

Energy and Telecommunications

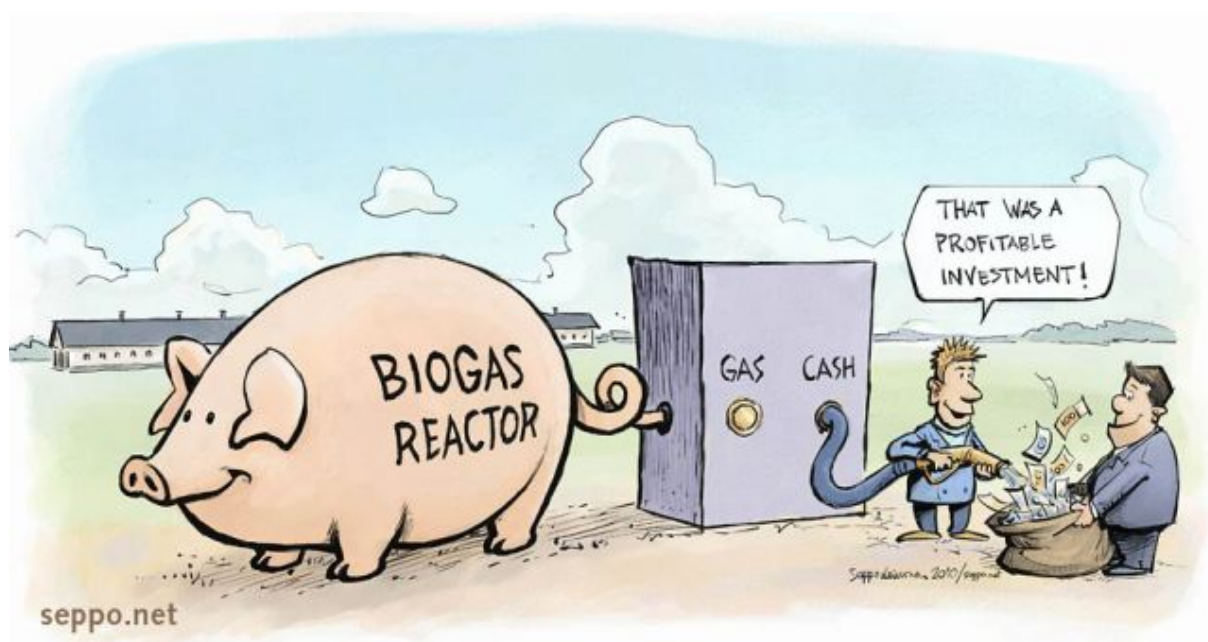
Lecture Notes

Jesús Mirapeix Serrano

Photonics Engineering Group
University of Cantabria

Revision of the English version by
Karen Louise Murphy





Cartoon: Seppo Leinonen, www.seppo.net. Permission granted by the author.

“Once the renewable infrastructure is built, the fuel is free forever. Unlike carbon-based fuels, the wind and the sun and the earth itself provide fuel that is free, in amounts that are effectively limitless. ”

Al Gore, former USA Vice-President and environmental activist.

Energy and Telecommunications

Mirapeix Serrano, Jesús

© 2023 Jesús Mirapeix Serrano.

This work is available under a Creative Commons License.

<https://creativecommons.org/licenses/by-nc-sa/4.0/>

University of Cantabria

39005 Santander

ENERGY AND TELECOMMUNICATIONS: RENEWABLE ENERGIES

Solar Energy

A Part from solar and wind renewable technologies, there are **other renewable energies** whose fundamentals are worth reviewing. The most significant of these technologies is probably **hydro-power** which, although not considered a “modern” RE, exhibits remarkable figures in terms of global electricity production. **Biomass, geothermal and ocean energies** will be also briefly presented and discussed.

The **main goals** of this chapter on “other” RE are:

To understand the importance of hydro-power, as well as its fundamentals

To become familiar with the fundamentals of biomass energy

To become familiar with the fundamentals of geothermal energy

To become familiar with the different technologies derived from ocean energy and their corresponding working principles

ENERGY AND TELECOMMUNICATIONS: RENEWABLE ENERGIES

Course Structure

This course has been divided into 4 chapters covering an introduction to renewable energies and related concepts, solar energy (including thermal and photovoltaics technologies) and wind energy. The final chapter will be focused on other REs, such as hydro-power, biomass, ocean energies, etc.

▷ **Chapter 1: Introduction to REs**

The goal of this chapter is for students to become familiar with the basics of REs. This includes understanding the reasons why these technologies came about, with a special focus on climate change. Basic information is also provided on the current situation in terms of renewable energies around the world and, obviously, in our country: Spain. Which is the leading country Photovoltaics or wind energy? How has the situation in China evolved over the last decade? What is Spain's current situation foreseeable future?

▷ **Chapter 2: Solar Energy**

Solar Energy can be divided into thermal and photovoltaics. We will devote little time to the former, talking about solar thermal installations (and their design) and also about CSP (Concentrating Solar Power), where the sun's energy is converted into heat and, afterwards, into electricity. Solar Photovoltaics (PV) will be the main topic of this course, given its relevance to telecom engineers. PV basics and practical issues will be dealt with, and some grid-connected and stand-alone installation examples will be analyzed.

▷ **Chapter 3: Wind Energy**

Wind energy is a well-known technology, with several installations in Spain. From a different perspective, more related to communications and sensing, this technology is also associated with the telecom industry. Wind turbine theory basics, the structure of a modern wind turbine and current technological trends will be briefly explained.

▷ **Chapter 4: Other Renewable Energies**

Hydro, biomass, geothermal and ocean energies will be dealt with in this final chapter. The relevance of hydro-power for electricity production will be discussed. In addition, the fundamentals of both biomass and geothermal energy will be also discussed. Finally, the different technologies associated with ocean energy will be briefly reviewed.

Acronyms

BTS	Base Transceiver Station	IR	Infrared
CAES	Compressed Air Energy Storage	LCOE	Levelized Cost of Energy
CSP	Concentrating Solar Power	PV	Photovoltaics
E	Energy	RE	Renewable Energy
EU	European Union	REE	Red Eléctrica Española [Operator of the Spanish Electricity Grid]
GH	Green-house	SHM	Structural Health Monitoring
GHG	Green-house Gas	TFC	Total Final Consumption
IDAE	Instituto para la Diversificación y Ahorro de la Energía [The Institute for the Diversification and Saving of Energy]	TPES	Total Primary Energy Supply
IPCC	Intergovernmental Panel on Climate Change	UV	Ultraviolet

Symbols

°C	Celsius (temperature)
J	Joule (energy)
K	Kelvin (temperature)
Mtoe	Million Tonnes of Oil Equivalent
ppm	Parts per million
ppb	Parts per billion
ppt	Parts per trillion
Wh	Watt-hour (energy)
W	Watt (power)(capacity)

Glossary

Biomass is an industrial term for obtaining energy by burning wood, and other organic matter. Burning biomass releases carbon emissions, but has been classed as a renewable energy source in the EU and UN legal frameworks, because plant stocks can be replaced with new growth. As an energy source, biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of biofuel.

Concentrating solar power (also called concentrated solar thermal, and CSP) systems generate solar power by using mirrors or lenses to concentrate a large area of sunlight, or solar thermal energy, onto a small area. Electricity is generated when the concentrated light is converted to heat, which drives a heat engine (usually a steam turbine) connected to an electrical power generator.

Dynamic calibration (of power lines) refers to the possibility of transmitting a higher current than the one associated with the nominal ampacity of the line by measuring weather parameters such as sun radiation and wind speed and estimating their cooling effect upon the line.

End-Use Energy is the energy directly consumed by the user, like electricity, gasoline or natural gas.

Feed-in solar PV installation operates as a power plant, generating energy and injecting it into the power grid for its distribution.

Fossil fuel is a fuel formed by natural processes, such as anaerobic decomposition of buried dead organisms, containing energy originating in ancient photosynthesis. Examples of fossil fuels are oil, carbon and natural gas.

Greenhouse gas is an atmospheric gas able to trap or reflect heat (infrared radiation). Example of green-house gases are CO₂ or methane.

Grid Parity occurs when an alternative energy source can generate power at a levelized cost of energy (LCOE) that is less than or equal to the price of purchasing power from the electricity grid. The term is most commonly used when discussing renewable energy sources, notably solar power and wind power

Hydro Power refers to the power derived from the energy of falling water or fast running water.

Levelized Cost of Energy is a parameter that allows making a direct comparison between different energy technologies, as it measures the lifetime costs of a given power plant (cost of building, operation, etc.) divided by the energy production. Its units are \$/Wh.

Photoelectric effect is the emission of electrons or other free carriers when light shines on a material.

Primary Energy is the energy that is directly harvested from natural resources.

Pumped-Hydro Power is based on the transportation of water to a higher reservoir, where that potential energy can be recovered by letting the water run to the base reservoir and activating a turbine located between both sites.

Renewable Energy is the energy obtained from the continuous or repetitive currents of energy recurring in the natural environment.

Self-consumption solar PV installation designed to provide energy to the building/system where it is located, for example a single-family home.

Solar PV Energy is based on the conversion of sun radiation (photons) to electricity (electrons) by means of the photoelectric effect.

Sustainable Development Development which meets the needs of current generations without compromising the ability of future generations to meet their own needs.

Sustainable Energy is the energy that does not significantly decrease with a continuous use, does not imply significant contaminant emissions or other environmental risks and does not imply the perpetuation of health risks or social injustices.

Contents

Acronyms	I
Symbols	II
Units	II
Contents	V
4 Other Renewable Energies	1
4.1 Other Renewable Energies: Introduction	1
4.2 Hydro-power	1
4.2.1 Hydro-power: Current Situation	2
4.2.2 Hydro-power: types of plants	5
4.2.3 Hydro-power: Additional Information	6
4.3 Ocean Energies	8
4.3.1 Tidal Energy	9
4.3.2 Wave Energy	13
4.3.3 Ocean Energies: Evolution and Forecast	20
4.3.4 Levelized Cost of Energy: LCOE	21
4.3.5 Ocean Energies: Pros and Cons	22
4.4 Geothermal Energy	23
4.4.1 Geothermal Energy: a brief History	23
4.4.2 Geothermal Power Plants: Types	24
4.4.3 Geothermal Energy: Locations	25
4.4.4 Geothermal Energy: Environmental Impact	27
4.5 Biomass	27

4.6	Conclusions	29
-----	-----------------------	----

CHAPTER 4

Other Renewable Energies

4.1 Other Renewable Energies: Introduction

Having explained the fundamentals of both solar and wind energy in this course, it could prove interesting to make a short review of other important renewable technologies such as biomass, geothermal or ocean power. Although the potential involvement of a telecom engineer in these technologies might seem less likely, we can provide a number of examples, such as the development of monitoring systems for ocean power technologies.

This chapter will therefore be devoted to briefly presenting the main concepts and relevant aspects of the following REs:

- Hydro-power
- Ocean energy
- Geothermal energy
- Biomass

4.2 Hydro-power

We should start this section by answering the following question: **Can hydro-power be considered a RE?**

To answer this question, we should refer to the definition presented in the first chapter of this course: is hydro-power obtained from natural resources that can be considered virtually inexhaustible?

The answer is YES: the water cycle on the Earth can be considered continuous, thus enabling a virtually inexhaustible resource.



Figure 1. Hydro-power plant in a river in Toba Montrose. Source: Alterrapower. License CC BY-SA 3.0. Link: <http://bit.ly/2GaNtnN>.

Hydro-power is based on **capturing the kinetic energy of water**, converting it initially into mechanical energy and, finally, into electricity by means of a generator (turbine)¹.

4.2.1 Hydro-power: Current Situation

Which are the leading countries in terms of hydro-power capacity/production? [Figure 2](#) answers this question: China, Brazil, Canada and USA are the main countries in terms of installed capacity, with an accumulated global capacity of 51%.

It should be mentioned that hydro-power is a very mature technology. This explains the data represented in both [Figure 4](#) and [Figure 5](#). On the one hand, additions in hydro-power are relatively modest in comparison to other modern REs like solar PV or wind energy. On the other hand, this maturity helps to understand the remarkable contribution of hydro-power to electricity production among REs, as has been represented in [Figure 5](#). Note that the total renewable power capacity (as of end-2021) is 3146 GW, whit **hydro-power contributing 1195 GW, below 50% of the total and showing a decreasing trend**.

Despite this technological maturity, hydro-power plants face challenges and update requirements. A good example are the droughts that are currently affecting many areas, thus giving rise to a significant impact on hydro production, for example in America or Southeast Asia.

Spain has also suffered from this situation, as already discussed in Chapter 1. Hydro-power was responsible for almost all the capacity additions in Spain in 2015, as the hydro-power plants of La Muela II (878 MW, Cortes del Pallás (Valencia))² and San Pedro II (23 MW,

¹Conversion into electricity is common nowadays, but not required, as mechanical energy can be used to grind cereals, for example. The first water mills are described by Vitrubio (1st century), referring to those used in Persia.

²When La Muela II was inaugurated in 2013, it was the largest hydro-power plant in Europe. You can

Hydropower Global Capacity, Shares of Top 10 Countries and Rest of World, 2021

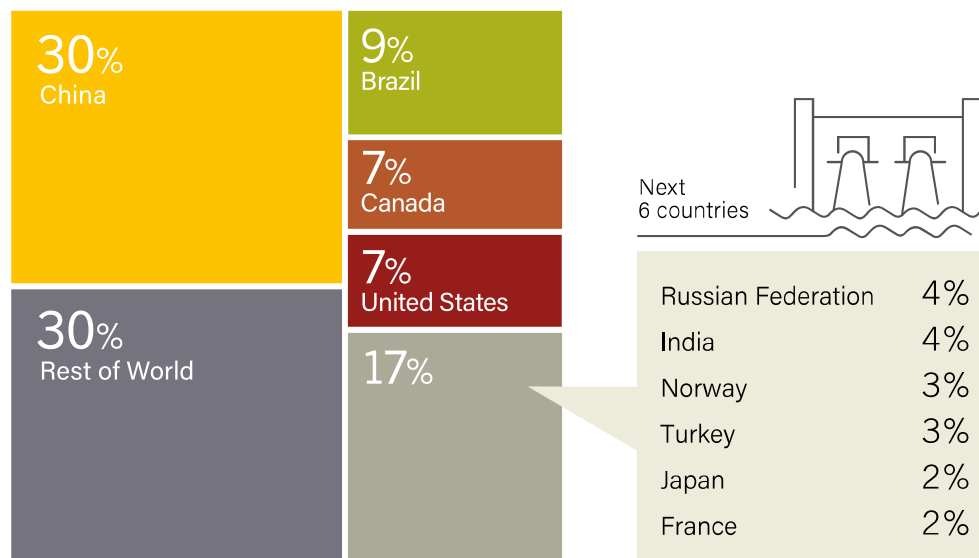


Figure 2. Hydro-power global capacity in 2021. Source: REN21 (2022 Report). Link: <https://bit.ly/3MR1R7x>.

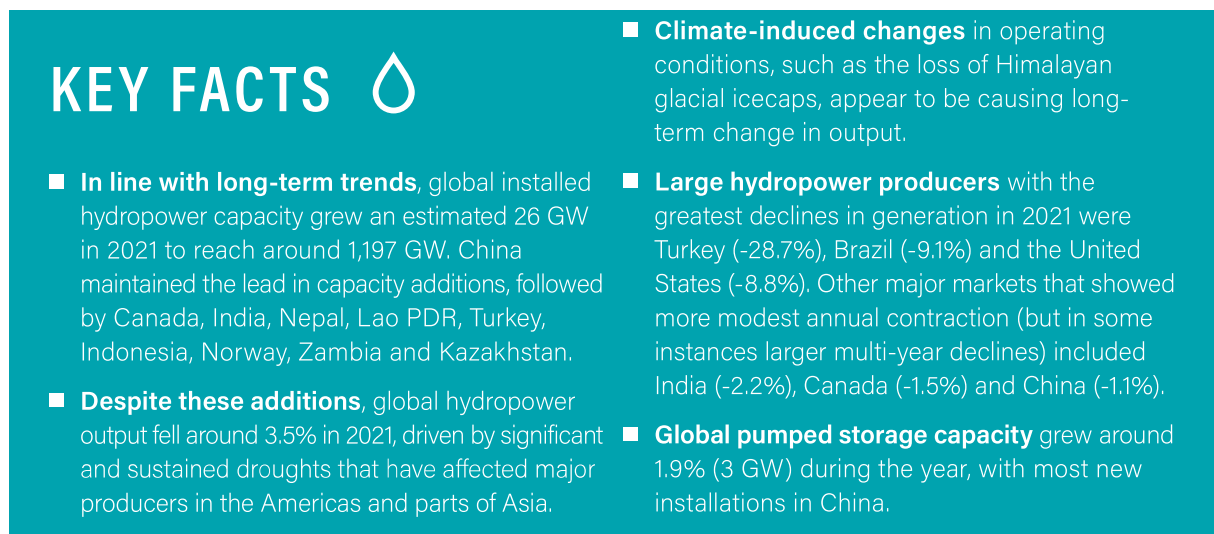


Figure 3. Key facts to understand the current global scenario of hydro power. Source: REN21 (2022 Report). Link: <https://bit.ly/3MR1R7x>.

río Sil, Orense) started operating that year.

Both climate change effects and the greater contribution of modern REs (solar, wind, etc.) are factors that contribute to the adaption of hydro-power plants. New plants and expansions are focused on achieving higher efficiencies and flexibility, with a special emphasis on **pumped hydro**, given its special significance as a **large-scale storage solution**.

Hydro-power can be classified as follows:

view this video from Iberdrola about La Muela I and II plants: <https://youtu.be/lcq3Ql128bA>

Hydropower Global Capacity and Additions, Shares of Top 10 Countries, 2021

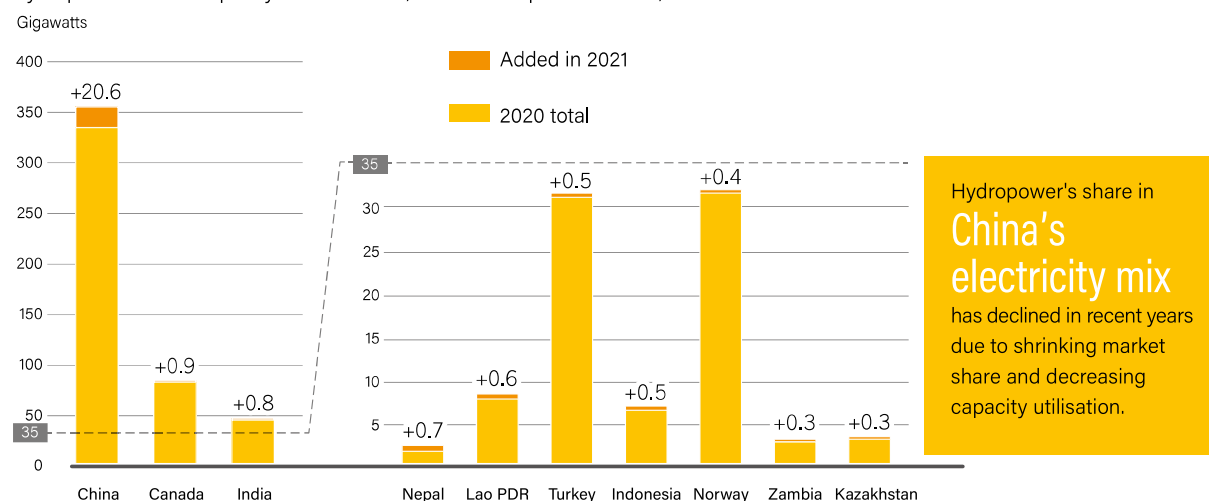


Figure 4. Hydro-power installed capacity and additions. Top 10 countries by 2021 additions. Source: REN21 (2022 Report). Link: <https://bit.ly/3MR1R7x>.

Renewable Energy Indicators 2021

		2020	2021
INVESTMENT			
New investment (annual) in renewable power and fuels ¹	billion USD	342.7	365.9
POWER			
Renewable power capacity (including hydropower)	GW	2,840	3,146
Renewable power capacity (not including hydropower)	GW	1,672	1,945
Hydropower capacity ²	GW	1,168	1,195
Solar PV capacity ³	GW	767	942
Wind power capacity ⁴	GW	745	845
Bio-power capacity	GW	133	143
Geothermal power capacity	GW	14.2	14.5
Concentrating solar thermal power (CSP) capacity	GW	6.2	6.0
Ocean power capacity	GW	0.5	0.5

Figure 5. Renewable energies' power capacity as of end-2021. Source: REN21 (2022 Report). Link: <https://bit.ly/3MR1R7x>.

- Type:
 - Dam (conventional)
 - Run-of-the-river
 - Pumped storage
- Size:
 - Large-scale > 30MW
 - Small-scale = 100 kW to 30 MW
 - Micro-hydro < 100 kW

4.2.2 Hydro-power: types of plants

The most well-known hydro-power plants are **dams**, where water is stored and then released and forced to go through a channel to a lower elevation reservoir. During this process, electricity is produced by means of a turbine.

An alternative is **run-of-the-river hydro plants**, whose working principle has been represented in Figure 6.

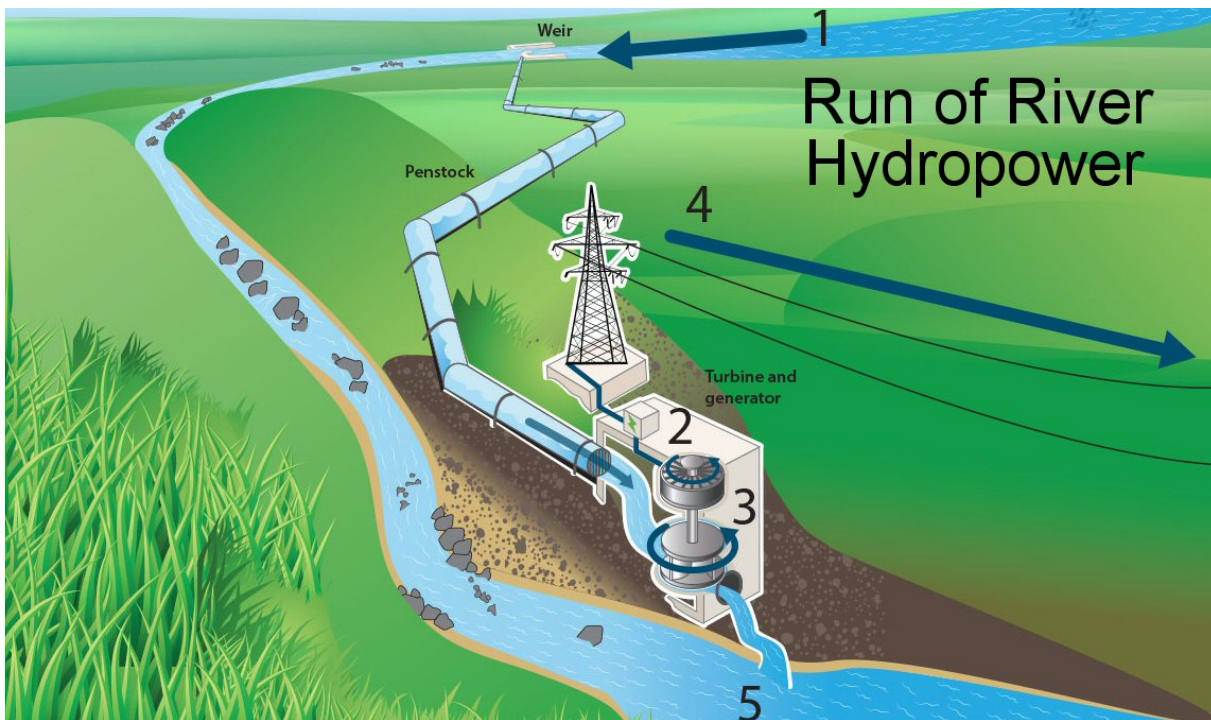


Figure 6. Run-of-the-river power plant. Source: <http://bit.ly/2naIlYe>

A run-of-the-river power plant works as follows:

- The water of the river is redirected by a channel
- Water is forced to go through turbines
- Electricity is produced in the associated generator
- Electricity is injected into the power grid
- Water is returned to the river

Pumped hydro plants work slightly differently. There is a lower elevation reservoir where energy is stored. Then, energy is transported to a higher elevation reservoir by means of a turbine in those periods where electricity demand is low (at night, for example). Electricity is produced then (when needed) by releasing the water of the upper reservoir, which will pass through a turbine. Thus, pumped hydro is, in fact, a **large-scale energy storage solution integrated within the power grid**. This is of particular interest within the framework of

renewable energies, whose intermittent nature has been already discussed. The efficiency of these solutions, considering turbines and other factors as friction, can be estimated at around 75%.

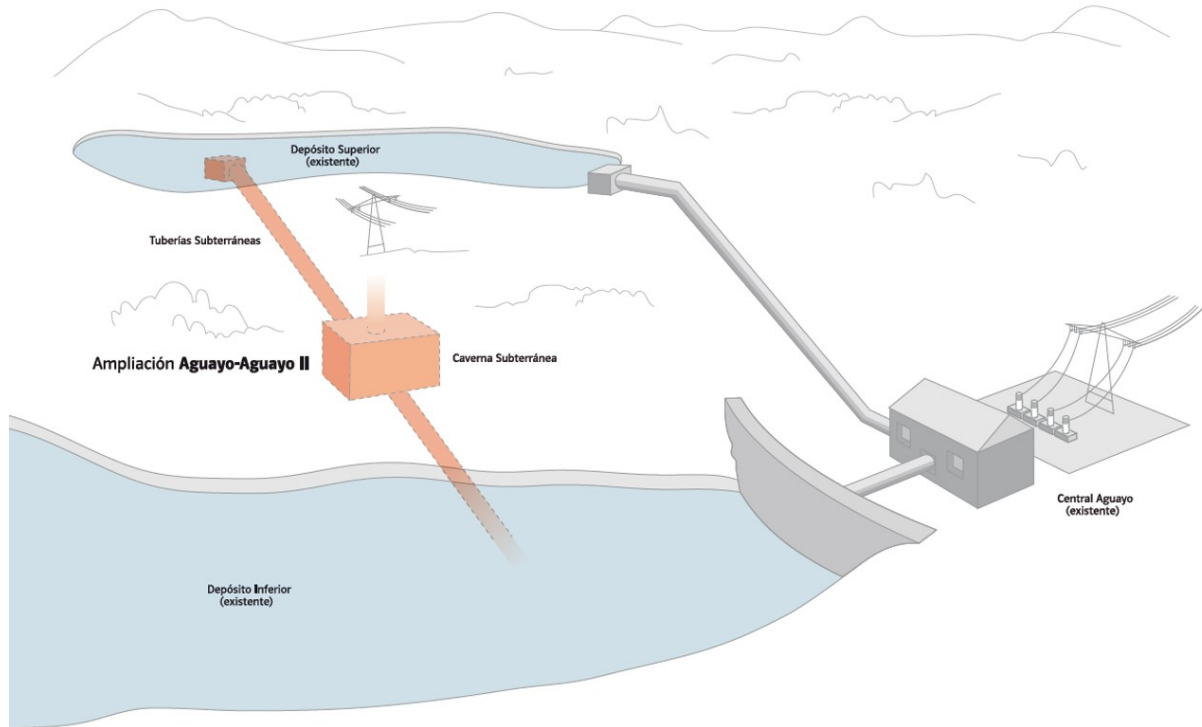


Figure 7. Schematic representation of the pumped hydro-power plant Aguayo II). Source: Viesgo. *Proyecto de ampliación de la central eléctrica Aguayo II.*

4.2.3 Hydro-power: Additional Information

To understand the working principle of hydro-power, it is important to remember that the potential energy associated with a mass of water m located at a height h is given by mgh . The power p generated by the moving water is therefore given by the following expression, where m and V indicate the (water) mass flow (kg/s) and the water (volume) flow rate (m^3/s). ρ is the water density ($1000kg/m^3$).

$$p = \frac{mgh}{t} = \dot{m}gh = \rho\dot{V}gh \quad (4.1)$$

A detailed analysis of turbine types is beyond the scope of this course. However, it is worth pointing out that they can be classified in to two main categories: impulse and reaction.

Impulse Turbines In these turbines, their movement is governed by water speed, and thus great heights (high heads) and low flows are recommended.



Figure 8. Turbines used in hydro-power plants. Source: (Left: Audrius Meskauskas - Own work / The rotor of the water turbine. Taken in the plant that manufactures the water turbines, Zurich); (Right: © Tamarhydro <http://bit.ly/2E4ilWi>)

Reaction Turbines In this case energy is generated by the combined action of pressure and water movement. In this case low heads and high flows are preferred.

Important! 4.1: Hydro-Power: Turbines

More information about these turbines can be found in the following video: <https://youtu.be/k0BLOKEZ3KU>



Figure 9. Image of the Tamega pumped-hydro power plant in Portugal (project by Iberdrola). Source: Iberdrola.

Important! 4.2: The Tamegra Project

A remarkable pumped-hydro power plant is being deployed in Portugal, in the metropolitan area of Oporto. The project will try to achieve a combined storage capacity of 1.150 MW, where 2 wind farms will also be considered in the vicinity allowing, in this way, to store their energy in the pumped-hydro giga-battery when demand in the grid allows it.

A final thought should be devoted to the **environmental impact of hydro-power**. Even if we are talking about a renewable non-emitting energy, there are some environmental factors to be considered:

- Flooding of large areas (that could be devoted to other uses, or even considered agricultural or natural sensitive areas)
- Relocation of population
- Impact on aquatic animals
- Blocking the natural course of rivers

4.3 Ocean Energies



Figure 10. Waves in Pacifica (California). Source: Wikimedia/Brocken Inaglory. License: CC BY-SA 4.0. <http://bit.ly/10C68IY>

If you have ever been to the beach, or bathed in a river, you will have probably experienced the “power” of the sea/ocean. Tides and waves are good examples in this respect.

Ocean/Marine energies are relatively young technologies, whose relevance has increased in recent years. We are in fact talking about different technologies, although a

low maturity is common to almost all of them. In fact, most of them are currently in a research and development stage and their figures in terms of capacity and generation are rather low.

Important! 4.3: Instituto de Hidráulica (Hydraulics Institute)

A well known research center devoted, in part, to the development of these Ocean energies is the Instituto de Hidráulica (Hydraulics Institute), located in Santander (Spain). <http://www.ihcantabria.com/WebIH/en/>

A possible classification of ocean energies could be as follows:

- Tidal Power
- Wave Power
- Ocean Thermal Energy Conversion (OTEC)

Figure 11 shows a comparison between conventional hydro-power technologies (also known as *Freshwater hydro*) and ocean energies. It is worth noting the huge potential of OTEC that, despite the low adoption that this technology has had to date. The only ocean energy with some commercial installations is tidal power.

Table 8.2 Relative Sizes of Some Various Hydro Resources

Energy Source	Potential (GW)	Practical (GW)	To Date
Freshwater hydro	4,000	1,000	654
Waves	1,000–10,000	500–2,000	2.5
Tides	2,500	1,000	59
OTEC	200,000	10,000	0

Source: Tester, J.W. et al., *Sustainable Energy: Choosing among Options*, The MIT Press, Cambridge, MA, 2005.

Figure 11. Comparison between freshwater hydro and ocean energies (potential and installed capacity). Source: Renewable Energy: A First Course (Robert Ehrlich)

A brief review of tidal, wave and ocean thermal energies is given in the following sections:

4.3.1 Tidal Energy

Tides are periodic (and predictable, as they depend on the relative position of the Earth, Moon ... and Sun!) variations of sea and ocean levels. This phenomenon can be explained using **Newton's law of universal gravitation**¹, taking into account the gravitational forces that the Moon and Sun exhibit on the Earth. Tides depend on the inverse of the cubed distance between the Earth and the Moon/Sun. To find the corresponding expression, it is only necessary to apply Newton's law and determine the gravitational force of the Moon upon the Earth:

¹<http://bit.ly/2fKxvW9>

$$F = \frac{gMm}{r^2} \quad (4.2)$$

From this equation, it is easy to derive:

$$F_x = \pm \frac{2gMmR}{r^3} \quad (4.3)$$

$$F_y = \pm \frac{gMmR}{2r^3} \quad (4.4)$$

In these equations, g is the gravitational constant, M the mass of the Earth, m the mass of the Moon, r the distance between the Moon and the Earth and R the Earth's radius.¹ F_x indicates the opposite forces that act on the opposite sides considering the Earth's axis to be the line that connects it to the Moon. This will imply an “enlarging” effect of the Earth, while F_y would imply a “compression” of the axis orthogonal to x .

There are **two main strategies** for the exploitation of tidal energy: by means of **dams or by the direct activation of turbines**. The global potential of this renewable energy is estimated to be 3000 GW, although a small percentage (let's say around 3%) would be at locations suitable for its exploitation.

An important limitation of this technology is the difficulty in finding **suitable locations**, as the difference between the level for low and high tides should be above 5 meters, at least. Some of the best global locations have been indicated in [Figure 13](#). Usually, these best locations are tidal rivers, bays and related places, where the construction of a dam is feasible. It is interesting to note that the average tidal difference is about 1 meter, although the best known location is probably Fundy Bay (Canada) with 16-20 meters.

The **tidal power plant located on the Rance river (Bretagne, France)**² (see [Figure 14](#)) is the best worldwide example of this technology. It began its operation in 1966 and is formed by 24 turbines with 10 MW generators. It is a reversible plant, as it works in both directions (when the dam is filled and emptied). The LCOE of this plant is supposed to be similar to that of conventional plants, although the **environmental impact was significant**, affecting for example the salinity of the river and, consequently, its animal life.

Tidal power plants based on dams like the one located on the Rance river are not the only possibility for extracting energy from tides. The **Direct activation of turbines** is also being investigated, with some similarities to wind turbines. A good example is the **Lanstrom turbine** shown in [Figure 15](#), with a rotor diameter of 20 meters and fixed to the seabed. These turbines are manufactured by the Norwegian company Andritz Hydro Hammerfest, which installed its first turbines in 2003³.

¹A more detailed explanation can be found in the book “*Renewable Energy: A First Course*” de Robert Ehrlich.

²<http://bit.ly/1GLZQ8g>

³The installation process of these turbines is shown in this video: <https://youtu.be/cHEXrBcdTck>

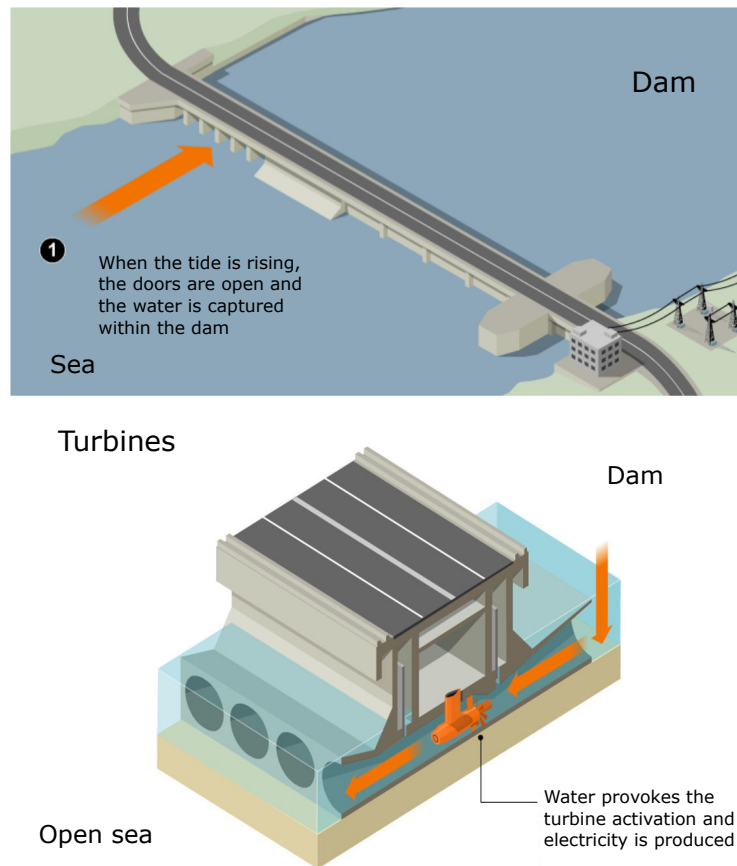


Figure 12. Scheme of a tidal power plant. Source: Consumer.es <http://bit.ly/1qsdtw0> (License for teaching purposes.)



Figure 13. High potential areas for tidal resources. Source: Consumer.es <http://bit.ly/1qsdtw0> (License for teaching purposes.)

A similar approach, although with a different design, is found in **Seagen turbines**, manu-



Figure 14. Rance river tidal power plant. Source: Wikimedia / Dani 7C3. License: CC BY-2.5 <http://bit.ly/1GLZQ8g>



Figure 15. Installation of a Lanstrom turbine. Source: Andritz Hydro Hammerfest (hammerfest-strom). License: YouTube standard <https://youtu.be/cHEXRbCdTck>

factured by Siemens. They are supposed to be the first commercial direct activation turbines produced on a global scale (2008). Each system is equipped with 2 turbines, summing up a total capacity of 1.2 MW. Some units have been installed in Northern Ireland¹.

A different solution is proposed by the **Vivace system**, whose operation is based on the

¹The working principle of these turbines is explained in the following video: https://youtu.be/AfGRBFdw2_g

turbulence generated by marine currents that go through cylinders, as shown in [Figure 17](#). The top of the figure shows the working principle of this device, and the bottom shows a test performed in the laboratories of Michigan University¹.

Having presented some examples of tidal energy, it is now time to analyze the pros and cons of these technologies:

Pros	Cons
No CO2 emissions	Limited potential locations
Predictable	Long distances to the power grid
Low flow speeds	Production limited to 40 days/year
Efficiencies $\approx 80\%$	Environmental Impact
Low operation costs	Component deterioration
Lifetime $\approx 75/100$ years	Visual impact



Figure 16. Seagen turbine. Source: Marine Current Turbines Limited <http://bit.ly/2E8RVTr>

4.3.2 Wave Energy

Wave energy is based on the use of the energy associated with waves. Waves are created by the wind that blows over the ocean/sea surface. There are many places around the world

¹A video of this test can be found here: <https://youtu.be/IcR8HszacOE>

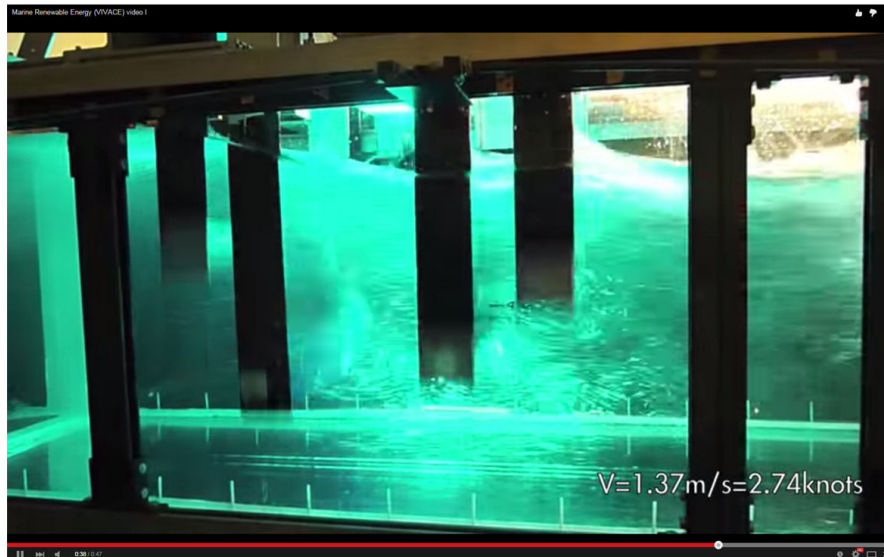
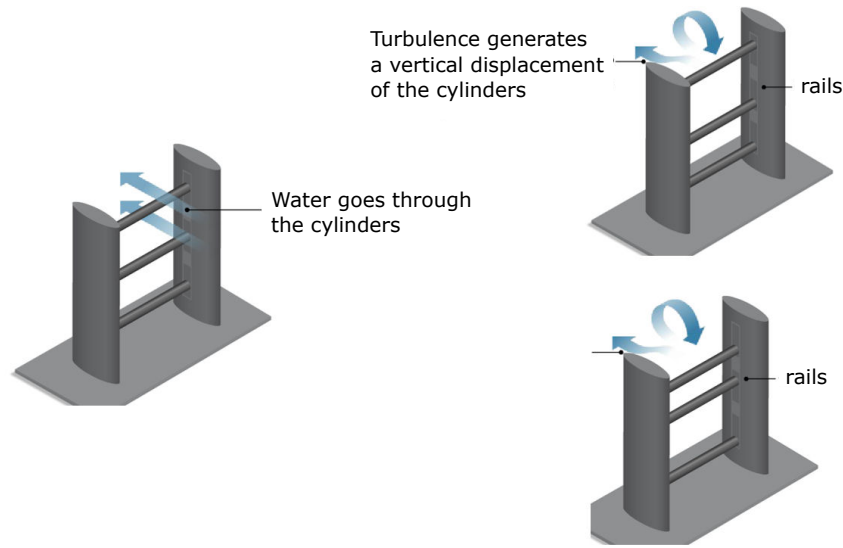


Figure 17. Vivace tidal system. Source: (Top: Consumer.es <http://bit.ly/1qsdtw0>); (Bottom: UMOVIVACE. License: YouTube standard. <https://youtu.be/IcR8Hszac0E>)

where waves are constant enough so as to produce energy continuously. Some estimations indicate that the potential of wave energy could be around 140 to 750 TWh/year. Figure 18 shows the conclusions of a study performed to evaluate wave energy potential. The average power density has been indicated for each location.

To better understand Figure 18, it is important to know the expression that allows estimating the power of a given wave:

$$P_{avg} = \frac{\rho g^2 T H^2}{8\pi}$$

As can be appreciated, the power of a wave is directly proportional to its squared height (H) and its period (T) (ρ is the water density (1025 kg/m^3)), and g acceleration due to gravity (9.81 m/s^2).

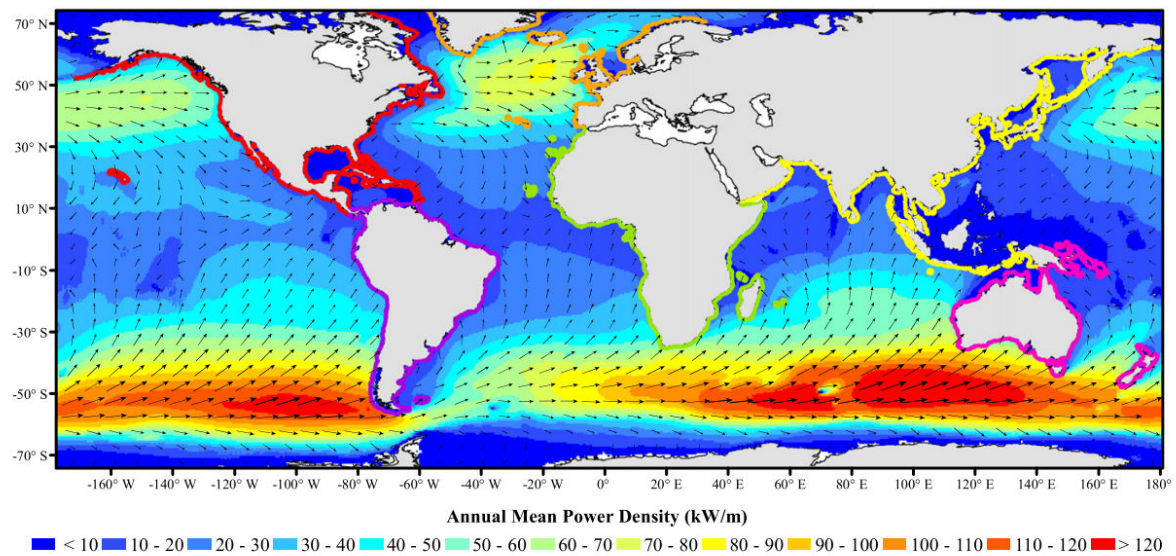


Fig. 1. Annual mean wave power density (colour) and annual mean best direction (\rightarrow). The land buffers used to quantify the resource are also shown, coloured by continent (see Section 3). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Figure 18. Average power density (kW/m) (annual) associated with wave energy (arrows indicate prevalent wave directions). Source: Gunn y Stock-Williams (2012) “Quantifying the global power wave resource”. <http://bit.ly/2DL7mU4>

Important! 4.4: Wave Power

In a storm, waves can easily reach 10 meters (not necessarily close to the coast) every 15 seconds. Using the above equation, and considering a water density of $\rho = 1025 \text{ kg/m}^3$, the associated power will be $P = 5.9 \text{ MW}$.

Within wave energy, there are different devices that can be used to generate electricity. A typical classification is shown in Figure 19.

Wave activated bodies

Wave activated bodies are probably the most common wave energy devices, especially the so-called **point absorber buoys**. Their working principle is based on:

- The deployment of buoys attached to the seabed
- Wave kinetic energy that moves the buoys, thus displacing an axis that allows electricity production by means of a linear generator

Figure 20 presents a point absorber buoy installed in Santoña (Cantabria): the buoy has a power pump that transfers the mechanical energy to an alternator, whose current is afterwards injected into a power cable. Its capacity is 40 KW and it is an experimental device used to analyze the feasibility of a larger deployment.

An alternative wave energy solution is based on an **attenuating wave energy converter**. Figure 21 shows a photo-montage of a wave energy “plant” (left) and a picture of a Pelamis

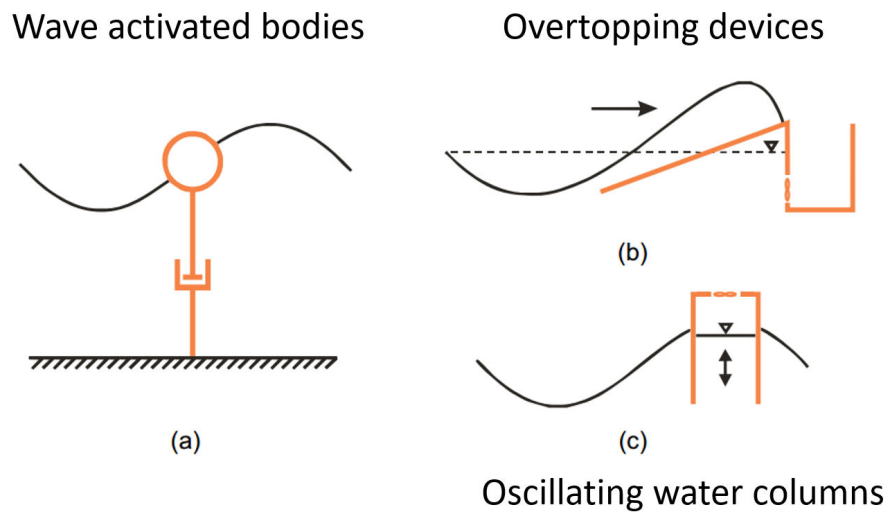


Figure 19. Wave energy technologies: a) Wave activated bodies, b) Overtopping devices and c) Oscillating water columns.



Figure 20. Point absorber buoy installed in Santoña (Cantabria). Source: Europapress <http://bit.ly/2DBFuhC>

model (right). As can be observed, this device is made up of several segments. The relative movement between consecutive segments generated by the waves is used to produce electricity via power pumps or other generators¹. The Pelamis design favors the durability of the device over its efficiency, as it is supposed to be deployed in locations with extremely bad weather conditions. Currently deployed systems are fundamentally for experimental purposes.

¹In the following video, the working principle of these devices is explained: <https://youtu.be/mcTNkoyvLFs>.



Figure 21. Attenuating wave energy converters: a) Pelamis wave energy plant (Source: Jumanji Solar (Flickr) <http://bit.ly/2DHM9dE>, b) Pelamis device tested in EMEC (European Marine Energy Test Centre) (Source: Wikimedia <http://bit.ly/2rDoZjU> (License: public domain)).

Overtopping devices

The working principle of **overtopping devices** is very simple (see [Figure 22](#)). The idea is to develop a reservoir with a given elevation above sea level. It is filled with water from the waves and, afterwards, that water will go through a hole in the reservoir, thus activating a turbine. Both onshore and offshore systems can be considered.

Wave Dragon is one of the main examples of these devices. It is commercialized by a Danish company and was developed by a European consortium with participants from Austria, Denmark, Ireland, Portugal, Sweden and the UK. The first prototype was connected to the Danish (Nisum Bredning) power grid in 2003. More information about the Wave Dragon can be found at: <http://bit.ly/2nbmz7g>.

Oscillating water columns

Wave energy can also be used in installations deployed on the coast, the so-called **oscillating water columns** (OWC). Waves propel the air confined in a chamber (see [Figure 23](#)) that will move a turbine to produce electricity. This way, it is air and not water that is used to activate the turbine. In fact, the turbine is activated when the wave reaches the coast, but also when it returns to the sea.

There is an OWC system deployed in Mutriku (País Vasco)¹. A lab-test of this device is presented in this video: https://youtu.be/mVQ3ZTli_Hs.

Question 4.1: Oscillating Water Columns [300 XP]

What is your opinion about OWC? Do you think that this is a mature technology? Which turbines are used in these devices?

¹<http://bit.ly/2E8HS0k>

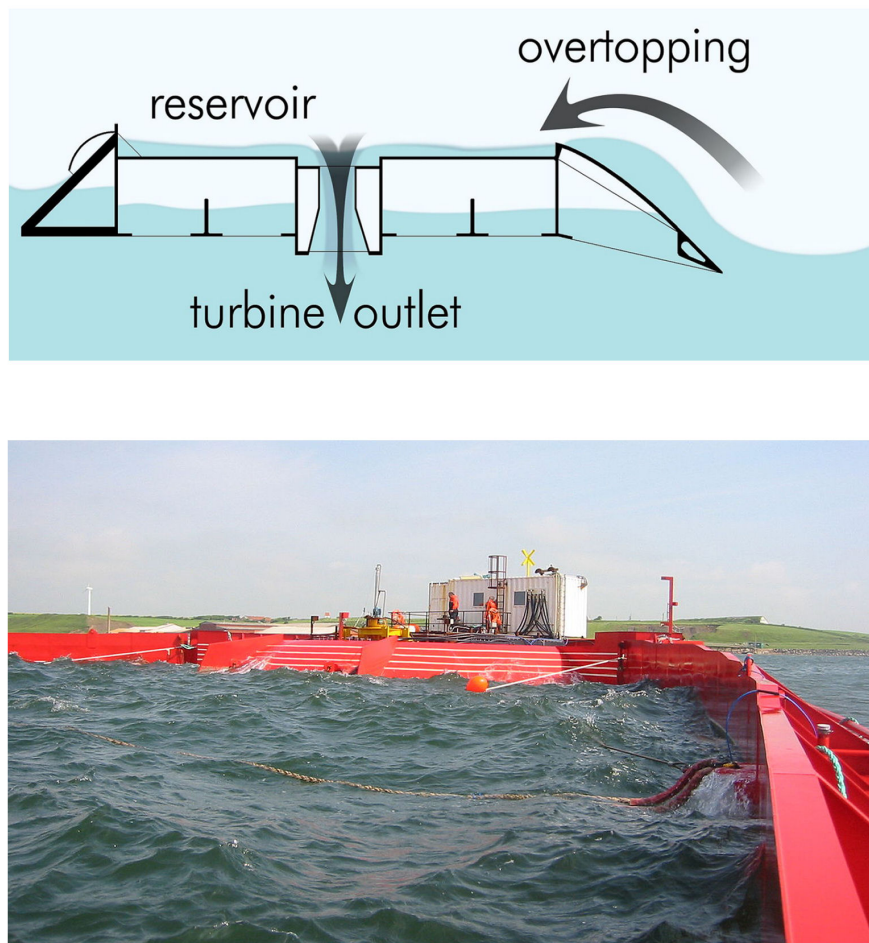


Figure 22. Overtopping device: a) Working principle (top); b) Wave Dragon (example of overtopping device) (bottom). Source: Erik Friis-Madsen / License: Creative Commons Attribution 3.0 Unported (top and bottom).

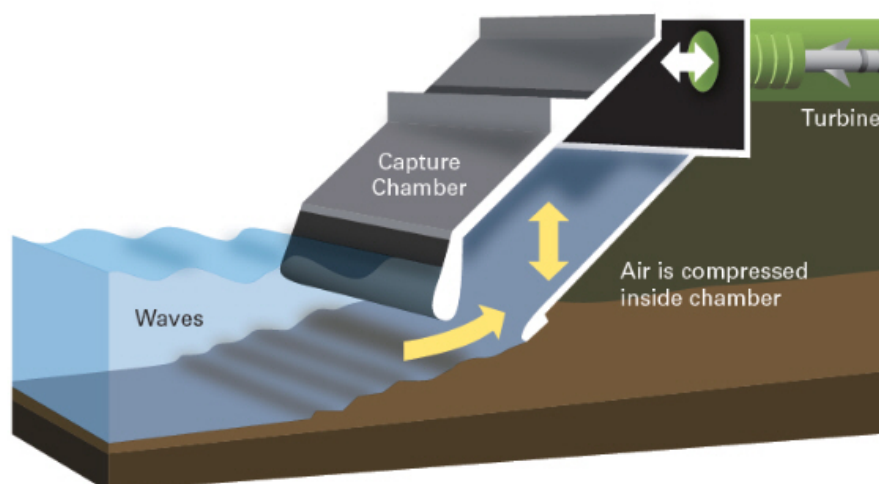


Figure 23. Oscillating water column. Source: UIOWA Wiki <http://bit.ly/2nb1HMR>

OTEC: Ocean Thermal Energy Conversion

Oceans cover around 70% of the Earth's surface. Solar radiation captured by the oceans is equivalent to 600 times the global demand. Consequently, if we were able to use the thermal energy captured by the oceans, a potentially huge capacity would be at our disposal.

OTEC is based on the different temperatures to be found at different layers (depths) in the oceans. The following layers are typically considered:

- Surface layer: with a thickness from 100 to 200 meters, it works as heat collector, with temperatures from 25 to 30 °C
- Intermediate layer: from 200 to 400 meter depth, it exhibits a fast temperature variation and acts as a thermal barrier between the surface and deep layers
- Deep layer: where temperature decreases to 4 °C at 1000 m and 2 °C at 5000 m

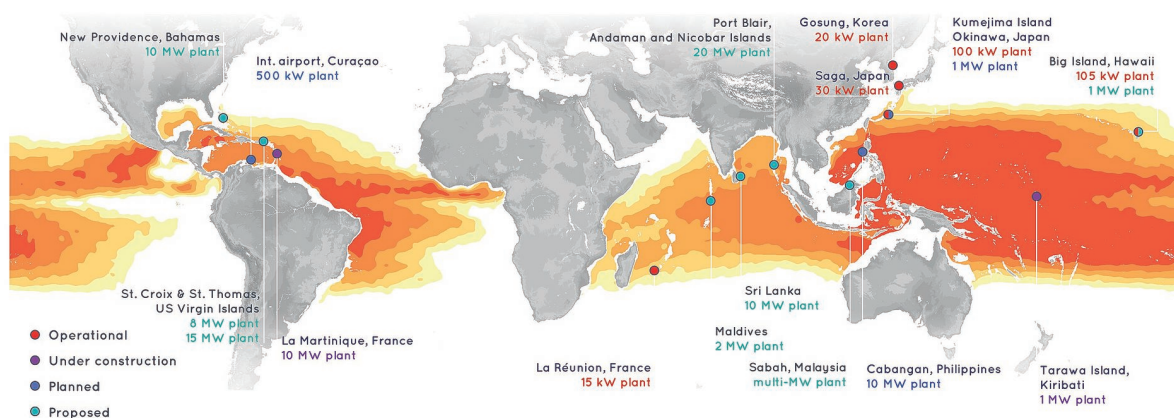


Figure 24. OTEC potential locations. Source: Wikimedia. License: CC BY-SA 4.0. <http://bit.ly/2DCvTv5>.

Coastal areas in the tropics offer high temperature gradients, as represented in [Figure 24](#), where the currently operational installations (or those planned for future years) have also been indicated.

[Figure 25](#) shows the working principle of OTEC, which is based on the so-called Rankine cycle. A fluid, ideally with a boiling point lower and a vapor pressure higher than water, is used to activate a turbine. The water heated at the ocean surface is pumped into a heat exchanger, where heat will be transferred from the sea water to the chosen fluid. The latter will be evaporated, thus activating the turbine. The cooled sea water will be transported to a second heat exchanger, where vapor will be condensed to a liquid state for its reuse.

It is worth noting that, as suggested, water is not the most suitable fluid for these systems. Ammonia is far better for the above mentioned reasons. If water is used, the system is an **open-cycle OTEC**, while a **close-cycle OTEC** refers to systems employing ammonia. The

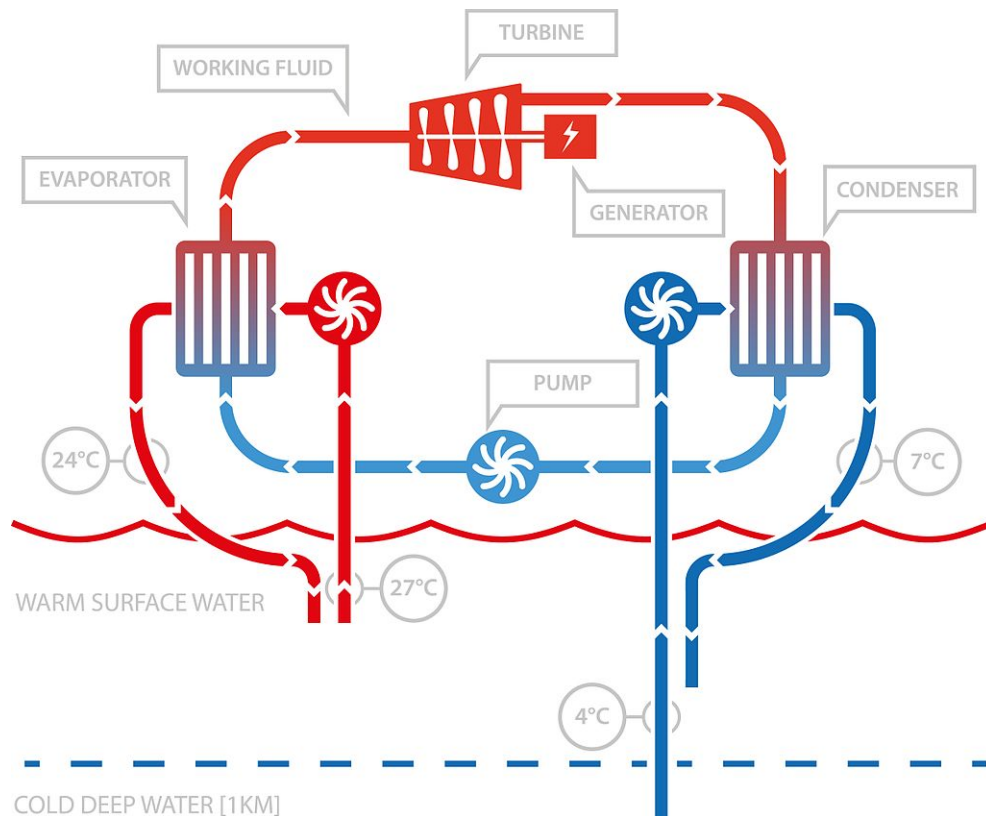


Figure 25. Working principle of an OTEC plant. Source: Wikimedia. License: CC BY-SA 4.0. <http://bit.ly/2DyHDdX>.

latter indicates the necessity of confining the ammonia within the system, due to the serious environmental impact that could be caused.

The potential of OTEC is remarkable, but it is not clear if a significant development will be achieved in future years. Current efficiencies are low due to its low maturity, which also implies high LCOEs. Current plants exhibit production in the KW range, while future OTEC systems are expected to increase to the MW range.

Question 4.2: Fluids and Boiling Points [300 XP]

Regarding open and close cycle OTEC systems: do you know what the boiling points of water and ammonia are? Is it possible to modify the temperatures associated with these boiling points?

4.3.3 Ocean Energies: Evolution and Forecast

Having presented the fundamentals of ocean energies, it would be very interesting to analyze the forecasts of these systems. There is a fantastic study in the IDAE report entitled “Evolución tecnológica y prospectiva de costes de las energías renovables”¹. Figure 26 (from this report) relates generation costs to technological maturity. Obviously, when a technol-

¹[Technological evolution and cost prospective of REs] <http://bit.ly/2nRALmR>

ogy is in its early stages (experimental, research and development), generation costs will be high. However, as this technology evolves toward a more mature stage, these costs will be significantly decreased.

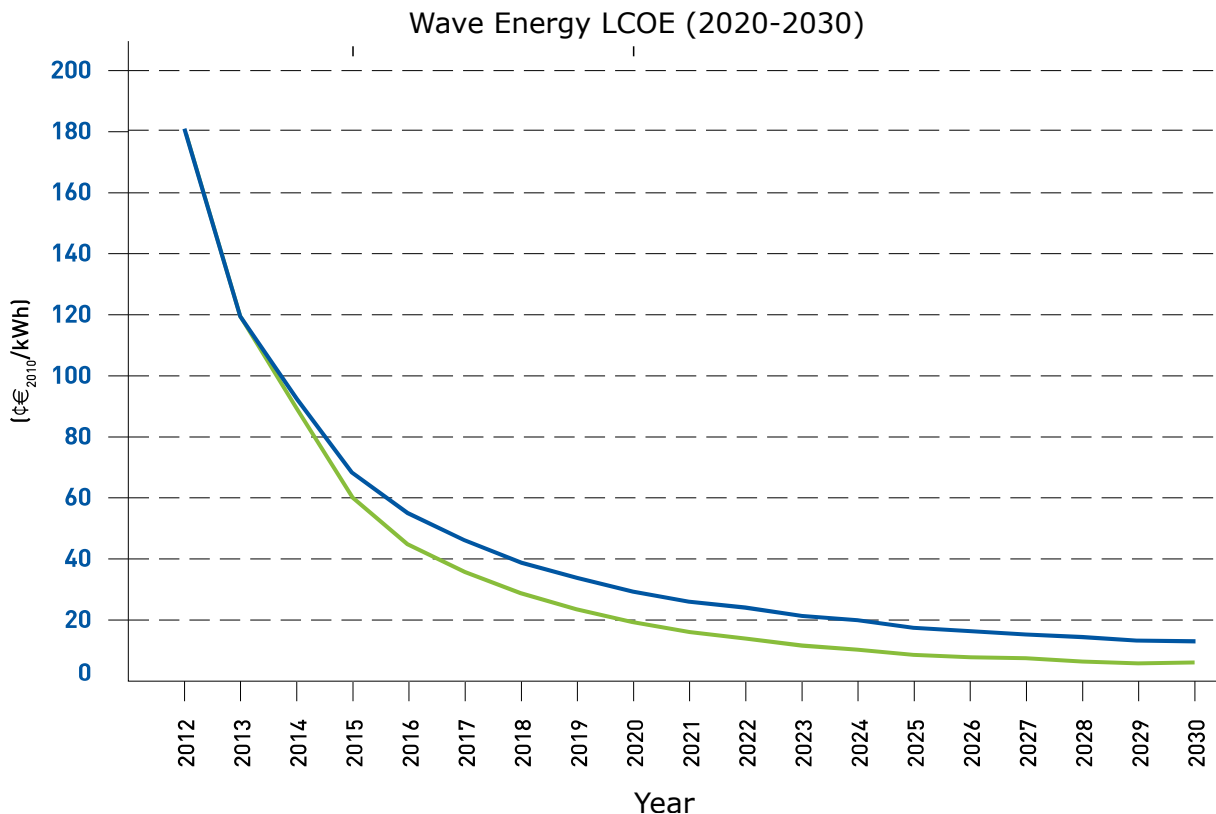


Figure 26. Forecast of the generation cost evolution for wave energy. Source: IDAE “Evolución tecnológica y prospectiva de costes de las energías renovables” <http://bit.ly/2nRALmR>.

Three phases have been represented in terms of technological maturity (this particular case concerns wave power, but it could be perfectly extrapolated to any other RE):

Reliability confirmation: The achieved technological development does not allow conclusions to be made about lifetime, efficiency or generation cost.

Take-off: Where lifetime and efficiency improve and generation costs decrease towards grid parity.

Consolidation: Lifetime and efficiency come close to their expected values

4.3.4 Levelized Cost of Energy: LCOE

The concept of LCOE was already introduced in the first chapter of this course. Some graphs were also discussed in Chapter 2; however, data regarding the LCOE of ocean energies don't appear in these reports¹. This is due to their lack of maturity, which gives rise to very high LCOEs.

¹See for example: Renewables 2018 Global Status Report (REN21). <http://bit.ly/2TltWKU>

Figure 27 is specifically focused on ocean energies and it can be appreciated how all these technologies, **with the only exception of tidal energy**, are in low stages of maturity. For example, wave power is currently dealing with several buoy designs, in an attempt to find the most suitable devices for development in the near future.

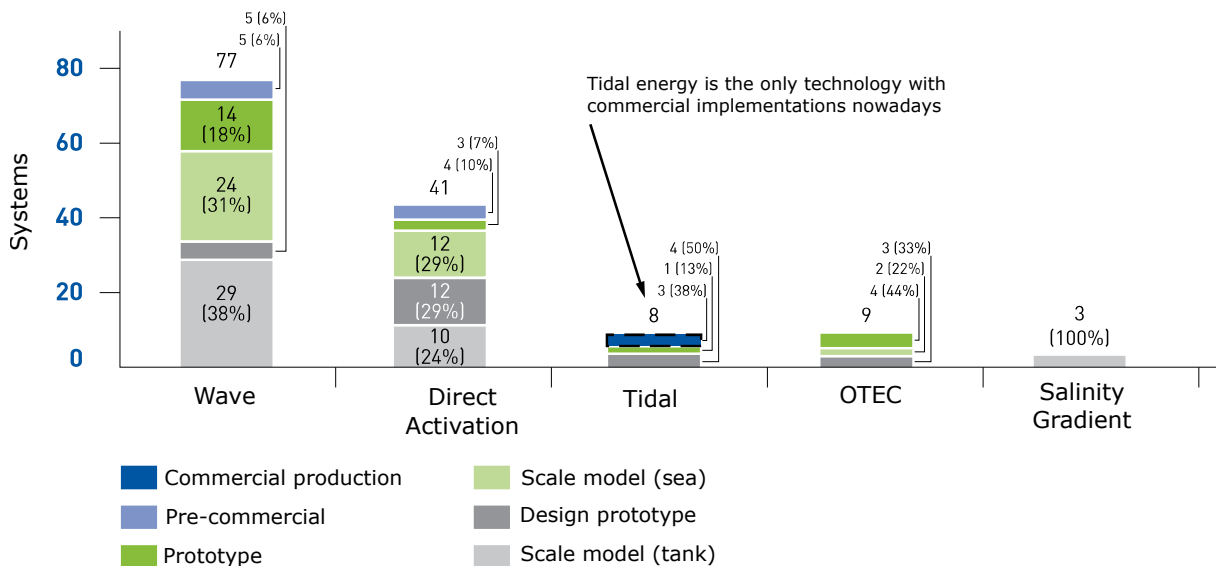


Figure 27. Technological maturity of ocean energies. Source: IDAE “Evolución tecnológica y perspectiva de costes de las energías renovables” <http://bit.ly/2nRALmR>.

Question 4.3: Salinity Gradient [500 XP]

In Figure 27, a new technology appears: **Salinity Gradient**. As it has not been mentioned in the course, look for information about it and explain, **in your own words**, the working principle of this technology. Also comment on the technological maturity of this technology and current projects.

4.3.5 Ocean Energies: Pros and Cons

Ocean energies exhibit some clear advantages, like their non-emitting nature or the absence of noise. Moreover, islands are normally complicated locations in terms of power grid energy distribution, however they are perfect locations for the development of these systems.

As disadvantages, these projects usually imply visual and environmental impacts, affecting animals. Technological maturity is, generally speaking low, thus currently giving rise to high LCOEs. Finally, these systems have to be deployed in very harsh environments, given the effect of sea water on electronics, metallic structures and so on.

Pros	Cons
Renewable	Visual and environmental impact
Non-emitting	Impact on animals
Silent	Limited power
Suitable for islands	High LCOEs
	Complicated maintenance
	Low maturity

Question 4.4: Wave Power: Problems [400 XP]

Let's assume that you are an engineer working for a company interested in the development of wave power systems. You are asked to write a list of possible problems derived from the installation and maintenance of a wave power system. Draw up this list with as many entries as possible.

KEY FACTS



- **More than USD 180 million** in new investment flowed into the sector from diverse sources, including public funding programmes, private investment, initial public offerings and crowdfunding
- **The ocean power industry** rebounded in 2021 as supply chains recovered from disruptions caused by the COVID-19 pandemic.
- **Maintaining revenue support** for ocean power technologies remains crucial for helping the industry achieve greater maturity.

Figure 28. Key facts of the current situation of ocean energies. Source: REN21 (2022 Report). Link: <https://bit.ly/3MR1R7x>.

4.4 Geothermal Energy

Geothermal Energy refers to the use of the energy stored as heat (associated with volcanoes, hot springs, geysers, etc.) beneath the Earth's surface. This is one of the few REs that is not directly related to the Sun as an energy source, as geothermal heat has its origin in radioactive isotopes, in the movement of the surface layers of the Earth and in the latent heat coming from inner core crystallization.

Taking into consideration the entire surface of the Earth, the available potential geothermal energy is $4.2 \cdot 10^{12}$ J. This is obviously a huge amount of energy, but only a small fraction can be collected by us. The geothermal resource is, therefore, the heat fraction that, coming from the inside of the Earth, can be used by us for different purposes, for example electricity production.

4.4.1 Geothermal Energy: a brief History

Geothermal energy has been used for many centuries. Bath, for example, a city located in South West England, was named after the baths built by the Romans. However, it was only



Figure 29. Geothermal power plant in Iceland. Source: Wikimedia / Gretar Ivarsson - Edited by Fir0002 - Gretar Ivarsson, geologist at Nesjavellir. The Nesjavellir Geothermal Power Plant in Pingvellir, Iceland. License: Public Domain <http://bit.ly/2nJVk0v>

in the 20th century when the potential of this energy source was exploited for electricity production. In 1904 the first geothermal plant was built. The Larderello geothermal plant (Northern Italy, close to Pisa and Florence) was built in 1911 (see [Figure 30](#)).

Important! 4.5: Larderello Geothermal Plant

More than 100 years later, the Larderello Geothermal plant is still working, operated by Enel and with an estimated 10% of the global geothermal power capacity (4800 MW).

In terms of its use, high temperature geothermal resources are often used to produce electricity, with temperatures above 100-150 °C). For resources with lower temperatures, heating applications are considered.

4.4.2 Geothermal Power Plants: Types

Electricity generation by means of geothermal power is carried out in 3 different types of power plants: dry steam, flash and binary cycle.

Dry steam power plants are probably the less common of the three. In this case, the vapor required to activate the turbine comes spontaneously from the well, thus locations with



Figure 30. Larderello geothermal plant in 1913. Source: manodemandiocaambiente.blogspot.com.es <http://bit.ly/2DH8dG8>

very high temperature gradients are required.

Flash power plants are based on the use of high-pressure water pulled from the well. This water is vaporized as the pressure decreases and the resulting vapor is used to activate the turbine. This is probably the most common geothermal power plant.

Finally, **geothermal binary cycle** power plants use an intermediate stage, with a heat exchanger where vapor is generated at lower temperatures.

Apart from electricity production, it is worth mentioning that geothermal energy can also be used for heated water and heating in homes and buildings.

4.4.3 Geothermal Energy: Locations

There are not suitable geothermal locations everywhere and, unlike other renewable sources like solar and wind energy, in this case it is necessary to “extract” the resource, as it is initially “hidden” from us. In Spain, for example, suitable geothermal locations are mainly located in Andalusia and the Canary Islands.

In terms of global capacity, **USA** leads the list of **TOP 10 countries**, with Indonesia, Philippines and Turkey in the following positions.

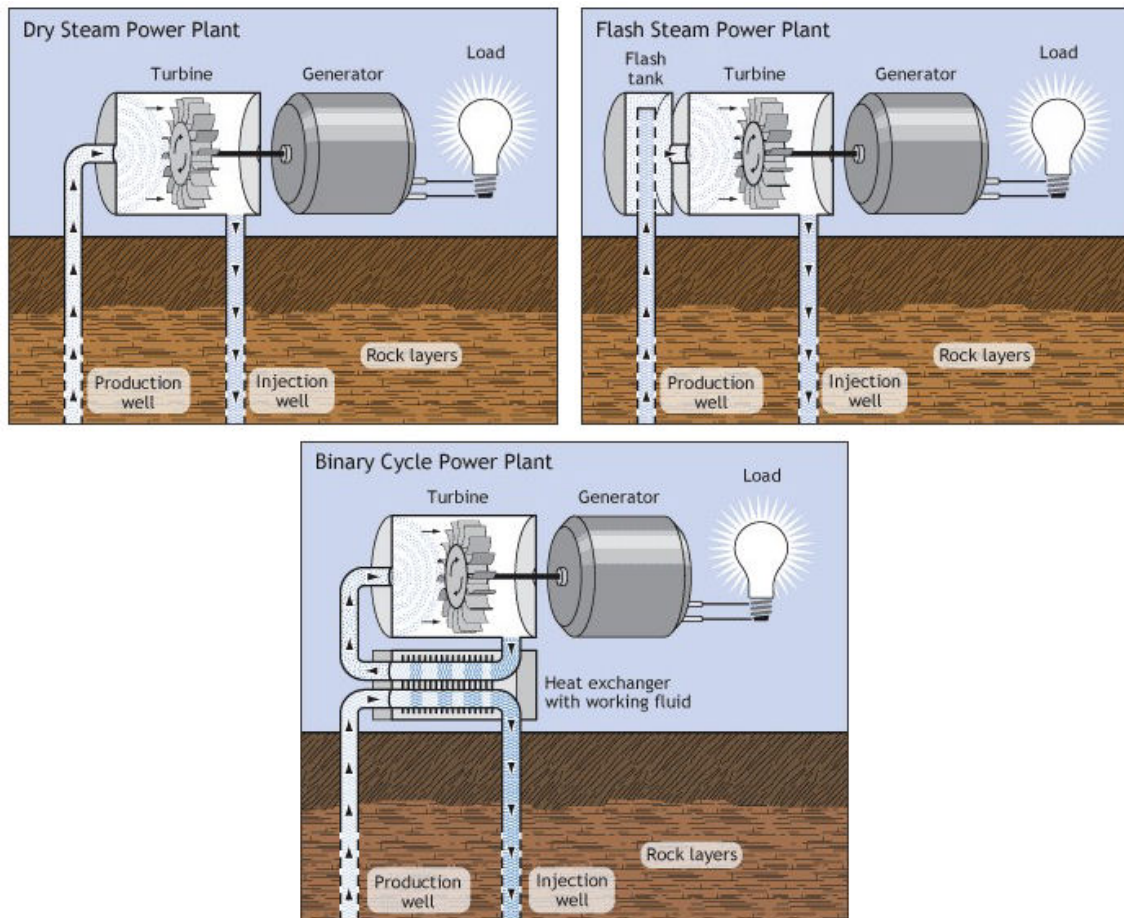
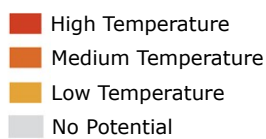
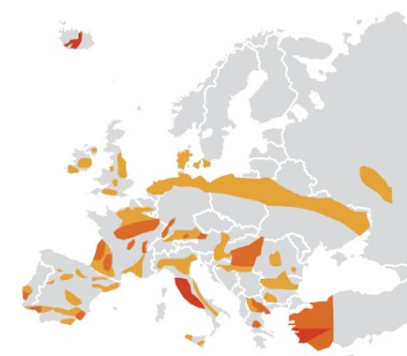


Figure 31. Geothermal power plants: types. Source: energyalmanac <http://bit.ly/1N50wjm>

Geothermal Potential in Europe



Geothermal Potential in Spain

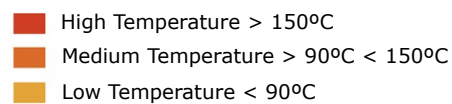
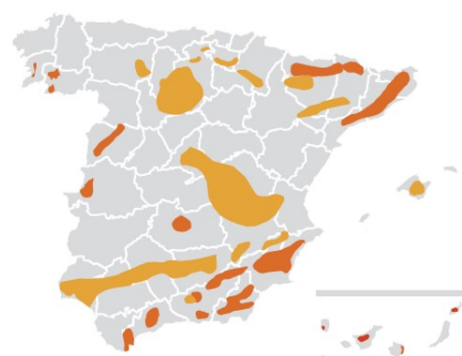


Figure 32. Suitable geothermal locations in Europe and Spain. Source: EGE (European Geothermal Energy Council)

Geothermal Power Capacity and Additions, Top 10 Countries and Rest of World, 2021
Megawatts

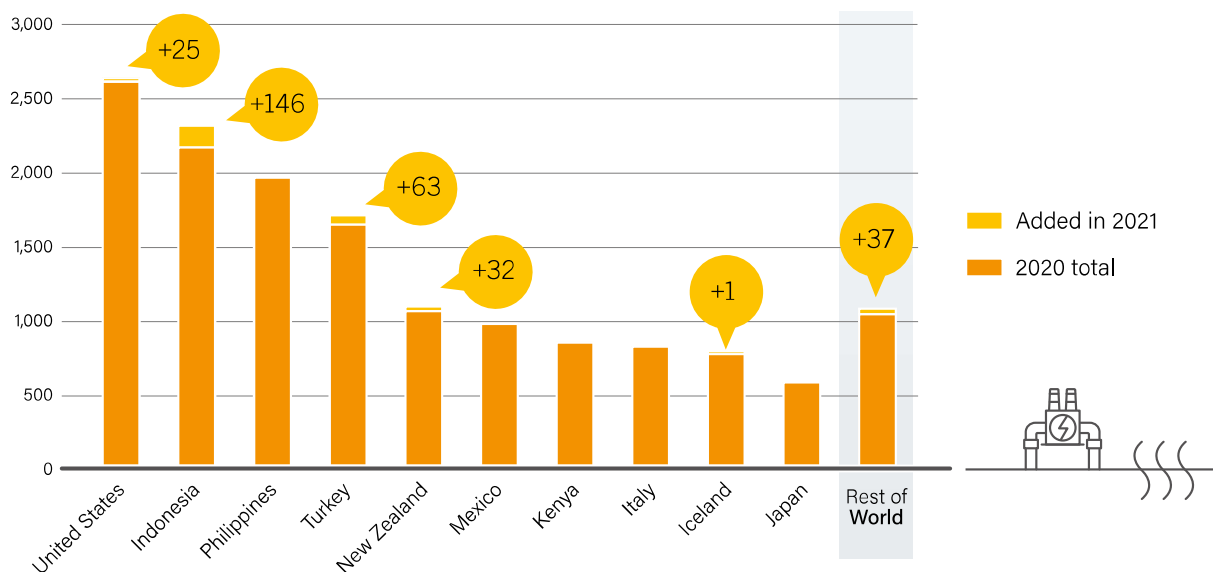


Figure 33. Top 10 countries for geothermal capacity and additions. Source: REN21 (2022 Report).
Link: <https://bit.ly/3MR1R7x>.

Normally, the excavation of a well is required to evaluate the temperature and determine whether or not the location is suitable. In addition, other techniques can also be employed:

- Satellite/airborne imaging
- Volcanic studies
- Geological and structural mapping
- Geo-chemical and geo-physical studies

4.4.4 Geothermal Energy: Environmental Impact

Are there any environmental impacts associated with geothermal power plants? The answer is YES. CO₂ or other GHG emissions are low and, in any case, much lower than those generated in fossil fuel power plants. However, low concentrations of Radon may appear as a by-product of Uranium, one of the isotopes responsible for the heat accumulated below the Earth's surface. Radon is the second cause of lung cancer. All in all, this problem has few consequences, as geothermal plants include recycling procedures to avoid the emission of these particles.

4.5 Biomass

Bio-Energy can be defined as the energy that comes from materials derived from biological sources. Biomass can be understood as the organic matter that has been able to transform

KEY FACTS

- **New geothermal power** generating capacity of 0.3 gigawatts (GW) came online in 2021, bringing the global total to around 14.5 GW. This was more than double the additions in 2020 but below the five-year average of 0.5 GW since 2016.
- **Geothermal power** and heat development is highly concentrated across a few countries and typically is concentrated in key geographic locations within countries.
- **During 2016-2021**, the top markets in reported power capacity additions were Turkey (0.9 GW added), Indonesia (0.7 GW), Kenya (0.2 GW) and the United States (0.2 GW), followed by Iceland, Chile, Japan, New Zealand, Costa Rica and Mexico (all less than 0.1 GW each).
- **In the most active markets** (Turkey and Indonesia), further development of geothermal resources is contingent on government support mechanisms; however, lower feed-in tariffs in Turkey may be causing a slowdown.
- **Geothermal heat (direct) use** may have increased nearly 10% in 2021, mostly in China. The top countries for geothermal direct use remain (in descending order) China, Turkey, Iceland and Japan.

Figure 34. Key facts regarding geothermal energy. Source: REN21 (2022 Report). Link: <https://bit.ly/3MR1R7x>.

solar radiation into chemical energy. Within biomass energy, there are certain categories depending on the use. **Traditional biomass**, for example, is used (mostly in developing countries) for heating and cooking. It implies the burning of wood or similar biomass resources at homes and, consequently, it might be unsafe (and even unsustainable).

Modern biomass also includes the use of **biomass boilers in homes or buildings**. They use the so-called “pellets”, which are small cylinders of compressed sawdust, as fuel.



Figure 35. Scheme of a domestic biomass boiler. Source: <http://bit.ly/2Gjping>.

Important! 4.6: Biomass Boilers: Examples

As an example, a 22 KW pellet boiler can be used for a 250 m^2 home, at an estimated cost of 16000 euros. For a building with 48 apartments, two 450 KW boilers would be necessary.

Biomass power plants use the same principle to generate electricity. Biomass has often been classified as renewable energy, for example by the European Union, because plant stocks can be replaced with new growth. However, it should be considered that this is an emitting technology, with CO₂ release.

Important! 4.7: Biomass Plants

The largest biomass plant is located in Drax (North Yorkshire, UK), where 6 million pellets are used per year to supply 3 generators (600 MW)^a. It is worth noting that the biomass material used in this plant comes mainly from the USA and Canada, what has led to some controversy^b.

^a<http://bit.ly/2DAKpj0>

^b<http://bit.ly/1qZxm3j>

Biomass power plants do not only generate GHG emissions, but also **PM (Particulate Matter) particles** that are also present in car emissions. PM is a complex mixture of extremely small particles and liquid droplets that get into the air. Once inhaled, these particles can affect the heart and lungs and cause **serious health effects**. There are some research groups working on the real-time detection of PM, for example the following one carried out by Ceder/Ciemat: <http://bit.ly/2revnvr>.

Question 4.5: Biomass [500 XP]

Read this article: <http://bit.ly/1qZxm3j>. Give your opinion on Biomass, providing any additional relevant data of your choice.

Question 4.6: Technological Brainstorming [500 XP]

Several RE technologies have been presented in this chapter: hydro-power, ocean (tidal, wave and OTEC), geothermal and biomass energies. Taking into account all the information provided during the course, try to imagine a **NEW renewable technology**. Briefly explain its working principle.

4.6 Conclusions

This course has placed a special emphasis on RE fundamentals, as well as on solar PV and wind energies. However, basic information has also been provided on **hydro-power, ocean, geothermal and biomass energies**, in order to give a more complete picture of the renewable energy scenario.