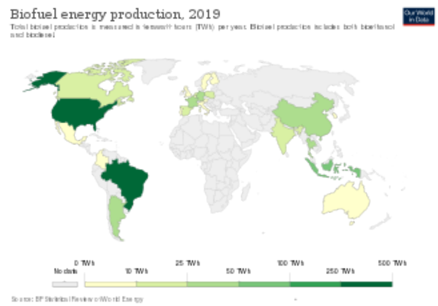
# Biofuel

**Biofuel** is fuel that is produced through contemporary processes from biomass, rather than by the very slow geological processes involved in the formation of fossil fuels, such as oil. Since biomass technically can be used as a fuel directly (e.g. wood logs), some people use the terms biomass and biofuel interchangeably. More often than not, however, the word biomass simply denotes the biological raw material the fuel is made of, or some form of thermally/chemically altered *solid* end product, like torrefied pellets or briquettes.



Biofuel energy production, 2019

The word biofuel is usually reserved for *liquid* or *gaseous* fuels, used for transportation. The U.S. Energy Information Administration (EIA) follows this naming practice.[1] Drop-in biofuels are functionally equivalent to petroleum fuels and fully compatible with the existing petroleum infrastructure.[2] They require no engine modification of the vehicle.[3]


A bus fueled by biogas

Biofuel can be produced from plants (i.e. energy crops), or from agricultural, commercial, domestic, and/or industrial wastes (if the waste has a biological origin).[4] Biofuel generally involve contemporary carbon fixation, such as those that occur in plants or microalgae through the process of photosynthesis. The greenhouse gas mitigation potential of biofuel varies considerably, from emission levels comparable to fossil fuels in some scenarios to negative emissions in others. The IPCC (Intergovernmental Panel on Climate Change) defines bioenergy as a renewable form of energy.[5]

The two most common types of biofuel are bioethanol and biodiesel.

- 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 (E100), 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.
- Biodiesel is produced from oils or fats using transesterification and is the most common biofuel in Europe. It can be used as a fuel for vehicles in its pure form (B100), but it is usually used as a diesel additive to reduce levels of particulates, carbon monoxide, and hydrocarbons from diesel-powered vehicles.

In 2019, worldwide biofuel production reached 161 billion liters (43 billion gallons US), up 6% from 2018,[6] and biofuels provided 3% of the world's fuels for road transport. The International Energy Agency want biofuels to meet more than a quarter of world demand for transportation fuels by 2050, in order to reduce dependency on petroleum.[6] However, the production and consumption of biofuels are not on track to meet the IEA's sustainable development scenario. From 2020 to 2030 global biofuel output has to increase by 10% each year to reach IEA's goal. Only 3% growth annually is expected in the next 5 years.[6]

# Contents



# Generations

## First-generation biofuels

Types and generation of biofuels[7]

First-generation biofuels are fuels made from food crops grown on arable land. The crop's sugar, starch, or oil content is converted into biodiesel or ethanol, using transesterification, or yeast fermentation.[8]

## Second-generation biofuels

Second-generation biofuels are fuels made from lignocellulosic or woody biomass, or agricultural residues/waste. The feedstock used to make the fuels either grow on arable land but are byproducts of the main crop, or they are grown on marginal land.[9] Second-generation feedstocks include straw, bagasse, perennial grasses, jatropha, waste vegetable oil, municipal solid waste and so forth.[10]

## Third-generation biofuels

Algae can be produced in ponds or tanks on land, and out at sea.[11][12] Algal fuels have high yields,[13] can be grown with minimal impact on fresh water resources,[14][15] can be produced using saline water and wastewater, have a high ignition point,[16] and are biodegradable and relatively harmless to the environment if spilled.[17][18] Production requires large amounts of energy and fertilizer, the produced fuel degrades faster than other biofuels, and it does not flow well in cold temperatures.[11] By 2017, due to economic considerations, most efforts to produce fuel from algae have been abandoned or changed to other applications.[19]


**Biofuel production from microalgae**
Microalgae are cultivated by different methods e.g. photoautotrophic, heterotrophic, photoheterotrophic and mixotrophic, then harvested by the bulking method in which microalgae are isolated from suspension through floatation, flocculation or gravity sedimentation. Thickening is the second stage used to concentrate the algal slurry after bulking process.[7]

### Fourth-generation biofuels

This class of biofuels includes electrofuels and solar fuels. Electrofuels are made by storing electrical energy in the chemical bonds of liquids and gases. The primary targets are butanol, biodiesel, and hydrogen, but include other alcohols and carbon-containing gases such as methane and butane. A solar fuel is a synthetic chemical fuel produced from solar energy. Light is converted to chemical energy, typically by reducing protons to hydrogen, or carbon dioxide to organic compounds.

# Types

The following fuels can be produced using first, second, third or fourth-generation biofuel production procedures. Most of these can be produced using two or three of the different biofuel generation procedures.[20]

## Gaseous biofuel

### Biogas and biomethane

Biogas is methane produced by the process of anaerobic digestion of organic material by anaerobes.[21] It can be produced either from biodegradable waste materials or by the use of energy crops fed into anaerobic digesters to supplement gas yields. The solid byproduct, digestate, can be used as a biofuel or a fertilizer. When $CO_2$ and other impurities are removed from biogas, it is called biomethane.

Biogas

Biogas can be recovered from mechanical biological treatment waste processing systems. Landfill gas, a less clean form of biogas, is produced in landfills through naturally occurring anaerobic digestion. If it escapes into the atmosphere, it acts as a greenhouse gas.

Farmers can produce biogas from manure from their cattle by using anaerobic digesters.[22]

### Syngas

Syngas, a mixture of carbon monoxide, hydrogen and other hydrocarbons, is produced by partial combustion of biomass, that is, combustion with an amount of oxygen that is not sufficient to convert the biomass completely to carbon dioxide and water.[23] Before partial combustion, the biomass is dried, and sometimes pyrolysed. The resulting gas mixture, syngas, is more efficient than direct combustion of the original biofuel; more of the energy contained in the fuel is extracted.

Syngas may be burned directly in internal combustion engines, turbines or high-temperature fuel cells.[24] The wood gas generator, a wood-fueled gasification reactor, can be connected to an internal combustion engine.

Syngas can be used to produce methanol, DME and hydrogen, or converted via the Fischer–Tropsch process to produce a diesel substitute, or a mixture of alcohols that can be blended into gasoline. Gasification normally relies on temperatures greater than 700 °C.

Lower-temperature gasification is desirable when co-producing biochar, but results in syngas polluted with tar.

## Liquid biofuel

### Ethanol

Biologically produced alcohols, most commonly ethanol, and less commonly propanol and butanol, are produced by the action of microorganisms and enzymes through the fermentation of sugars or starches (easiest), or cellulose (which is more difficult). Biobutanol (also called biogasoline) is often claimed to provide a direct replacement for gasoline, because it can be used directly in a gasoline engine.

Neat ethanol on the left (A), gasoline on the right (G) at a filling station in Brazil

Ethanol fuel is the most common biofuel worldwide, particularly in Brazil. Alcohol fuels are produced by fermentation of sugars derived from wheat, corn, sugar beets, sugar cane, molasses and any sugar or starch from which alcoholic beverages such as whiskey, can be made (such as potato and fruit waste, etc.). The ethanol production methods used are enzyme digestion (to release sugars from stored starches), fermentation of the sugars, distillation and drying. The distillation process requires significant energy input for heat (sometimes unsustainable natural gas fossil fuel, but cellulosic biomass such as bagasse, the waste left after sugar cane is pressed to extract its juice, is the most common fuel in Brazil, while pellets, wood chips and also waste heat are more common in Europe) Waste steam fuels ethanol factory[25] – where waste heat from the factories also is used in the district heating grid.

Ethanol can be used in petrol engines as a replacement for gasoline; it can be mixed with gasoline to any percentage. Most existing car petrol engines can run on blends of up to 15% bioethanol with petroleum/gasoline. Ethanol has a smaller energy density than that of gasoline; this means it takes more fuel (volume and mass) to produce the same amount of work. An advantage of ethanol ($CH_3CH_2OH$) is that it has a higher octane rating than ethanol-free gasoline available at roadside gas stations, which allows an increase of an engine's compression ratio for increased thermal efficiency. In high-altitude (thin air) locations, some states mandate a mix of gasoline and ethanol as a winter oxidizer to reduce atmospheric pollution emissions.

Ethanol is also used to fuel bioethanol fireplaces. As they do not require a chimney and are "flueless", bioethanol fires[26] are extremely useful for newly built homes and apartments without a flue. The downsides to these fireplaces is that their heat output is slightly less than electric heat or gas fires, and precautions must be taken to avoid carbon monoxide poisoning.

Corn-to-ethanol and other food stocks has led to the development of cellulosic ethanol. According to a joint research agenda conducted through the US Department of Energy,[27] the fossil energy ratios (FER) for cellulosic ethanol, corn ethanol, and gasoline are 10.3, 1.36, and 0.81, respectively.[28][29][30]

Ethanol has roughly one-third lower energy content per unit of volume compared to gasoline. This is partly counteracted by the better efficiency when using ethanol (in a long-term test of more than 2.1 million km, the BEST project found FFV vehicles to be 1–26% more energy efficient than petrol cars, but the volumetric consumption increases by approximately 30%, so more fuel stops are required).

### Other bioalcohols

Methanol is currently produced from natural gas, a non-renewable fossil fuel. In the future it is hoped to be produced from biomass as biomethanol. This is technically feasible, but the production is currently being postponed for concerns that the economic viability is still pending.[31] The methanol economy is an alternative to the hydrogen economy to be contrasted with today's hydrogen production from natural gas.

Butanol ($C_4H_9OH$) is formed by ABE fermentation (acetone, butanol, ethanol) and experimental modifications of the process show potentially high net energy gains with butanol as the only liquid product. Butanol will produce more energy than ethanol because of its lower oxygen content[32] and allegedly can be burned "straight" in existing gasoline engines (without modification to the engine or car),[33] and is less corrosive and less water-soluble than ethanol, and could be distributed via existing infrastructures. DuPont and BP are working together to help develop butanol. *Escherichia coli* strains have also been successfully engineered to produce butanol by modifying their amino acid metabolism.[34] One drawback to butanol production in E. coli remains the high cost of nutrient rich media, however, recent work has demonstrated E. coli can produce butanol with minimal nutritional supplementation.[35]

### Biodiesel

Biofuel pumps DCA 07 2010 9834

Biodiesel is the most common biofuel in Europe. It is produced from oils or fats using transesterification and is a liquid similar in composition to fossil/mineral diesel. Chemically, it consists mostly of fatty acid methyl (or ethyl) esters (FAMEs). Feedstocks for biodiesel include animal fats, vegetable oils, soy, rapeseed, jatropha, mahua, mustard, flax, sunflower, palm oil, hemp, field pennycress, *Pongamia pinnata* and algae. Pure biodiesel (B100, also known as "neat" biodiesel) currently reduces emissions with up to 60% compared to diesel Second generation B100.[36] As of 2020, researchers at Australia's CSIRO have been studying safflower oil as an engine lubricant, and researchers at Montana State University's Advanced Fuel Centre in the US have been studying the oil's performance in a large diesel engine, with results described as a "game-changer".[37]

Biodiesel can be used in any diesel engine when mixed with mineral diesel. It can also be used in its pure form (B100) in diesel engines, but some maintenance and performance problems may then occur during wintertime utilization, since the fuel becomes somewhat more viscous at lower temperatures, depending on the feedstock used.[38]

In some countries, manufacturers cover their diesel engines under warranty for B100 use, although Volkswagen of Germany, for example, asks drivers to check by telephone with the VW environmental services department before switching to B100. In most cases, biodiesel is compatible with diesel engines from 1994 onwards, which use 'Viton' (by DuPont) synthetic rubber in their mechanical fuel injection systems. Note however, that no vehicles are certified for using pure biodiesel before 2014, as there was no emission control protocol available for biodiesel before this date.

Targray Biofuels Division railcar transporting Biodiesel.

Electronically controlled 'common rail' and 'Unit Injector' type systems from the late 1990s onwards may only use biodiesel blended with conventional diesel fuel. These engines have finely metered and atomized multiple-stage injection systems that are very sensitive to the viscosity of the fuel. Many current-generation diesel engines are made so that they can run on B100 without altering the engine itself, although this depends on the fuel rail design. Since biodiesel is an effective solvent and cleans residues deposited by mineral diesel, engine filters may need to be replaced more often, as the biofuel dissolves old deposits in the fuel tank and pipes. It also effectively cleans the engine combustion chamber of carbon deposits, helping to maintain efficiency. In many European countries, a 5% biodiesel blend is widely used and is available at thousands of gas stations.[39][40] Biodiesel is also an oxygenated fuel, meaning it contains a reduced amount of carbon and higher hydrogen and oxygen content than fossil diesel. This improves the combustion of biodiesel and reduces the particulate emissions from unburnt carbon. However, using pure biodiesel may increase $NO_x$-emissions[41]

Biodiesel is also safe to handle and transport because it is non-toxic and biodegradable, and has a high flash point of about 300 °F (148 °C) compared to petroleum diesel fuel, which has a flash point of 125 °F (52 °C).[42]

In the US, more than 80% of commercial trucks and city buses run on diesel. The emerging US biodiesel market is estimated to have grown 200% from 2004 to 2005. "By the end of 2006 biodiesel production was estimated to increase fourfold [from 2004] to more than" 1 billion US gallons (3,800,000 $m^3$).[43]

In France, biodiesel is incorporated at a rate of 8% in the fuel used by all French diesel vehicles.[44] Avril Group produces under the brand Diester, a fifth of 11 million tons of biodiesel consumed annually by the European Union.[45] It is the leading European producer of biodiesel.[44]

### Green diesel

Green diesel is produced through hydrocracking biological oil feedstocks, such as vegetable oils and animal fats.[46][47] Hydrocracking is a refinery method that uses elevated temperatures and pressure in the presence of a catalyst to break down larger molecules, such as those found in vegetable oils, into shorter hydrocarbon chains used in diesel engines.[48] It may also be called renewable diesel, hydrotreated vegetable oil (HVO fuel)[48] or hydrogen-derived renewable diesel.[47] Unlike biodiesel, green diesel has exactly the same chemical properties as petroleum-based diesel.[48][49] It does not require new engines, pipelines or infrastructure to distribute and use, but has not been produced at a cost that is competitive with petroleum.[47] Gasoline versions are also being developed.[50] Green diesel is being developed in Louisiana and Singapore by ConocoPhillips, Neste Oil, Valero, Dynamic Fuels, and Honeywell UOP[47][51] as well as Preem in Gothenburg, Sweden, creating what is known as Evolution Diesel.[52]

### Straight vegetable oil

Straight unmodified edible vegetable oil is generally not used as fuel, but lower-quality oil has been used for this purpose. Used vegetable oil is increasingly being processed into biodiesel, or (more rarely) cleaned of water and particulates and then used as a fuel.

As with 100% biodiesel (B100), to ensure the fuel injectors atomize the vegetable oil in the correct pattern for efficient combustion, vegetable oil fuel must be heated to reduce its viscosity to that of diesel, either by electric coils or heat exchangers. This is easier in warm or temperate climates. MAN B&W Diesel, Wärtsilä, and Deutz AG, as well as a number of smaller companies, such as Elsbett, offer engines that are compatible with straight vegetable oil, without the need for after-market modifications.

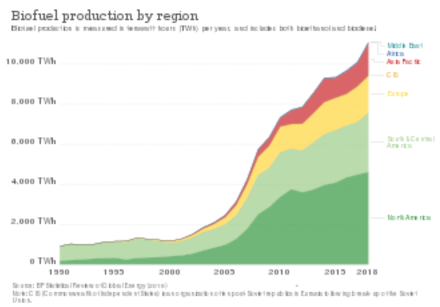
This truck is one of 15 based at Walmart's Buckeye, Arizona distribution center that was converted to run on a biofuel made from reclaimed cooking grease produced during food preparation at Walmart stores.[53]

Vegetable oil can also be used in many older diesel engines that do not use common rail or unit injection electronic diesel injection systems. Due to the design of the combustion chambers in indirect injection engines, these are the best engines for use with vegetable oil. This system allows the relatively larger oil molecules more time to burn. Some older engines, especially Mercedes, are driven experimentally by enthusiasts without any conversion. A handful of drivers have experienced limited success with earlier pre-"Pumpe Duse" VW TDI engines and other similar engines with direct injection. Several companies, such as Elsbett or Wolf, have developed professional conversion kits and successfully installed hundreds of them over the last decades.

Oils and fats can be hydrogenated to give a diesel substitute. The resulting product is a straight-chain hydrocarbon with a high cetane number, low in aromatics and sulfur and does not contain oxygen. Hydrogenated oils can be blended with diesel in all proportions. They have several advantages over biodiesel, including good performance at low temperatures, no storage stability problems and no susceptibility to microbial attack.[23]

### Bioethers

Bioethers (also referred to as fuel ethers or oxygenated fuels) are cost-effective compounds that act as octane rating enhancers."Bioethers are produced by the reaction of reactive iso-olefins, such as iso-butylene, with bioethanol."[54] Bioethers are created from wheat or sugar beets.[55] They also enhance engine performance, while significantly reducing engine wear and toxic exhaust emissions. Although bioethers are likely to replace petroethers in the UK, it is highly unlikely they will become a fuel in and of itself due to the low energy density.[56] By greatly reducing the amount of ground-level ozone emissions, they contribute to air quality.[57][58]



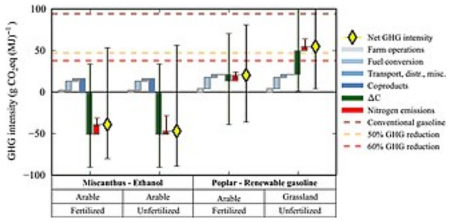
Biofuel production by region

When it comes to transportation fuel there are six ether additives: dimethyl ether (DME), diethyl ether (DEE), methyl *tert*-butyl ether (MTBE), ethyl *tert*-butyl ether (ETBE), *tert*-amyl methyl ether (TAME), and *tert*-amyl ethyl ether (TAEE).[59]

The European Fuel Oxygenates Association (EFOA) identifies methyl *tert*-butyl ether (MTBE) and ethyl *tert*-butyl ether (ETBE) as the most commonly used ethers in fuel to replace lead. Ethers were introduced in Europe in the 1970s to replace the highly toxic compound.[60] Although Europeans still use bioether additives, the US no longer has an oxygenate requirement therefore bioethers are no longer used as the main fuel additive.[61]

## Biofuels and the environment

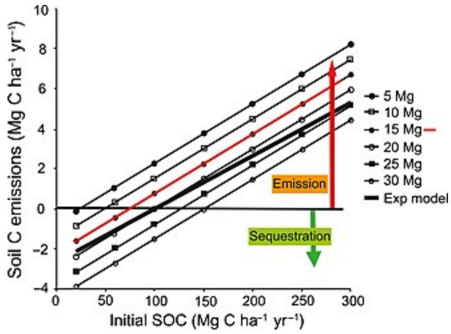
## Carbon neutrality




Carbon negative (miscanthus) and carbon positive (poplar) production pathways.

A biofuel project is said to be carbon-neutral if the $CO_2$ absorbed by the crop compensate for the greenhouse gas (GHG) emissions related to the project. $CO_2$ is the most important of the greenhouse gases, and there is approximately 27% carbon in $CO_2$ (12/44).[62] This includes any emissions caused by direct or indirect land use change. Many first generation biofuel projects are not carbon neutral given this definition. Some have even higher emissions than some fossil based alternatives.[63][64][65]

It is the total amount of absorption and emissions that together determines if the GHG life cycle cost of a biofuel project is positive, neutral or negative. If emissions during production, processing, transport and combustion are higher than what is absorbed, both above and below ground during crop growth, the GHG life cycle cost is positive. Likewise, if total absorption is higher than total emissions, the life cycle cost is negative.




Relationship between above-ground yield (diagonal lines), soil organic carbon (X axis), and soil's potential for successful/unsuccessful carbon sequestration (Y axis). Basically, the higher the yield, the more land is usable as a GHG mitigation tool (including relatively carbon rich land.)

Whitaker et al. argue that a miscanthus crop with a yield of 10 tonnes per hectare per year sequesters so much carbon that the crop more than compensates for both farm operations emissions and transport emissions. (The emissions originating from *combustion* are fully absorbed by next seasons' above-ground plant growth.) The top chart on the right displays two $CO_2$ negative miscanthus production pathways, and two $CO_2$ positive poplar production pathways, represented in gram $CO_2$-equivalents per megajoule. The bars are sequential and move up and down as atmospheric $CO_2$ is estimated to increase and decrease. The grey/blue bars represent agriculture, processing and transport related emissions, the green bars represents soil carbon change, and the yellow diamonds represent total final emissions.[66]

Successful sequestration is dependent on planting sites, as the best soils for sequestration are those that are currently low in carbon. The varied results displayed in the graph highlights this fact.[67] For the UK, successful sequestration is expected for arable land over most of England and Wales, with unsuccessful sequestration expected in parts of Scotland, due to already carbon rich soils (existing woodland) plus lower yields. Soils already rich in carbon includes peatland and mature forest. Grassland can also be carbon rich, however Milner et al. argue that the most successful carbon sequestration in the UK takes place below improved grasslands.[68] The bottom chart displays the estimated yield necessary to achieve $CO_2$ negativity for different levels of existing soil carbon saturation. The higher the yield, the more likely $CO_2$ negativity becomes.

## Air pollution

In general, substance or energy is considered pollution when released into the environment at a rate faster than the environment can disperse, dilute, decompose, recycle, or store it in some harmless form.[69] Based on this definition, both fossil fuels and some traditional biofuels are polluting the environment. For instance, the IPCC argues that the traditional use of wood in cook stoves and open fires produces pollutants, which can lead to severe health and environmental consequences. However, a shift to modern bioenergy contribute to improved livelihoods and can reduce land degradation and impacts on ecosystem services.[a] According to the IPCC, there is strong evidence that modern bioenergy has "large positive impacts" on air quality.[70] When combusted in industrial facilities, most of the pollutants originating from woody biomass reduce by 97-99%, compared to open burning.[71] A study of the giant brown haze that periodically covers large areas in South Asia determined that two thirds of it had been principally produced by residential cooking and agricultural burning, and one third by fossil-fuel burning.[72]

## Power production compared to other renewables

To calculate land use requirements for different kinds of power production, it is essential to know the relevant area-specific power densities. Smil estimates that the average area-specific power densities for biofuels, wind, hydro and solar power production are 0.30 $W/m^2$, 1 $W/m^2$, 3 $W/m^2$ and 5 $W/m^2$, respectively (power in the form of heat for biofuels, and electricity for wind, hydro and solar).[73] The average human power consumption on ice-free land is 0.125 $W/m^2$ (heat and electricity combined),[74] although rising to 20 $W/m^2$ in urban and industrial areas.[75] The reason for the low area-specific power density for biofuels is a combination of low yields and only partial utilization of the plant when making liquid fuels (for instance, ethanol is typically made from sugarcane's sugar content or corn's starch content, while biodiesel is often made from rapeseed and soybean's oil content).

Smil estimates the following densities:

### Ethanol

- Winter wheat (USA) 0.08 $W/m^2$ [76]
- Corn 0.26 $W/m^2$ (yield 10 t/ha) [77]
- Wheat (Germany) 0.30 $W/m^2$ [76]
- *Miscanthus x giganteus* 0.40 $W/m^2$ (yield 15 t/ha) [78]
- Sugarcane (Brazil) 0.50 $W/m^2$ (yield 80 t/ha wet) [79]

### Jet fuel

- Soybean 0.06 $W/m^2$ [79]
- Jathropa (marginal land) 0.20 $W/m^2$ [79]
- Palm oil 0.65 $W/m^2$ [79]

### Biodiesel

- Rapeseed 0.12 $W/m^2$ (EU average)[80]
- Rapeseed (adjusted for energy input, the Netherlands) 0.08 $W/m^2$ [81]
- Sugar beets (adjusted for energy input, Spain) 0.02 $W/m^2$ [81]

Combusting solid biomass is more energy efficient than combusting biofuel (liquids), as the whole plant is utilized. For instance, corn plantations producing solid biomass for combustion generate more than double the amount of power per square metre compared to corn plantations producing for ethanol, when the yield is the same: 10 t/ha generates 0.60 $W/m^2$ and 0.26 $W/m^2$ respectively.[82] Oven dry biomass in general have a calorific content of roughly 18 GJ/t,[83] and every t/ha of dry biomass yield increases a plantation's power production by 0.06 $W/m^2$.[84]

As mentioned above, Smil estimates that the world average for wind, hydro and solar power production is 1 $W/m^2$, 3 $W/m^2$ and 5 $W/m^2$ respectively. In order to match these power densities, plantation yields must reach 17 t/ha, 50 t/ha and 83 t/ha for wind, hydro and solar respectively. This seems achievable for tropical plantations – Smil estimate that large scale plantations with eucalyptus, acacia, leucaena, pinus and dalbergia in tropical and subtropical regions yield 20–25 t/ha, equivalent to 1.20–1.50 $W/m^2$.[85] It also seems achievable for elephant grasses, e.g. miscanthus (10–40 t/ha, or 0.6–2.4 $W/m^2$), and napier (15–80 t/ha, or 0.9–4.8 $W/m^2$), but unlikely for forest and many other types of biomass crops – Smil's estimate for natural temperate mixed forests is 1.5–2 dry tonnes per hectare (2–2,5 $m^3$, equivalent to 0.1 $W/m^2$), ranging from 0.9 m3 in Greece to 6 $m^3$ in France).[86]

## See also

- Aviation biofuel
- Bioenergy Europe
- BioEthanol for Sustainable Transport
- Biofuels Center of North Carolina
- Biofuelwatch
- Biogas powerplant
- Ecological sanitation
- International Renewable Energy Agency
- List of biofuel companies and researchers
- List of emerging technologies
- List of vegetable oils used for biofuel
- Renewable energy by country
- Renewable Energy Transition
- Residue-to-product ratio
- Sustainable aviation fuel
- Sustainable transport
- Table of biofuel crop yields

## References


1. The IEA states: "Biofuels are transportation fuels such as ethanol and biodiesel that are made from biomass materials." https://www.eia.gov/energyexplained/index.php?page=biofuel_home
2. Karatzos, Sergios; McMillan, James D.; Saddler, Jack N. (July 2014). *The Potential and Challenges of Drop-in Biofuels* (http://task39.sites.olt.ubc.ca/files/2014/01/Task-39-Drop-in-Biofuels-Report-FINAL-2-Oct-2014-ecopy.pdf) (PDF). IEA Bioenergy Task 39. p. 2. ISBN 978-1-910154-07-6. Report T39-T1. Archived (https://web.archive.org/web/20171112021600/http://task39.sites.olt.ubc.ca/files/2014/01/Task-39-Drop-in-Biofuels-Report-FINAL-2-Oct-2014-ecopy.pdf) (PDF) from the original on 12 November 2017. Retrieved 9 October 2018.
3. "Alternative Fuels Data Center: Renewable Hydrocarbon Biofuels" (https://afdc.energy.gov/fuels/emerging_hydrocarbon.html). *afdc.energy.gov*.
4. "What is biofuel? definition and meaning" (http://www.businessdictionary.com/definition/biofuel.html). *BusinessDictionary.com*. Retrieved 30 May 2015.
5. "Renewable Energy Sources and Climate Change Mitigation. Special Report of the Intergovernmental Panel on Climate Change" (https://www.ipcc.ch/site/assets/uploads/2018/03/SRREN_Full_Report-1.pdf) (PDF). *IPCC*.
6. "Transport biofuels" (https://www.iea.org/reports/transport-biofuels). *IEA*.