Green Energy

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Annotation

This course describes technologies, applications and basic concepts related to most relevant sources of renewable energies.

Objectives

After this course in Green Energy, the student will achieve knowledge about main characteristics and applications of most relevant sources of renewable energies as hydroelectric, wind and geothermal energies, biomass, and photovoltaic solar energy.

Keywords

hydroelectric energy, wind energy, photovoltaics, hydrogen technologies, biomass, geothermal energy

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Literature

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CHAPTER 1

Introduction

Main energy source before the nineteenth century was wood. The use of Coal as energy source started with the First Industrial Revolution and was replaced by oil and gas in the Second. Nowadays, major fossil fuels coexisting alongside with nuclear are the main energy sources used worldwide.

Nuclear energy presents clear problems associated with the storage and recycling of the waste it produces. In addition, recent accidents in this type of nuclear plants have made clear the potential danger it poses.

On the other hand, fossil fuels are main responsible of the global warming and climate change.

The energy demand is still growing worldwide, and this trend will continue in the future. However, it is necessary to change the energy production ways, trying to avoid the massive use of fossil fuels in order to reduce the greenhouse effect and stop climate change.

DEFINITION

Green energy is any energy type that comes from renewable energy sources. It is generated from natural resources, such as sunlight, wind, or water.

Nowadays just the 27.3% of the electricity generation comes from renewable sources of energy, as it can be seen in Table 1, while the other 72.7% is achieved by means of non-renewable electricity generation sources.

Table 1. Estimated Renewable Share of Global Electricity production (End-2019)

Renewable Energy	%
Wind Power	5.9
Solar Photovoltaic	2.8
Bio-power	2.2
Geothermal, CSP and ocean power	0.4

In this context, renewable or green energies must play a major role in the energy generation of the future. The key with green energy resources is that they do not harm the environment through factors such as releasing greenhouse gases into the atmosphere. This course describes main sources and technologies used in green energy generation.

CHAPTER 2

Hydroelectric Energy

Hydroelectric energy is the main renewable source in the world since the great availability of water allows to obtain a high yield. Currently, it covers about 20% of the world's electricity demand. Hydroelectric energy has an important role to play in the future since it plays a major role in reducing greenhouse gas emissions.

DEFINITION

Hydroelectric energy is obtained from the use of kinetic and potential energies of the water current, waterfalls or tides, either through mills or dams.

Hydroelectric energy has been exploited for centuries. Farmers since the ancient Greeks have used water wheels to grind wheat into flour. Placed in a river, a water wheel picks up flowing water in buckets located around the wheel. The kinetic energy of the flowing river turns the wheel and is converted into mechanical energy that runs the mill. [1]

DEFINITION

Hydroelectric energy is the electrical energy that is generated in a hydroelectric plant from water in motion, by using flowing water or a waterfall to drive a water turbine and generator. The generation process is highly efficient, being able to reach levels of efficiency between 90 and 95%.

Hydroelectric energy is characterized by being one of the most profitable energies. The initial construction investment of a hydroelectric plant is high. However, maintenance costs for this type of infrastructure are low.

2.1 Types of hydroelectric plants

Hydroelectric plants are usually located far from the large consumption centers and the place of their settlement is conditioned by the characteristics of the terrain.

DEFINITION

Not all hydroelectric plants are the same. Some hydroelectric plants use dams, and some do not. Depending on their mode of operation, there are basically three predominant types: Storage, Run-of-river, and Pumped storage [2].

Storage

This is the most widespread hydroelectric plant. They are large plants. By building one or more dams, reservoirs are formed that are used to retain large amounts of water and, in this way, regulate the flow that passes through the turbines that generate electricity. This allows energy production to be stable throughout the year and satisfy the electricity needs of each moment.

Run-of-river

Most small hydroelectric plants are based on the run-of-river type. All of them are characterized by not having a water storage capability which makes this type of plant subject to seasonal river flows. To minimize this, run-of-river plants are usually installed on rivers with a consistent and steady flow or with a large reservoir at the head of the river.

In run-of-river plants the flowing water of the river is diverted to a channel to spin a turbine that generates electricity. Afterwards, the diverted water is returned to the main river. The generation of electricity depends on the speed of the water.

Pumped storage

Its operation is very similar to that of a large rechargeable battery. The plant has two reservoirs at different heights and connected to each other. In times of low electricity consumption, the excess energy is used to raise the water contained in the reservoir located at the lowest level to the upper reservoir by means of a hydraulic pump. In the hours of greatest energy demand, the pumping station works like a conventional storage hydroelectric plant.

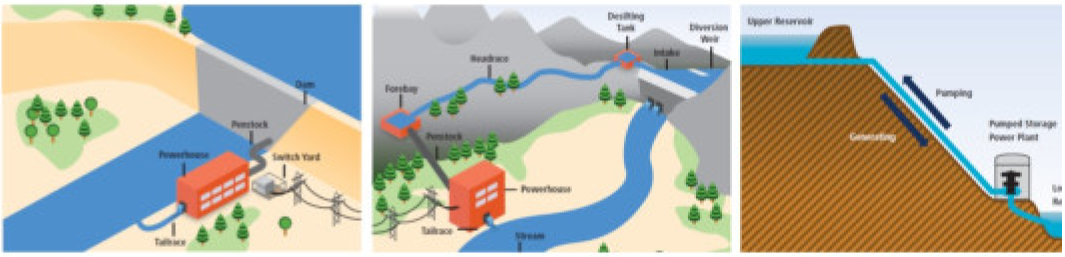

Fig. 1. Types of hydroelectric plants [2]

Hydroelectric plants can also be classified by size according to the power output although there is no international consensus for setting the size threshold between small and large hydroelectric plants. In some countries the threshold is set at 30MW while in others it is set at 10 MW. The following table shows the usual classification: [3]

Table 2. Hydroelectric plants classification according to power generation

Size of the hydroelectric plant	Power output
Large plant	Above 10-30 MW
Small plant	1 MW to 10-30 MW
Mini plant	100 kW to 1 MW
Micro plant	Below 100 kW

Fig. 2. Hydroelectric plant of Mequinenza (Spain)

2.2 Advantages and disadvantages of hydroelectric energy

The following are some advantages of the use of hydroelectric energy: [4]

- **Flexibility**. It is possible to adapt the flow of water that passes through the turbines to the electricity needs of each moment.
- **Clean energy**. The generation process of electrical energy is clean, since it does not produce waste, as occurs with energy derived from fossil fuels or nuclear energy.
- **Safety**. The risks of water leaks are quite low, due to the safety measures that are currently taken in the hydroelectric plants today.
- **Inexhaustible resource**. The source of energy, water, is free and inexhaustible since it is renewed with the rains and thaws.
- **Stable source of energy**. Hydroelectric energy is very stable unlike, for example, solar energy which directly depends on the sky situation. In other words, hydroelectric energy does not depend on rain every day to produce electricity because there are very important water reserves.

There are also several negative points about this type of energy, such as:

- **Environmental effects**. The construction of a dam has important environmental consequences, since it influences the course of a river and floods an area of land, which produces effects on flora and fauna. On the other hand, when the dams open and close there are effects on the fish and on the river ecosystem.
- **High cost of a hydroelectric plant**. In the long run, hydroelectric energy is very cheap, and maintenance is simple, but the construction of a hydroelectric plant involves a high cost.
- **Depends on environmental conditions**. It is true that hydroelectric energy does not depend on rain on a daily basis. However, the lack of rains will affect energy production. So, seasons with many droughts reduce the amount of water stored and the amount of electricity that can be produced.
- **A dam cannot be built anywhere**. The characteristics of the terrain and the height that the dam may have been essential for a hydroelectric plant to be installed.

2.3 Hydroelectrical energy in the world

The leading producer of hydroelectric energy in the world is China, with a total installed capacity of 356.4 GW, who also owns the largest hydroelectric plant in the world, the Three Gorges Dam with is a capacity of 22.5 GW. [5]

China is followed by Brazil with a capacity of 109.1 GW, followed closely by the US with an installed capacity of 102.8 GW. One of the main plants in the US is the Grand Coulee with 6.81 GW of capacity and located in the Columbia River, Washington.

In the list of top 10 hydroelectric producing countries in the world in 2020, it follows with Canada, 81.4 GW, India (50.1 GW), Japan and Russia, both with 49.9 GW, Norway (32.7 GW), Turkey with 28.5 GW and finally France, that closes the list with a total installed capacity of 25.6 GW.

Interaktivní prvek

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CHAPTER 3

Wind energy

Wind energy is one of the oldest energy sources exploited by humans and today is the most established and efficient renewable energy source in the world.

DEFINITION

After hydroelectric energy, wind energy is the second largest renewable energy source worldwide.

Solar radiation is not received equally at the entire surface of the Earth. Some areas get hotter than others and in those areas the air tends to rise, generating areas of low pressure. On the other hand, in the coldest areas the air descends creating areas of high pressure. The difference between pressures causes the air to move and the wind originates.

DEFINITION

Wind energy is a renewable energy which is obtained from the force of the wind passing through a wind turbine that transforms the kinetic energy of the air flow into electrical energy.

Wind energy is a renewable, efficient, mature, and safe energy that is key to the energy transition and the decarbonization of the economy.

DEFINITION

Generally, wind turbines are grouped to form what is known as a wind farm.

The number of wind turbines that make up a wind farm is highly variable and depends fundamentally on the available surface and the characteristics of the wind at the location. Before setting up a wind farm, the wind is studied at the chosen location for a period that is usually longer than a year. Important parameters are the directions of the wind and its speed.

DEFINITION

Wind farms can be located on land or offshore (overseas), the former is the most common, although offshore parks have experienced significant growth in Europe in recent years.

The world's first offshore wind farm was installed in Vindeby, off the southern coast of Denmark, in 1991. Thirty years later, offshore wind energy is a mature, large-scale technology providing energy for millions of people across the globe. New installations have high-capacity factors and the costs have steadily fallen over the last 10 years. [6]

3.1 Types of wind turbines

There are two types of wind turbines depending on the direction of the rotation axis: the horizontal-axis wind turbines (HAWTs) and vertical-axis wind turbines (VAWTs) [7-8]. HAWTs are the most common type of wind turbine and are the ones we can find in these large wind farms where this type of wind turbine can be used above 1 MW of power.

A HAWT consists of a steel tower with heights between 60 and 100 meters. At the top of the tower there is a gondola where the most important elements of the wind turbine are located. At the front of the gondola, two or three long (20-60 meters) and thin blades are positioned so that they face directly into the wind. Most blades for large wind turbines are made of glass fibers or epoxy composites. The lifetime of a blade is approximately 15-20 years. This type of wind turbine can generate a very variable power, up to 10-12 MW depending on the wind of the place and the weather.

A VAWT is essentially a wind turbine in which the rotor shaft is installed upright and can generate electricity no matter where the wind is coming from. VAWTs have shorter, wider curved blades that resemble the beaters used in an electric mixer. The advantage of this type of vertical wind turbine is that it can generate electricity even in places with little wind and urban areas where building regulations generally prohibit the installation of horizontal wind turbines. VAWTs do not need an orientation mechanism and what would be the electric generator can be located on the ground. The advantage of these vertical wind turbines is that they are smaller and lighter than horizontal wind turbines, but the energy production is lower because their much lower efficiency compared to HAWTs.

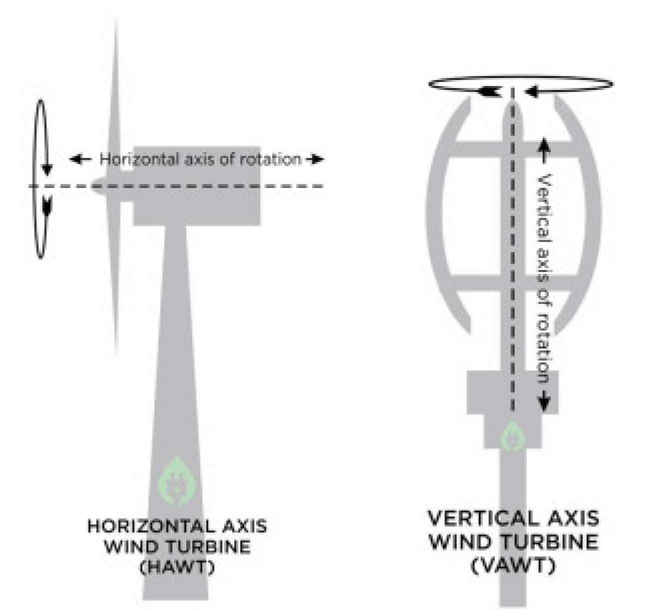

Fig. 3. HAWT vs VAWT wind turbines [8]

DEFINITION

The amount of electricity generated by a wind turbine is proportional to the cube of the wind speed.

Therefore wind turbines are generally placed in areas with high wind speeds, typically on tops of hills or in flat open areas. Wind turbines require a minimum wind speed to begin generating electricity, generally 12-14 km/h. This is also known as the cut-in speed. Strong winds between 50-60 km/h provide the maximum output power. At wind speeds beyond 90 km/h, the turbine is stopped to avoid damage. This is the cut-out speed.

3.2 Advantages and disadvantages of wind energy

Wind energy offers numerous benefits and helps to minimize the impact of climate change. The following are some of the main benefits:

- **Renewable and clean energy**. It is a renewable natural resource that does not produce atmospheric emissions or pollutants.
- **Availability**. Wind energy is available almost everywhere on the planet; therefore it fosters wealth and the generation of local employment.
- **Deployed at almost any location**. Wind turbines can be installed in locations not suitable for other purposes, such as desert areas and can also coexist with other uses of the land, such as cultivation or livestock.
- **Quick installation**. Wind turbines can be installed at different heights to achieve stable production.
- **Cheap energy**. It is considered a low-cost energy whose price remains quite stable, so it can compete in profitability with traditional energy sources, as well as being a source of savings.

One of the biggest disadvantages of this type of energy is the planning of obtaining energy due to the randomness of the wind. The following are the main disadvantages:

- **Lack of wind**. This reason prevents wind energy from being used as the sole source of electrical energy. However, this could be solved by using electrical energy storage devices.
- **Wind speed limit**. If the wind speed is higher than the maximum that the wind turbine can withstand, it causes damage to the shaft and production of electricity is reduced, so control systems are required to disconnect the wind turbine or modify the blades.
- **High voltage lines must be built**. To distribute electrical energy from wind farms, it is necessary to build high voltage lines capable of transmitting the maximum amount of electricity generated.
- **Environmental impact.** The deployment of wind farms causes damage and deaths to birds and bats and also has a visual impact on natural landscapes. New wind turbine designs are changing this trend.
- **Wind farms occupy large areas**. Wind turbines must be separate, although this same area can be used simultaneously for other purposes.
- **Unstable source of energy**. The randomness of the wind is a serious obstacle to plan a stable energy production, even though the latest meteorological advances for wind forecasting have greatly improved the situation.

3.3 Wind energy in the world

The International Renewable Energy Agency (IRENA) estimates that global wind generation exceeded 732GW by the end of 2020. [9] China had the largest installed wind capacity in 2021, 342 GW, which is over one quarter of the wind power capacity of the world.

China is followed by The United States, with a capacity of 139 GW. The state of Texas alone produces a quarter of the wind power of The United States, with 24.9 GW, providing more wind power than 25 other US states combined.

At a certain distance they are followed by Germany, with a capacity of 64 GW, being the first European country in installed wind capacity. Then it follows India with 42 GW and Spain with 29 GW.

Finally, Italy, with an installed wind capacity of 12.7 GW closes the list of the top 10 wind energy producing countries.

Video 1

CHAPTER 4

Photovoltaic Solar Energy

The solar energy that affects the entire earth's surface annually represents about five thousand times the energy demand of the world population, for that reason it is the main source of renewable energy within our reach. In addition, solar energy offers a series of advantages over other renewable energies: It is not polluting since it does not emit any type of waste into the atmosphere, nor does it produce noise pollution, since its generation is silent, and it is available all over the planet. Although not all points on the earth receive the same amount of energy from the sun. Two types of technologies are used to take advantage of solar energy: photovoltaic solar technology and solar thermal technology.

The term photovoltaic (PV) comes from the Greek word Photo (light) and the name of the Italian physicist Alessandro Volta, inventor of the chemical battery.

DEFINITION

Photovoltaic solar technology allows direct transformation of sunlight or solar radiation into electricity. It is responsible for harnessing the energy of photons into electrical energy, generating electrons, with photovoltaic solar modules, for this purpose, it uses devices called solar cells.

Edmund Bequerel discovered the photovoltaic effect in 1839. Albert Einstein proposed a mathematical description of the photoelectric effect in which the emission of electrons was produced by the absorption of quanta of light that would later be called photons. [10] For this explanation of the photoelectric effect, Einstein received the Nobel Prize in Physics in 1921.

Solar thermal technology takes advantage of the sun's energy to heat water that can be used for domestic consumption: Heating, sanitary hot water, or to produce mechanical energy, which we can then transform into electrical energy. Solar thermal energy is also used to power absorption cooling machines, which instead of using electricity to produce cold, use heat.

The basic elements of solar thermal energy are solar collectors, responsible for capturing solar radiation and converting it into thermal energy: Heat, which is used to heat water directly or a special liquid that in a later stage would heat water through an exchanger.

SUMMARY

In this chapter, we will focus on analyzing photovoltaic solar energy in detail.

Video 2

4.1 Solar Radiation

DEFINITION

Solar radiation is the energy emitted by the Sun, which propagates in all directions through space using electromagnetic waves.

The radiation that comes from the sun is equivalent to that radiated by a black body at a temperature of 6000 K. Part of the energy that reaches us from the sun, about 30% of this radiation, is reflected into space. Gas molecules and suspended particles that are present in the different layers of the atmosphere absorb another part and the rest reaches the earth's surface.

In the equatorial zones the solar radiation affects directly, in the poles, the radiation that arrives is much less. Because the atmosphere filters sunlight, when we are at a higher altitude and, therefore, the atmospheric layer is thinner, the energy we receive from the sun is greater.

DEFINITION

The term solar radiation refers to the values of solar irradiation, that is, the amount of energy received per unit area in each time.

The values of solar radiation express the energy that comes from direct radiation from the sun and diffuse radiation that, scattered through the atmosphere, comes from the rest of the sky.

The radiant power of the sun at the outer limit of the Earth's atmosphere, at about 150 million kilometers, corresponds to about 1,360 W/m^2. This value is called the Solar Constant: Gsc. Fig. 4 shows the irradiance spectral density that we receive from the sun on the earth's surface as a function of its wavelength, outside the atmosphere and on the earth's surface, as well as the absorption in the atmosphere associated with different elements present in it. As can be seen in the figure, most of the energy is centered in the visible spectrum, between 0.4 and 0.8 μm wavelength.

DEFINITION

The energy of the photons depends on the wavelength as shown by the following equation:

$$E = h\,\frac{c}{\lambda}$$

where h is Planck's constant, c the speed of light and λ the wavelength associated with the photon.

For a photon to be absorbed and generate a pair of carriers, electron / hole, in a material it is necessary that the energy of the photon is higher than the energy of the gap, E.g., of the material. In addition, each semiconductor material, the materials most used in the manufacture of solar cells, has a certain absorption coefficient, α. When light passes through a material, it is attenuated, and its absorption is proportional to its intensity at each wavelength. The number of photons that penetrate a semiconductor material decreases exponentially as a function of α and the distance they travel following Lambert's law. [11]

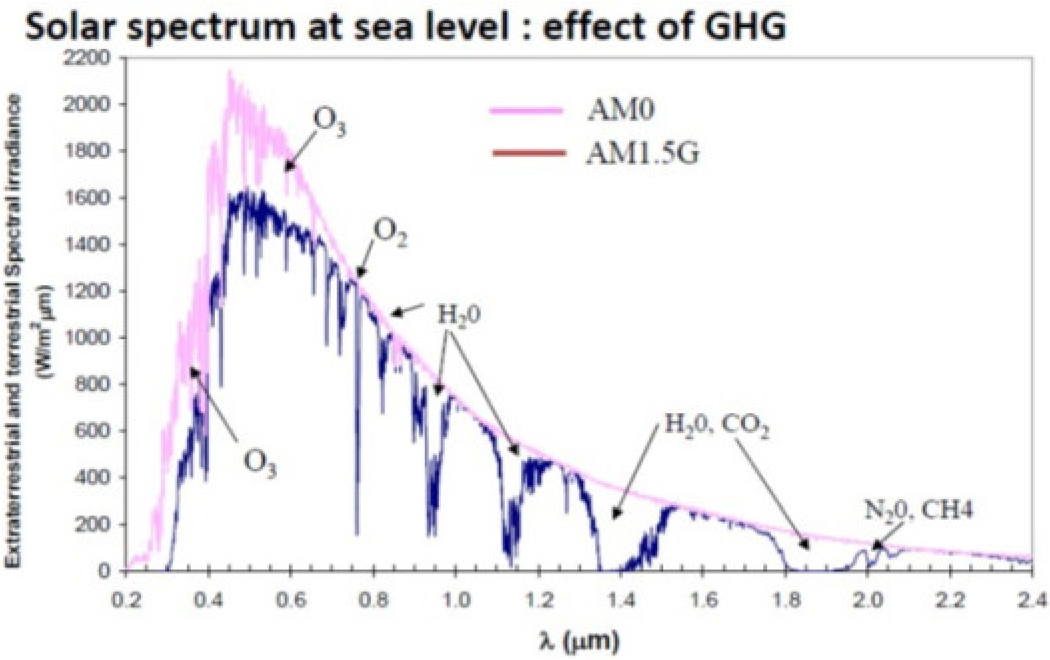

Fig. 4. Incident solar radiation on the earth's surface

DEFINITION

The reference solar spectrum outside the Earth's atmosphere is known as AM0, (AM: Air mass, amount of atmosphere that solar radiation passes through). At the earth's surface, the reference spectrum is AM1.5.

4.2 Photovoltaic Generator

DEFINITION

The electronic device in charge of transforming the sun's energy, incident photons, into electrical energy, a flow of free electrons that give rise to electric current, from the photoelectric effect is the solar cell.

An important characteristic of the solar cell is its efficiency.

DEFINITION

The efficiency of a solar cell, η, is defined as the relationship between the electrical power that it can deliver at its output with respect to the power of light incident on its surface:

$$\eta = \frac{Vm\, Im}{G\, A}$$

where *Vm, Im* are respectively the maximum voltage and current at the output of the solar cell under standard conditions (STC): Irradiance, $G = 1000\text{W/m}^2$ and temperature of 25 °C and A is the area of the solar cell.

W.G. Adams and R.E. Day manufactured the first solar cell on selenium (Se) in 1877, but it was not until 1954 that the first silicon (Si) solar cell was manufactured at Bell Laboratories, with efficiencies of 6%. This gives us an idea of how recent solar photovoltaic technology is. Despite this, today it is a very mature technology.

Most solar cells are based on semiconductor materials where a p-n junction has been created, a region with a defect of electrons (p) in contact with another one with excess electrons (n), which generates an electric field that allows the electrons to move in a certain direction and thus obtain an electrical current at the output of the device.

Solar cells are connected in series to obtain a higher output voltage and thus form PV modules. [12] Some PV modules have several branches of cells in series connected in parallel, which allows obtaining greater output current from the PV module. On the market, we can find PV modules with very different output powers depending on the number of solar cells they incorporate and how they are connected to each other. The efficiencies of PV modules depend on the efficiency of their solar cells and therefore on the material and technologies used in their manufacture.

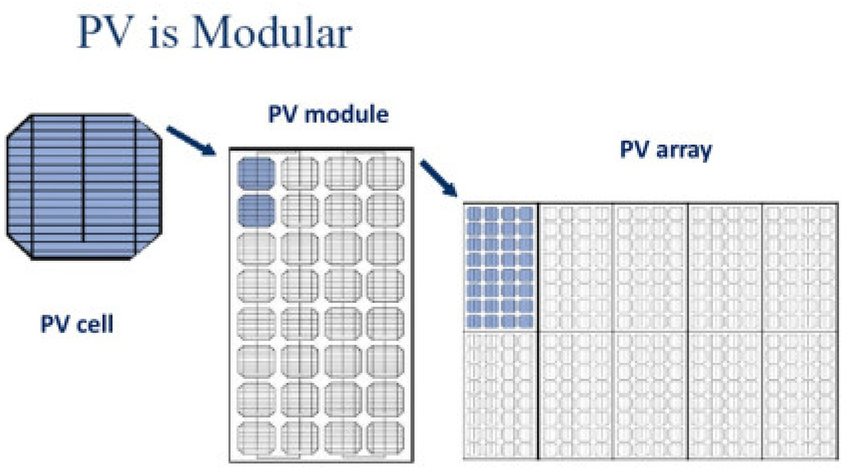

Fig. 5. From solar cells to PV arrays

PV is a modular and scalable technology. Thus, a PV generator is also constituted by the interconnection of parallel branches of PV modules connected in series, as shown in Fig. 5.

Video 3

4.3 PV modules manufacturing technologies

The 95% of the solar cells manufactured in 2020 were developed on silicon (Si) wafers, most of them, 84%, used mono-crystalline silicon (c-Si) and the rest multi-crystalline silicon (mc-Si). [13] The efficiency record for c-Si cells stands at 26.7%, while for mc-Si the maximum efficiency achieved for the solar cell is 24.4%.

Some thin film technologies are used in the manufacture of solar cells that are based on cheaper materials, but with lower efficiencies such as: CIGS or CdTe. Recently, research and production of solar cells has increased in materials such as Perovskites or Kesterites, also cheaper than Si, reaching efficiencies of 25.5% in the case of solar cells based on Perovskites.

The highest efficiency values in solar cells, up to 47% [14], are obtained in tandems of solar cells that take better advantage of the solar spectrum, based on compounds of groups III-V. These tandems are made up of several solar cells stacked in series and are expensive to manufacture, which is why their use is limited to space applications.

Currently, most commercial PV modules based on c-Si or mc-Si present efficiencies around 20%. The highest efficiency values achieved in PV solar modules of different technologies are summarized in the following Table.

Table 3. PV module top efficiencies 2020. [14]

Technology	Efficiency (%)	Manufacturer
c-Si	24.4	Kaneka
mc-Si	24.4	Hanwha Q cells
GaAs (thin film)	25.1	Alta devices
CdTe (thin film)	19	First Solar
Perovskite	17.9	Panasonic
Multi Junction (III-V)	31.2	Sharp

The cost of photovoltaic modules has dropped 26% in the last 40 years.

Today, photovoltaic solar energy is a mature technology and allows producing electricity at competitive costs, between 14 and 20 USD / MWh [13], with the rest of traditional energies based on fossil fuels. As an example, in 2021 the cost of electricity in Spain stands at 200 Euros / MWh and as in the rest of the countries of the European community, the price of electricity produced from non-renewable sources is expected to continue rising in the future.

DEFINITION

The total photovoltaic power installed worldwide is today 760 GW and allows avoiding the emission of 875 million tons of CO_2 per year into the atmosphere. However, it still represents a small percentage of global electrical energy production.

Undoubtedly, the growth of photovoltaic solar energy will continue to be exponential worldwide, as in recent decades, and it is called to be one of the most important solutions to global warming and to play a key role in the energy transition.

4.4 Photovoltaic Systems

Photovoltaic systems can be divided into two types: Stand-alone PV systems and Grid connected PV systems.

DEFINITION

Stand-alone PV systems are used when it is not possible to connect to an electrical distribution network.

Stand-alone PV systems were the first systems used in this field and their applications are multiple: Water pumping, telecommunication stations, radio and television repeaters, space applications in satellites or space vehicles, applications in households etc.

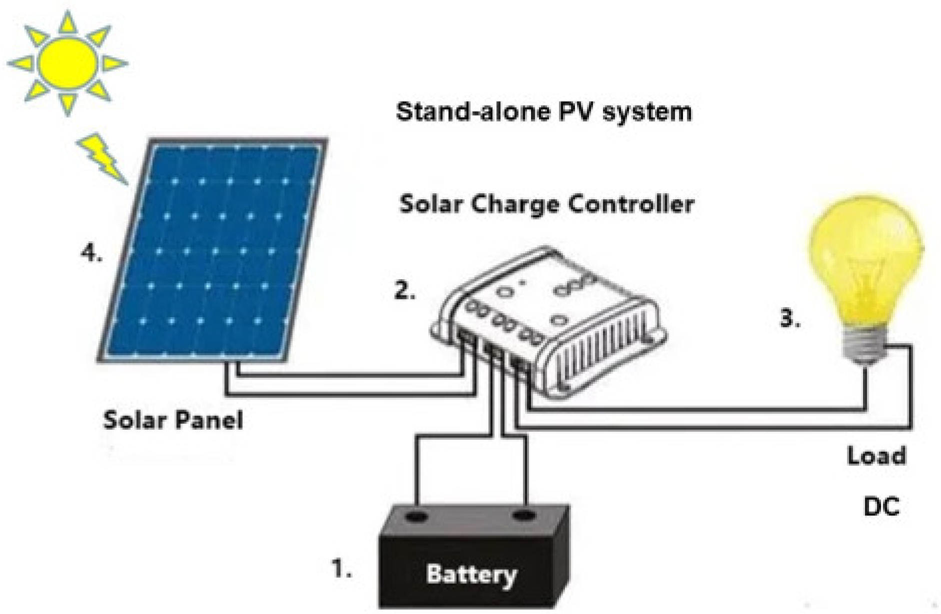

Fig. 6. Stand-alone PV system

Table 4. Elements included in a stand-alone PV system

Element	Description
[1] PV modules	Depending on the application, the size of the generator can vary from very low power systems with a single module to generators with several kW of peak power.

[2] Charge regulator	This element is responsible for protecting the batteries and keeping them in a suitable state of charge, depending on the energy demand of the system and the power available at the output of the photovoltaic generator. They can incorporate maximum power point trackers: MPPT, to maximize the use of the energy produced. This allows the photovoltaic generator to work at the point of maximum output power while the rest of the system works at the battery voltage and the current required by the loads at all times.
[3] Batteries	They are the energy accumulators that allow supplying electrical current to the loads when the PV generator does not produce, for example, at night. When the generator produces power, it recharges the batteries.
[4] System loads	Electrical loads that the PV system must supply in DC. If there are loads present that need to be powered in AC, it is possible to incorporate a DC / AC converter called an inverter.

DEFINITION

The second type of PV systems are systems connected to the electrical distribution network or grid- connected PV systems.

Nowadays, more than the 90% of existing PV installations are connected to the grid. In this group of systems, we can find facilities designed as large electricity generators, up to hundreds of MW of power, which are used to inject energy into the distribution network. In addition, medium power systems, up to 500 kWp, designed for industrial or commercial warehouses that pour energy into the grid, but also used to feed the internal consumption of these facilities. Every day more PV systems connected to the grid are installed in homes for self-consumption applications, where the energy generated is used for domestic consumption and if there is a surplus, it can be poured into the grid if the country's regulations allow it. In these cases, there are two types of strategies to compensate for this energy injected into the grid.

DEFINITION

Net metering, where the electricity companies to which the system is connected discount the energy injected into consumption costs, and the second case in which electricity companies pay directly for the energy injected into the grid by the photovoltaic system to the owner of the same, feed-in tariffs.

In grid-connected PV systems, especially in applications designed for self-consumption, batteries are also included to store the energy produced by the PV generator, thus reducing direct consumption from the grid when the generator is not able to satisfy the energy demand of the loads.

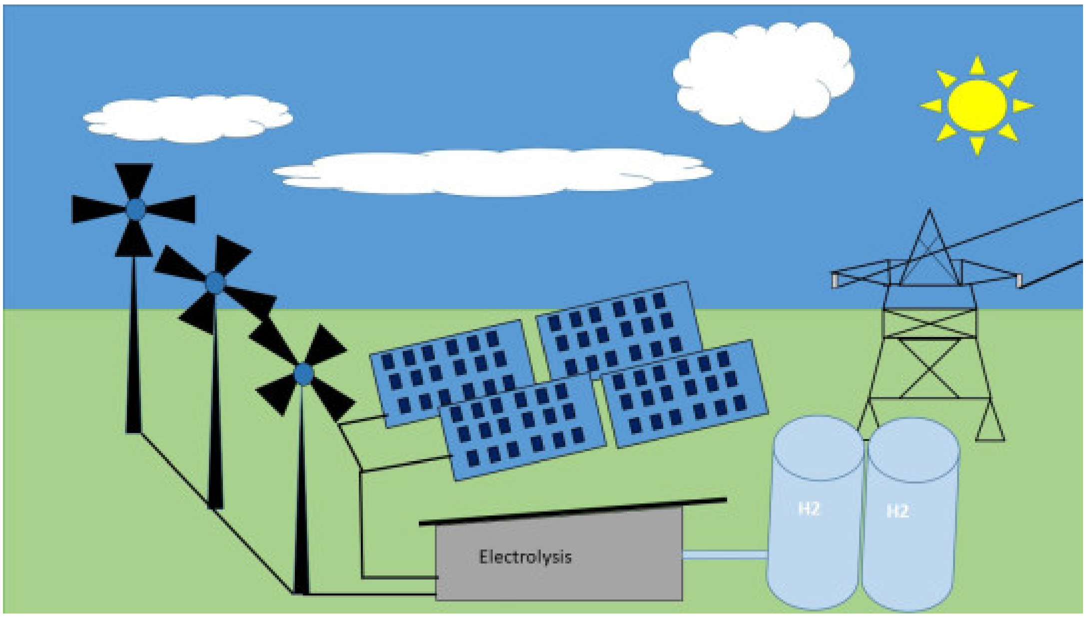

Fig. 7. Block diagram of a grid-connected PV system

Its main elements are the following:

Table 5. Main elements of grid-connected PV systems

Element	Description
Photovoltaic generator	From a few kW to hundreds of MW depending on the application.
Inverter	In charge of converting the DC output of the photovoltaic generator into AC. Depending on the size of the system, the number of inverters and their nominal power may vary in each application. These inverters incorporate MMPT systems to ensure that the PV generator always works at the maximum power point.
Protections	Fuses, bypass diodes, blocking diodes, manual and automatic switches or breakers, earth connections, power protection systems, etc. (depending on the regulations of each country).
Meters	They measure the energy injected into the grid. In the case of self-consumption applications, bidirectional meters can be used that measure both the injection into the network and its consumption.
Loads	AC loads present in the system.

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CHAPTER 5

Hydrogen Technologies

DEFINITION

Hydrogen, H_2, is a colorless and odorless diatomic gas that is also non-toxic. It has a high-energy value per unit mass (energy density), much more than traditional fuels. It is a renewable fuel, and the reserves are inexhaustible.

This element, on Earth, is always combined with other elements, such as with oxygen forming water (H_2O), with carbon forming hydrocarbons, or with other elements forming an infinity of different compounds. For its production, chemical or electrochemical processes are necessary that require an amount of energy that will always be greater than the energy that will be obtained later in its final application.

At present, it is already used in many industrial applications: In the chemical, petrochemical, metallurgy, or electronics sector, but its great potential lies in the energy sector. H_2 can be used as fuel, obtaining heat from its combustion, in the same way as natural gas, with the advantage that when H_2 burns it only leaves behind water vapor, instead of greenhouse gases that come from fossil fuels. On the other hand, it also allows the generation of electricity through electrochemical processes.

The use of H_2 will allow the development of a wide number of associated technologies. A good example is H_2-powered fuel cells, which have high efficiencies and a wide variety of possible applications, both mobile and stationary.

The results achieved in recent years in the research, development and demonstration programs have clearly increased international interest in these technologies, which present great potential, are expected to have a relevant weight in the global energy sector and could help much to alleviate the effects of climate change.

The H_2 technologies include all the processes derived from its generation, storage, transport, and combustion.

5.1 Production of H_2

The H_2 is usually classified according to the energy sources used in its production and their sustainability. Following this classification, we can talk of three different types: Gray H_2, blue H_2 and green H_2.

Gray H_2 is the one produced by energy sources of fossil origin: Natural gas (Methane CH4), oil or coal. These processes entail associated pollutant emissions, but currently 99% of the world's H_2 production is of this type, which generates very significant CO_2 emissions.

The most common methods of producing gray H_2 are steam reforming of natural gas and gasification of coal.

The steam reforming method of natural gas is the cheapest and most widely used. This process is based on subjecting the reactants to temperatures between 700 and 850 ° C, at pressures below 25 bar, as shown by the following reaction:

$$H_2O + CH_4 + heat \ \rightarrow CO + 3H_2$$

The resulting CO can be reacted with steam to convert it to CO_2 for additional hydrogen production as follows:

$$CO + \ H_2O \ \rightarrow residual\ heat + H_2 + CO_2$$

The second most used process in the production of H_2 is the gasification of coal. The simplest stoichiometry of the reaction is as follows:

$$3C + \ O_2 \ + H_2O \ \rightarrow H_2 + 3CO$$

In order to avoid CO_2 emissions and reduce the effects of climate change, it is necessary to make a transition from gray H_2 to blue H_2 and above all to promote the production of green H_2, renewable and without direct CO_2 emissions.

The blue H_2 is also obtained from energy sources of fossil origin, but in this case less polluting production processes are used. These processes usually include CO_2 capture and storage mechanisms. If the process does not involve associated pollutant emissions, the resulting H_2 is called turquoise, which can be obtained by pyrolysis following the reaction shown below:

Another well-known process that has undergone great development in the last decade is the electrolysis of H_2O, by this method. The water is separated into H_2 and O_2 by applying electricity:

$$H_2O + e^- \rightarrow H_2 + \frac{1}{2}O_2$$

The electrolysis of H_2O can also be carried out by using the energy of the sun, photons, directly to break the water molecule. This process is called photolysis:

$$H_2O + h\nu \rightarrow H_2 + \frac{1}{2}O_2$$

DEFINITION

The H_2 obtained from renewable energy sources: Wind, solar, marine, etc., with low or no associated pollutant emissions of CO_2 is known as green or renewable H_2.

This H_2 has as its main characteristic that it allows electricity to be transformed into a storable, transportable product with multiple applications. However, the concept is broader, since there are other renewable and inexhaustible sources that can be used in processes that give rise to green H_2 from forest biomass or organic compounds, among others.

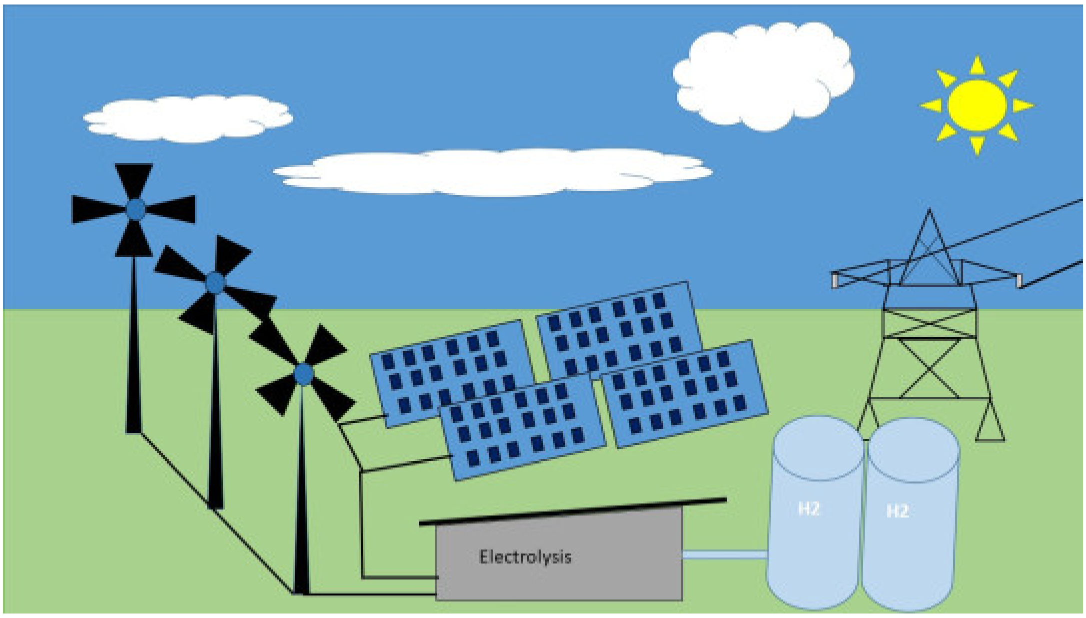

Fig. 8. Green H_2 production

The most used methods to produce H_2 are shown in the following Table.

Table 6. H_2 Production processes [15]

Processes of Chemistry Conversion	**Electrolytic Processes**	**Thermolytic Processes**	**Biological Processes**	**Photonic Processes**
Steam reformed from natural gas	Electrolysis (H_2O)	Direct thermolysis from H_2O	Fermentation (Bacteria)	Photoelectrolysis
Gasification (Gas or Coal)		Thermal cycles	Anaerobic digestion (Biomass)	Photobiolysis
Pyrolysis (Biomass or natural gas)				Photocatalysis

5.2 Transportation and storage of H_2

Among the main energy storage technologies, H_2 and synthetic methane, also produced from H_2, represent some of the most promising options for storing large amounts of renewable electricity for long periods of time.

One of the challenges that H_2 storage presents is the large volume it occupies, given its low density and despite its high-energy capacity. To increase its volumetric density, different methods are used, such as compression or liquefaction.

The most conventional way of storing H_2 gas is under pressure in conventional steel cylinders or in light carbon fiber tanks. This is the most mature storage technology.

Hydrogen can also be stored in liquid form at cryogenic temperatures: -253 °C, greatly improving its energy density per unit volume even at low pressures. A major drawback is that the liquefaction process requires a large amount of energy and that the low temperatures required make its application in transport vehicles very difficult.

Finally, H_2 can be stored in a solid state by using carbon-based materials (nanotubes and graphite nanofibers) or rechargeable hydrides. In this case, storage is carried out on the surfaces of the solids, by adsorption, or within them, by absorption.

Sea to cover long distances or isolated areas, land transportation by tanker trucks or in trains and pipelines like gas pipelines. This last option requires a significant investment in the infrastructure, but subsequently allows lower transport costs than the other options given the large amount of volume it allows to transport. The cost of a gas pipeline for H_2 is much higher than that required for a natural gas pipeline, given its lower energy density per unit volume. Therefore, larger diameter pipes or higher pressures are required to supply the same amount of energy.

5.3 Applications

Nowadays, most of the H_2 is used to make ammonia and other chemicals, most of them fertilizers. It is also applied in the oil industry in refineries in different processes.

Another important application in metallurgy is its use to obtain steel from iron. On the other hand, its use is important in the manufacture of basic chemical products such as methanol or ammonia, as well as in the development of synthetic hydrocarbons.

Without a doubt, one of the applications with the greatest potential for H_2 is transport. Its application in vehicles: Cars, trucks, buses, motorcycles and even bicycles, using fuel cells, generates H_2O as the only waste, which contributes to improving air quality and reducing global warming.

DEFINITION

Fuel cells are devices that make it possible to generate electricity from the chemical energy of H_2 and O_2 without combustion. Instead, an electrochemical H_2 oxidation reaction occurs.

This process has much higher efficiencies than conventional combustion.

There are several types of fuel cells. They are usually classified according to their operating temperature, although they can also be classified according to the nature of the ion carried by the electrolyte that is between the cathode and the anode of the fuel cell.

The distribution of hydrogen for use in mobility and transportation will require the creation of a new network of service stations: Hydroelectric plants or hydroelectric stations, which are service stations that store and supply H_2 for transport and are usually located on highways.

Its applications in maritime transport are so far limited to small vessels, but it is expected to be applied to large vessels in the future.

HYDROGEN DRIVE
That's how it works

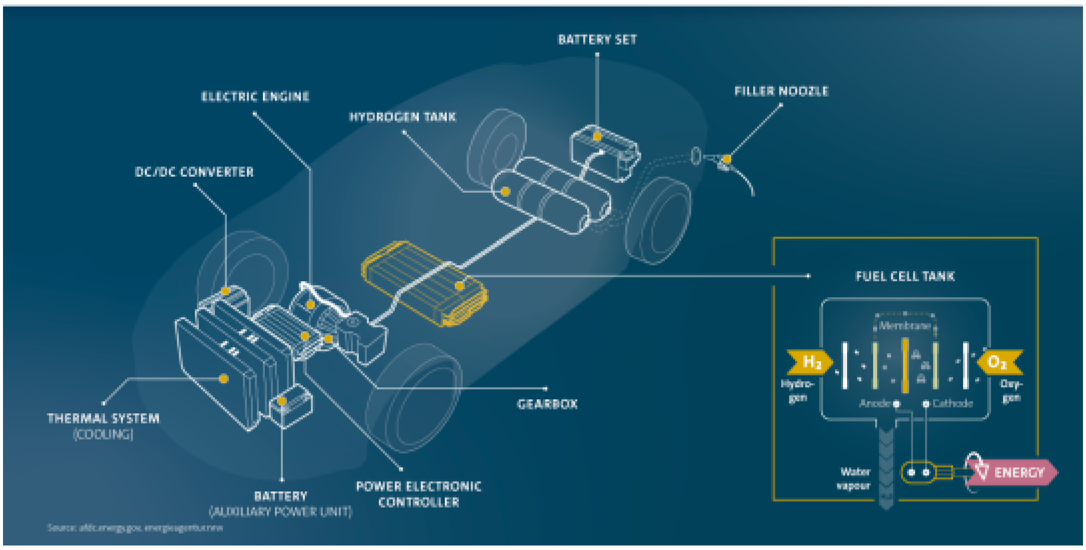

Fig. 9. H2-powered car

Finally, other applications are combustion in boilers for domestic heating or applications for heat generation in industry.

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CHAPTER 6

Biomass

The use of biomass energy is, in fact, one of the oldest known, already used by the earliest cavemen for keeping warm or cooking food. However, with the arrival of the industrial revolution and the need to generate a greater amount of energy in an increasingly reduced space, it promoted the use of fossil fuels and slowed down the use of biomass energy. Nowadays, however, the use of biomass energy is gaining in popularity since is a clean, sustainable, and renewable source of energy.

DEFINITION

Biomass refers to all organic matter existing in the biosphere, whether of plant or animal origin, as well as those materials obtained through their natural or artificial transformation.

According to the 2009/28/EC Directive related to the promotion of the use of energy from renewable sources, 'biomass' means the biodegradable fraction of products, waste, and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste. [17]

DEFINITION

In other words, biomass is a very broad concept that includes everything from waste from forestry, agricultural and livestock activities to the organic fraction of domestic and industrial waste, including by-products from the agri-food and wood processing industries.

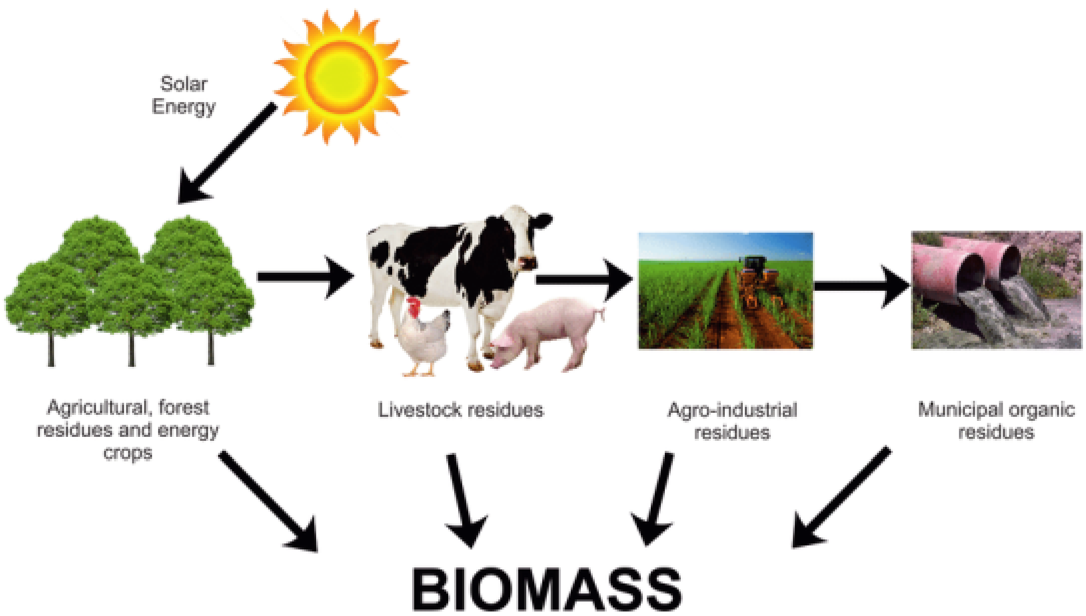

Fig. 10. Biomass creation

Biomass is a source of renewable energy. Biomass energy comes in the last instance from the Sun. Plants absorb the Sun's energy through the process of photosynthesis and convert carbon dioxide and water into nutrients. Also, animals that eat plants transforms these nutrients into biomass. Biomass can be transformed into usable energy through direct and indirect conversion. Biomass can be burned to create heat or converted into electricity (direct) or processed into biofuel (indirect).

6.1 Types of biomass

According to its origin, biomass can be classified into three main groups:

- **Natural biomass**. It occurs spontaneously in nature, without human intervention. For example, the natural pruning of forests.
- **Residual biomass**. Waste products that come from agricultural or forestry activities (e.g. sawdust), from agri-food industries or from biodegradable waste formed by urban, industrial and livestock wastewater (e.g. guano).
- **Produced biomass**. These are energy crops. A specific crop is grown in farms with the sole purpose of being used as energy source.

6.2 Conversion technologies

Conversion technologies use biomass in an efficient and sustainable way to generate heat, electricity, biofuels, chemicals, and biomaterials.

DEFINITION

There are two main conversion technologies to convert biomass into energy: thermo-chemical and biochemical.

Thermo-chemical conversion consists of directly burning biomass at very high temperatures (between 600 and 1,300 °C) and in the presence of large amounts of air and with yields of up to 95%. Different thermochemical conversion processes include combustion, gasification, and pyrolysis, being combustion the most practiced process.

Bio-chemical conversion involves use of bacteria, microorganisms, and enzymes to breakdown biomass into gaseous or liquid fuels, such as biogas or bioethanol. The most popular biochemical processes are anaerobic digestion and fermentation. Anaerobic digestion occurs in the absence of oxygen. In the process, the degradation of organic matter is achieved thanks to the activity of the microorganisms, which transform it into a gas with a high energy content (biogas) and other products that can be used to produce secondary products.

Table 7. A General Comparison of Biochemical and Thermochemical Processes [18]

Thermochemical	Biochemical
Effectively applied to almost any biomass feedstock	Involves the use of microbes, enzymes, and/or chemicals
No pretreatment	Pretreatment is essential
Relatively higher productivity due to completely chemical nature of reaction	Productivity is limited due to biological conversion
Multiple high-value products possible using fractional separation of products	Normally, limited to one or few products and would require additional microbes, enzymes for more products
Independent of climatic conditions	Mostly susceptible to ambient temperature, anaerobic digester
Complete utilization of waste/biomass	Production of secondary wastes such as biomass sludge
Less reaction time	High reaction time

6.3 Advantages and disadvantages of biomass

Some advantages of the use of biomass as a source of energy are: [19]

ADVANTAGE

- It is a renewable source of energy.
- It helps to reduce volumes of waste, with the added benefit of putting it to use.
- It is found in large quantities.
- It does not mean a greater impact than the greenhouse effect, since when it is used as a fuel it causes less emission of gases that are harmful to the environment.
- It is quite inexpensive.
- It can economically benefit rural sectors.

There are also some drawbacks, including:

DISADVANTAGE

- Its scope is still limited.
- Its performance is lower than that of other types of energy sources such as fossil fuels.
- Biomass plants require a large land available for its production and a lot of space for subsequent storage.
- Can lead to deforestation.
- Its distribution channels are not sufficiently developed.
- It can make the price of some foods consumed by people and animals more expensive because certain crops are used to produce this energy source.
- Biomass energy is not as efficient as fossil fuels.

6.4 The use of biomass in the world

The use of biomass in the world differs depending on each country. It continues to be the main source of energy in less developed countries. In some areas of Asia, Africa, and Latin America two thirds of the energy generated comes from biomass. On the other hand, countries such as Finland or the United Kingdom are at the forefront in the use of biomass as an energy source and use more complex transformation processes. For instance, Finland covers 50% of its heat needs and 20% of its primary energy consumption with biomass.

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CHAPTER 7

Geothermal energy

The first geothermal plant was built in 1904 in Larderello, Italy. Although geothermal energy has been exploited for more than 100 years, it is less well-known than other alternative energy sources such as photovoltaic solar and wind energies.

DEFINITION

Geothermal energy is the thermal energy generated and stored beneath the Earth's crust. It is a renewable energy resource that does not require the combustion of any material, thus avoiding emissions of carbon dioxide.

Geothermal energy is obtained by harnessing the heat stored in rocks, soils, and groundwater, whatever their temperature and depth. To exploit this type of energy, it is necessary to drill the earth's surface 1.6 miles or deeper to reach a reservoir of steam or hot water. Generally, the deeper you drill, the hotter you get.

Geothermal applications depend on the temperature of the geothermal resource. So, high temperature geothermal reservoirs, above 100 °C, can be used to generate electricity. Heat is used to heat water to produce steam and drive a turbine connected to a generator to produce electricity. When the reservoir temperature is below 100 °C, the heat is used directly to provide heating and cooling in homes and businesses by using heat pumps. Finally, low temperature reservoirs, below 25-30 °C, are used in air-conditioning applications and for obtaining hot water.

7.1 How it works

Geothermal energy is generated in a geothermal plant. Wells are drilled to reach a reservoir of steam or hot water. Geothermal plants are located close to tectonically active regions where the potential for geothermal energy is high. Next figure illustrates how a geothermal plant works: [20]

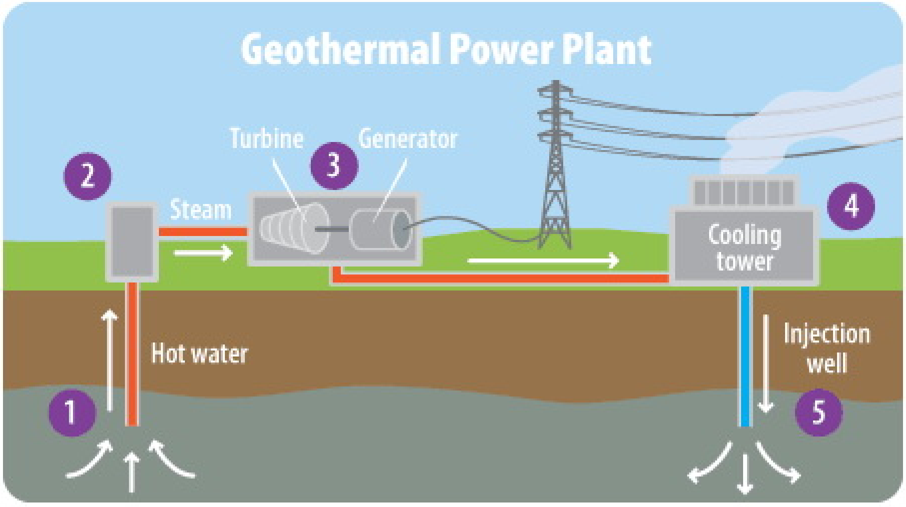

Fig. 11. Geothermal power plant diagram [20]

1. Hot water is pumped from deep underground through a well under high pressure
2. When the water reaches the surface, the pressure is dropped, which causes the water to turn into steam.
3. The steam spins a turbine, which is connected to a generator that produces electricity.
4. The steam cools off in a cooling tower and condenses back to water.
5. The cooled water is pumped back into the Earth to begin the process again.

7.2 Advantages and disadvantages of geothermal energy

Geothermal energy has some advantages over fossil fuels but also advantages over other renewable energies such as solar and wind energy. Some of these advantages include: [21]

ADVANTAGE

- Compared with fossil fuels, geothermal energy is cleaner, often has no emissions, and cheaper.
- It is constantly available. Unlike other renewable energies, it does not matter if it is day or night or what are the current weather conditions.
- It can be produced domestically and with less land surface than wind and solar energy.
- It works very well for heating and cooling

Despite the great number of advantages, the geothermal energy has, there are also some disadvantages that must be considered:

DISADVANTAGE

- Production is limited to sites close to tectonic plate boundaries.
- High initial costs. Although it is cheaper than fossil fuels once a plant has been built, the drilling and exploration of these sites is expensive.
- Risk of accidentally releasing harmful greenhouse gases in the process
- Can trigger surface instability which can lead to earthquakes.
- Power electricity can only be generated on an industrial scale. In the case of homes, geothermal energy can only be used for heating and cooling.

7.3 Geothermal energy in the world

The US is the leading producer of geothermal energy in the world, with 16.7 billion kWh a year, having an installed capacity of 3,639 MW, according to data from 2020. The Geysers Geothermal Complex based in San Francisco, California, is comprised of 18 geothermal plants and is the largest geothermal installation in the world.

The US is followed by Indonesia with an installed capacity of 2,133 MW, followed by Philippines with 1,918 MW, Turkey with 1,688 MW and New Zealand with 1,005 MW. These countries form what is known as the 1GW country club. [22]

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CHAPTER 8

Test

The production of Photovoltaic Solar Energy in the global electricity production represents the

- ◯ 10 % of the total electricity production
- ◯ 7 % of the total electricity production
- ◯ 5.5 % of the total electricity production
- ◯ 2.8 % of the total electricity production

The oldest energy source exploited by humans is

- ◯ Photovoltaic Solar energy
- ◯ Swind energy
- ◯ Geothermal energy
- ◯ Hydroelectric energy

The horizontal-axis wind turbines used in wind energy production are called

- ◯ HAWTs
- ◯ VAWTs
- ◯ HTWAs
- ◯ A1WT

The country sith more wind energy capacity installed is

- ◯ Spain
- ◯ USA

- China
- India

Natural biomass

- Occurs spontaneously in nature
- Cannot be controlled
- It uses waste products from industry
- It uses waste products from agricultural activities

Thermo-chemical conversion

- depends on climatic conditions
- it needs high reaction time
- It is independent of climatic conditions
- It needs essential pretreatment

The biomass as a source of energy

- It does not help to reduce waste
- Can economically benefit rural sectors
- Can reduce deforestation
- It has very high initital costs

The energy that continues to be the main source of energy in less developed countires is

- Biomass
- Solar energy
- Geothermal energy
- Hydroelectric energy

One of the geothermal energy disadvantages is that

- ◯ It cannot be produced domestically
- ◯ The initial costs are very high
- ◯ It depends on the weather conditions
- ◯ It cannot be used for heating

The energy of the photons depends on

- ◯ Temperature
- ◯ frequency
- ◯ Voltage
- ◯ electrical current

Who discovered the photovoltaic effect ?

- ◯ Albert Einstein
- ◯ Johann Heinrich Lambert
- ◯ Edmund Bequerel
- ◯ Max Plank

What are standard conditions (STC) of irradiance and temperature ?

- ◯ Temperature of 20ºC and irradiance of 800W/m2
- ◯ Temperature of 30ºC and irradiance of 800W/m2
- ◯ Temperature of 0ºC and irradiance of 900W/m2
- ◯ Temperature of 25ºC and irradiance of 1000W/m2

What does gray H2 mean ?

- ◯ H2 produced from energy sources of fossil origin
- ◯ H2 produced for car applications
- ◯ H2 produced from nuclear energy
- ◯ H2 used in heating appplications

What does green H2 mean ?

- ◯ H2 produced from energy sources of fossil origin
- ◯ H2 produced from renewable energy sources
- ◯ H2 for chemical applications
- ◯ H2 used in transport appplications

How fuel cells generate electricity ?

- ◯ From O2 combustion
- ◯ From the comustion of H2
- ◯ from chemical energy of H2
- ◯ from chemical energy of O2