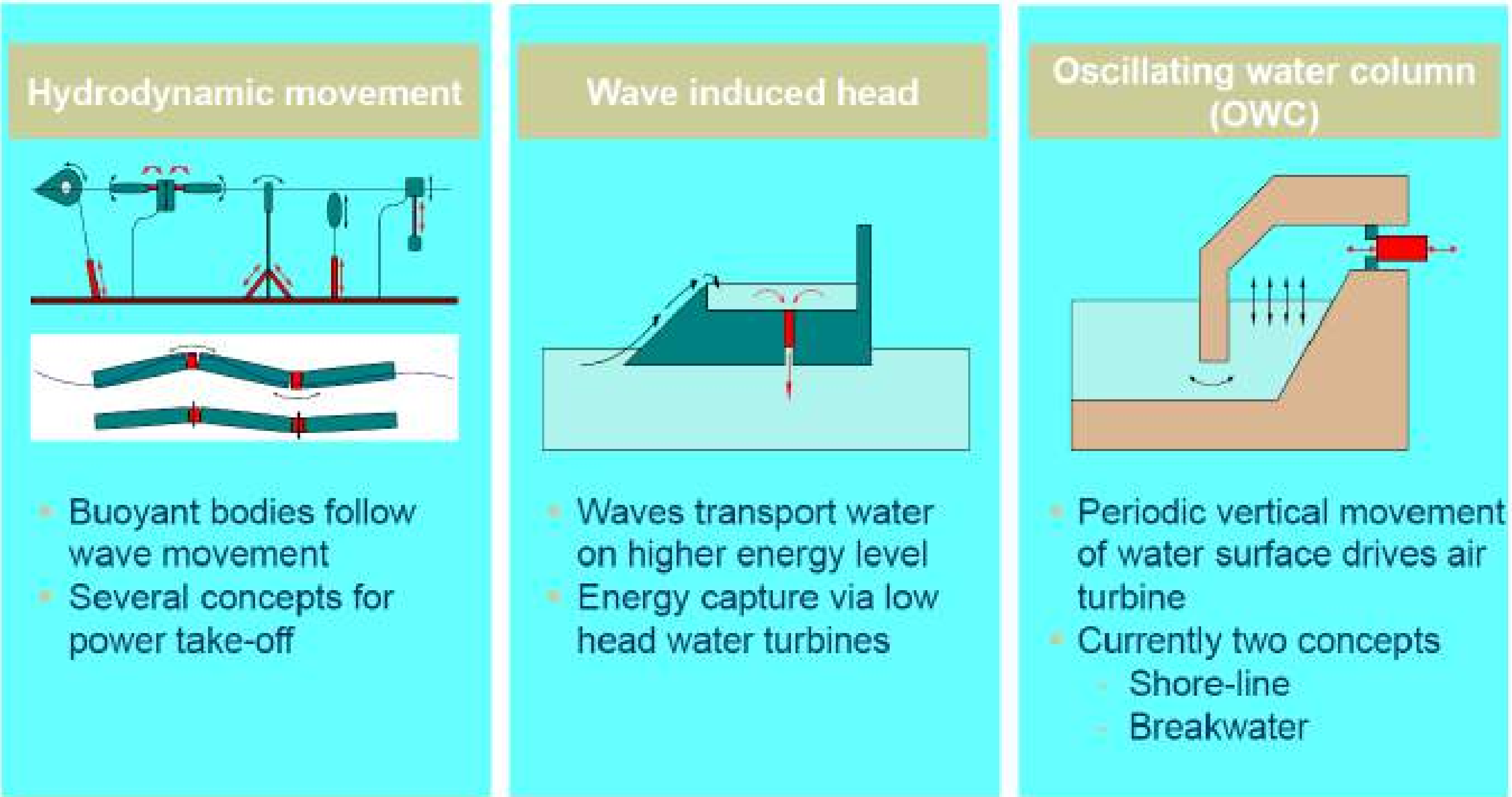
New drilling technologies, only very recently available, combine different strategies with micro-waves, or plasma and claim to reach a depth of 10,000 m, and more!

A very important result:

- The temperature of the extracted heat would be about 500°C, or more, the same as coal-fed thermal power plants,
- The heat production would become independent of the geological characteristics of the site,
- The wells could be placed where old thermal power plants already exist, taking advantage of the existing electric facility.

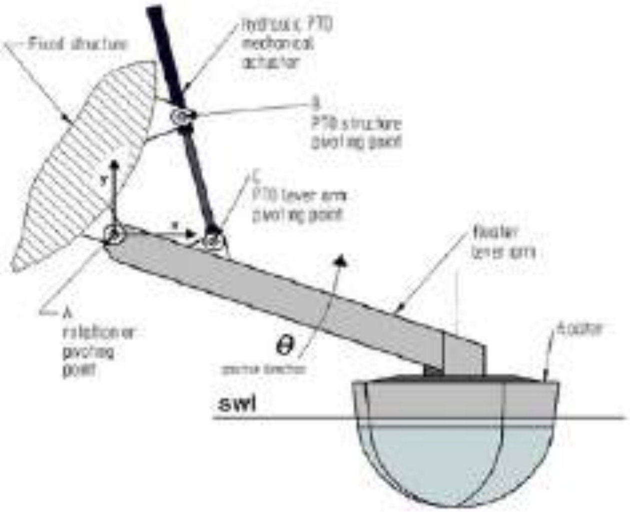
Technologies for RES conversion: Wave energy

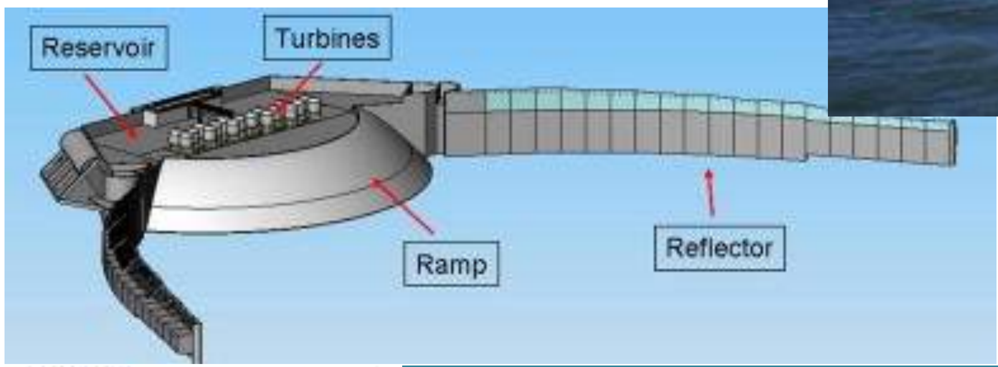
Waves on the sea surface represent a force field: even if the displacement of a single point on the surface is small, the whole field contains a lot of energy!



Technologies for RES conversion: Wave energy

Wave star





Wave Dragon

“Electrification”

The main RES conversion technologies do not produce directly any fuel, but:

- heat (for «local» use, or storage), like solar thermal, or geothermal,
- electric power (easy to transport, but difficult to be stored) like solar PV or wind turbines.

If industry, transport, and buildings have to be fed by RES, to obtain the decarbonization of these sectors implies that they have to be maily **operated with electric power!**

"Electrification"

The main RES conversion technologies do not produce directly any fuel, but:

- heat (for «local» use, or storage), like solar thermal, or geothermal,
- electric power (easy to transport, but difficult to be stored) like solar PV or wind turbines.

If industry, transport, and buildings have to be fed by RES, to obtain the decarbonization of these sectors implies that they have to be maily **operated with electric power!** The "electrification" means, for instance:

- All buildings that cannot be heated by a thermal solar system, must replace their gas boilers with electric HEAT PUMPS,
- All Cooking processes must use induction (or ohmic) heating devices,
- All transport systems must be electric, trains (easy), cars (ongoing) ships (not so easy) aircraft (difficult)!
- All heat required by the industrial sector that cannot be produced by a thermal solar system, must be produced by electric HEAT PUMPS (it is possible for temperature up to about 200°C) or ohmic/infrared heating devices (possible, but generally not efficient).

"Electrification"

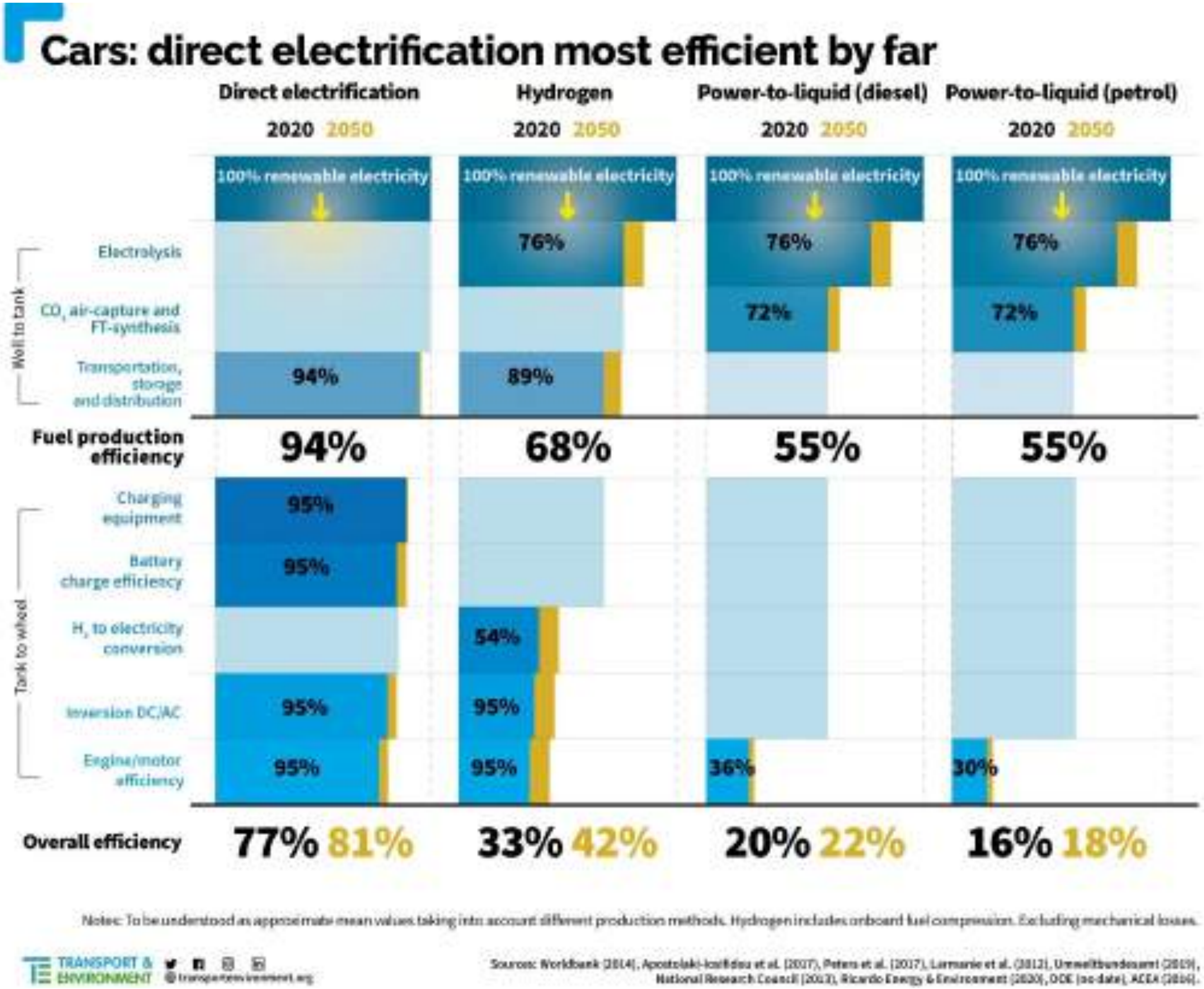
The alternative could be producing a "green fuel" by using electricity from RES.

It may be H_2 or NH_3.

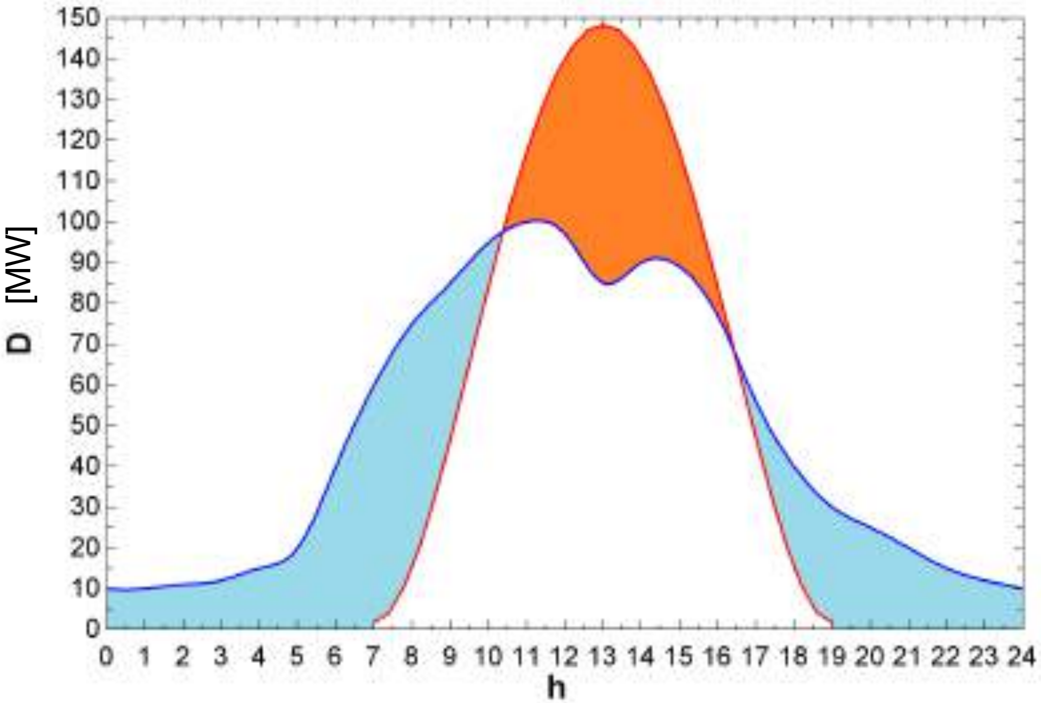
In general, such an alternative is not efficient, because each energy conversion process implies some energy losses.

Nevertheless, it is expected to be unavoidable in some specific applications, like a long-distance ships or airplane transport.

Therefore, High-temperature HEAT PUMPS and chemical processes for producing H_2 or NH_3 are further essential technologies for the mitigation of climate warming.



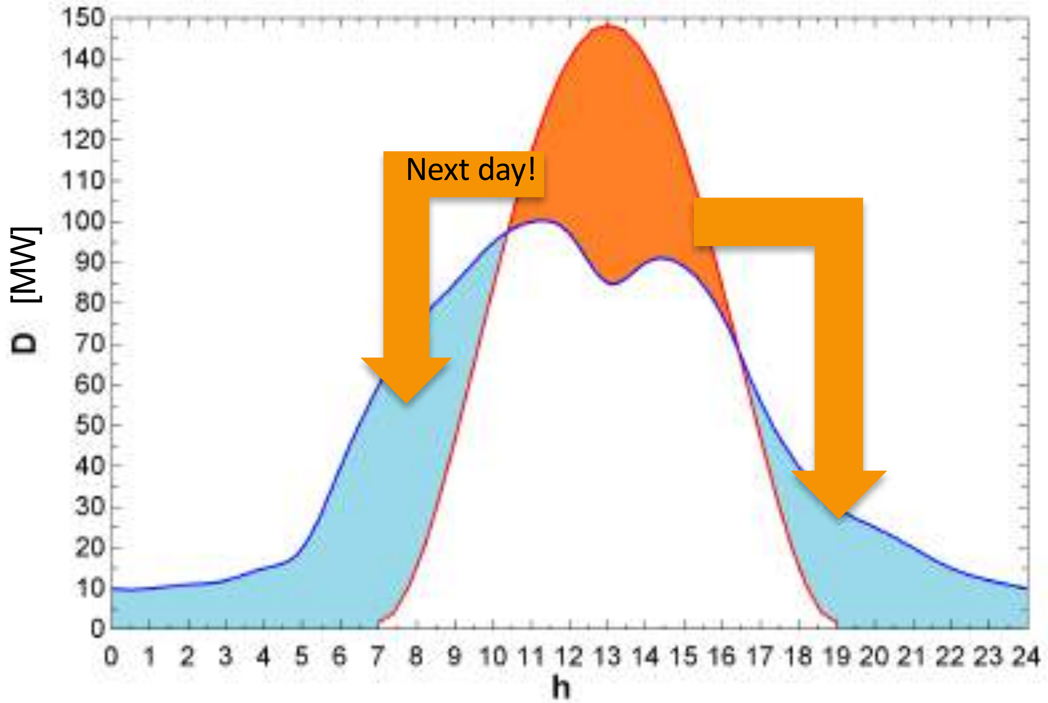
The crucial role of energy storage technologies



<u>Without any storage system</u>
D=1150 MWh/day
S= 940 MWh/day

Direct use of solar = 760 MWh/day
Solar overproduction = 180 MWh/day
Integration required = 390 MWh/day

The crucial role of energy storage technologies



<u>Without any storage system</u>
D=1150 MWh/day
S= 940 MWh/day

Direct use of solar = 760 MWh/day
Solar overproduction = 180 MWh/day
Integration required = 390 MWh/day
(34.0% of Demand)

<u>With an ideal storage system</u>
Direct use of solar = 760 MWh/day
Solar overproduction = 0 MWh/day
Solar from storage = 180 MWh/day
Integration required = 210 MWh/day
(18.3% of Demand)

The energy storage technologies are expected:

- **Eliminating overproduction (curtailment),**
- **Reducing integration of local RES production.**

The crucial role of energy storage technologies: some alternatives

Electro-Chemical

Mechanical

Bulk Mechanical

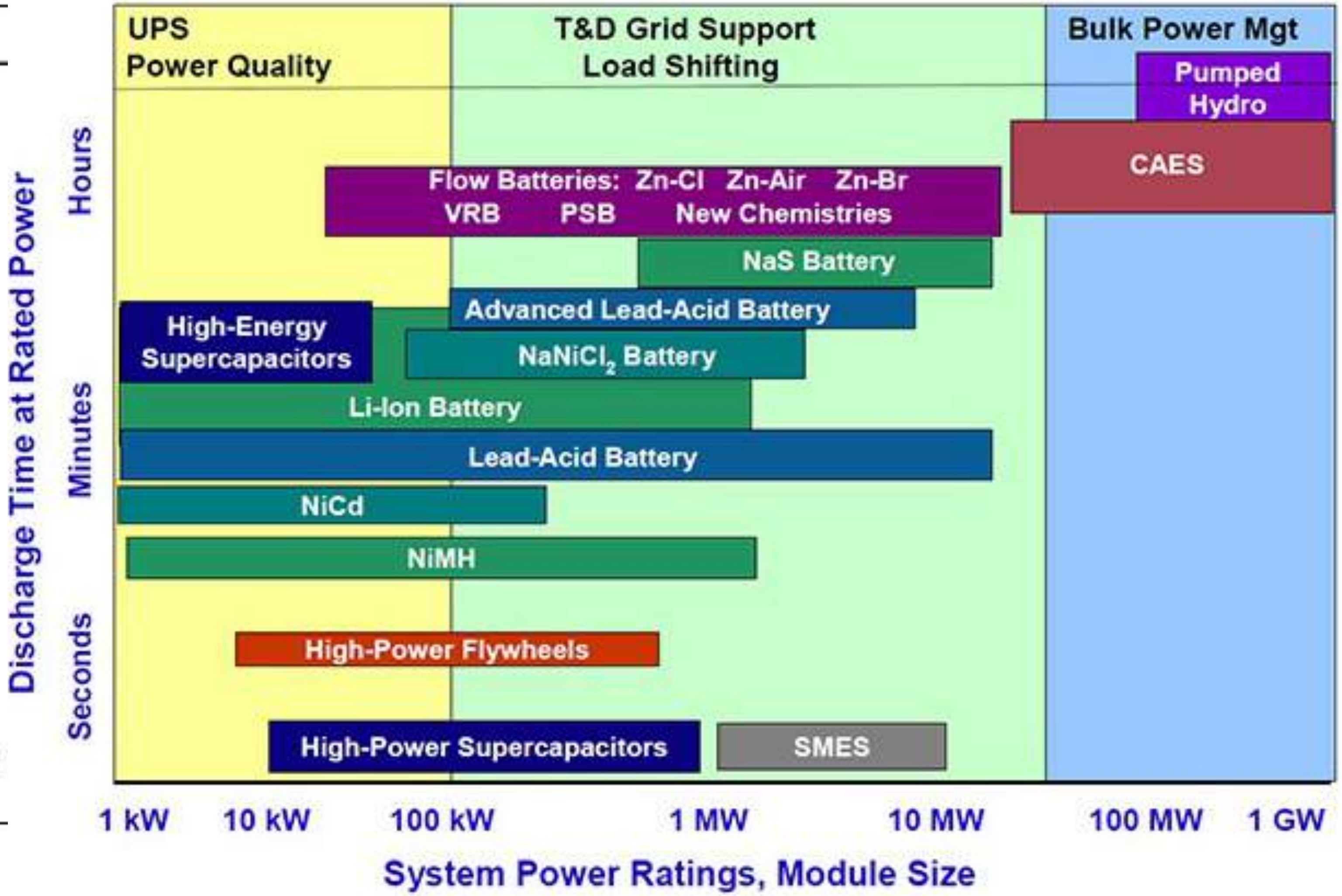
Thermal

Bulk Gravitational

Chemical (H2 NH3)

The crucial role of energy storage technologies

ESS Type
Pumped Hydro
Compressed Air
Lithium-ion Battery
Zn-air Battery
Redox Flow Batteries
Hydrogen Storage
Ammonia Storage
Reversible Fuel Cell
Super Magnetic Storage
Super Capacitor
Hot Water Storage
Molten Salt Thermal Storage

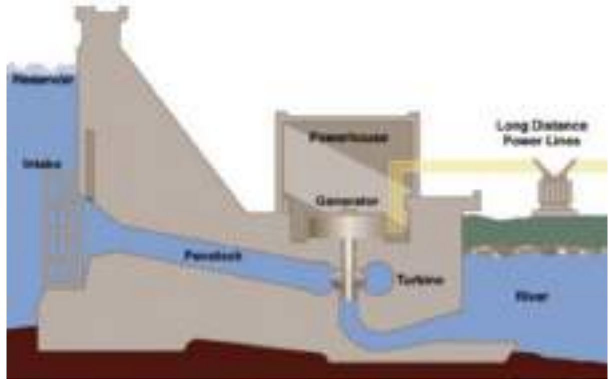


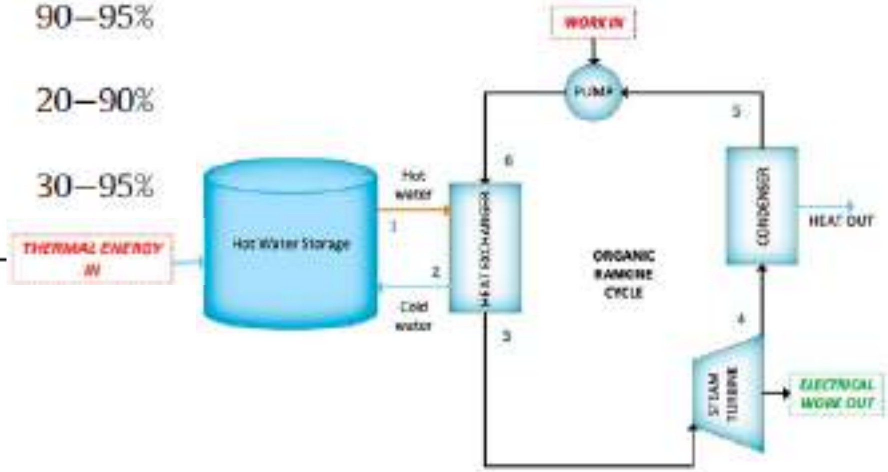
The crucial role of energy storage technologies

Mechanical

ESS Type	Technical Maturity	Efficiency Ranges (%)
Pumped Hydro	Mature	65–85%
Compressed Air	Developed	40–65%
Lithium-ion Battery	Mature	85–95%
Zn-air Battery	R&D Demonstration Commercial	-50%
Redox Flow Batteries	Developed	60–85%
Hydrogen Storage	R&D Demonstration Commercial	30–70%
Ammonia Storage	R&D Demonstration Commercial	30–70%
Reversible Fuel Cell	R&D Demonstration Pre-commercial/commercial	50–70%
Super Magnetic Storage	R&D Demonstration Pre-commercial	90–95%
Super Capacitor	R&D Demonstration Pre-commercial	90–95%
Hot Water Storage	R&D Demonstration Commercial	20–90%
Molten Salt Thermal Storage	R&D Demonstration Commercial	30–95%

Thermal



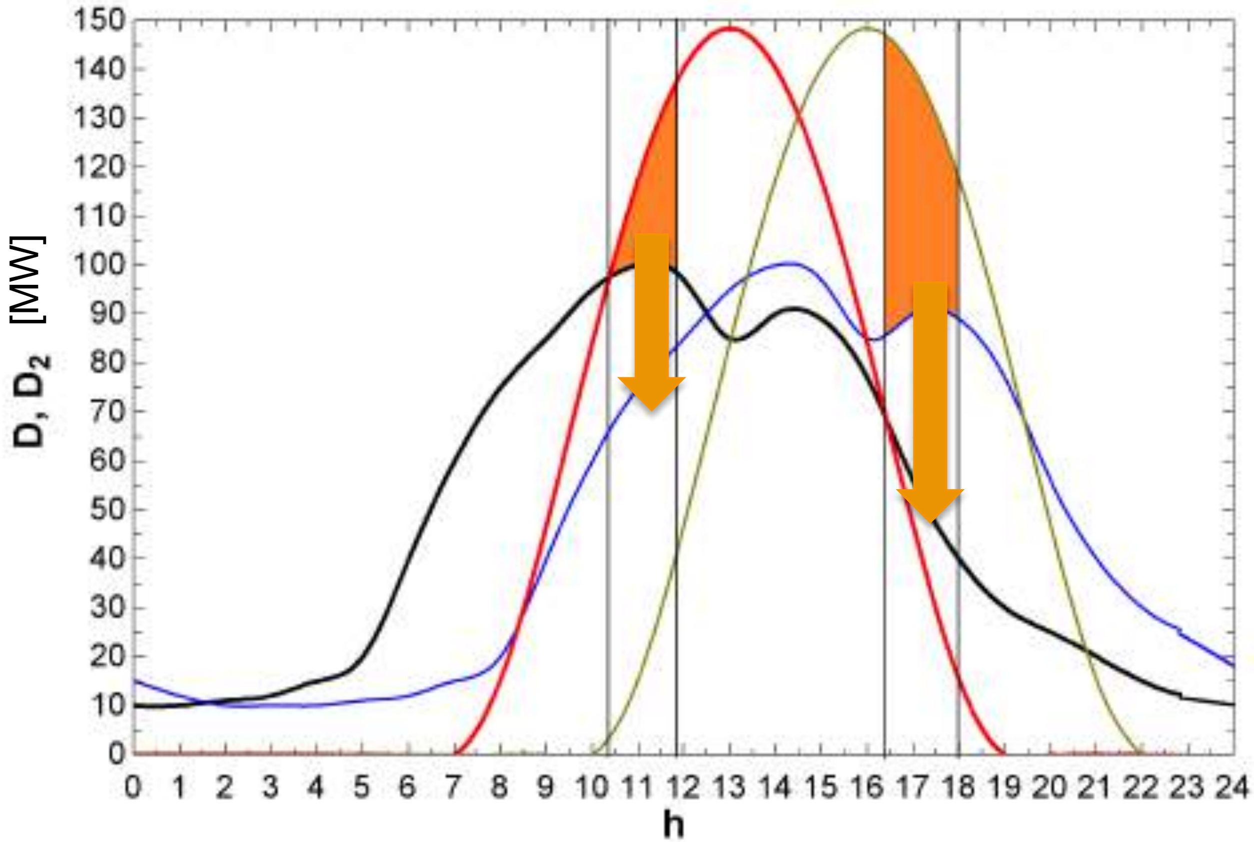


"Interconnection" among different geographical areas

The electrical interconnection between 2 different areas can also help decarbonization.

Let's consider two areas with similar Demands and similar availability of solar energy, but with a time delay of only 3 hours.

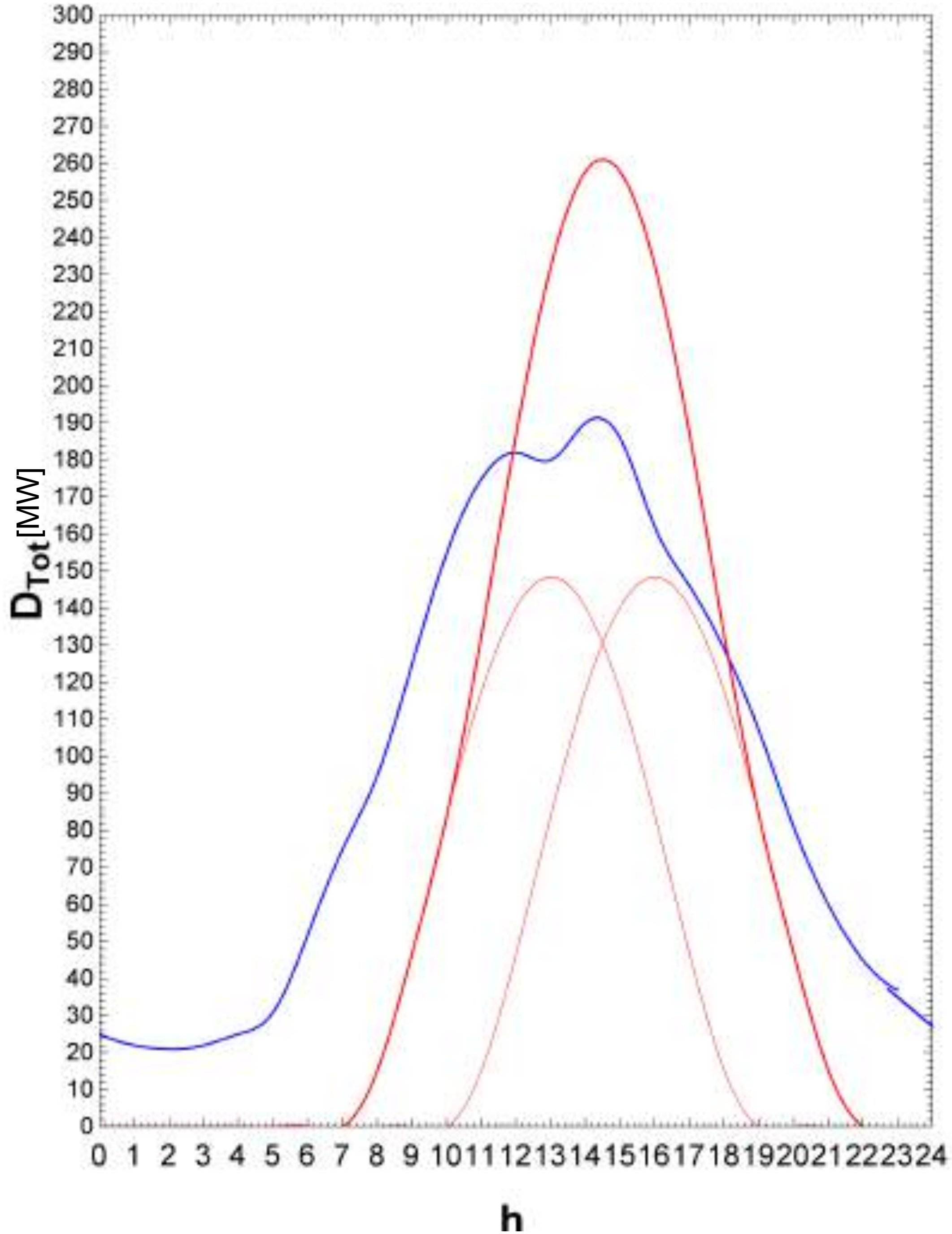
By comparing the two areas alone and the set of the two with interconnection, it appears immediately that:



- In the morning, there is a time interval when the excess solar production by area 1 (in black) can be **directly used** by area 2(in blu), without storage.
- The opposite happens in the afternoon when area 2 has still an excess of solar production to be sent to area 1, where **solar energy is not enough** for its demand.

“Interconnection”

By combining the two diagrams in a single one:



"Interconnection"

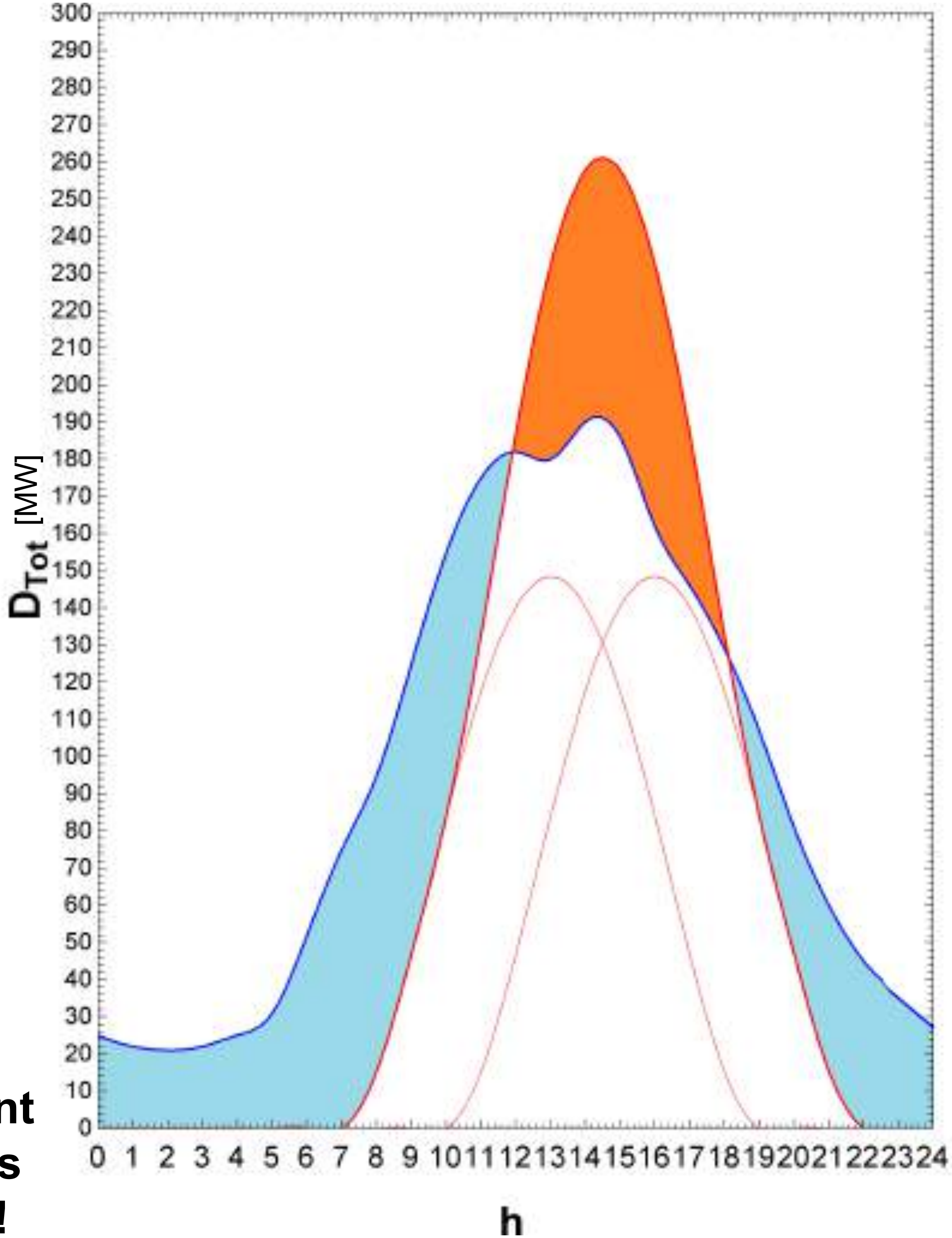
By combining the two diagrams in a single one:

<u>Without interconnection</u>
D=2300 MWh/day
S= 1880 MWh/day

Direct use of solar = 1520 MWh/day
Solar overproduction = 360 MWh/day
Integration required = 780 MWh/day
(34.0% of Demand)

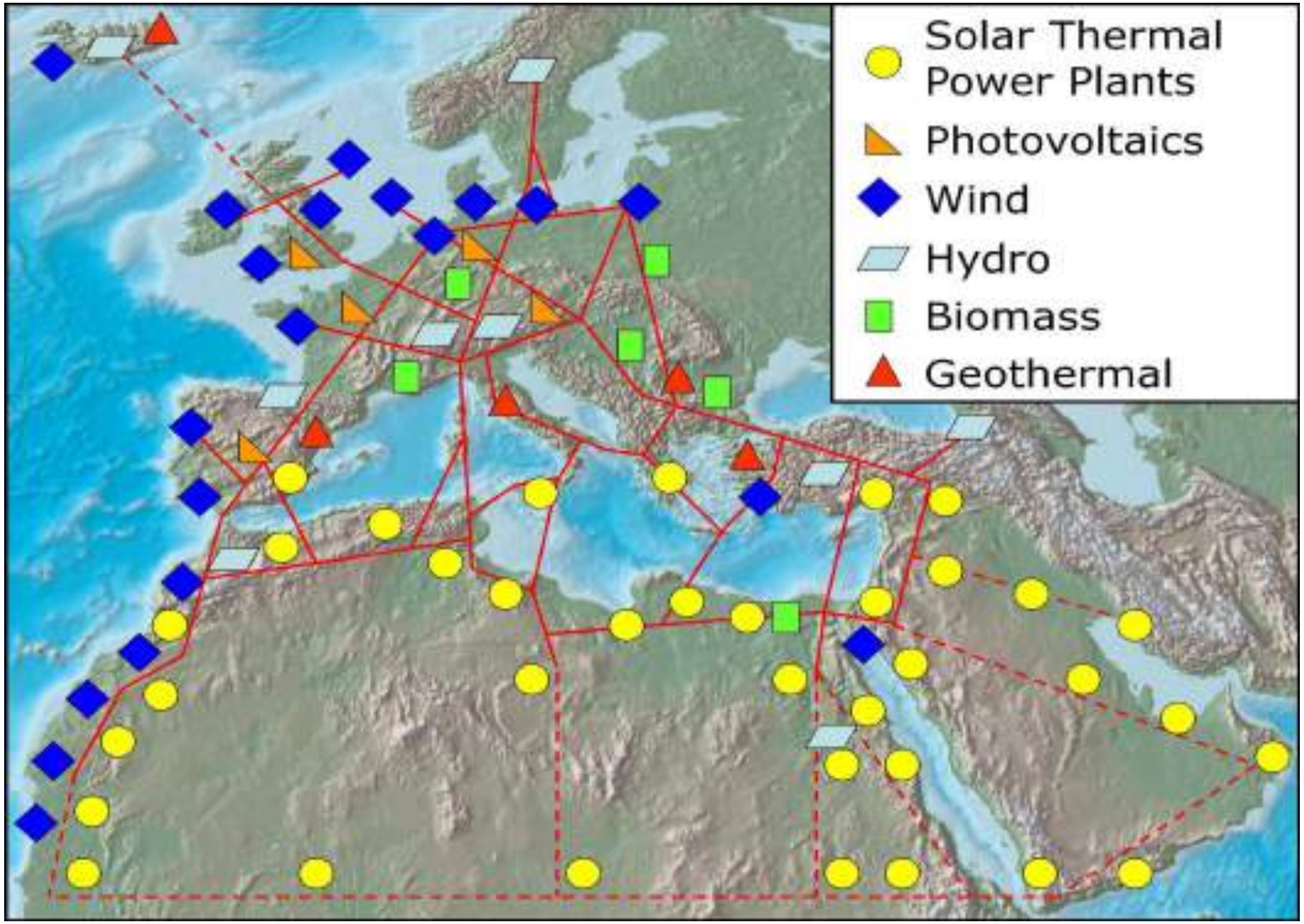
<u>With interconnection (no losses)</u>
Direct use of solar = 1630 MWh/day
Solar overproduction = 315 MWh/day
Integration required = 670 MWh/day
(29.1% of Demand)

The integration of areas with different Demand profiles and different RES is expected to be even more favorable!



"Interconnection" among different geographical areas

- Desertec project



To make possible this kind of interconnection, also very-high-voltage power lines have to be developed (VHVDC, possibly superconductive power lines), to reduce losses.

Integration of energy production and recovery technologies

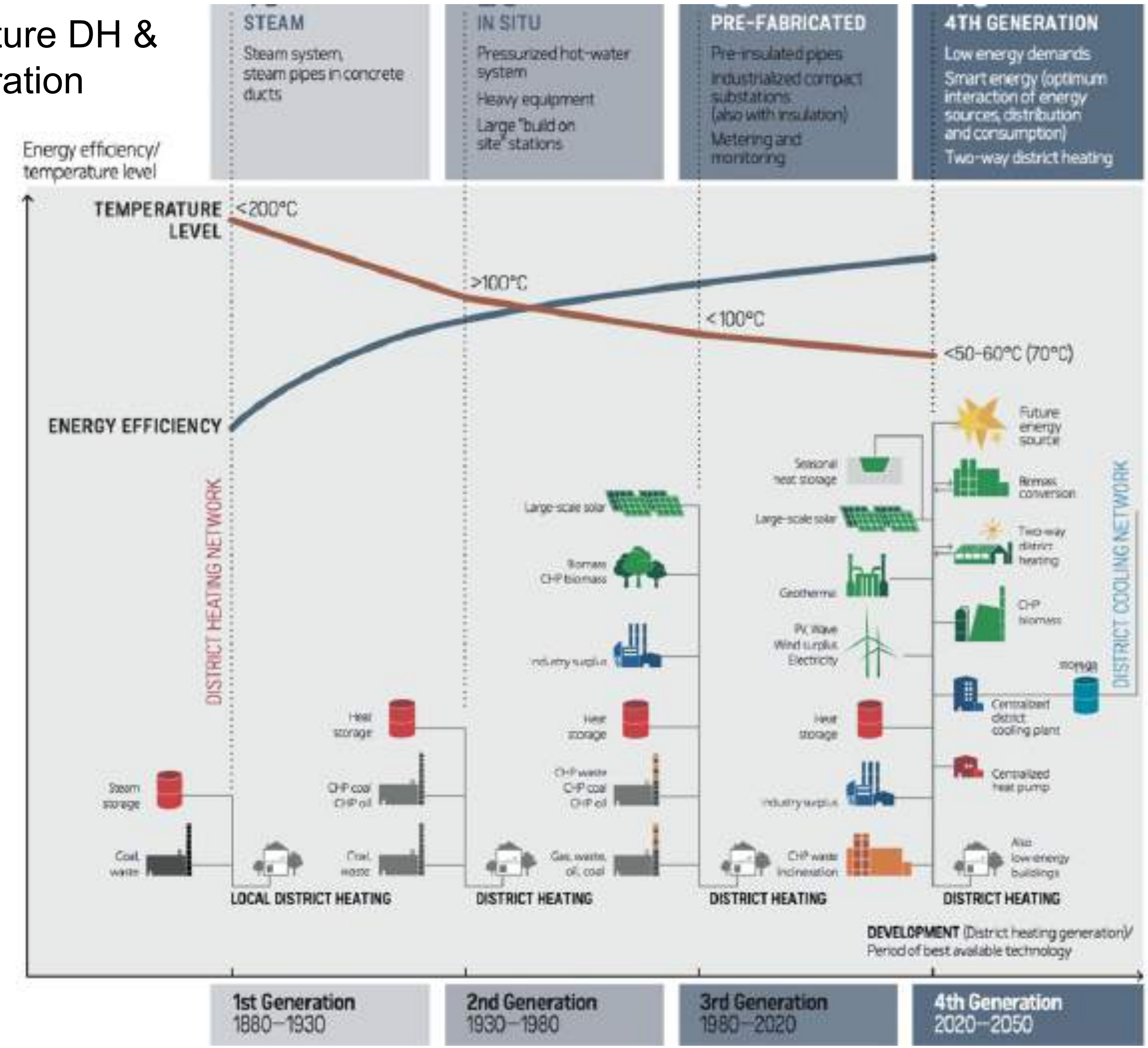
Not only electric interconnection is positive. The thermal integration of different users/producers can be also very useful. In addition, other technologies may be considered:

- Thermal energy recovery from industrial processes,
- Cogeneration of heat and power with engines,
- Production of chilled water for air conditioning from low-temperature heat (absorption chiller),
- Electric energy production from waste heat,
- Production of bio-fuels from residual biomass, or urban waste,
- Production of synthetic fuels from electric power.

All these technologies together allow a lot of integration options that can be exploited, in order of reducing thermal dissipation and RES curtailment.

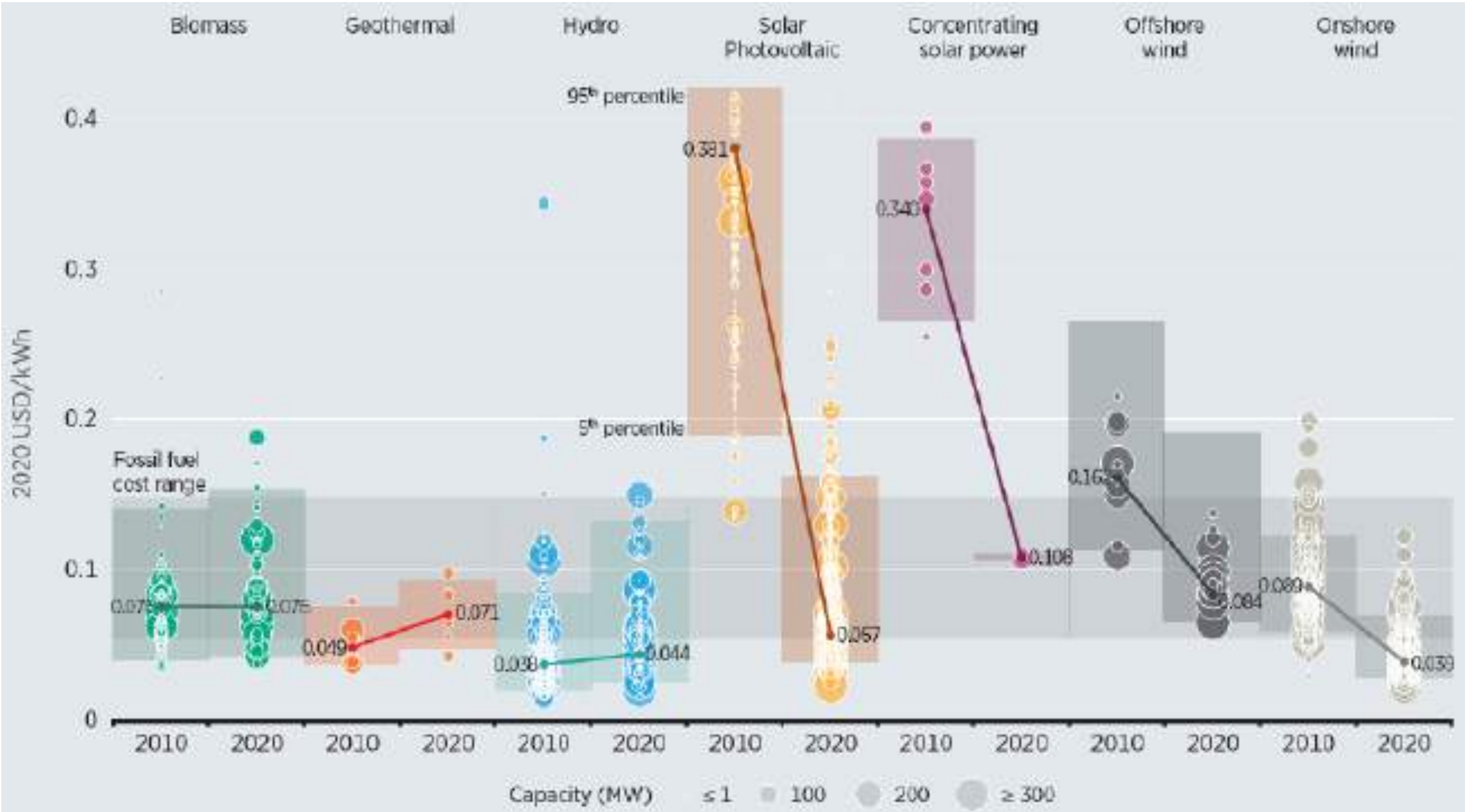
Integration of energy production and recovery technologies

Low-temperature DH & thermal integration



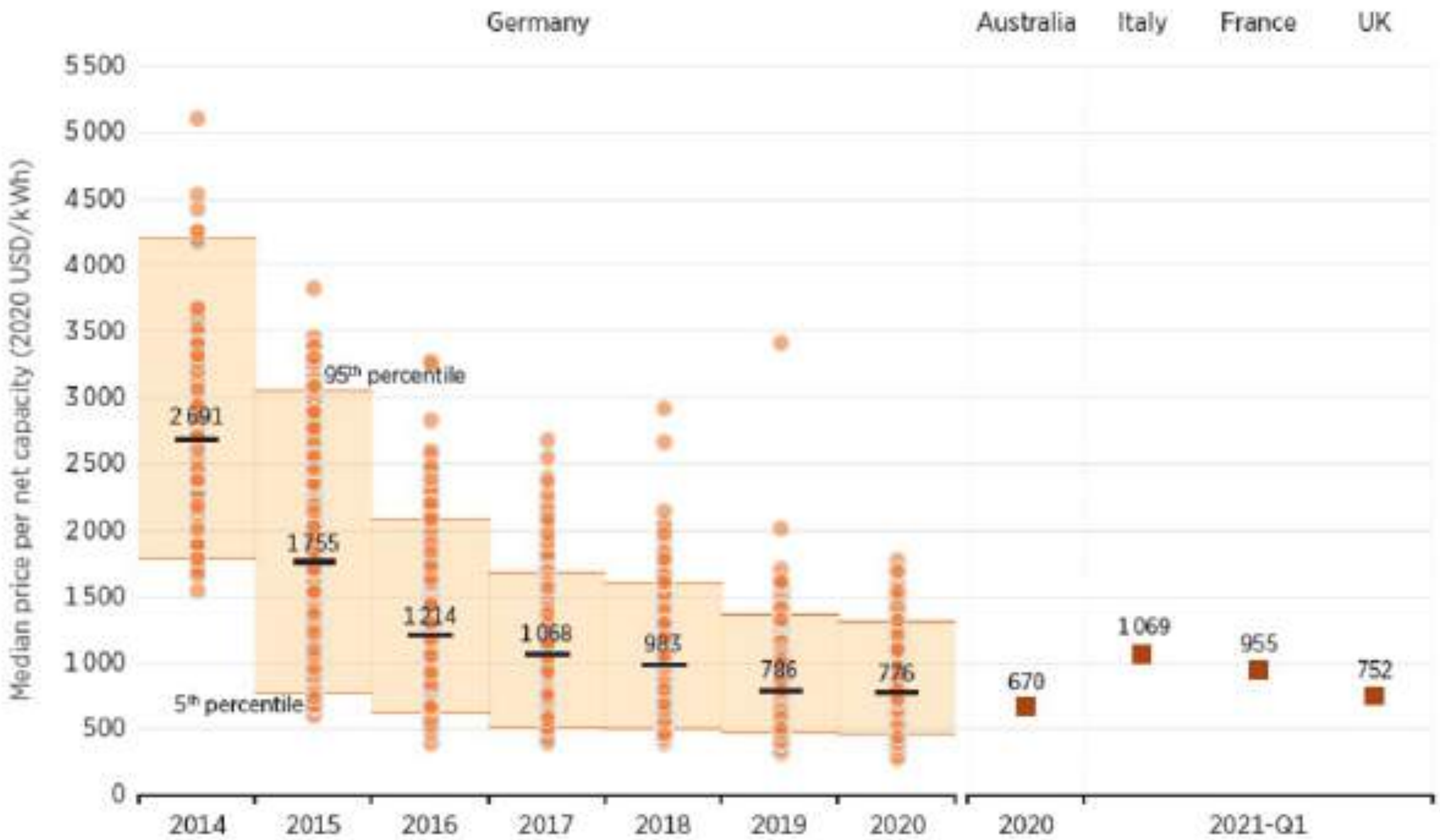
Is the energy transition possible?

The average LCOE of all renewable power generation technologies is reducing and falling in the fossil fuel cost range in 2020.



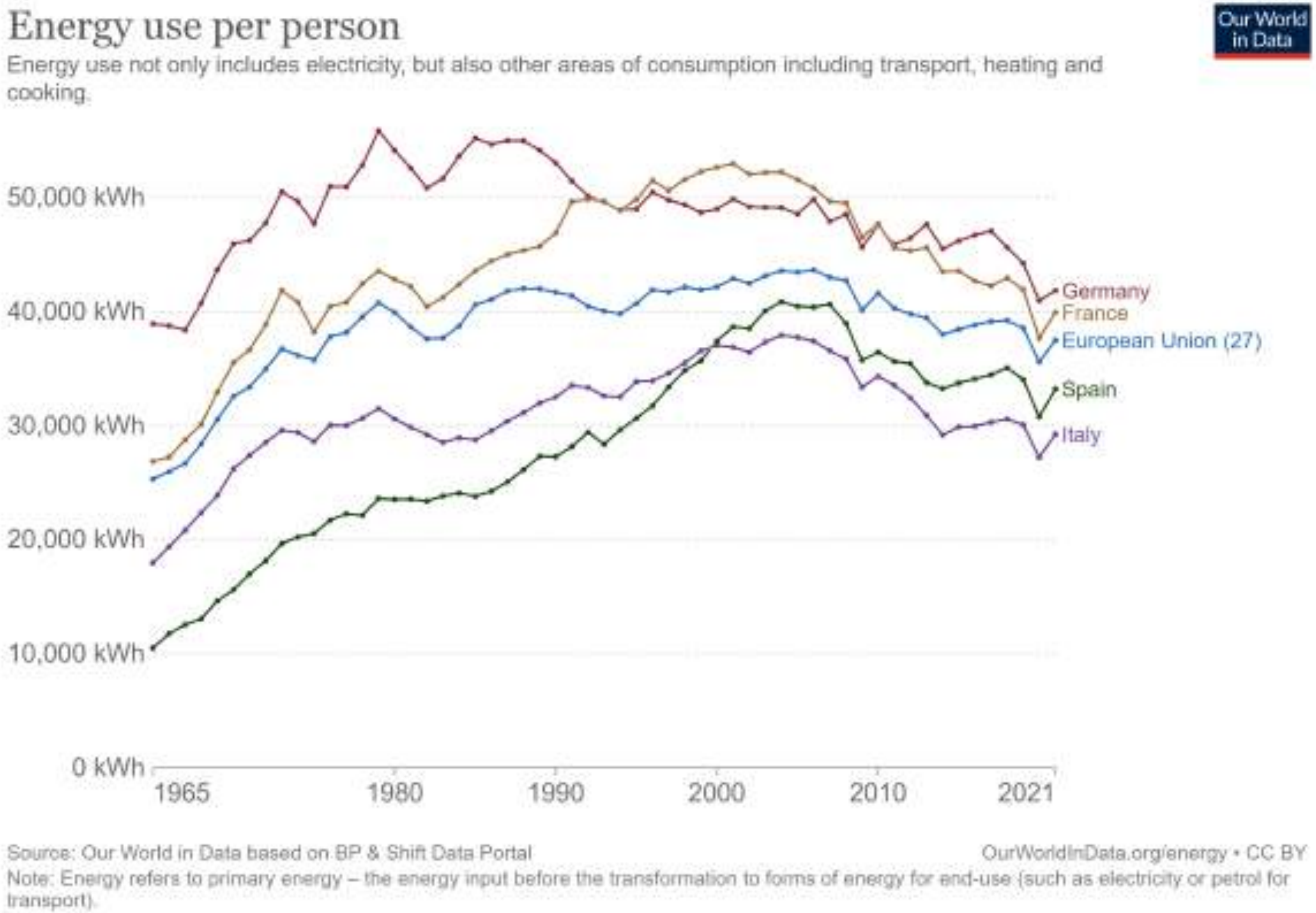
Is the energy transition possible?

The same for storage technologies: US utility-scale battery costs fell 71% between 2015 and 2018.



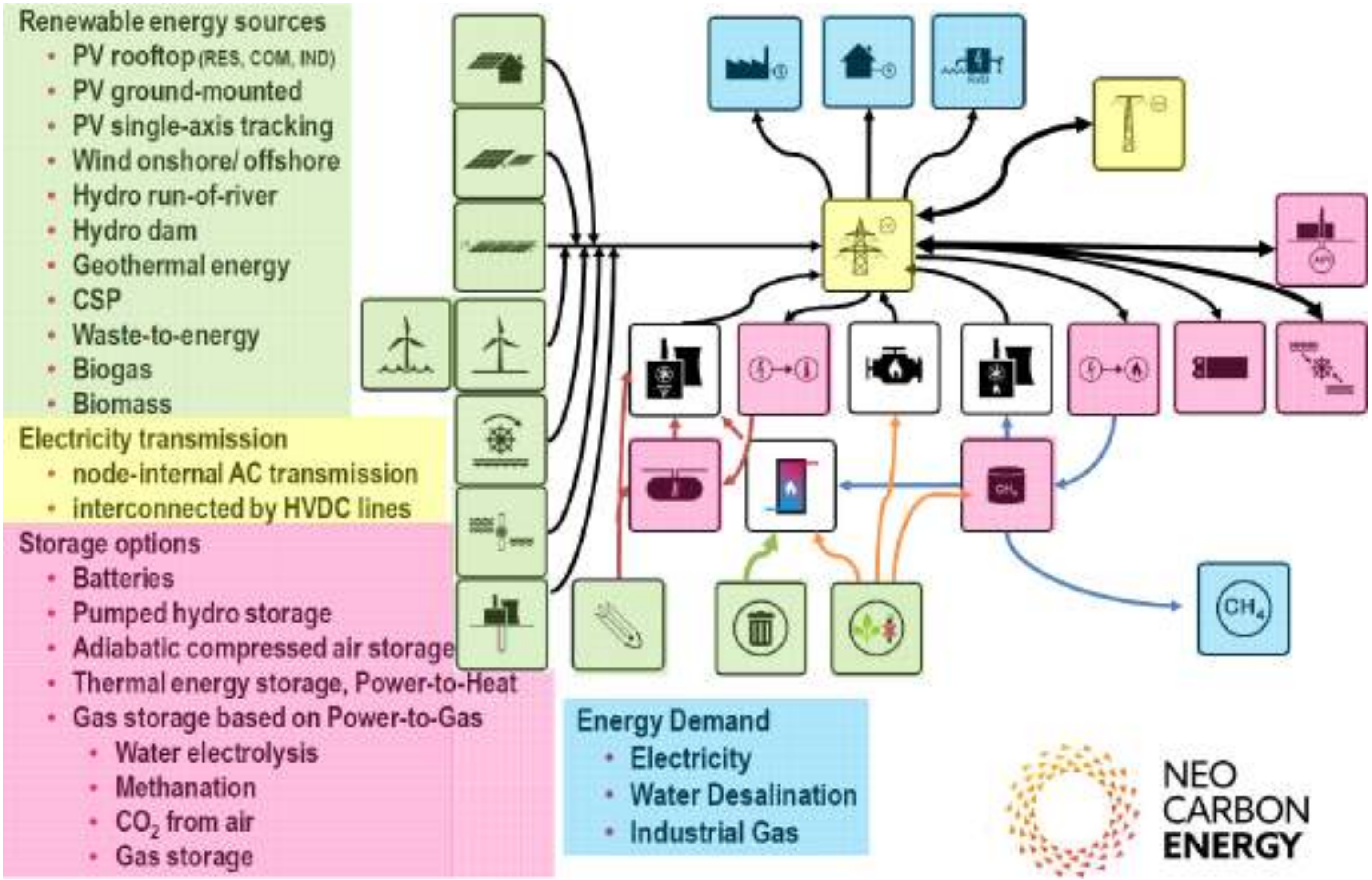
Is the energy transition possible?

In the last 10-15 years, the energy use per person is also declining, in particular in Europe (EU-27).

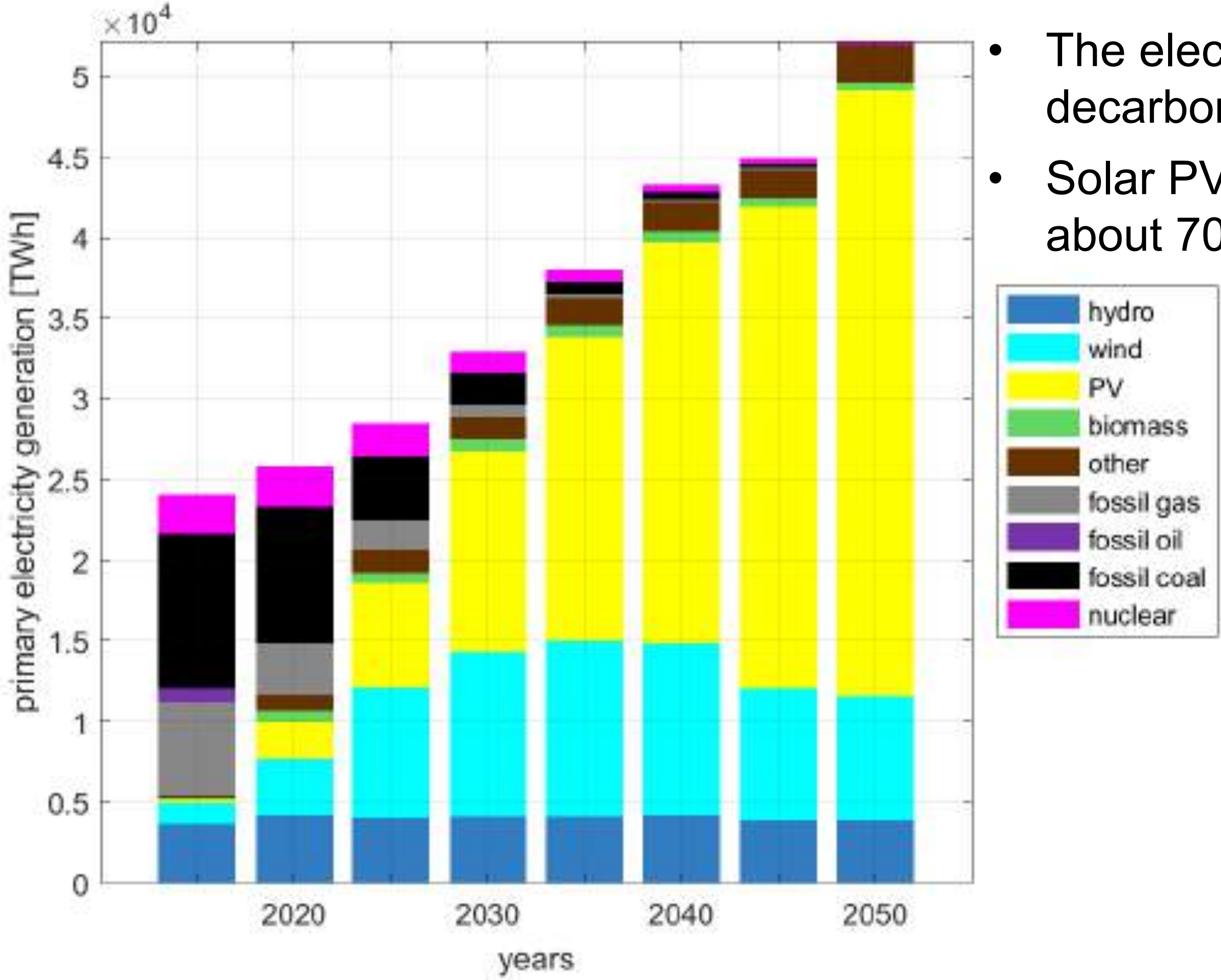


Is the energy transition possible?

The LUT model extrapolates these trends and performs an economic optimization of the energy technology mix, with their interconnections, year-by-year, up to 2050.



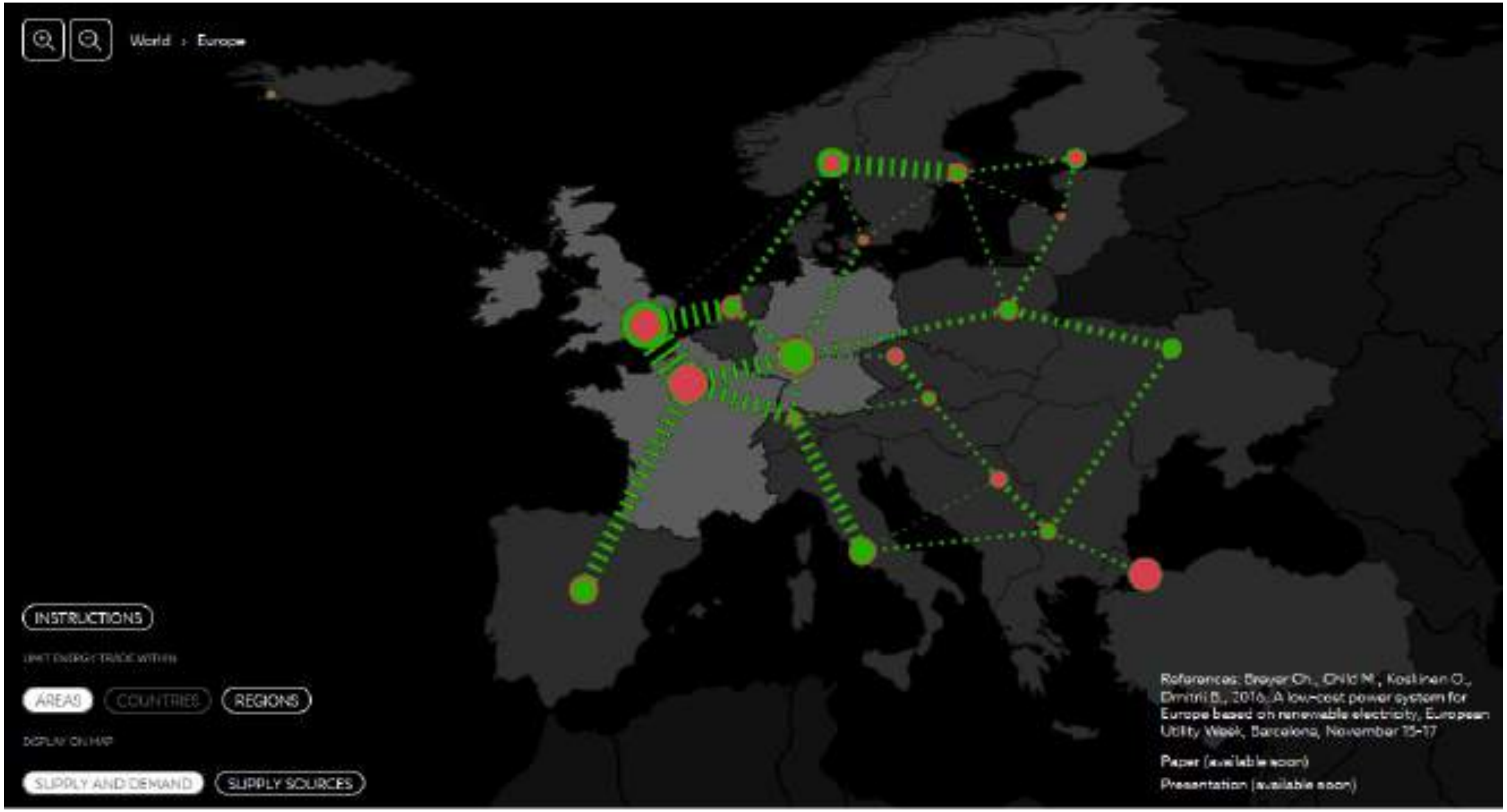
Is the energy transition possible?



- The electrification implies a double of electricity generation from 2020 to 2050.
- The electricity sector is completely decarbonized by 2050.
- Solar PV supply share in 2050 at about 70%, as least cost.

“Interconnection” among different geographical areas

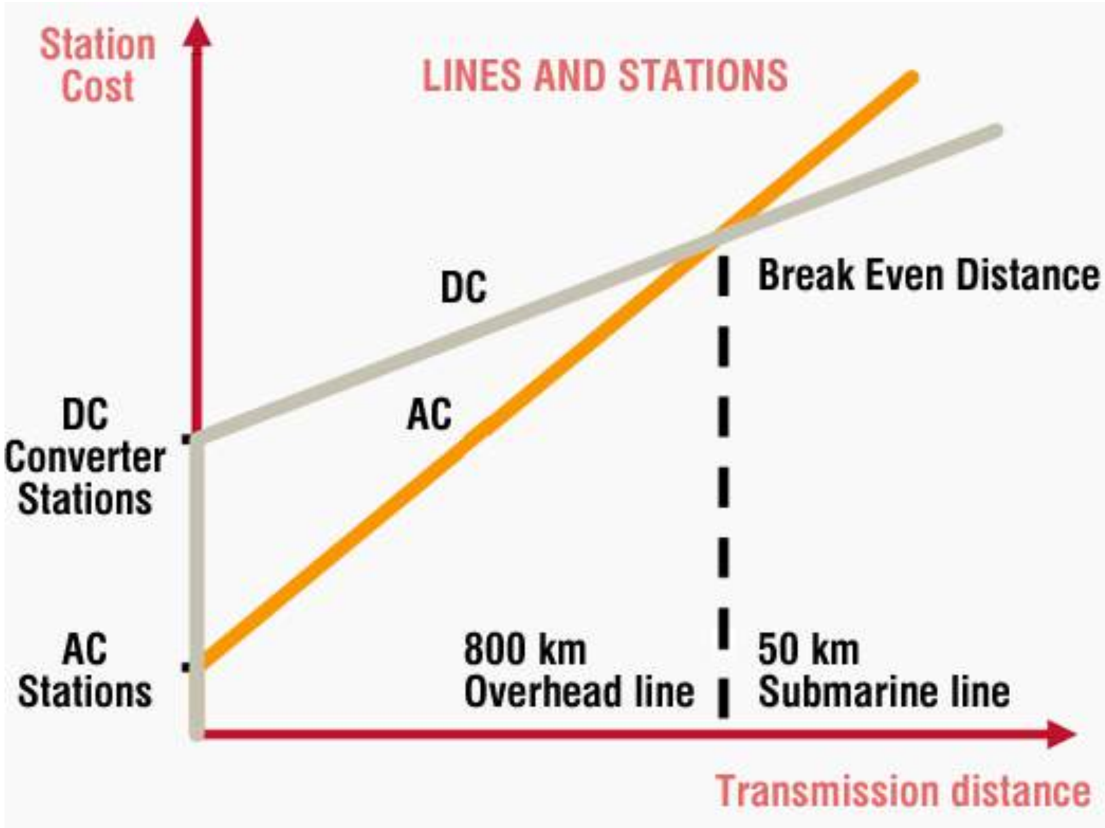
- A strong interconnection among the European Countries is required by the LUT model to achieve a carbon-free and convenient electricity generation.



CONCLUSIONS

- Decarbonization is the main strategy to reduce climate warming and allow us an easier adaptation to future climate conditions.
- Solar thermal collectors could play a role in replacing low-temperature gas boilers.
- Concentrating solar technology is expected to feed thermal power plants and replace fossil fuels in high-temperature industrial processes.
- Wide wind farms located offshore, will be installed in the next 30 years, because of their efficiency. Nevertheless, Solar PV supply is expected to share in 2050 at about 70% of electricity production, because of the least cost.
- Ultra-depth geothermal and wave energy conversion claim promising performance.
- In view of a fully decarbonized society, the role of energy storage technologies will be crucial, together with the "interconnection" among different geographical areas and the integration of different energy production, or recovery technologies.
- High-temperature HEAT PUMPS and chemical processes for producing H2 or NH3 are further essential technologies for achieving decarbonization and allowing mitigation of climate warming.
- According to the models, the transition is possible and could be completed by 2050.

UNIVERSITÀ DEGLI STUDI DI TRIESTE


Station
Cost
LINES AND STATIONS
DC
Break Even Distance
AC
DC
Converter
Stations
AC
Stations
800 km
Overhead line
50 km
Submarine line
Transmission distance