

# Renewable energy

**Renewable energy** is energy that is collected from renewable resources, which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat.<sup>[2]</sup> Renewable energy often provides energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services.<sup>[3]</sup>

Based on REN21's 2016 report, renewables contributed 19.2% to humans' global energy consumption and 23.7% to their generation of electricity in 2014 and 2015, respectively. This energy consumption is divided as 8.9% coming from traditional biomass, 4.2% as heat energy (modern biomass, geothermal and solar heat), 3.9% hydro electricity and 2.2% is electricity from wind, solar, geothermal, and biomass. Worldwide investments in renewable technologies amounted to more than US\$286 billion in 2015, with countries like China and the United States heavily investing in wind, hydro, solar and biofuels.<sup>[4]</sup> Globally, there are an estimated 7.7 million jobs associated with the renewable energy industries, with solar photovoltaics being the largest renewable employer.<sup>[5]</sup> As of 2015 worldwide, more than half of all new electricity capacity installed was renewable.<sup>[6]</sup>

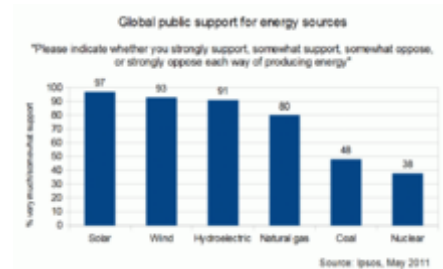
Renewable energy resources exist over wide geographical areas, in contrast to other energy sources, which are concentrated in a limited number of countries. Rapid deployment of renewable energy and energy efficiency is resulting in significant energy security, climate change mitigation, and economic benefits.<sup>[7]</sup> The results of a recent review of the literature<sup>[8]</sup> concluded that as greenhouse gas (GHG) emitters begin to be held liable for damages resulting from GHG emissions resulting in climate change, a high value for liability mitigation would provide powerful incentives for deployment of renewable energy technologies. In international public opinion surveys there is strong support for promoting renewable sources such as solar power and wind power.<sup>[9]</sup> At the national level, at least 30 nations around the world already have renewable energy contributing more than 20 percent of energy supply. National renewable energy markets are projected to continue to grow strongly in the coming decade and beyond.<sup>[10]</sup> Some places and at least two countries, Iceland and Norway generate all their electricity using renewable energy already, and many other countries have the set a goal to reach 100% renewable energy in the future. For example, in Denmark the government decided to switch the total energy supply (electricity, mobility and heating/cooling) to 100% renewable energy by 2050.<sup>[11]</sup>

While many renewable energy projects are large-scale, renewable technologies are also suited to rural and remote areas and developing countries, where energy is often crucial in human development.<sup>[12]</sup> Former United Nations Secretary-General Ban Ki-moon has said that renewable energy has the ability to lift the poorest nations to new levels of prosperity.<sup>[13]</sup> As most of renewables provide electricity, renewable energy deployment is often applied in conjunction with further electrification, which has several benefits: Electricity can be converted to heat (where necessary generating higher temperatures than fossil fuels), can be converted into mechanical energy with high efficiency and is clean at the point of consumption.<sup>[14][15]</sup> In addition to that electrification with renewable energy is much more efficient and therefore leads to a significant reduction in primary energy requirements, because most renewables don't have a steam cycle with high losses (fossil power plants usually have losses of 40 to 65%).<sup>[16]</sup>

Renewable energy systems are rapidly becoming more efficient and cheaper. Their share of total energy consumption is increasing. Growth in consumption of coal and oil could end by 2020 due to increased uptake of renewables and natural gas.<sup>[17][18]</sup>



Wind, solar, and hydroelectricity are three emerging renewable sources of energy.



Global public support for different energy sources (2011) based on a poll by Ipsos Global @dviso<sup>[1]</sup>

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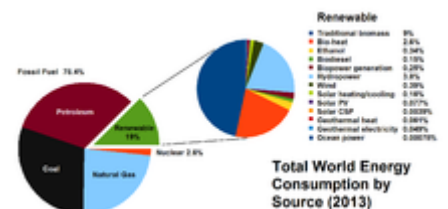
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## Overview

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Renewable energy flows involve natural phenomena such as sunlight, wind, tides, plant growth, and geothermal heat as the International Energy Agency explains:<sup>[19]</sup>

Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources.



World energy consumption by source. Renewables accounted for 19% in 2012.

Renewable energy resources and significant opportunities for energy efficiency exist over wide geographical areas, in contrast to other energy sources, which are concentrated in a limited number of countries. Rapid deployment of renewable energy and energy efficiency, and technological diversification of energy sources, would result in significant energy security and economic benefits.<sup>[7]</sup> It

would also reduce environmental pollution such as air pollution caused by burning of fossil fuels and improve public health, reduce premature mortalities due to pollution and save associated health costs that amount to several hundred billion dollars annually only in the United States.<sup>[20]</sup> Renewable energy sources, that derive their energy from the sun, either directly or indirectly, such as hydro and wind, are expected to be capable of supplying humanity energy for almost another 1 billion years, at which point the predicted increase in heat from the sun is expected to make the surface of the earth too hot for liquid water to exist.<sup>[21][22]</sup>



PlanetSolar, the world's largest solar-powered boat and the first ever solar electric vehicle to circumnavigate the globe (in 2012)

Climate change and global warming concerns, coupled with high oil prices, peak oil, and increasing government support, are driving increasing renewable energy legislation, incentives and commercialization.<sup>[9]</sup> New government spending, regulation and policies helped the industry weather the global financial crisis better than many other sectors.<sup>[23]</sup> According to a 2011 projection by the International Energy Agency, solar power generators may produce most of the world's electricity within 50 years, reducing the emissions of greenhouse gases that harm the environment.<sup>[24]</sup>

As of 2011, small solar PV systems provide electricity to a few million households, and micro-hydro configured into mini-grids serves many more. Over 44 million households use biogas made in household-scale digesters for lighting and/or cooking, and more than 166 million households rely on a new generation of more-efficient biomass cookstoves.<sup>[25]</sup> United Nations' Secretary-General Ban Ki-moon has said that renewable energy has the ability to lift the poorest nations to new levels of prosperity.<sup>[13]</sup> At the national level, at least 30 nations around the world already have renewable energy contributing more than 20% of energy supply. National renewable energy markets are projected to continue to grow strongly in the coming decade and beyond, and some 120 countries have various policy targets for longer-term shares of renewable energy, including a 20% target of all electricity generated for the European Union by 2020. Some countries have much higher long-term policy targets of up to 100% renewables. Outside Europe, a diverse group of 20 or more other countries target renewable energy shares in the 2020–2030 time frame that range from 10% to 50%.<sup>[10]</sup>

Renewable energy often displaces conventional fuels in four areas: electricity generation, hot water/space heating, transportation, and rural (off-grid) energy services.<sup>[3]</sup>

#### ■ Power generation

By 2040, renewable energy is projected to equal coal and natural gas electricity generation. Several jurisdictions, including Denmark, Germany, the state of South Australia and some US states have achieved high integration of variable renewables. For example, in 2015 wind power met 42% of electricity demand in Denmark, 23.2% in Portugal and 15.5% in Uruguay. Interconnectors enable countries to balance electricity systems by allowing the import and export of renewable energy. Innovative hybrid systems have emerged between countries and regions.<sup>[26]</sup>

#### ■ Heating

Solar water heating makes an important contribution to renewable heat in many countries, most notably in China, which now has 70% of the global total (180 GWth). Most of these systems are installed on multi-family apartment buildings and meet a portion of the hot water needs of an estimated 50–60 million households in China. Worldwide, total installed solar water heating systems meet a portion of the water heating needs of over 70 million households. The use of biomass for heating continues to grow as well. In Sweden, national use of biomass energy has surpassed that of oil. Direct geothermal for heating is also growing rapidly.<sup>[27]</sup> The newest addition to Heating is from Geothermal Heat Pumps which provide both heating and cooling, and also flatten the electric demand curve and are thus an increasing national priority<sup>[28][29]</sup> (see also Renewable thermal energy).

#### ■ Transportation

Bioethanol is an alcohol made by fermentation, mostly from carbohydrates produced in sugar or starch crops such as corn, sugarcane, or sweet sorghum. Cellulosic biomass, derived from non-food sources such as trees and grasses is also being developed as a feedstock for ethanol production. Ethanol can be used as a fuel for vehicles in its pure form, but it is usually used as a gasoline additive to increase octane and improve vehicle emissions. Bioethanol is widely used in the USA and in Brazil. Biodiesel can be used as a fuel for vehicles in its pure form, but it is usually used as a diesel additive to reduce levels of particulates, carbon monoxide, and hydrocarbons from diesel-powered vehicles. Biodiesel is produced from oils or fats using transesterification and is the most common biofuel in Europe.



A bus fueled by biodiesel

A solar vehicle is an electric vehicle powered completely or significantly by direct solar energy. Usually, photovoltaic (PV) cells contained in solar panels convert the sun's energy directly into electric energy. The term "solar vehicle" usually implies that solar energy is used to power all or part of a vehicle's propulsion. Solar power may be also used to provide power for communications or controls or other auxiliary functions. Solar vehicles are not sold as practical day-to-day transportation devices at present, but are primarily demonstration vehicles and engineering exercises, often sponsored by government agencies. However, indirectly solar-charged vehicles are widespread and solar boats are available commercially.

## History

Prior to the development of coal in the mid 19th century, nearly all energy used was renewable. Almost without a doubt the oldest known use of renewable energy, in the form of traditional biomass to fuel fires, dates from 790,000 years ago. Use of biomass for fire did not become commonplace until many hundreds of thousands of years later, sometime between 200,000 and 400,000 years ago.<sup>[30]</sup> Probably the second oldest usage of renewable energy is harnessing the wind in order to drive ships over water. This practice can be traced back some 7000 years, to ships in the Persian Gulf<sup>[31]</sup> and on the Nile.<sup>[32]</sup> Moving into the time of recorded history, the primary sources of traditional renewable energy were human labor, animal power, water power, wind, in grain crushing windmills,<sup>[31]</sup> and firewood, a traditional biomass. A graph of energy use in the United States up until 1900 shows oil and natural gas with about the same importance in 1900 as wind and solar played in 2010.

In the 1860s and '70s there were already fears that civilization would run out of fossil fuels and the need was felt for a better source. In 1873 Professor Augustin Mouchot wrote:<sup>[33]</sup>

The time will arrive when the industry of Europe will cease to find those natural resources, so necessary for it. Petroleum springs and coal mines are not inexhaustible but are rapidly diminishing in many places. Will man, then, return to the power of water and wind? Or will he emigrate where the most powerful source of heat sends its rays to all? History will show what will come.<sup>[34]</sup>

In 1885, Werner von Siemens commenting on the discovery of the photovoltaic effect in the solid state, wrote:

In conclusion, I would say that however great the scientific importance of this discovery may be, its practical value will be no less obvious when we reflect that the supply of solar energy is both without limit and without cost, and that it will continue to pour down upon us for countless ages after all the coal deposits of the earth have been exhausted and forgotten.<sup>[35]</sup>

Max Weber mentioned the end of fossil fuel in the concluding paragraphs of his Die protestantische Ethik und der Geist des Kapitalismus, published in 1905.<sup>[36]</sup>

Development of solar engines continued until the outbreak of World War I. The importance of solar energy was recognized in a 1911 *Scientific American* article: "in the far distant future, natural fuels having been exhausted [solar power] will remain as the only means of existence of the human race"<sup>[37]</sup>

The theory of peak oil was published in 1956.<sup>[38]</sup> In the 1970s environmentalists promoted the development of renewable energy both as a replacement for the eventual depletion of oil, as well as for an escape from dependence on oil, and the first electricity generating wind turbines appeared. Solar had long been used for heating and cooling, but solar panels were too costly to build solar farms until 1980.<sup>[39]</sup>

The IEA 2014 World Energy Outlook projects a growth of renewable energy supply from 1,700 gigawatts in 2014 to 4,550 gigawatts in 2040. Fossil fuels received about \$550 billion in subsidies in 2013, compared to \$120 billion for all renewable engines.<sup>[40]</sup>

## Mainstream technologies

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### Wind power

Airflows can be used to run wind turbines. Modern utility-scale wind turbines range from around 600 kW to 5 MW of rated power, although turbines with rated output of 1.5–3 MW have become the most common for commercial use. The largest generator capacity of a single installed onshore wind turbine reached 7.5 MW in 2015. The power available from the wind is a function of the cube of the wind speed, so as wind speed increases, power output increases up to the maximum output for the particular turbine.<sup>[41]</sup> Areas where winds are stronger and more constant, such as offshore and high altitude sites, are preferred locations for wind farms. Typically full load hours of wind turbines vary between 16 and 57 percent annually, but might be higher in particularly favorable offshore sites.<sup>[42]</sup>



The 845 MW Shepherds Flat Wind Farm near Arlington, Oregon, USA

Wind-generated electricity met nearly 4% of global electricity demand in 2015, with nearly 63 GW of new wind power capacity installed. Wind energy was the leading source of new capacity in Europe, the US and Canada, and the second largest in China. In Denmark, wind energy met more than 40% of its electricity demand while Ireland, Portugal and Spain each met nearly 20%.

Globally, the long-term technical potential of wind energy is believed to be five times total current global energy production, or 40 times current electricity demand, assuming all practical barriers needed were overcome. This would require wind turbines to be installed over large areas, particularly in areas of higher wind resources, such as offshore. As offshore wind speeds average ~90% greater than that of land, so offshore resources can contribute substantially more energy than land stationed turbines.<sup>[43]</sup> In 2014 global wind generation was 706 terawatt-hours or 3% of the world's total electricity.<sup>[44]</sup>

### Hydropower

In 2015 hydropower generated 16.6% of the world's total electricity and 70% of all renewable electricity.<sup>[45]</sup> Since water is about 800 times denser than air, even a slow flowing stream of water, or moderate sea swell, can yield considerable amounts of energy. There are many forms of water energy:

- Historically hydroelectric power came from constructing large hydroelectric dams and reservoirs, which are still popular in third world countries. The largest of which is the Three Gorges Dam (2003) in China and the Itaipu Dam (1984) built by Brazil and Paraguay
- Small hydro systems are hydroelectric power installations that typically produce up to 50 MW of power. They are often used on small rivers or as a low impact development on larger rivers. China is the largest producer of hydroelectricity in the world and has more than 45,000 small hydro installations.<sup>[46]</sup>



The Three Gorges Dam on the Yangtze River in China

- Run-of-the-river hydroelectricity plants derive kinetic energy from rivers without the creation of a large reservoir. This style of generation may still produce a large amount of electricity such as the Chief Joseph Dam on the Columbia river in the United States.

Hydropower is produced in 150 countries, with the Asia-Pacific region generating 32 percent of global hydropower in 2010. For countries having the largest percentage of electricity from renewables, the top 50 are primarily hydroelectric. China is the largest hydroelectricity producer, with 721 terawatt-hours of production in 2010, representing around 17 percent of domestic electricity use. There are now three hydroelectricity stations larger than 10 GW: the Three Gorges Dam in China, Itaipu Dam across the Brazil/Paraguay border, and Guri Dam in Venezuela.<sup>[47]</sup>

Wave power, which captures the energy of ocean surface waves, and tidal power, converting the energy of tides, are two forms of hydropower with future potential; however, they are not yet widely employed commercially. A demonstration project operated by the Ocean Renewable Power Company on the coast of Maine, and connected to the grid, harnesses tidal power from the Bay of Fundy, location of world's highest tidal flow. Ocean thermal energy conversion, which uses the temperature difference between cooler deep and warmer surface waters, has currently no economic feasibility

## Solar energy

Solar energy, radiant light and heat from the sun, is harnessed using a range of ever-evolving technologies such as solar heating photovoltaics, concentrated solar power (CSP), concentrator photovoltaics (CPV), solar architecture and artificial photosynthesis.<sup>[48][49]</sup> Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air. Active solar technologies encompass solar thermal energy, using solar collectors for heating, and solar power, converting sunlight into electricity either directly using photovoltaics (PV), or indirectly using concentrated solar power (CSP).



Satellite image of the 550-megawatt Topaz Solar Farm in California, USA

A photovoltaic system converts light into electrical direct current (DC) by taking advantage of the photoelectric effect.<sup>[50]</sup> Solar PV has turned into a multi-billion, fast-growing industry, continues to improve its cost-effectiveness, and has the most potential of any renewable technologies together with CSP.<sup>[51][52]</sup> Concentrated solar power (CSP) systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Commercial concentrated solar power plants were first developed in the 1980s. CSP-Stirling has by far the highest efficiency among all solar energy technologies.

In 2011, the International Energy Agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries' energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating climate change, and keep fossil fuel prices lower than otherwise. These advantages are global. Hence the additional costs of the incentives for early deployment should be considered learning investments; they must be wisely spent and need to be widely shared".<sup>[48]</sup> Italy has the largest proportion of solar electricity in the world, in 2015 solar supplied 7.8% of electricity demand in Italy.<sup>[53]</sup> In 2016, after another year of rapid growth, solar generated 1.3% of global power.<sup>[54]</sup>

## Geothermal energy

High Temperature Geothermal energy is from thermal energy generated and stored in the Earth. Thermal energy is the energy that determines the temperature of matter. Earth's geothermal energy originates from the original formation of the planet and from radioactive decay of minerals (in currently uncertain<sup>[55]</sup> but possibly roughly equal<sup>[56]</sup> proportions). The geothermal gradient, which is the difference in temperature between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the core to the surface. The adjective *geothermal* originates from the Greek roots *geo*, meaning earth, and *thermos*, meaning heat.

The heat that is used for geothermal energy can be from deep within the Earth, all the way down to Earth's core – 4,000 miles (6,400 km) down. At the core, temperatures may reach over 9,000 °F (5,000 °C). Heat conducts from the core to surrounding rock. Extremely high temperature and pressure cause some rock to melt, which is commonly known as magma. Magma convects upward since it is lighter than the solid rock. This magma then heats rock and water in the crust, sometimes up to 700 °F (371 °C):<sup>[57]</sup>

From hot springs, geothermal energy has been used for bathing since Paleolithic times and for space heating since ancient Roman times, but it is now better known for electricity generation<sup>[58]</sup>

Low Temperature Geothermal<sup>[28]</sup> refers to the use of the outer crust of the earth as a Thermal Battery to facilitate Renewable thermal energy for heating and cooling buildings, and other refrigeration and industrial uses. In this form of Geothermal, a Geothermal Heat Pump and Ground-coupled heat exchanger are used together to move heat energy into the earth (for cooling) and out of the earth (for heating) on a varying seasonal basis. Low temperature Geothermal (generally referred to as "GHP") is an increasingly important renewable technology because it both reduces total annual energy loads associated with heating and cooling, and it also flattens the electric demand curve eliminating the extreme summer and winter peak electric supply requirements. Thus Low Temperature Geothermal/GHP is becoming an increasing national priority with multiple tax credit support<sup>[59]</sup> and focus as part of the ongoing movement toward Net Zero Energy.<sup>[60][29]</sup> New York City has even just passed a law<sup>[61]</sup> to require GHP anytime is shown to be economical with 20 year financing including the Socialized Cost of Carbon.<sup>[62][63]</sup>

## Bio energy

Biomass is biological material derived from living, or recently living organisms. It most often refers to plants or plant-derived materials which are specifically called lignocellulosic biomass.<sup>[64]</sup> 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. Conversion of biomass to biofuel can be achieved by different methods which are broadly classified into: *thermal*, *chemical*, and *biochemical* methods. Wood remains the largest biomass energy source today;<sup>[65]</sup> examples include forest residues – such as dead trees, branches and tree stumps –, yard clippings, wood chips and even municipal solid waste. In the second sense, biomass includes plant or animal matter that can be converted into fibers or other industrial chemicals, including biofuels. Industrial biomass can be grown from numerous types of plants, including miscanthus, switchgrass, hemp, corn, poplar, willow, sorghum, sugarcane, bamboo,<sup>[66]</sup> and a variety of tree species, ranging from eucalyptus to oil palm (palm oil).

Plant energy is produced by crops specifically grown for use as fuel that offer high biomass output per hectare with low input energy. Some examples of these plants are wheat, which typically yield 7.5–8 tonnes of grain per hectare, and straw, which typically yield 3.5–5 tonnes per hectare in the UK.<sup>[67]</sup> The grain can be used for liquid transportation fuels while the straw can be burned to produce heat or electricity. Plant biomass can also be degraded from cellulose to glucose through a series of chemical treatments, and the resulting sugar can then be used as a first generation biofuel.

Biomass can be converted to other usable forms of energy like methane gas or transportation fuels like ethanol and biodiesel. Rotting garbage, and agricultural and human waste, all release methane gas – also called landfill gas or biogas. Crops, such as corn and sugarcane, can be fermented to produce the transportation fuel, ethanol.



Steam rising from the Nesjavellir Geothermal Power Station in Iceland



Sugarcane plantation to produce ethanol in Brazil



A CHP power station using wood to supply 30,000 households in France

Biodiesel, another transportation fuel, can be produced from left-over food products like vegetable oils and animal fats.<sup>[68]</sup> Also, biomass to liquids (BTLs) and cellulosic ethanol are still under research.<sup>[69][70]</sup> There is a great deal of research involving algal fuel or algae-derived biomass due to the fact that it's a non-food resource and can be produced at rates 5 to 10 times those of other types of land-based agriculture, such as corn and soy. Once harvested, it can be fermented to produce biofuels such as ethanol, butanol, and methane, as well as biodiesel and hydrogen. The biomass used for electricity generation varies by region. Forest by-products, such as wood residues, are common in the United States. Agricultural waste is common in Mauritius (sugar cane residue) and Southeast Asia (rice husks). Animal husbandry residues, such as poultry litter, are common in the United Kingdom.<sup>[71]</sup>

Biofuels include a wide range of fuels which are derived from biomass. The term covers solid, liquid, and gaseous fuels.<sup>[72]</sup> Liquid biofuels include bioalcohols, such as bioethanol, and oils, such as biodiesel. Gaseous biofuels include biogas, landfill gas and synthetic gas. Bioethanol is an alcohol made by fermenting the sugar components of plant materials and it is made mostly from sugar and starch crops. These include maize, sugarcane and, more recently, sweet sorghum. The latter crop is particularly suitable for growing in dryland conditions, and is being investigated by International Crops Research Institute for the Semi-Arid Tropics for its potential to provide fuel, along with food and animal feed, in arid parts of Asia and Africa.<sup>[73]</sup>

With advanced technology being developed, cellulosic biomass, such as trees and grasses, are also used as feedstocks for ethanol production. Ethanol can be used as a fuel for vehicles in its pure form, but it is usually used as a gasoline additive to increase octane and improve vehicle emissions. Bioethanol is widely used in the United States and in Brazil. The energy costs for producing bioethanol are almost equal to, the energy yields from bio-ethanol. However, according to the European Environment Agency, biofuels do not address global warming concerns.<sup>[74]</sup> Biodiesel is made from vegetable oils, animal fats or recycled greases. It can be used as a fuel for vehicles in its pure form, or more commonly as a diesel additive to reduce levels of particulates, carbon monoxide, and hydrocarbons from diesel-powered vehicles. Biodiesel is produced from oils or fats using transesterification and is the most common biofuel in Europe. Biofuels provided 2.7% of the world's transport fuel in 2010.<sup>[75]</sup>

Biomass, biogas and biofuels are burned to produce heat/power and in doing so harm the environment. Pollutants such as sulphurous oxides (SO<sub>x</sub>), nitrous oxides (NO<sub>x</sub>), and particulate matter (PM) are produced from the combustion of biomass; the World Health Organisation estimates that 7 million premature deaths are caused each year by air pollution.<sup>[76]</sup> Biomass combustion is a major contributor.<sup>[76][77][78]</sup>

## Energy storage

Energy storage is a collection of methods used to store electrical energy on an electrical power grid, or off it. Electrical energy is stored during times when production (especially from intermittent power plants such as renewable electricity sources such as wind power, tidal power, solar power) exceeds consumption, and returned to the grid when production falls below consumption. Pumped-storage hydroelectricity is used for more than 90% of all grid power storage. Costs of lithium ion batteries are dropping rapidly, and are increasingly being deployed as fast acting sources of grid power (i.e. operating reserve) and for domestic storage.

## Market and industry trends

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Renewable power has been more effective in creating jobs than coal or oil in the United States.<sup>[79]</sup>

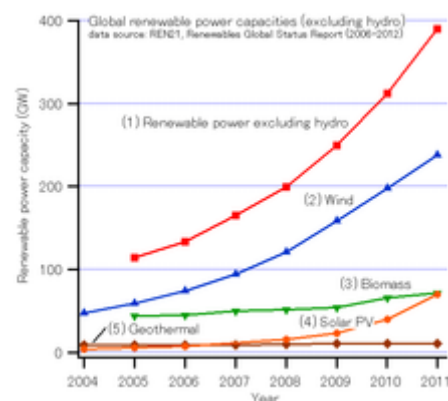
### Growth of renewables

From the end of 2004, worldwide renewable energy capacity grew at rates of 10–60% annually for many technologies. In 2015 global investment in renewables rose 5% to \$285.9 billion, breaking the previous record of \$278.5 billion in 2011. 2015 was also the first year that saw renewables, excluding large hydro, account for the majority of all new power capacity (134 GW, making up 53.6% of the total). Of the renewables total, wind accounted for 72 GW and solar photovoltaics 56 GW; both record-breaking numbers and sharply up from 2014 figures (49 GW and 45 GW respectively). In financial terms, solar made up 56% of total new investment and wind accounted for 38%.

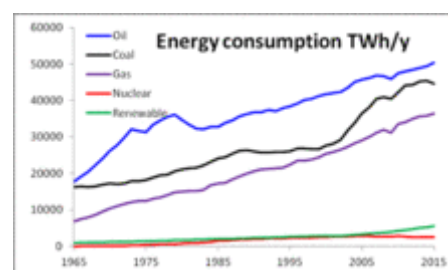
Projections vary. The EIA has predicted that almost two thirds of net additions to power capacity will come from renewables by 2020 due to the combined policy benefits of local pollution, decarbonisation and energy diversification. Some studies have set out roadmaps to power 100% of the world's energy with wind, hydroelectric and solar by the year 2030.

According to a 2011 projection by the International Energy Agency, solar power generators may produce most of the world's electricity within 50 years, reducing the emissions of greenhouse gases that harm the environment. Cedric Philibert, senior analyst in the renewable energy division at the IEA said: "Photovoltaic and solar-thermal plants may meet most of the world's demand for electricity by 2060 – and half of all energy needs – with wind, hydropower and biomass plants supplying much of the remaining generation". "Photovoltaic and concentrated solar power together can become the major source of electricity", Philibert said.<sup>[24]</sup>

In 2014 global wind power capacity expanded 16% to 369,553 MW.<sup>[82]</sup> Yearly wind energy production is also growing rapidly and has reached around 4% of worldwide electricity usage,<sup>[83]</sup> 11.4% in the EU,<sup>[84]</sup> and it is widely used in Asia, and the United States. In 2015, worldwide installed photovoltaics capacity increased to 227 gigawatts (GW), sufficient to supply 1 percent of global electricity demands.<sup>[85]</sup> Solar thermal energy stations operate in the USA and Spain, and as of 2016, the largest of these is the 392 MW Ivanpah Solar Electric Generating System in California.<sup>[86][87]</sup> The world's largest geothermal power installation is The Geysers in California, with a rated capacity of 750 MW. Brazil has one of the largest renewable energy programs in the world, involving production of ethanol fuel from sugar cane, and ethanol now provides 18% of the country's automotive fuel. Ethanol fuel is also widely available in the USA.



Global growth of renewables through to 2011<sup>[80]</sup>

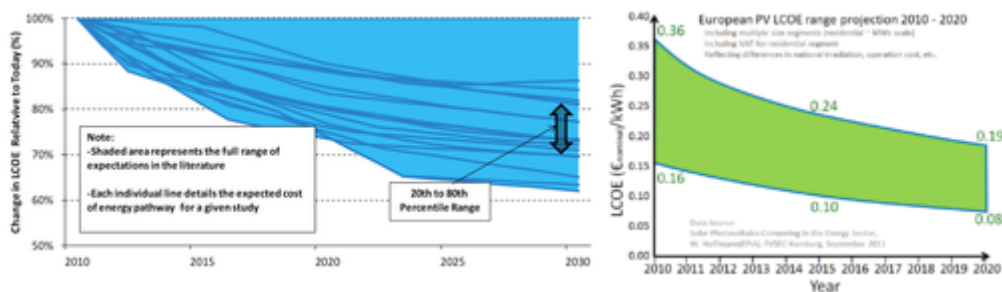


Comparing worldwide energy use, the growth of renewable energy is shown by the green line<sup>[81]</sup>

| Selected renewable energy global indicators                                         | 2008  | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  |
|-------------------------------------------------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Investment in new renewable capacity (annual) (10 <sup>9</sup> USD) <sup>[88]</sup> | 182   | 178   | 237   | 279   | 256   | 232   | 270   | 285   | 241   |
| Renewables power capacity (existing) (GWe)                                          | 1,140 | 1,230 | 1,320 | 1,360 | 1,470 | 1,578 | 1,712 | 1,849 | 2,017 |
| Hydropower capacity (existing) (GWe)                                                | 885   | 915   | 945   | 970   | 990   | 1,018 | 1,055 | 1,064 | 1,096 |
| Wind power capacity (existing) (GWe)                                                | 121   | 159   | 198   | 238   | 283   | 319   | 370   | 433   | 487   |
| Solar PV capacity (grid-connected) (GWe)                                            | 16    | 23    | 40    | 70    | 100   | 138   | 177   | 227   | 303   |
| Solar hot water capacity (existing) (GWth)                                          | 130   | 160   | 185   | 232   | 255   | 373   | 406   | 435   | 456   |
| Ethanol production (annual) (10 <sup>9</sup> litres)                                | 67    | 76    | 86    | 86    | 83    | 87    | 94    | 98    | 98.6  |
| Biodiesel production (annual) (10 <sup>9</sup> litres)                              | 12    | 17.8  | 18.5  | 21.4  | 22.5  | 26    | 29.7  | 30    | 30.8  |
| Countries with policy targets for renewable energy use                              | 79    | 89    | 98    | 118   | 138   | 144   | 164   | 173   | 176   |

Source: The Renewable Energy Policy Network for the 21st Century (REN21)—Global Status Report<sup>[89][90][91][92][93][94]</sup>

## Economic trends



Projection of levelized cost for wind in the U.S. (left) and solar power in Europe<sup>[95][96]</sup>

Renewable energy technologies are getting cheaper, through technological change and through the benefits of mass production and market competition. A 2011 IEA report said: "A portfolio of renewable energy technologies is becoming cost-competitive in an increasingly broad range of circumstances, in some cases providing investment opportunities without the need for specific economic support," and added that "cost reductions in critical technologies, such as wind and solar are set to continue."<sup>[97]</sup>

Hydro-electricity and geothermal electricity produced at favourable sites are now the cheapest way to generate electricity. Renewable energy costs continue to drop, and the levelised cost of electricity (LCOE) is declining for wind power, solar photovoltaic (PV), concentrated solar power (CSP) and some biomass technologies.<sup>[98]</sup> Renewable energy is also the most economic solution for new grid-connected capacity in areas with good resources. As the cost of renewable power falls, the scope of economically viable applications increases. Renewable technologies are now often the most economic solution for new generating capacity. Where "oil-fired generation is the predominant power generation source (e.g. on islands, off-grid and in some countries) a lower-cost renewable solution almost always exists today".<sup>[98]</sup> A series of studies by the US National Renewable Energy Laboratory modeled the "grid in the Western US under a number of different scenarios where intermittent renewables accounted for 33 percent of the total power." In the models, inefficiencies in cycling the fossil fuel plants to compensate for the variation in solar and wind energy resulted in an additional cost of "between \$0.47 and \$1.28 to each MegaWatt hour generated"; however, the savings in the cost of the fuels saved "adds up to \$7 billion, meaning the added costs are, at most, two percent of the savings."<sup>[99]</sup>

## Hydroelectricity

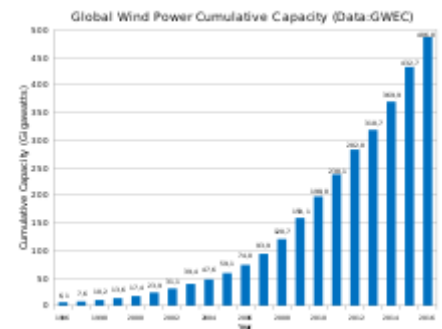
Only a quarter of the world's estimated hydroelectric potential of 14,000 TWh/year has been developed, the regional potentials for the growth of hydropower around the world are, 71% Europe, 75% North America, 79% South America, 95% Africa, 95% Middle East, 82% Asia Pacific. However, the political realities of new reservoirs in western countries, economic limitations in the third world and the lack of a transmission system in undeveloped areas, result in the possibility of developing 25% of the remaining potential before 2050, with the bulk of that being in the Asia Pacific area.<sup>[100]</sup> There is slow growth taking place in Western countries, but not in the conventional dam and reservoir style of the past. New projects take the form of run-of-the-river and small hydro, neither using large reservoirs. It is popular to repower old dams thereby increasing their efficiency and capacity as well as quicker responsiveness on the grid.<sup>[101]</sup> Where circumstances permit existing dams like the Russell Dam built in 1985 may be updated with "pump back" facilities for pumped-storage which is useful for peak loads or to support intermittent wind and solar power. Countries with large hydroelectric developments like Canada and Norway are spending billions to expand their grids to trade with neighboring countries having limited hydro.<sup>[102]</sup>

## Wind power development

Wind power is widely used in Europe, China, and the United States. From 2004 to 2014, worldwide installed capacity of wind power has been growing from 47 GW to 369 GW—a more than sevenfold increase within 10 years with 2014 breaking a new record in global installations (51 GW). As of the end of 2014, China, the United States and Germany combined accounted for half of total global capacity.<sup>[82]</sup> Several other countries have achieved relatively high levels of wind power penetration, such as 21% of stationary electricity production in Denmark, 18% in Portugal, 16% in Spain, and 14% in Ireland in 2010 and have since continued to expand their installed capacity.<sup>[103][104]</sup> More than 80 countries around the world are using wind power on a commercial basis.<sup>[75]</sup>

- Offshore wind power

As of 2014, offshore wind power amounted to 8,771 megawatt of global installed capacity. Although offshore capacity doubled within three years (from 4,117 MW in 2011), it accounted for only 2.3% of the total wind power capacity. The United Kingdom is the undisputed leader of offshore power with half of the world's installed capacity ahead of Denmark, Germany, Belgium and China.



Worldwide growth of wind capacity (1996–2014)<sup>[82]</sup>

- List of offshore and onshore wind farms

As of 2012, the Alta Wind Energy Center (California, 1,020 MW) is the world's largest wind farm.<sup>[105]</sup> The London Array (630 MW) is the largest offshore wind farm in the world. The United Kingdom is the world's leading generator of offshore wind power, followed by Denmark.<sup>[106]</sup> There are several large offshore wind farms operational and under construction and these include Anholt (400 MW), BARD (400 MW), Clyde (548 MW), Fântânele-Cogealac (600 MW), Greater Gabbard (500 MW), Lincs (270 MW), London Array (630 MW), Lower Snake River (343 MW), Macarthur (420 MW), Shepherds Flat (845 MW), and the Sheringham Shoal (317 MW).



Four offshore wind farms are in the Thames Estuary area: Kentish Flats, Gunfleet Sands, Thanet and London Array. The latter is the largest in the world as of April 2013.

## Solar thermal

The United States conducted much early research in photovoltaics and concentrated solar power. The U.S. is among the top countries in the world in electricity generated by the Sun and several of the world's largest utility-scale installations are located in the desert Southwest.

The oldest solar thermal power plant in the world is the 354 megawatt (MW) SEGS thermal power plant, in California.<sup>[107]</sup> The Ivanpah Solar Electric Generating System is a solar thermal power project in the California Mojave Desert, 40 miles (64 km) southwest of Las Vegas, with a gross capacity of 377 MW.<sup>[108]</sup> The 280 MW Solana Generating Station is a solar power plant near Gila Bend, Arizona, about 70 miles (110 km) southwest of Phoenix, completed in 2013. When commissioned it was the largest parabolic troughplant in the world and the first U.S. solar plant with molten salt thermal energy storage.<sup>[109]</sup>



The 377 MW Ivanpah Solar Electric Generating System with all three towers under load, Feb 2014. Taken from I-15.

The solar thermal power industry is growing rapidly with 1.3 GW under construction in 2012 and more planned. Spain is the epicenter of solar thermal power development with 873 MW under construction, and a further 271 MW under development.<sup>[110]</sup> In the United States, 5,600 MW of solar thermal power projects have been announced.<sup>[111]</sup> Several power plants have been constructed in the Mojave Desert, Southwestern United States. The Ivanpah Solar Power Facility being the most recent. In developing countries, three World Bank projects for integrated solar thermal/combined-cycle gas-turbine power plants in Egypt, Mexico, and Morocco have been approved!<sup>[112]</sup>

## Photovoltaic development

Photovoltaics (PV) uses solar cells assembled into solar panels to convert sunlight into electricity. It's a fast-growing technology doubling its worldwide installed capacity every couple of years. PV systems range from small, residential and commercial rooftop or building integrated installations, to large utility-scale photovoltaic power station. The predominant PV technology is crystalline

silicon, while thin-film solar cell technology accounts for about 10 percent of global photovoltaic deployment. In recent years, PV technology has improved its electricity generating efficiency, reduced the installation cost per watt as well as its energy payback time, and has reached grid parity in at least 30 different markets by 2014.<sup>[113]</sup> Financial institutions are predicting a second solar "gold rush" in the near future.<sup>[114][115][116]</sup>

At the end of 2014, worldwide PV capacity reached at least 177,000 megawatts. Photovoltaics grew fastest in China, followed by Japan and the United States, while Germany remains the world's largest overall producer of photovoltaic power, contributing about 7.0 percent to the overall electricity generation. Italy meets 7.9 percent of its electricity demands with photovoltaic power—the highest share worldwide.<sup>[117]</sup> For 2015, global cumulative capacity is forecasted to increase by more than 50 gigawatts (GW). By 2018, worldwide capacity is projected to reach as much as 430 gigawatts. This corresponds to a tripling within five years.<sup>[118]</sup> Solar power is forecasted to become the world's largest source of electricity by 2050, with solar photovoltaics and concentrated solar power contributing 16% and 11%, respectively. This requires an increase of installed PV capacity to 4,600 GW, of which more than half is expected to be deployed in China and India.<sup>[119]</sup>

## Photovoltaic power stations

Commercial concentrated solar power plants were first developed in the 1980s. As the cost of solar electricity has fallen, the number of grid-connected solar PV systems has grown into the millions and utility-scale solar power stations with hundreds of megawatts are being built. Solar PV is rapidly becoming an inexpensive, low-carbon technology to harness renewable energy from the Sun.

Many solar photovoltaic power stations have been built, mainly in Europe, China and the USA.<sup>[120]</sup> The 579 MW Solar Star, in the United States, is the world's largest PV power station

Many of these plants are integrated with agriculture and some use tracking systems that follow the sun's daily path across the sky to generate more electricity than fixed-mounted systems. There are no fuel costs or emissions during operation of the power stations.

However, when it comes to renewable energy systems and PV, it is not just large systems that matter. Building-integrated photovoltaics or "onsite" PV systems use existing land and structures and generate power close to where it is consumed.<sup>[121]</sup>

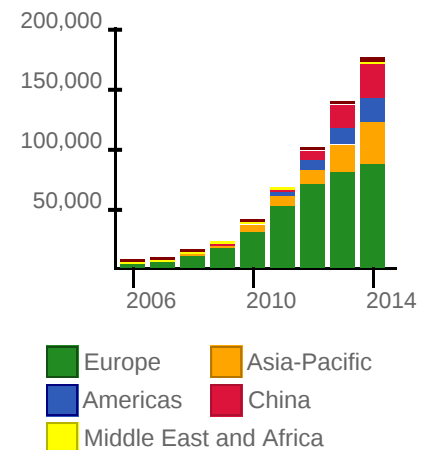
## Biofuel development

Biofuels provided 3% of the world's transport fuel in 2010.<sup>[75]</sup> Mandates for blending biofuels exist in 31 countries at the national level and in 29 states/provinces.<sup>[75]</sup> According to the International Energy Agency, biofuels have the potential to meet more than a quarter of world demand for transportation fuels by 2050.<sup>[122]</sup>

Since the 1970s, Brazil has had an ethanol fuel program which has allowed the country to become the world's second largest producer of ethanol (after the United States) and the world's largest exporter.<sup>[123]</sup> Brazil's ethanol fuel program uses modern equipment and cheap sugarcane as feedstock, and the residual cane-waste (bagasse) is used to produce heat and power.<sup>[124]</sup> There are no longer light



Solar Towers of the PS10 and PS20 solar thermal plants in Spain



Worldwide growth of PV capacity grouped by region in MW (2006–2014)



Solar panels at the 550 MW Topaz Solar Farm

vehicles in Brazil running on pure gasoline. By the end of 2008 there were 35,000 filling stations throughout Brazil with at least one ethanol pump.<sup>[125]</sup> Unfortunately, Operation Car Wash has seriously eroded public trust in oil companies and has implicated several high ranking Brazilian officials.

Nearly all the gasoline sold in the United States today is mixed with 10% ethanol,<sup>[126]</sup> and motor vehicle manufacturers already produce vehicles designed to run on much higher ethanol blends. Ford, Daimler AG, and GM are among the automobile companies that sell "flexible-fuel" cars, trucks, and minivans that can use gasoline and ethanol blends ranging from pure gasoline up to 85% ethanol. By mid-2006, there were approximately 6 million ethanol compatible vehicles on U.S. roads.<sup>[127]</sup>

## Geothermal development

Geothermal power is cost effective, reliable, sustainable, and environmentally friendly,<sup>[128]</sup> but has historically been limited to areas near tectonic plate boundaries. Recent technological advances have expanded the range and size of viable resources, especially for applications such as home heating, opening a potential for widespread exploitation. Geothermal wells release greenhouse gases trapped deep within the earth, but these emissions are much lower per energy unit than those of fossil fuels. As a result, geothermal power has the potential to help mitigate global warming if widely deployed in place of fossil fuels.

The International Geothermal Association (IGA) has reported that 10,715 MW of geothermal power in 24 countries is online, which is expected to generate 67,246 GWh of electricity in 2010.<sup>[129]</sup> This represents a 20% increase in geothermal power online capacity since 2005. IGA projects this will grow to 18,500 MW by 2015, due to the large number of projects presently under consideration, often in areas previously assumed to have little exploitable resource.<sup>[129]</sup>

In 2010, the United States led the world in geothermal electricity production with 3,086 MW of installed capacity from 77 power plants;<sup>[130]</sup> the largest group of geothermal power plants in the world is located at The Geysers, a geothermal field in California.<sup>[131]</sup> The Philippines follows the US as the second highest producer of geothermal power in the world, with 1,904 MW of capacity online; geothermal power makes up approximately 18% of the country's electricity generation.<sup>[130]</sup>

## Developing countries

Renewable energy technology has sometimes been seen as a costly luxury item by critics, and affordable only in the affluent developed world. This erroneous view has persisted for many years, but 2015 was the first year when investment in non-hydro renewables, was higher in developing countries, with \$156 billion invested, mainly in China, India, and Brazil.<sup>[132]</sup>

Renewable energy can be particularly suitable for developing countries. In rural and remote areas, transmission and distribution of energy generated from fossil fuels can be difficult and expensive. Producing renewable energy locally can offer a viable alternative.<sup>[133]</sup>



Nellis Solar Power Plant  
photovoltaic power plant in Nevada,  
USA



Brazil produces bioethanol made from sugarcane available throughout the country. A typical gas station with dual fuel service is marked "A" for alcohol (ethanol) and "G" for gasoline.



Geothermal plant at The Geysers, California, USA

Technology advances are opening up a huge new market for solar power: the approximately 1.3 billion people around the world who don't have access to grid electricity. Even though they are typically very poor, these people have to pay far more for lighting than people in rich countries because they use inefficient kerosene lamps. Solar power costs half as much as lighting with kerosene.<sup>[134]</sup> As of 2010, an estimated 3 million households get power from small solar PV systems.<sup>[135]</sup> Kenya is the world leader in the number of solar power systems installed per capita. More than 30,000 very small solar panels, each producing 12 to 30 watts, are sold in Kenya annually. Some Small Island Developing States (SIDS) are also turning to solar power to reduce their costs and increase their sustainability.<sup>[136]</sup>



Solar cookers use sunlight as energy source for outdoor cooking

Micro-hydro configured into mini-grids also provide power. Over 44 million households use biogas made in household-scale digesters for lighting and/or cooking, and more than 166 million households rely on a new generation of more-efficient biomass cookstoves.<sup>[25]</sup> Clean liquid fuel sourced from renewable feedstocks are used for cooking and lighting in energy-poor areas of the developing world. Alcohol fuels (ethanol and methanol) can be produced sustainably from non-food sugary, starchy, and cellulosic feedstocks. Project Gaia, Inc. and CleanStar Mozambique are implementing clean cooking programs with liquid ethanol stoves in Ethiopia, Kenya, Nigeria and Mozambique.<sup>[137]</sup>

Renewable energy projects in many developing countries have demonstrated that renewable energy can directly contribute to poverty reduction by providing the energy needed for creating businesses and employment. Renewable energy technologies can also make indirect contributions to alleviating poverty by providing energy for cooking, space heating, and lighting. Renewable energy can also contribute to education, by providing electricity to schools.<sup>[138]</sup>

## Industry and policy trends

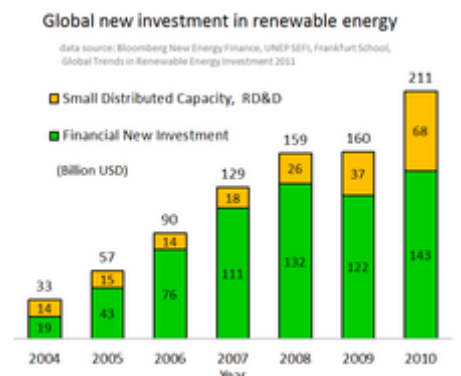
U.S. President Barack Obama's American Recovery and Reinvestment Act of 2009 includes more than \$70 billion in direct spending and tax credits for clean energy and associated transportation programs. Leading renewable energy companies include First Solar, Gamesa, GE Energy, Hanwha Q Cells, Sharp Solar, Siemens, SunOpta, Suntech Power, and Vestas.<sup>[140]</sup>

Many national, state, and local governments have also created green banks. A green bank is a quasi-public financial institution that uses public capital to leverage private investment in clean energy technologies.<sup>[141]</sup> Green banks use a variety of financial tools to bridge market gaps that hinder the deployment of clean energy.

The military has also focused on the use of renewable fuels for military vehicles. Unlike fossil fuels, renewable fuels can be produced in any country, creating a strategic advantage. The US military has already committed itself to have 50% of its energy consumption come from alternative sources.<sup>[142]</sup>

The International Renewable Energy Agency (IRENA) is an intergovernmental organization for promoting the adoption of renewable energy worldwide. It aims to provide concrete policy advice and facilitate capacity building and technology transfer. IRENA was formed on 26 January 2009, by 75 countries signing the charter of IRENA.<sup>[143]</sup> As of March 2010, IRENA has 143 member states who all are considered as founding members, of which 14 have also ratified the statute.<sup>[144]</sup>

As of 2011, 119 countries have some form of national renewable energy policy target or renewable support policy. National targets now exist in at least 98 countries. There is also a wide range of policies at state/provincial and local levels.<sup>[75]</sup>



Global New Investments in Renewable Energy<sup>[139]</sup>

United Nations' Secretary-General Ban Ki-moon has said that renewable energy has the ability to lift the poorest nations to new levels of prosperity.<sup>[13]</sup> In October 2011, he "announced the creation of a high-level group to drum up support for energy access, energy efficiency and greater use of renewable energy. The group is to be co-chaired by Kandeh Yumkella, the chair of UN Energy and director general of the UN Industrial Development Organisation, and Charles Holliday chairman of Bank of America".<sup>[145]</sup>

## 100% renewable energy

The incentive to use 100% renewable energy, for electricity, transport, or even total primary energy supply globally, has been motivated by global warming and other ecological as well as economic concerns. The Intergovernmental Panel on Climate Change has said that there are few fundamental technological limits to integrating a portfolio of renewable energy technologies to meet most of total global energy demand. Renewable energy use has grown much faster than even advocates anticipated.<sup>[146]</sup> At the national level, at least 30 nations around the world already have renewable energy contributing more than 20% of energy supply. Also, Professors S. Pacala and Robert H. Socolow have developed a series of "stabilization wedges" that can allow us to maintain our quality of life while avoiding catastrophic climate change, and "renewable energy sources," in aggregate, constitute the largest number of their "wedges".<sup>[147]</sup>

Using 100% renewable energy was first suggested in a Science paper published in 1975 by Danish physicist Bent Sørensen.<sup>[148]</sup> It was followed by several other proposals, until in 1998 the first detailed analysis of scenarios with very high shares of renewables were published. These were followed by the first detailed 100% scenarios. In 2006 a PhD thesis was published by Czisch in which it was shown that in a 100% renewable scenario energy supply could match demand in every hour of the year in Europa and North Africa. In the same year Danish Energy professor Henrik Lund published a first paper<sup>[149]</sup> in which he addresses the optimal combination of renewables, which was followed by several other papers on the transition to 100% renewable energy in Denmark. Since then Lund has been publishing several papers on 100% renewable energy. After 2009 publications began to rise steeply, covering 100% scenarios for countries in Europa, America, Australia and other parts of the world.<sup>[150]</sup>

In 2011 Mark Z. Jacobson, professor of civil and environmental engineering at Stanford University, and Mark Delucchi published a study on 100% renewable global energy supply in the journal Energy Policy. They found producing all new energy with wind power, solar power, and hydropower by 2030 is feasible and existing energy supply arrangements could be replaced by 2050. Barriers to implementing the renewable energy plan are seen to be "primarily social and political, not technological or economic". They also found that energy costs with a wind, solar, water system should be similar to today's energy costs.<sup>[151]</sup>

Similarly, in the United States, the independent National Research Council has noted that "sufficient domestic renewable resources exist to allow renewable electricity to play a significant role in future electricity generation and thus help confront issues related to climate change, energy security, and the escalation of energy costs ... Renewable energy is an attractive option because renewable resources available in the United States, taken collectively, can supply significantly greater amounts of electricity than the total current or projected domestic demand."<sup>[152]</sup>

The most significant barriers to the widespread implementation of large-scale renewable energy and low carbon energy strategies are primarily political and not technological. According to the 2013 *Post Carbon Pathways* report, which reviewed many international studies, the key roadblocks are: climate change denial, the fossil fuels lobby, political inaction, unsustainable energy consumption, outdated energy infrastructure, and financial constraints.<sup>[153]</sup>

## Emerging technologies

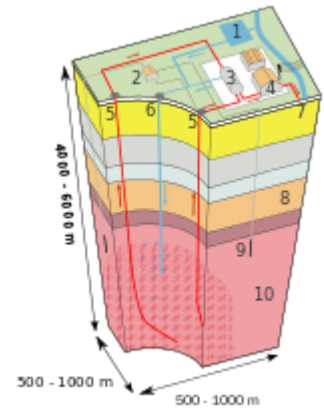
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Other renewable energy technologies are still under development, and include cellulosic ethanol, hot-dry-rock geothermal power, and marine energy.<sup>[154]</sup> These technologies are not yet widely demonstrated or have limited commercialization. Many are on the horizon and may have potential comparable to other renewable energy technologies, but still depend on attracting sufficient attention and research, development and demonstration (RD&D) funding.<sup>[154]</sup>

There are numerous organizations within the academic, federal, and commercial sectors conducting large scale advanced research in the field of renewable energy. This research spans several areas of focus across the renewable energy spectrum. Most of the research is targeted at improving efficiency and increasing overall energy yields.<sup>[155]</sup> Multiple federally supported research organizations have focused on renewable energy in recent years. Two of the most prominent of these labs are Sandia National Laboratories and the National Renewable Energy Laboratory (NREL), both of which are funded by the United States Department of Energy and supported by various corporate partners.<sup>[156]</sup> Sandia has a total budget of \$2.4 billion<sup>[157]</sup> while NREL has a budget of \$375 million.<sup>[158]</sup>

- Enhanced geothermal system

Enhanced geothermal systems (EGS) are a new type of geothermal power technologies that do not require natural convective hydrothermal resources. The vast majority of geothermal energy within drilling reach is in dry and non-porous rock.<sup>[159]</sup> EGS technologies "enhance" and/or create geothermal resources in this "hot dry rock (HDR)" through hydraulic stimulation. EGS and HDR technologies, like hydrothermal geothermal, are expected to be baseload resources which produce power 24 hours a day like a fossil plant. Distinct from hydrothermal, HDR and EGS may be feasible anywhere in the world, depending on the economic limits of drill depth. Good locations are over deep granite covered by a thick (3–5 km) layer of insulating sediments which slow heat loss.<sup>[160]</sup> There are HDR and EGS systems currently being developed and tested in France, Australia, Japan, Germany, the U.S. and Switzerland. The largest EGS project in the world is a 25 megawatt demonstration plant currently being developed in the Cooper Basin, Australia. The Cooper Basin has the potential to generate 5,000–10,000 MW.



Enhanced geothermal system (see file description for details)

- Cellulosic ethanol

Several refineries that can process biomass and turn it into ethanol are built by companies such as logen, POET, and Abengoa, while other companies such as the Verenium Corporation, Novozymes, and Dyadic International<sup>[161]</sup> are producing enzymes which could enable future commercialization. The shift from food crop feedstocks to waste residues and native grasses offers significant opportunities for a range of players, from farmers to biotechnology firms, and from project developers to investors.<sup>[162]</sup>

- Marine energy

Marine energy (also sometimes referred to as ocean energy) refers to the energy carried by ocean waves, tides, salinity, and ocean temperature differences. The movement of water in the world's oceans creates a vast store of kinetic energy, or energy in motion. This energy can be harnessed to generate electricity to power homes, transport and industries. The term marine energy encompasses both wave power – power from surface waves, and tidal power – obtained from the kinetic energy of large bodies of moving water. Reverse electrodialysis (RED) is a technology for generating electricity by mixing fresh river water and salty sea water in large power cells designed for this purpose; as of 2016 it is being tested at a small scale (50 kW). Offshore wind power is not a form of marine energy, as wind power is derived from the wind, even if the wind turbines are placed over water. The oceans have a tremendous amount of energy and are close to many if not most concentrated populations. Ocean



Rance Tidal Power Station, France

energy has the potential of providing a substantial amount of new renewable energy around the world.<sup>[163]</sup>

| #  | Station                                            | Country     | Location                               | Capacity | Refs  |
|----|----------------------------------------------------|-------------|----------------------------------------|----------|-------|
| 1. | <a href="#">Sihwa Lake Tidal Power Station</a>     | South Korea | <a href="#">37°18'47"N 126°36'46"E</a> | 254 MW   | [164] |
| 2. | <a href="#">Rance Tidal Power Station</a>          | France      | <a href="#">48°37'05"N 02°01'24"W</a>  | 240 MW   | [165] |
| 3. | <a href="#">Annapolis Royal Generating Station</a> | Canada      | <a href="#">44°45'07"N 65°30'40"W</a>  | 20 MW    | [165] |

- Experimental solar power

Concentrated photovoltaics (CPV) systems employ sunlight concentrated onto photovoltaic surfaces for the purpose of electricity generation. Thermoelectric, or "thermovoltaic" devices convert a temperature difference between dissimilar materials into an electric current.

- Floating solar arrays

Floating solar arrays are PV systems that float on the surface of drinking water reservoirs, quarry lakes, irrigation canals or remediation and tailing ponds. A small number of such systems exist in France, India, Japan, South Korea, the United Kingdom, Singapore and the United States.<sup>[166][167][168][169][170]</sup> The systems are said to have advantages over photovoltaics on land. The cost of land is more expensive, and there are fewer rules and regulations for structures built on bodies of water not used for recreation. Unlike most land-based solar plants, floating arrays can be unobtrusive because they are hidden from public view. They achieve higher efficiencies than PV panels on land, because water cools the panels. The panels have a special coating to prevent rust or corrosion.<sup>[171]</sup> In May 2008, the Far Niente Winery in Oakville, California, pioneered the world's first floatovoltaic system by installing 994 solar PV modules with a total capacity of 477 kW onto 130 pontoons and floating them on the winery's irrigation pond.<sup>[172]</sup> Utility-scale floating PV farms are starting to be built. Kyocera will develop the world's largest, a 13.4 MW farm on the reservoir above Yamakura Dam in [Chiba Prefecture](#)<sup>[173]</sup> using 50,000 solar panels.<sup>[174][175]</sup> Salt-water resistant floating farms are also being constructed for ocean use.<sup>[176]</sup> The largest so far announced floatovoltaic project is a 350 MW power station in the Amazon region of Brazil.<sup>[177]</sup>

- Solar-assisted heat pump

A heat pump is a device that provides heat energy from a source of heat to a destination called a "heat sink". Heat pumps are designed to move thermal energy opposite to the direction of spontaneous heat flow by absorbing heat from a cold space and releasing it to a warmer one. A solar-assisted heat pump represents the integration of a heat pump and thermal solar panels in a single integrated system. Typically these two technologies are used separately (or only placing them in parallel) to produce hot water.<sup>[178]</sup> In this system the solar thermal panel performs the function of the low temperature heat source and the heat produced is used to feed the heat pump's evaporator.<sup>[179]</sup> The goal of this system is to get high COP and then produce energy in a more efficient and less expensive way.

It is possible to use any type of solar thermal panel (sheet and tubes, roll-bond, heat pipe, thermal plates) or hybrid (mono/polycrystalline, thin film) in combination with the heat pump. The use of a hybrid panel is preferable because it allows covering a part of the electricity demand of the heat pump and reduce the power consumption and consequently the variable costs of the system.

- Artificial photosynthesis

Artificial photosynthesis uses techniques including nanotechnology to store solar electromagnetic energy in chemical bonds by splitting water to produce hydrogen and then

using carbon dioxide to make methanol.<sup>[180]</sup> Researchers in this field are striving to design molecular mimics of photosynthesis that utilize a wider region of the solar spectrum, employ catalytic systems made from abundant, inexpensive materials that are robust, readily repaired, non-toxic, stable in a variety of environmental conditions and perform more efficiently allowing a greater proportion of photon energy to end up in the storage compounds, i.e., carbohydrates (rather than building and sustaining living cells).<sup>[181]</sup> However, prominent research faces hurdles, Sun Catalytix a MIT spin-off stopped scaling up their prototype fuel-cell in 2012, because it offers few savings over other ways to make hydrogen from sunlight.<sup>[182]</sup>

- Algae fuels

Producing liquid fuels from oil-rich varieties of algae is an ongoing research topic. Various microalgae grown in open or closed systems are being tried including some system that can be set up in brownfield and desert lands.

- Solar aircraft

An electric aircraft is an aircraft that runs on electric motors rather than internal combustion engines, with electricity coming from fuel cells, solar cells, ultracapacitors, power beaming,<sup>[183]</sup> or batteries.

Currently, flying manned electric aircraft are mostly experimental demonstrators, though many small unmanned aerial vehicles are powered by batteries. Electrically powered model aircraft have been flown since the 1970s, with one report in 1957.<sup>[184][185]</sup> The first man-carrying electrically powered flights were made in 1973.<sup>[186]</sup> Between 2015–2016, a manned, solar-powered plane, Solar Impulse 2, completed a circumnavigation of the Earth.<sup>[187]</sup>



In 2016, *Solar Impulse 2* was the first solar-powered aircraft to complete a circumnavigation of the world.

- Solar updraft tower

The Solar updraft tower is a renewable-energy power plant for generating electricity from low temperature solar heat. Sunshine heats the air beneath a very wide greenhouse-like roofed collector structure surrounding the central base of a very tall chimney tower. The resulting convection causes a hot air updraft in the tower by the chimney effect. This airflow drives wind turbines placed in the chimney updraft or around the chimney base to produce electricity. Plans for scaled-up versions of demonstration models will allow significant power generation, and may allow development of other applications, such as water extraction or distillation, and agriculture or horticulture. A more advanced version of a similarly themed technology is the Vortex engine which aims to replace large physical chimneys with a vortex of air created by a shorter, less-expensive structure.

- Space-based solar power

For either photovoltaic or thermal systems, one option is to loft them into space, particularly Geosynchronous orbit. To be competitive with Earth-based solar power systems, the specific mass (kg/kW) times the cost to loft mass plus the cost of the parts needs to be \$2400 or less. I.e., for a parts cost plus rectenna of \$1100/kW, the product of the \$/kg and kg/kW must be \$1300/kW or less.<sup>[188]</sup> Thus for 6.5 kg/kW, the transport cost cannot exceed \$200/kg. While that will require a 100 to one reduction, SpaceX is targeting a ten to one reduction, Reaction Engines may make a 100 to one reduction possible.

## Debate

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Renewable electricity production, from sources such as wind power and solar power, is sometimes criticized for being variable or intermittent, but is not true for concentrated solar, geothermal and biofuels, that have continuity. In any case, the International Energy Agency has stated that deployment of renewable technologies usually increases the diversity of electricity sources and, through local generation, contributes to the flexibility of the system and its resistance to central shocks.<sup>[189]</sup>

There have been "not in my back yard" (NIMBY) concerns relating to the visual and other impacts of some wind farms, with local residents sometimes fighting or blocking construction.<sup>[190]</sup> In the USA, the Massachusetts Cape Wind project was delayed for years partly because of aesthetic concerns. However, residents in other areas have been more positive. According to a town councilor, the overwhelming majority of locals believe that the Ardrossan Wind Farm in Scotland has enhanced the area.<sup>[191]</sup>

A recent UK Government document states that "projects are generally more likely to succeed if they have broad public support and the consent of local communities. This means giving communities both a say and a stake".<sup>[192]</sup> In countries such as Germany and Denmark many renewable projects are owned by communities, particularly through cooperative structures, and contribute significantly to overall levels of renewable energy deployment.<sup>[193][194]</sup>

The market for renewable energy technologies has continued to grow. Climate change concerns and increasing in green jobs, coupled with high oil prices, peak oil, oil wars, oil spills, promotion of electric vehicles and renewable electricity, nuclear disasters and increasing government support, are driving increasing renewable energy legislation, incentives and commercialization.<sup>[9]</sup> New government spending, regulation and policies helped the industry weather the 2009 economic crisis better than many other sectors.<sup>[23][195]</sup>

While renewables have been very successful in their ever-growing contribution to electrical power there are no countries dominated by fossil fuels who have a plan to stop and get that power from renewables. Only Scotland and Ontario have stopped burning coal, largely due to good natural gas supplies. In the area of transportation, fossil fuels are even more entrenched and solutions harder to find.<sup>[196]</sup> It's unclear if there are failures with policy or renewable energy, but twenty years after the Kyoto Protocol fossil fuels are still our primary energy source and consumption continues to grow.<sup>[197]</sup>

## Environmental impact

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The ability of biomass and biofuels to contribute to a reduction in CO<sub>2</sub> emissions is limited because both biomass and biofuels emit large amounts of air pollution when burned and in some cases compete with food supply. Furthermore, biomass and biofuels consume large amounts of water.<sup>[198]</sup> Other renewable sources such as wind power, photovoltaics, and hydroelectricity have the advantage of being able to conserve water, lower pollution and reduce CO<sub>2</sub> emissions.

## Gallery

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Burbo,  
England



NW- Sunrise at the Fenton Wind  
Farm in Minnesota, USA



The CSP-station Andasol in  
Andalusia, Spain



Ivanpah solar plant in the  
Mojave Desert, California,  
United States



Three Gorges Dam and Gezhouba  
Dam, China



Shop selling PV panels in  
Ouagadougou, Burkina Faso



Stump harvesting increases  
recovery of biomass from  
forests



A small, roof-top mounted  
PV system in Bonn,  
Germany



The community-owned  
Westmill Solar Park in South  
East England



Komekurayama photovoltaic  
power station in Kofu, Japan



Krafla, a geothermal power  
station in Iceland

## See also

- Design feasibility of Wind turbine systems
- Distributed generation
- Efficient energy use
- Energy harvesting
- Energy storage

- Thermal energy storage
- Renewable energy by country

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## Further reading

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- Jaffe, Amy Myers, "Green Giant: Renewable Energy and Chinese Power", *Foreign Affairs*, vol. 97, no. 2 (March / April 2018), pp. 83–93. Discusses China's aspirations to become "...the renewable energy superpower of the future."

## External links

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-  The dictionary definition of renewable energy at Wiktionary
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  - Tethys is an online knowledge management system that provides the marine and hydrokinetic energy (MHK) and offshore wind (OSW) communities with access to information and scientific literature on environmental effects of MHK and OSW developments.
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