

Petroleum

Petroleum (/pəˈtroʊliəm/), also known as **crude oil** and **oil**, is a naturally occurring, yellowish-black liquid found in geological formations beneath the Earth's surface. It is commonly refined into various types of fuels. Components of petroleum are separated using a technique called [fractional distillation](#), i.e. separation of a liquid mixture into fractions differing in boiling point by means of distillation, typically using a [fractionating column](#). It consists of naturally occurring [hydrocarbons](#) of various molecular weights and may contain miscellaneous [organic compounds](#).^[1] The name *petroleum* covers both naturally occurring unprocessed crude oil and [petroleum products](#) that are made up of refined crude oil. A [fossil fuel](#), petroleum is formed when large quantities of dead organisms, mostly [zooplankton](#) and [algae](#), are buried underneath [sedimentary rock](#) and subjected to both intense heat and pressure.

Petroleum has mostly been recovered by oil drilling. Drilling is carried out after studies of structural geology, sedimentary basin analysis, and reservoir characterisation. Recent improvements to technologies have also led to exploitation of other unconventional reserves such as [oil sands](#) and [oil shale](#). Once extracted, oil is refined and separated, most easily by [distillation](#), into numerous products for direct use or use in manufacturing, such as [gasoline](#) (petrol), [diesel](#) and [kerosene](#) to [asphalt](#) and chemical [reagents](#) used to make plastics, pesticides and pharmaceuticals. Petroleum is used in manufacturing a wide variety of materials,^[2] and it is estimated that the world consumes about 100 million [barrels](#) each day. Petroleum production can be extremely profitable and was important for economic development in the 20th century, with some countries, so called "[oil states](#)", gaining significant economic and international power because of their control of oil production.

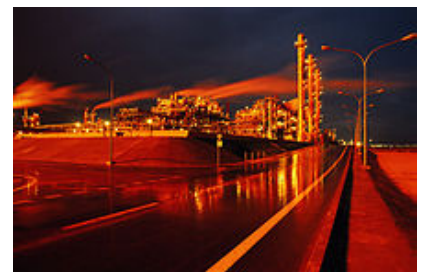
Petroleum exploitation has significant negative environmental and social consequences. Most significantly, [extraction](#), [refining](#) and [burning](#) of petroleum fuels all release large quantities of [greenhouse gases](#), so petroleum is one of the [major contributors to climate change](#). Furthermore, parts of the [petroleum industry](#) actively suppressed science and policy that aimed to prevent the [climate crisis](#). Other negative environmental effects include the environmental impacts of exploration and exploitation of petroleum reserves, such as oil spills, and air and water pollution at the sites of utilization. All of these environmental impacts have direct health consequences for humans. Additionally, oil has also been a source of conflict leading to both [state-led wars](#) and other kinds of conflicts (for example, [oil revenue funded the Islamic State of Iraq and the Levant](#)). Production of petroleum is expected to reach peak oil before 2040 as global economies reduce dependencies on petroleum as part of [climate change mitigation](#) and a transition towards [renewable energy](#) and electrification.^[3] This is expected to have significant economic impacts that stakeholders argue need to be anticipated by a [just transition](#) and addressing the [stranded assets](#) of the petroleum industry.



A sample of petroleum.



Pumpjack pumping an oil well near Lubbock, Texas.



An oil refinery in [Mina Al Ahmadi](#), [Kuwait](#).

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Etymology

The word *petroleum* comes from Medieval Latin *petroleum* (literally "rock oil"), which comes from Latin *petra*, "rock", (from Ancient Greek: πέτρα, romanized: *petra*, "rock") and Latin *oleum*, "oil", (from Ancient Greek: ἔλαιον, romanized: *élaion*, "oil").^{[4][5]}

The term was used in the treatise *De Natura Fossilium*, published in 1546 by the German mineralogist Georg Bauer, also known as Georgius Agricola.^[6] In the 19th century, the term *petroleum* was often used to refer to mineral oils produced by distillation from mined organic solids such as cannel coal (and later oil shale) and refined oils produced from them; in the United Kingdom, storage (and later transport) of these oils were regulated by a series of Petroleum Acts, from the *Petroleum Act 1863* onwards.



Fractional distillation apparatus.

History

Early

Petroleum, in one form or another, has been used since ancient times, and is now important across society, including in economy, politics and technology. The rise in importance was due to the invention of the internal combustion engine, the rise in commercial aviation, and the importance of petroleum to industrial organic chemistry, particularly the synthesis of plastics, fertilisers, solvents, adhesives and pesticides.

More than 4000 years ago, according to Herodotus and Diodorus Siculus, asphalt was used in the construction of the walls and towers of Babylon; there were oil pits near Ardericca (near Babylon), and a pitch spring on Zacynthus.^[7] Great quantities of it were found on the banks of the river Issus, one of the tributaries of the Euphrates. Ancient Persian tablets indicate the medicinal and lighting uses of petroleum in the upper levels of their society.

The use of petroleum in ancient China dates back to more than 2000 years ago. In I Ching, one of the earliest Chinese writings cites that oil in its raw state, without refining, was first discovered, extracted, and used in China in the first century BCE. In addition, the Chinese were the first to record the use of petroleum as fuel as early as the fourth century BCE.^{[8][9][10]} By 347 CE, oil was produced from bamboo-drilled wells in China.^{[11][12]}



Oil derrick in Okemah, Oklahoma, 1922.

Crude oil was often distilled by Persian chemists, with clear descriptions given in Arabic handbooks such as those of Muhammad ibn Zakarīya Rāzi (Rhazes).^[13] The streets of Baghdad were paved with tar, derived from petroleum that became accessible from natural fields in the region. In the 9th century, oil fields were exploited in the area around modern Baku, Azerbaijan. These fields were described by the Arab geographer Abu al-Hasan 'Alī al-Mas'ūdī in the 10th century, and by Marco Polo in the 13th century, who described the output of those wells as hundreds of shiploads.^[14] Arab and Persian chemists also distilled crude oil in order to produce flammable products for military purposes. Through Islamic Spain, distillation became available in Western Europe by the 12th century.^[15] It has also been present in Romania since the 13th century, being recorded as *păcură*.^[16]

Sophisticated oil pits, 15 to 20 feet deep, were dug by the Seneca People and other Iroquois in Western Pennsylvania as early as 1415-1450. The French General Louis-Joseph de Montcalm encountered Seneca using petroleum for ceremonial fires and as a healing lotion during a visit to Fort Duquesne in 1750.^[17]

Early British explorers to Myanmar documented a flourishing oil extraction industry based in Yenangyaung that, in 1795, had hundreds of hand-dug wells under production.^[18]

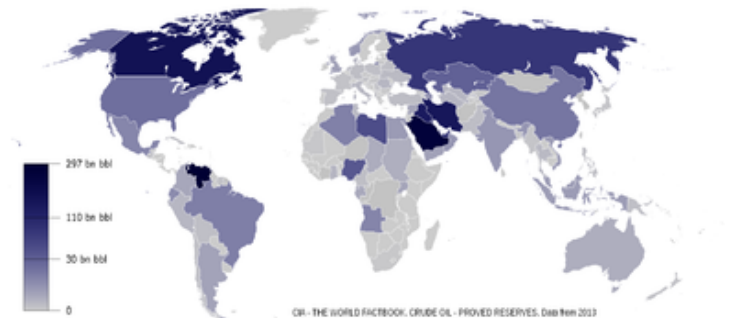
Pechelbronn (Pitch fountain) is said to be the first European site where petroleum has been explored and used. The still active Erdpechquelle, a spring where petroleum appears mixed with water has been used since 1498, notably for medical purposes. Oil sands have been mined since the 18th century.^[19]

In Wietze in lower Saxony, natural asphalt/bitumen has been explored since the 18th century.^[20] Both in Pechelbronn as in Wietze, the coal industry dominated the petroleum technologies.^[21]

Modern

Chemist James Young noticed a natural petroleum seepage in the Riddings colliery at Alfreton, Derbyshire from which he distilled a light thin oil suitable for use as lamp oil, at the same time obtaining a more viscous oil suitable for lubricating machinery. In 1848, Young set up a small business refining the crude oil.^[22]

Young eventually succeeded, by distilling cannel coal at a low heat, in creating a fluid resembling petroleum, which when treated in the same way as the seep oil gave similar products. Young found that by slow distillation he could obtain a number of useful liquids from it, one of which he named "paraffine oil" because at low temperatures it congealed into a substance resembling paraffin wax.^[22]



Proven world oil reserves, 2013. Unconventional reservoirs such as natural heavy oil and oil sands are included.

The production of these oils and solid paraffin wax from coal formed the subject of his patent dated 17 October 1850. In 1850 Young & Meldrum and Edward William Binney entered into partnership under the title of E.W. Binney & Co. at Bathgate in West Lothian and E. Meldrum & Co. at Glasgow; their works at Bathgate were completed in 1851 and became the first truly commercial oil-works in the world with the first modern oil refinery.^[23]

The world's first oil refinery was built in 1856 by Ignacy Łukasiewicz.^[24] His achievements also included the discovery of how to distill kerosene from seep oil, the invention of the modern kerosene lamp (1853), the introduction of the first modern street lamp in Europe (1853), and the construction of the world's first modern oil well (1854).^[25]

The demand for petroleum as a fuel for lighting in North America and around the world quickly grew.^[26] Edwin Drake's 1859 well near Titusville, Pennsylvania, is popularly considered the first modern well. Already 1858 Georg Christian Konrad Hunäus had found a significant amount of petroleum while drilling for lignite 1858 in Wietze, Germany. Wietze later provided about 80% of the German consumption in the Wilhelminian Era.^[27] The production stopped in 1963, but Wietze has hosted a Petroleum Museum since 1970.^[28]



Shale bings near Broxburn, 3 of a total of 19 in West Lothian.

Drake's well is probably singled out because it was drilled, not dug; because it used a steam engine; because there was a company associated with it; and because it touched off a major boom.^[29] However, there was considerable activity before Drake in various parts of the world in the mid-19th century. A group directed by Major Alexeyev of the Bakinskii Corps of Mining Engineers hand-drilled a well in the Baku region of Bibi-Heybat in 1846.^[30] There were engine-drilled wells in West Virginia in the same year as Drake's well.^[31] An early commercial well was hand dug in Poland in 1853,

and another in nearby Romania in 1857. At around the same time the world's first, small, oil refinery was opened at Jasło in Poland, with a larger one opened at Ploiești in Romania shortly after. Romania is the first country in the world to have had its annual crude oil output officially recorded in international statistics: 275 tonnes for 1857.^{[32][33]}

The first commercial oil well in Canada became operational in 1858 at Oil Springs, Ontario (then Canada West).^[34] Businessman James Miller Williams dug several wells between 1855 and 1858 before discovering a rich reserve of oil four metres below ground.^[35] Williams extracted 1.5 million litres of crude oil by 1860, refining much of it into kerosene lamp oil. Williams's well became commercially viable a year before Drake's Pennsylvania operation and could be argued to be the first commercial oil well in North America.^[36] The discovery at Oil Springs touched off an oil boom which brought hundreds of speculators and workers to the area. Advances in drilling continued into 1862 when local driller Shaw reached a depth of 62 metres using the spring-pole drilling method.^[37] On January 16, 1862, after an explosion of natural gas Canada's first oil gusher came into production, shooting into the air at a recorded rate of 3,000 barrels per day.^[38] By the end of the 19th century the Russian Empire, particularly the Branobel company in Azerbaijan, had taken the lead in production.^[39]

Access to oil was and still is a major factor in several military conflicts of the twentieth century, including World War II, during which oil facilities were a major strategic asset and were extensively bombed.^[40] The German invasion of the Soviet Union included the goal to capture the Baku oilfields, as it would provide much needed oil-supplies for the German military which was suffering from blockades.^[41] Oil exploration in North America during the early 20th century later led to the US becoming the leading producer by mid-century. As petroleum production in the US peaked during the 1960s, however, the United States was surpassed by Saudi Arabia and the Soviet Union.^{[42][43][44]}

In 1973, Saudi Arabia and other Arab nations imposed an oil embargo against the United States, United Kingdom, Japan and other Western nations which supported Israel in the Yom Kippur War of October 1973.^[45] The embargo caused an oil crisis with many short- and long-term effects on global politics and the global economy.^[46]

Today, about 90 percent of vehicular fuel needs are met by oil. Petroleum also makes up 40 percent of total energy consumption in the United States, but is responsible for only 1 percent of electricity generation.^[47] Petroleum's worth as a portable, dense energy source powering the vast majority of vehicles and as the base of many industrial chemicals makes it one of the world's most important commodities.

The top three oil producing countries are Russia, Saudi Arabia and the United States.^[48] In 2018, due in part to developments in hydraulic fracturing and horizontal drilling, the United States became the world's largest producer.^{[49][50]} About 80 percent of the world's readily accessible reserves are located in the Middle East, with 62.5 percent coming from the Arab 5: Saudi Arabia, United Arab Emirates, Iraq, Qatar and Kuwait. A large portion of the world's total oil exists as unconventional sources, such as bitumen in Athabasca oil sands and extra heavy oil in the Orinoco Belt. While significant volumes of oil are extracted from oil sands, particularly in Canada, logistical and technical hurdles remain, as oil extraction requires large amounts of heat and water, making its net energy content quite low relative to conventional crude oil. Thus, Canada's oil sands are not expected to provide more than a few million barrels per day in the foreseeable future.^{[51][52][53]}

Composition

Petroleum includes not only crude oil, but all liquid, gaseous and solid hydrocarbons. Under surface pressure and temperature conditions, lighter hydrocarbons methane, ethane, propane and butane exist as gases, while pentane and heavier hydrocarbons are in the form of liquids or solids. However, in an underground oil reservoir the proportions of gas, liquid, and solid depend on subsurface conditions and on the phase diagram of the petroleum mixture.^[54]

An oil well produces predominantly crude oil, with some natural gas dissolved in it. Because the pressure is lower at the surface than underground, some of the gas will come out of solution and be recovered (or burned) as *associated gas* or *solution gas*. A gas well produces predominantly natural gas. However, because the underground temperature is higher



This wartime propaganda poster promoted carpooling as a way to ration vital gasoline during World War II.

than at the surface, the gas may contain heavier hydrocarbons such as pentane, hexane, and heptane in the gaseous state. At surface conditions these will condense out of the gas to form "natural gas condensate", often shortened to *condensate*. Condensate resembles gasoline in appearance and is similar in composition to some volatile light crude oils.^{[55][56]}

The proportion of light hydrocarbons in the petroleum mixture varies greatly among different oil fields, ranging from as much as 97 percent by weight in the lighter oils to as little as 50 percent in the heavier oils and bitumens.

The hydrocarbons in crude oil are mostly alkanes, cycloalkanes and various aromatic hydrocarbons, while the other organic compounds contain nitrogen, oxygen and sulfur, and trace amounts of metals such as iron, nickel, copper and vanadium. Many oil reservoirs contain live bacteria.^[57] The exact molecular composition of crude oil varies widely from formation to formation but the proportion of chemical elements varies over fairly narrow limits as follows:^[58]

Composition by weight

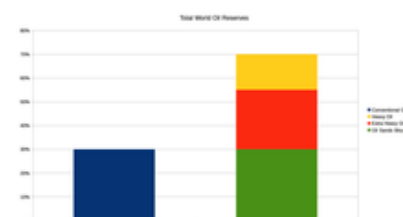
Element	Percent range
<u>Carbon</u>	83 to 85%
<u>Hydrogen</u>	10 to 14%
<u>Nitrogen</u>	0.1 to 2%
<u>Oxygen</u>	0.05 to 1.5%
<u>Sulfur</u>	0.05 to 6.0%
<u>Metals</u>	< 0.1%

Four different types of hydrocarbon molecules appear in crude oil. The relative percentage of each varies from oil to oil, determining the properties of each oil.^[54]

Composition by weight

Hydrocarbon	Average	Range
<u>Alkanes (paraffins)</u>	30%	15 to 60%
<u>Naphthenes</u>	49%	30 to 60%
<u>Aromatics</u>	15%	3 to 30%
<u>Asphaltics</u>	6%	remainder

Crude oil varies greatly in appearance depending on its composition. It is usually black or dark brown (although it may be yellowish, reddish, or even greenish). In the reservoir it is usually found in association with natural gas, which being lighter forms a "gas cap" over the petroleum, and saline water which, being heavier than most forms of crude oil, generally sinks beneath it. Crude oil may also be found in a semi-solid form mixed with sand and water, as in the Athabasca oil sands in Canada, where it is usually referred to as crude bitumen. In Canada, bitumen is considered a sticky, black, tar-like form of crude oil which is so thick and heavy that it must be heated or diluted before it will flow.^[60] Venezuela also has large amounts of oil in the Orinoco oil sands, although the hydrocarbons trapped in them are more fluid than in Canada and are usually called extra heavy oil. These oil sands resources are called unconventional oil to distinguish them from oil which can be extracted using traditional oil well methods. Between them, Canada and Venezuela contain an estimated 3.6 trillion barrels ($570 \times 10^9 \text{ m}^3$) of bitumen and extra-heavy oil, about twice the volume of the world's reserves of conventional oil.^[61]



Unconventional resources are much larger than conventional ones.^[59]

Petroleum is used mostly, by volume, for refining into fuel oil and gasoline, both important "primary energy" sources. 84 percent by volume of the hydrocarbons present in petroleum is converted into energy-rich fuels (petroleum-based fuels), including gasoline, diesel, jet, heating, and other fuel oils, and liquefied petroleum gas.^[62] The lighter grades of crude oil produce the best yields of these products, but as the world's reserves of light and medium oil are depleted, oil refineries are increasingly having to process heavy oil and bitumen, and use more complex and expensive methods to produce the

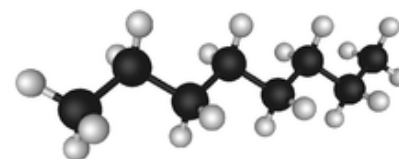
products required. Because heavier crude oils have too much carbon and not enough hydrogen, these processes generally involve removing carbon from or adding hydrogen to the molecules, and using fluid catalytic cracking to convert the longer, more complex molecules in the oil to the shorter, simpler ones in the fuels.

Due to its high energy density, easy transportability and relative abundance, oil has become the world's most important source of energy since the mid-1950s. Petroleum is also the raw material for many chemical products, including pharmaceuticals, solvents, fertilizers, pesticides, and plastics; the 16 percent not used for energy production is converted into these other materials. Petroleum is found in porous rock formations in the upper strata of some areas of the Earth's crust. There is also petroleum in oil sands (tar sands). Known oil reserves are typically estimated at around 190 km³ (1.2 trillion (short scale) barrels) without oil sands,^[63] or 595 km³ (3.74 trillion barrels) with oil sands.^[64] Consumption is currently around 84 million barrels (13.4 × 10⁶ m³) per day, or 4.9 km³ per year, yielding a remaining oil supply of only about 120 years, if current demand remains static.^[65] More recent studies, however, put the number at around 50 years.^{[66][67]}

Chemistry

Petroleum is a mixture of a very large number of different hydrocarbons; the most commonly found molecules are alkanes (paraffins), cycloalkanes (naphthenes), aromatic hydrocarbons, or more complicated chemicals like asphaltenes. Each petroleum variety has a unique mix of molecules, which define its physical and chemical properties, like color and viscosity.

The *alkanes*, also known as *paraffins*, are saturated hydrocarbons with straight or branched chains which contain only carbon and hydrogen and have the general formula C_nH_{2n+2}. They generally have from 5 to 40 carbon atoms per molecule, although trace amounts of shorter or longer molecules may be present in the mixture.



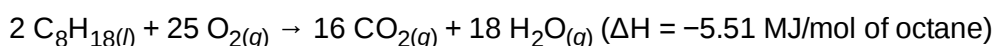
Octane, a hydrocarbon found in petroleum. Lines represent single bonds; black spheres represent carbon; white spheres represent hydrogen.

The alkanes from pentane (C₅H₁₂) to octane (C₈H₁₈) are refined into gasoline, the ones from nonane (C₉H₂₀) to hexadecane (C₁₆H₃₄) into diesel fuel, kerosene and jet fuel. Alkanes with more than 16 carbon atoms can be refined into fuel oil and lubricating oil. At the heavier end of the range, paraffin wax is an alkane with approximately 25 carbon atoms, while asphalt has 35 and up, although these are usually cracked by modern refineries into more valuable products. The shortest molecules, those with four or fewer carbon atoms, are in a gaseous state at room temperature. They are the petroleum gases. Depending on demand and the cost of recovery, these gases are either flared off, sold as liquefied petroleum gas under pressure, or used to power the refinery's own burners. During the winter, butane (C₄H₁₀), is blended into the gasoline pool at high rates, because its high vapour pressure assists with cold starts. Liquefied under pressure slightly above atmospheric, it is best known for powering cigarette lighters, but it is also a main fuel source for many developing countries. Propane can be liquefied under modest pressure, and is consumed for just about every application relying on petroleum for energy, from cooking to heating to transportation.

The *cycloalkanes*, also known as *naphthenes*, are saturated hydrocarbons which have one or more carbon rings to which hydrogen atoms are attached according to the formula C_nH_{2n}. Cycloalkanes have similar properties to alkanes but have higher boiling points.

The *aromatic hydrocarbons* are unsaturated hydrocarbons which have one or more planar six-carbon rings called benzene rings, to which hydrogen atoms are attached with the formula C_nH_{2n-6}. They tend to burn with a sooty flame, and many have a sweet aroma. Some are carcinogenic.

These different molecules are separated by fractional distillation at an oil refinery to produce gasoline, jet fuel, kerosene, and other hydrocarbons. For example, 2,2,4-trimethylpentane (isooctane), widely used in gasoline, has a chemical formula of C₈H₁₈ and it reacts with oxygen exothermically.^[68]



The number of various molecules in an oil sample can be determined by laboratory analysis. The molecules are typically extracted in a solvent, then separated in a gas chromatograph, and finally determined with a suitable detector, such as a flame ionization detector or a mass spectrometer.^[69] Due to the large number of co-eluted hydrocarbons within oil, many cannot be resolved by traditional gas chromatography and typically appear as a hump in the chromatogram. This Unresolved Complex Mixture (UCM) of hydrocarbons is particularly apparent when analysing weathered oils and extracts from tissues of organisms exposed to oil. Some of the component of oil will mix with water: the water associated fraction of the oil.

Incomplete combustion of petroleum or gasoline results in production of toxic byproducts. Too little oxygen during combustion results in the formation of carbon monoxide. Due to the high temperatures and high pressures involved, exhaust gases from gasoline combustion in car engines usually include nitrogen oxides which are responsible for creation of photochemical smog.

Empirical equations for thermal properties

Heat of combustion

At a constant volume, the heat of combustion of a petroleum product can be approximated as follows:

$$Q_v = 12,400 - 2,100d^2,$$

where Q_v is measured in calories per gram and d is the specific gravity at 60 °F (16 °C).

Thermal conductivity

The thermal conductivity of petroleum based liquids can be modeled as follows:^[70]

$$K = \frac{1.62}{API} [1 - 0.0003(t - 32)]$$

where K is measured in $\text{BTU} \cdot ^\circ\text{F}^{-1}\text{hr}^{-1}\text{ft}^{-1}$, t is measured in °F and API is degrees API gravity.

Specific heat

The specific heat of petroleum oils can be modeled as follows:^[71]

$$c = \frac{1}{d} [0.388 + 0.00046t],$$

where c is measured in $\text{BTU}/(\text{lb } ^\circ\text{F})$, t is the temperature in Fahrenheit and d is the specific gravity at 60 °F (16 °C).

In units of $\text{kcal}/(\text{kg} \cdot ^\circ\text{C})$, the formula is:

$$c = \frac{1}{d} [0.4024 + 0.00081t],$$

where the temperature t is in Celsius and d is the specific gravity at 15 °C.

Latent heat of vaporization

The latent heat of vaporization can be modeled under atmospheric conditions as follows:

$$L = \frac{1}{d} [110.9 - 0.09t],$$

where L is measured in BTU/lb, t is measured in °F and d is the specific gravity at 60 °F (16 °C).

In units of kcal/kg, the formula is:

$$L = \frac{1}{d}[194.4 - 0.162t],$$

where the temperature t is in Celsius and d is the specific gravity at 15 °C.^[72]

Formation

Fossil petroleum

Petroleum is a fossil fuel derived from ancient fossilized organic materials, such as zooplankton and algae.^{[75][76]} Vast amounts of these remains settled to sea or lake bottoms where they were covered in stagnant water (water with no dissolved oxygen) or sediments such as mud and silt faster than they could decompose aerobically. Approximately 1 m below this sediment, water oxygen concentration was low, below 0.1 mg/l, and anoxic conditions existed. Temperatures also remained constant.^[76]

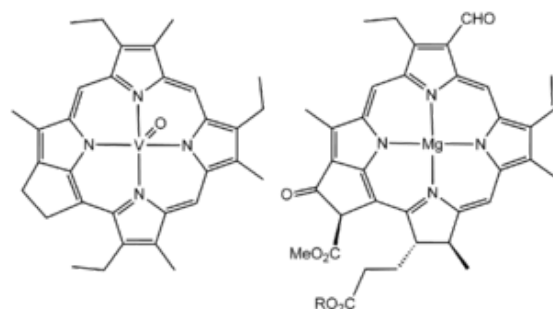
As further layers settled to the sea or lake bed, intense heat and pressure built up in the lower regions. This process caused the organic matter to change, first into a waxy material known as kerogen, found in various oil shales around the world, and then with more heat into liquid and gaseous hydrocarbons via a process known as catagenesis. Formation of petroleum occurs from hydrocarbon pyrolysis in a variety of mainly endothermic reactions at high temperature or pressure, or both.^{[76][77]} These phases are described in detail below.

Anaerobic decay

In the absence of plentiful oxygen, aerobic bacteria were prevented from decaying the organic matter after it was buried under a layer of sediment or water. However, anaerobic bacteria were able to reduce sulfates and nitrates among the matter to H_2S and N_2 respectively by using the matter as a source for other reactants. Due to such anaerobic bacteria, at first this matter began to break apart mostly via hydrolysis: polysaccharides and proteins were hydrolyzed to simple sugars and amino acids respectively. These were further anaerobically oxidized at an accelerated rate by the enzymes of the bacteria: e.g., amino acids went through oxidative deamination to imino acids, which in turn reacted further to ammonia and α -keto acids. Monosaccharides in turn ultimately decayed to CO_2 and methane. The anaerobic decay products of amino acids, monosaccharides, phenols and aldehydes combined to fulvic acids. Fats and waxes were not extensively hydrolyzed under these mild conditions.^[76]

Kerogen formation

Some phenolic compounds produced from previous reactions worked as bactericides and the actinomycetales order of bacteria also produced antibiotic compounds (e.g., streptomycin). Thus the action of anaerobic bacteria ceased at about 10 m below the water or sediment. The mixture at this depth contained fulvic acids, unreacted and partially reacted fats and waxes, slightly modified lignin, resins and other hydrocarbons.^[76] As more layers of organic matter settled to the sea or lake bed, intense heat and pressure built up in the lower regions.^[77] As a consequence, compounds of this mixture began to combine in poorly understood ways to kerogen. Combination happened in a similar fashion as phenol and formaldehyde molecules react to urea-formaldehyde resins, but kerogen formation occurred in a more complex manner due to a bigger variety of reactants. The total process of kerogen formation from the beginning of anaerobic decay is called **diagenesis**, a word that means a transformation of materials by dissolution and recombination of their constituents.^[76]



Structure of a vanadium porphyrin compound (left) extracted from petroleum by Alfred E. Treibs, father of organic geochemistry. Treibs noted the close structural similarity of this molecule and chlorophyll a (right).^{[73][74]}

Transformation of kerogen into fossil fuels

Kerogen formation continued to the depth of about 1 km from the Earth's surface where temperatures may reach around 50 °C. Kerogen formation represents a halfway point between organic matter and fossil fuels: kerogen can be exposed to oxygen, oxidize and thus be lost or it could be buried deeper inside the Earth's crust and be subjected to conditions which allow it to slowly transform into fossil fuels like petroleum. The latter happened through **catagenesis** in which the reactions were mostly radical rearrangements of kerogen. These reactions took thousands to millions of years and no external reactants were involved. Due to radical nature of these reactions, kerogen reacted towards two classes of products: those with low H/C ratio (anthracene or products similar to it) and those with high H/C ratio (methane or products similar to it); i.e., carbon-rich or hydrogen-rich products. Because catagenesis was closed off from external reactants, the resulting composition of the fuel mixture was dependent on the composition of the kerogen via reaction stoichiometry. 3 main types of kerogen exist: type I (algal), II (liptinic) and III (humic), which were formed mainly from algae, plankton and woody plants (this term includes trees, shrubs and lianas) respectively.^[76]

Catagenesis was pyrolytic despite of the fact that it happened at relatively low temperatures (when compared to commercial pyrolysis plants) of 60 to several hundred °C. Pyrolysis was possible because of the long reaction times involved. Heat for catagenesis came from the decomposition of radioactive materials of the crust, especially ⁴⁰K, ²³²Th, ²³⁵U and ²³⁸U. The heat varied with geothermal gradient and was typically 10-30 °C per km of depth from the Earth's surface. Unusual magma intrusions, however, could have created greater localized heating.^[76]

Geologists often refer to the temperature range in which oil forms as an "oil window".^{[78][76]} Below the minimum temperature oil remains trapped in the form of kerogen. Above the maximum temperature the oil is converted to natural gas through the process of thermal cracking. Sometimes, oil formed at extreme depths may migrate and become trapped at a much shallower level. The Athabasca Oil Sands are one example of this.^[76]

Abiogenic petroleum

An alternative mechanism to the one described above was proposed by Russian scientists in the mid-1850s, the hypothesis of abiogenic petroleum origin (petroleum formed by inorganic means), but this is contradicted by geological and geochemical evidence.^[79] Abiogenic sources of oil have been found, but never in commercially profitable amounts. "The controversy isn't over whether abiogenic oil reserves exist," said Larry Nation of the American Association of Petroleum Geologists. "The controversy is over how much they contribute to Earth's overall reserves and how much time and effort geologists should devote to seeking them out."^[80]

Reservoirs

Three conditions must be present for oil reservoirs to form:

- a source rock rich in hydrocarbon material buried deeply enough for subterranean heat to cook it into oil,
- a porous and permeable reservoir rock where it can accumulate,
- a caprock (seal) or other mechanism to prevent the oil from escaping to the surface. Within these reservoirs, fluids will typically organize themselves like a three-layer cake with a layer of water below the oil layer and a layer of gas above it, although the different layers vary in size between reservoirs. Because most hydrocarbons are less dense than rock or water, they often migrate upward through adjacent rock layers until either reaching the surface or becoming trapped within porous rocks (known as reservoirs) by impermeable rocks above. However, the process is influenced by underground water flows, causing oil to migrate hundreds of kilometres horizontally or even short distances downward before becoming trapped in a reservoir. When hydrocarbons are concentrated in a trap, an oil field forms, from which the liquid can be extracted by drilling and pumping.



A hydrocarbon trap consists of a reservoir rock (yellow) where oil (red) can accumulate, and a caprock (green) that prevents it from egressing.

The reactions that produce oil and natural gas are often modeled as first order breakdown reactions, where hydrocarbons are broken down to oil and natural gas by a set of parallel reactions, and oil eventually breaks down to natural gas by another set of reactions. The latter set is regularly used in petrochemical plants and oil refineries.

Petroleum has mostly been recovered by oil drilling (natural petroleum springs are rare). Drilling is carried out after studies of structural geology (at the reservoir scale), sedimentary basin analysis, and reservoir characterisation (mainly in terms of the porosity and permeability of geologic reservoir structures).^{[81][82]} Recent improvements to technologies have also led to exploitation of other unconventional reserves such as oil sands and oil shale. Wells are drilled into oil reservoirs to extract the crude oil. "Natural lift" production methods that rely on the natural reservoir pressure to force the oil to the surface are usually sufficient for a while after reservoirs are first tapped. In some reservoirs, such as in the Middle East, the natural pressure is sufficient over a long time. The natural pressure in most reservoirs, however, eventually dissipates. Then the oil must be extracted using "artificial lift" means. Over time, these "primary" methods become less effective and "secondary" production methods may be used. A common secondary method is "waterflood" or injection of water into the reservoir to increase pressure and force the oil to the drilled shaft or "wellbore." Eventually "tertiary" or "enhanced" oil recovery methods may be used to increase the oil's flow characteristics by injecting steam, carbon dioxide and other gases or chemicals into the reservoir. In the United States, primary production methods account for less than 40 percent of the oil produced on a daily basis, secondary methods account for about half, and tertiary recovery the remaining 10 percent. Extracting oil (or "bitumen") from oil/tar sand and oil shale deposits requires mining the sand or shale and heating it in a vessel or retort, or using "in-situ" methods of injecting heated liquids into the deposit and then pumping the liquid back out saturated with oil.

Unconventional oil reservoirs

Oil-eating bacteria biodegrade oil that has escaped to the surface. Oil sands are reservoirs of partially biodegraded oil still in the process of escaping and being biodegraded, but they contain so much migrating oil that, although most of it has escaped, vast amounts are still present—more than can be found in conventional oil reservoirs. The lighter fractions of the crude oil are destroyed first, resulting in reservoirs containing an extremely heavy form of crude oil, called crude bitumen in Canada, or extra-heavy crude oil in Venezuela. These two countries have the world's largest deposits of oil sands.

On the other hand, oil shales are source rocks that have not been exposed to heat or pressure long enough to convert their trapped hydrocarbons into crude oil. Technically speaking, oil shales are not always shales and do not contain oil, but are fined-grain sedimentary rocks containing an insoluble organic solid called kerogen. The kerogen in the rock can be converted into crude oil using heat and pressure to simulate natural processes. The method has been known for centuries and was patented in 1694 under British Crown Patent No. 330 covering, "A way to extract and make great quantities of pitch, tar, and oil out of a sort of stone." Although oil shales are found in many countries, the United States has the world's largest deposits.^[83]

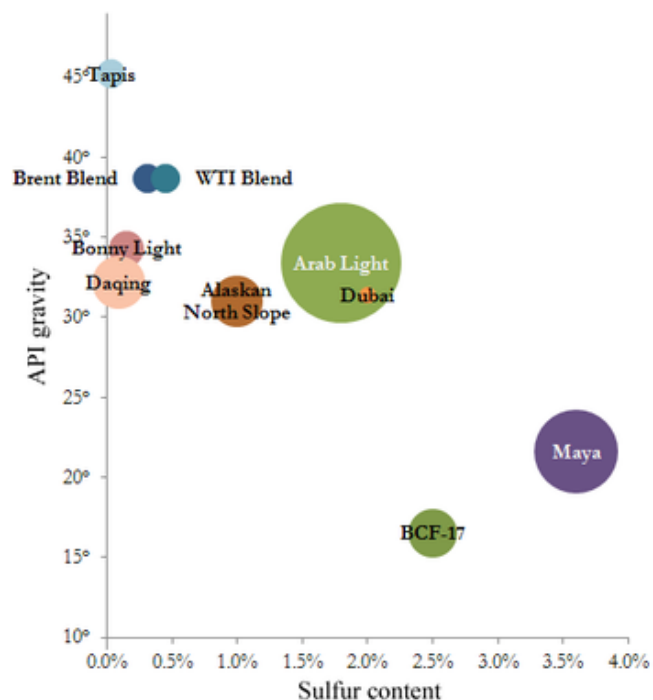
Classification

The petroleum industry generally classifies crude oil by the geographic location it is produced in (e.g., West Texas Intermediate, Brent, or Oman), its API gravity (an oil industry measure of density), and its sulfur content. Crude oil may be considered *light* if it has low density, *heavy* if it has high density, or *medium* if it has a density between that of *light* and *heavy*.^[84] Additionally, it may be referred to as sweet if it contains relatively little sulfur or sour if it contains substantial amounts of sulfur.^[85]

The geographic location is important because it affects transportation costs to the refinery. *Light* crude oil is more desirable than *heavy* oil since it produces a higher yield of gasoline, while *sweet* oil commands a higher price than *sour* oil because it has fewer environmental problems and requires less refining to meet sulfur standards imposed on fuels in consuming countries. Each crude oil has unique molecular characteristics which are revealed by the use of Crude oil assay analysis in petroleum laboratories.^[86]

Barrels from an area in which the crude oil's molecular characteristics have been determined and the oil has been classified are used as pricing references throughout the world. Some of the common reference crudes are:

- West Texas Intermediate (WTI), a very high-quality, sweet, light oil delivered at Cushing, Oklahoma for North American oil
- Brent Blend, consisting of 15 oils from fields in the Brent and Ninian systems in the East Shetland Basin of the North Sea. The oil is landed at Sullom Voe terminal in Shetland. Oil production from Europe, Africa and Middle Eastern oil flowing West tends to be priced off this oil, which forms a benchmark
- Dubai-Oman, used as benchmark for Middle East sour crude oil flowing to the Asia-Pacific region
- Tapis (from Malaysia, used as a reference for light Far East oil)
- Minas (from Indonesia, used as a reference for heavy Far East oil)
- The OPEC Reference Basket, a weighted average of oil blends from various OPEC (The Organization of the Petroleum Exporting Countries) countries
- Midway Sunset Heavy, by which heavy oil in California is priced^[87]
- Western Canadian Select the benchmark crude oil for emerging heavy, high TAN (acidic) crudes.^[88]



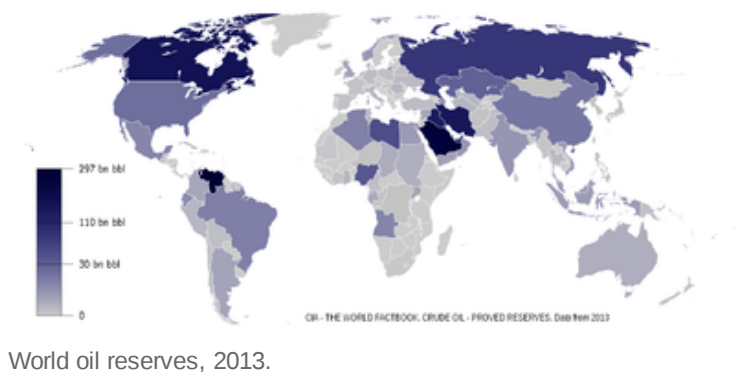
Some marker crudes with their sulfur content (horizontal) and API gravity (vertical) and relative production quantity.

There are declining amounts of these benchmark oils being produced each year, so other oils are more commonly what is actually delivered. While the reference price may be for West Texas Intermediate delivered at Cushing, the actual oil being traded may be a discounted Canadian heavy oil—Western Canadian Select—delivered at Hardisty, Alberta, and for a Brent Blend delivered at Shetland, it may be a discounted Russian Export Blend delivered at the port of Primorsk.^[89]

Once extracted, oil is refined and separated, most easily by distillation, into numerous products for direct use or use in manufacturing, such as gasoline (petrol), diesel and kerosene to asphalt and chemical reagents (ethylene, propylene, butene,^[90] acrylic acid,^{[91][92][93]} para-xylene^[94]) used to make plastics, pesticides and pharmaceuticals.^[95]

Industry

The petroleum industry, also known as the oil industry or the oil patch, includes the global processes of exploration, extraction, refining, transporting (often by oil tankers and pipelines), and marketing of petroleum products. The largest volume products of the industry are fuel oil and gasoline (petrol). Petroleum is also the raw material for many chemical products, including pharmaceuticals, solvents, fertilizers, pesticides, synthetic fragrances, and plastics. The extreme monetary value of oil and its products has led to it being known as "black gold". The industry is usually divided into three major components: upstream, midstream, and downstream. Upstream deals with Drilling and Production mainly.



Petroleum is vital to many industries, and is necessary for the maintenance of industrial civilization in its current configuration, making it a critical concern for many nations. Oil accounts for a large percentage of the world's energy consumption, ranging from a low of 32% for Europe and Asia, to a high of 53% for the Middle East.

Other geographic regions' consumption patterns are as follows: South and Central America (44%), Africa (41%), and North America (40%). The world consumes 36 billion barrels (5.8 km³) of oil per year,^[96] with developed nations being the largest consumers. The United States consumed 18% of the oil produced in 2015.^[97] The production, distribution, refining, and retailing of petroleum taken as a whole represents the world's largest industry in terms of dollar value.

Governments such as the United States government provide a heavy public subsidy to petroleum companies, with major tax breaks at virtually every stage of oil exploration and extraction, including the costs of oil field leases and drilling equipment.^[98]

In recent years, enhanced oil recovery techniques — most notably multi-stage drilling and hydraulic fracturing ("fracking") — have moved to the forefront of the industry as this new technology plays a crucial and controversial role in new methods of oil extraction.^[99]

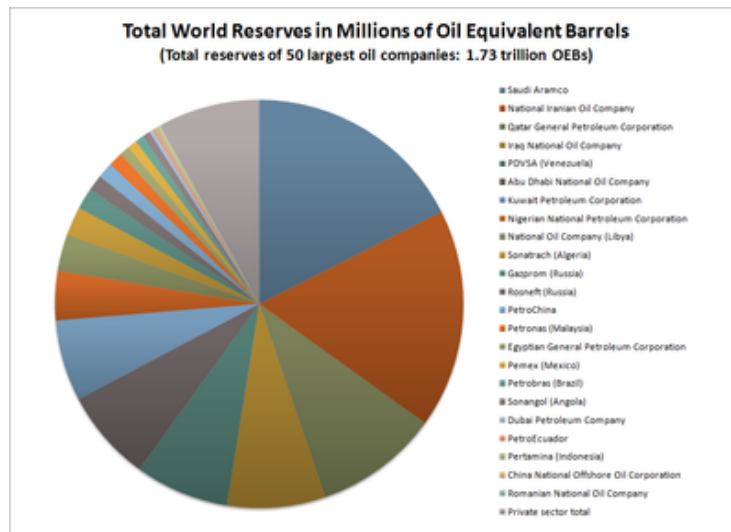
Transport

In the 1950s, shipping costs made up 33 percent of the price of oil transported from the Persian Gulf to the United States,^[100] but due to the development of supertankers in the 1970s, the cost of shipping dropped to only 5 percent of the price of Persian oil in the US.^[100] Due to the increase of the value of the crude oil during the last 30 years, the share of the shipping cost on the final cost of the delivered commodity was less than 3% in 2010.

Price

The price of oil, or the oil price, generally refers to the spot price of a barrel of benchmark crude oil—a reference price for buyers and sellers of crude oil such as West Texas Intermediate (WTI), Brent Crude, Dubai Crude, OPEC Reference Basket, Tapis crude, Bonny Light, Urals oil, Isthmus and Western Canadian Select (WCS).^{[101][102]} There is a differential in the price of a barrel of oil based on its grade—determined by factors such as its specific gravity or API gravity and its sulfur content—and its location—for example, its proximity to tidewater and refineries. Heavier, sour crude oils lacking in tidewater access—such as Western Canadian Select—are less expensive than lighter, sweeter oil—such as WTI.^[103]

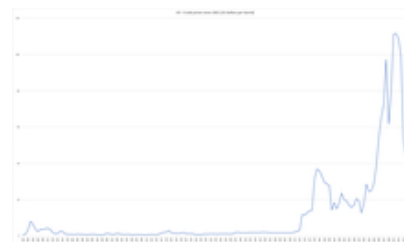
The price of oil rose dramatically from US\$50 in early 2007, to a peak of US\$147 in July 2008, before plunging to US\$34 in December 2008, as the financial crisis of 2007–2008 took hold.^{[104]:46} Large and persistent changes in the price of oil have occurred numerous times in the past as well, such as the well-known oil price shocks that followed the formation of OPEC in the 1970's. A quantitative analysis undertaken in [Trimbur, *International Journal of Forecasting*, 2010] entitled "Stochastic level shifts and outliers and the dynamics of oil price movements", showed that random shifts in the level of the real oil price are a regular statistical property. Indeed they occur even more commonly than additive or purely temporary outliers, which is an unusual trait of macroeconomic series.^[105]



The distribution of oil and gas reserves among the world's 50 largest oil companies. The reserves of the privately owned companies are grouped together. The oil produced by the "supermajor" companies accounts for less than 15 percent of the total world supply. Over 80% of the world's reserves of oil and natural gas are controlled by national oil companies. Of the world's 20 largest oil companies, 15 are state-owned oil companies.



Nominal and inflation-adjusted US dollar price of crude oil, 1861–2015.



Nominal price of oil from 1861 to 2020 from Our World in Data

According to a January 2020 EIA report, the average price of Brent crude oil in 2019 was \$64 per barrel compared to \$71 per barrel in 2018. The average price of WTI crude oil was \$57 per barrel in 2019 compared to \$64 in 2018.^[106] On 20 April 2020, WTI Crude futures contracts dropped below \$0 for the first time in history,^[107] and the following day Brent Crude fell below \$20 per barrel. The substantial decrease in the price of oil was caused by two main factors: the 2020 Russia–Saudi Arabia oil price war^[108] and the COVID-19 pandemic, which lowered demand for oil because of lockdowns around the world.^[108] In the fall of 2020, against the backdrop of the resurgent pandemic, the U.S. Energy Information Administration (EIA) reported that global oil inventories remained "quite high" while demand for gasoline—particularly in the United States—was "particularly worrisome."^[109] The price of oil was about US\$40 by mid-October.^[110]

Uses

The chemical structure of petroleum is heterogeneous, composed of hydrocarbon chains of different lengths. Because of this, petroleum may be taken to oil refineries and the hydrocarbon chemicals separated by distillation and treated by other chemical processes, to be used for a variety of purposes. The total cost per plant is about 9 billion dollars.

Fuels

The most common distillation fractions of petroleum are fuels. Fuels include (by increasing boiling temperature range):^[58]

Common fractions of petroleum as fuels

Fraction	Boiling range °C
<u>Liquefied petroleum gas</u> (LPG)	−40
<u>Butane</u>	−12 to −1
<u>Gasoline</u> /Petrol	−1 to 110
<u>Jet fuel</u>	150 to 205
<u>Kerosene</u>	205 to 260
<u>Fuel oil</u>	205 to 290
<u>Diesel fuel</u>	260 to 315

Petroleum classification according to chemical composition.^[111]

Class of petroleum	Composition of 250–300 °C fraction, wt. %				
	Par.	Napth	Arom.	Wax	Asph.
Paraffinic	46–61	22–32	12–25	1.5–10	0–6
Paraffinic-naphtenic	42–45	38–39	16–20	1–6	0–6
Naphtenic	15–26	61–76	8–13	Trace	0–6
Paraffinic-naphtenic-aromatic	27–35	36–47	26–33	0.5–1	0–10
Aromatic	0–8	57–78	20–25	0–0.5	0–20

Other derivatives

Certain types of resultant hydrocarbons may be mixed with other non-hydrocarbons, to create other end products:

- Alkenes (olefins), which can be manufactured into plastics or other compounds
- Lubricants (produces light machine oils, motor oils, and greases, adding viscosity stabilizers as required)

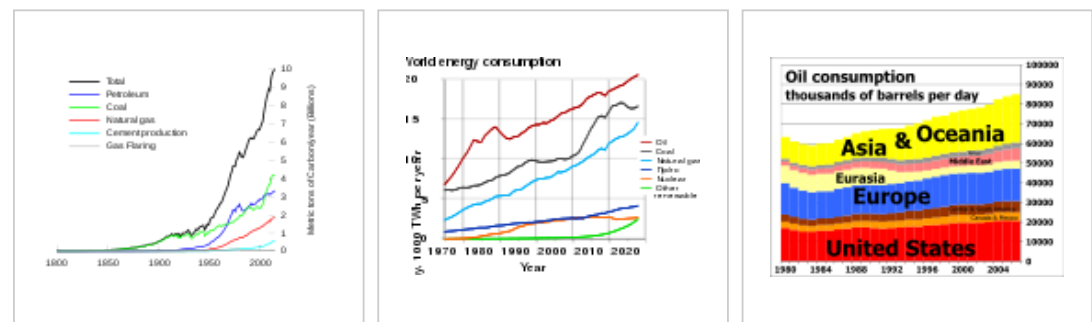
- Wax, used in the packaging of frozen foods, among others
- Sulfur or sulfuric acid. These are useful industrial materials. Sulfuric acid is usually prepared as the acid precursor oleum, a byproduct of sulfur removal from fuels.
- Bulk tar
- Asphalt
- Petroleum coke, used in speciality carbon products or as solid fuel
- Paraffin wax
- Aromatic petrochemicals to be used as precursors in other chemical production

Agriculture

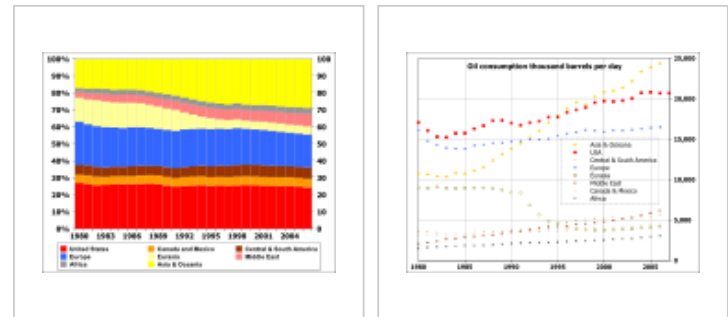
Since the 1940s, agricultural productivity has increased dramatically, due largely to the increased use of energy-intensive mechanization, fertilizers and pesticides.

Use by country

Consumption statistics



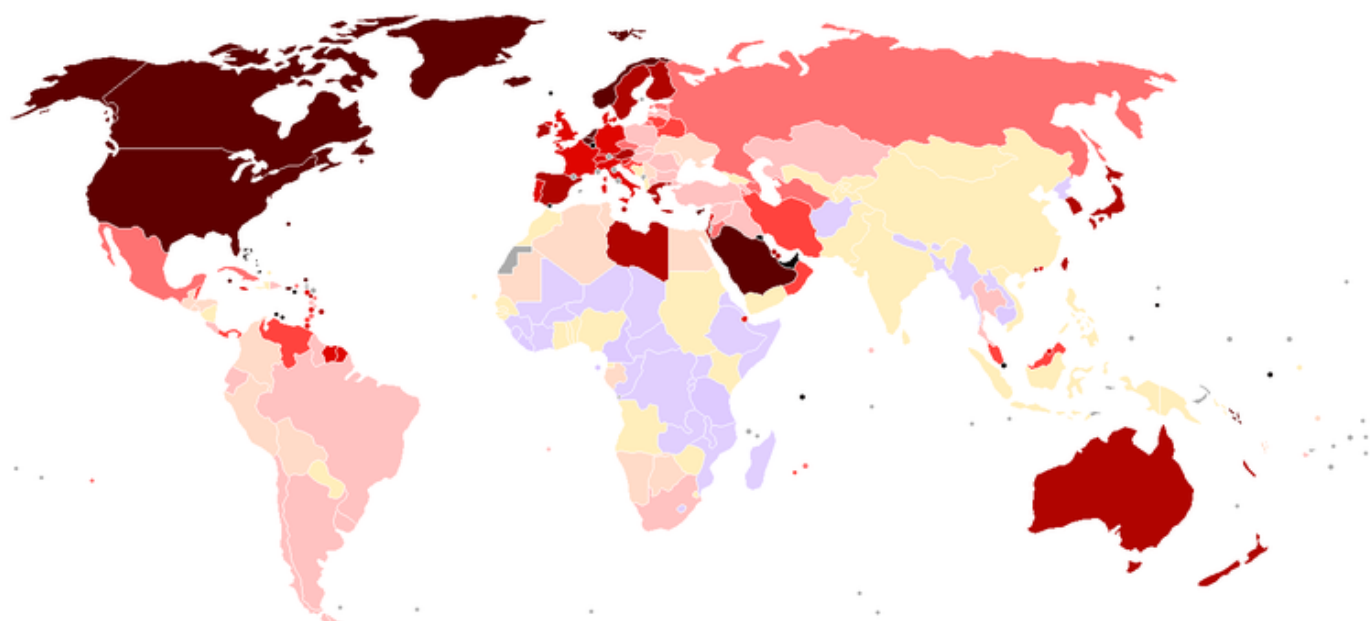
Global fossil carbon emissions, an indicator of consumption, from 1800. Rate of world energy usage per year from 1970. Daily oil consumption from 1980 to 2006.



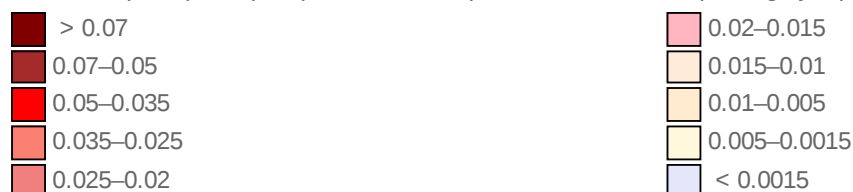
Oil consumption by percentage of total per region from 1980 to 2006: Oil consumption 1980 to 2007 by region.

Consumption

According to the US Energy Information Administration (EIA) estimate for 2017, the world consumes 98.8 million barrels of oil each day.^[113]



Oil consumption per capita (darker colors represent more consumption, gray represents no data) (source: see file description).



This table orders the amount of petroleum consumed in 2011 in thousand barrels (1000 bbl) per day and in thousand cubic metres (1000 m³) per day.^{[114][115]}

Consuming nation 2011	(1000 bbl/ day)	(1000 m ³ / day)	Population in millions	bbl/year per capita	m ³ /year per capita	National production/ consumption
<u>United States</u> ¹	18,835.5	2,994.6	314	21.8	3.47	0.51
<u>China</u>	9,790.0	1,556.5	1345	2.7	0.43	0.41
<u>Japan</u> ²	4,464.1	709.7	127	12.8	2.04	0.03
<u>India</u> ²	3,292.2	523.4	1198	1	0.16	0.26
<u>Russia</u> ¹	3,145.1	500.0	140	8.1	1.29	3.35
<u>Saudi Arabia (OPEC)</u>	2,817.5	447.9	27	40	6.4	3.64
<u>Brazil</u>	2,594.2	412.4	193	4.9	0.78	0.99
<u>Germany</u> ²	2,400.1	381.6	82	10.7	1.70	0.06
<u>Canada</u>	2,259.1	359.2	33	24.6	3.91	1.54
<u>South Korea</u> ²	2,230.2	354.6	48	16.8	2.67	0.02
<u>Mexico</u> ¹	2,132.7	339.1	109	7.1	1.13	1.39
<u>France</u> ²	1,791.5	284.8	62	10.5	1.67	0.03
<u>Iran (OPEC)</u>	1,694.4	269.4	74	8.3	1.32	2.54
<u>United Kingdom</u> ¹	1,607.9	255.6	61	9.5	1.51	0.93
<u>Italy</u> ²	1,453.6	231.1	60	8.9	1.41	0.10

Source: US Energy Information Administration (<http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=5&pid=5&aid=2>)

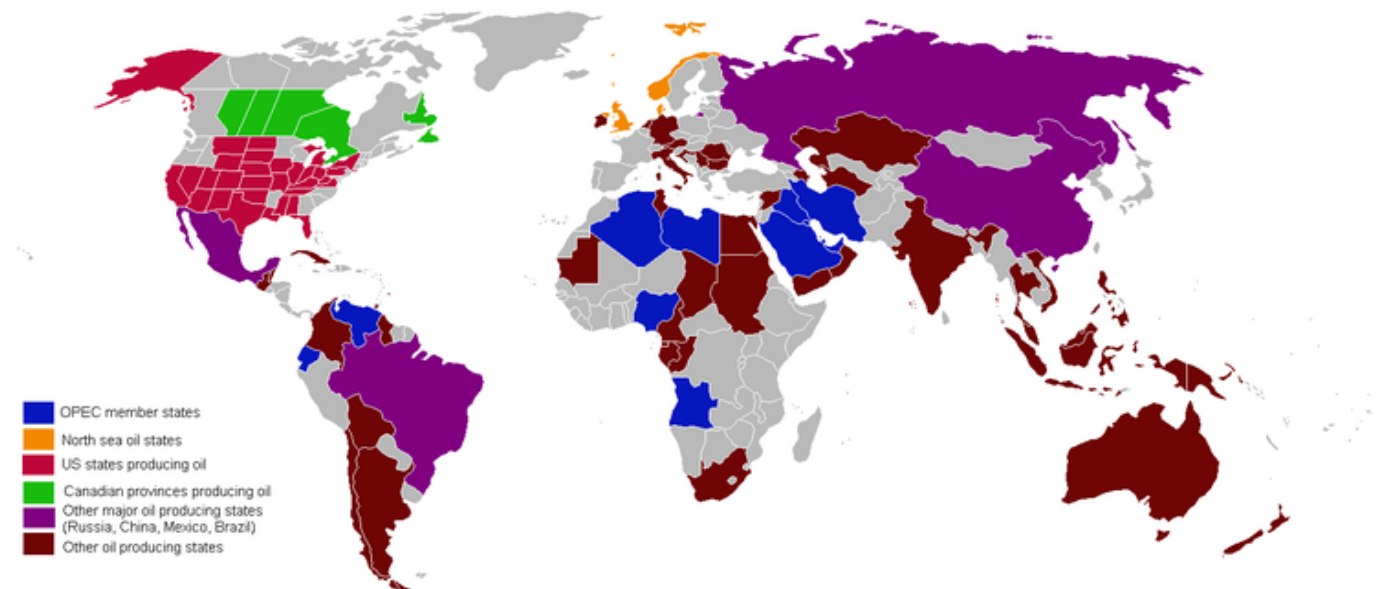
Population Data:^[116]

¹ peak production of oil already passed in this state

² This country is not a major oil producer



Production

Top oil-producing countries^[117]

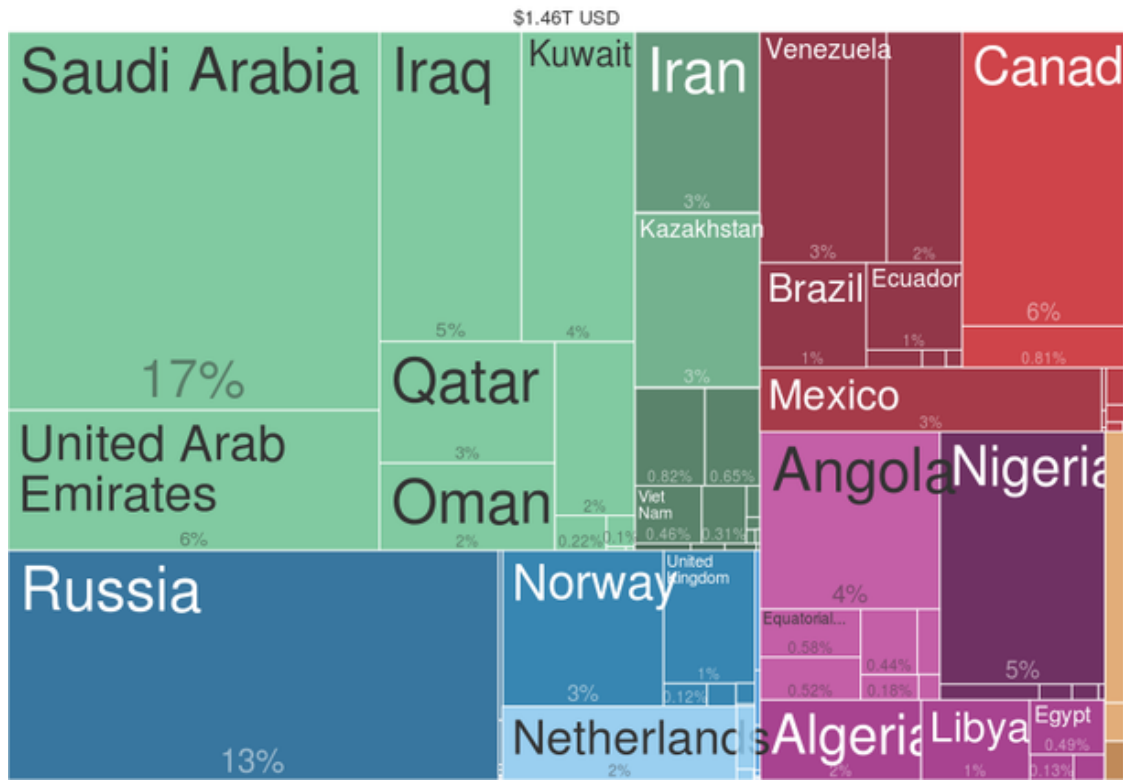


World map with countries by oil production (information from 2006–2012).

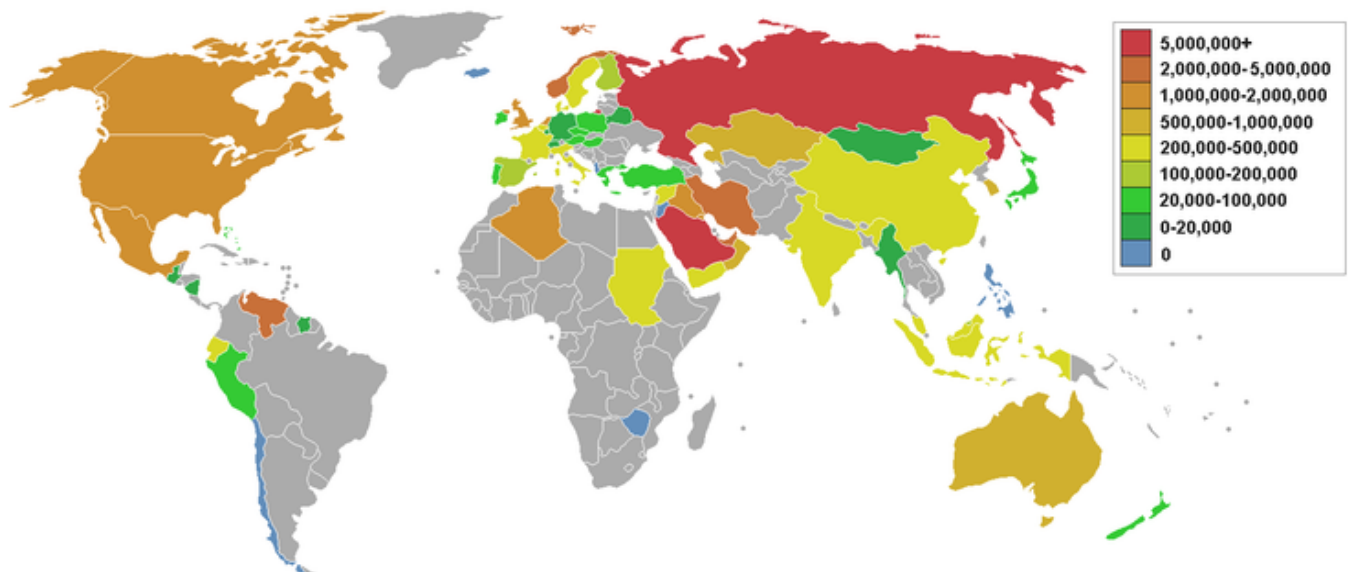
In petroleum industry parlance, *production* refers to the quantity of crude extracted from reserves, not the literal creation of the product.

	Country	Oil Production (bbl/day, 2016) ^[118]
1	 <u>Russia</u>	10,551,497
2	 <u>Saudi Arabia (OPEC)</u>	10,460,710
3	 <u>United States</u>	8,875,817
4	 <u>Iraq (OPEC)</u>	4,451,516
5	 <u>Iran (OPEC)</u>	3,990,956
6	 <u>China, People's Republic of</u>	3,980,650
7	 <u>Canada</u>	3,662,694
8	 <u>United Arab Emirates (OPEC)</u>	3,106,077
9	 <u>Kuwait (OPEC)</u>	2,923,825
10	 <u>Brazil</u>	2,515,459
11	 <u>Venezuela (OPEC)</u>	2,276,967
12	 <u>Mexico</u>	2,186,877
13	 <u>Nigeria (OPEC)</u>	1,999,885
14	 <u>Angola (OPEC)</u>	1,769,615
15	 <u>Norway</u>	1,647,975
16	 <u>Kazakhstan</u>	1,595,199
17	 <u>Qatar (OPEC)</u>	1,522,902
18	 <u>Algeria (OPEC)</u>	1,348,361
19	 <u>Oman</u>	1,006,841
20	 <u>United Kingdom</u>	939,760

Exportation



Petroleum Exports by Country (2014) from Harvard Atlas of Economic Complexity (http://atlas.cid.harvard.edu/explore/tree_map/export/show/all/2709/2014/).



Oil exports by country (barrels per day, 2006).

In order of net exports in 2011, 2009 and 2006 in thousand bbl/d and thousand m^3/d :

#	Exporting nation	10 ³ bbl/d (2011)	10 ³ m ³ /d (2011)	10 ³ bbl/d (2009)	10 ³ m ³ /d (2009)	10 ³ bbl/d (2006)	10 ³ m ³ /d (2006)
1	<u>Saudi Arabia (OPEC)</u>	8,336	1,325	7,322	1,164	8,651	1,376
2	<u>Russia</u> ¹	7,083	1,126	7,194	1,144	6,565	1,044
3	<u>Iran (OPEC)</u>	2,540	403	2,486	395	2,519	401
4	<u>United Arab Emirates (OPEC)</u>	2,524	401	2,303	366	2,515	400
5	<u>Kuwait (OPEC)</u>	2,343	373	2,124	338	2,150	342
6	<u>Nigeria (OPEC)</u>	2,257	359	1,939	308	2,146	341
7	<u>Iraq (OPEC)</u>	1,915	304	1,764	280	1,438	229
8	<u>Angola (OPEC)</u>	1,760	280	1,878	299	1,363	217
9	<u>Norway</u> ¹	1,752	279	2,132	339	2,542	404
10	<u>Venezuela (OPEC)</u> ¹	1,715	273	1,748	278	2,203	350
11	<u>Algeria (OPEC)</u> ¹	1,568	249	1,767	281	1,847	297
12	<u>Qatar (OPEC)</u>	1,468	233	1,066	169	–	–
13	<u>Canada</u> ²	1,405	223	1,168	187	1,071	170
14	<u>Kazakhstan</u>	1,396	222	1,299	207	1,114	177
15	<u>Azerbaijan</u> ¹	836	133	912	145	532	85
16	<u>Trinidad and Tobago</u> ¹	177	112	167	160	155	199

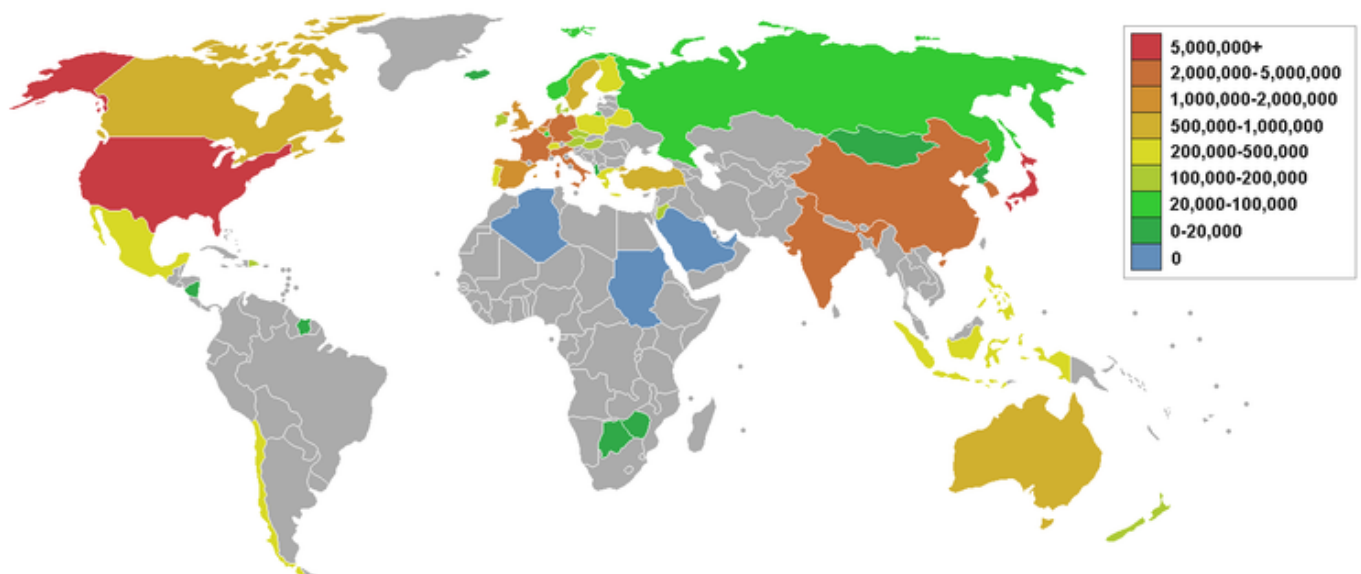
Source: US Energy Information Administration (<http://www.eia.gov/countries/index.cfm?topL=exp>)

¹ peak production already passed in this state

² Canadian statistics are complicated by the fact it is both an importer and exporter of crude oil, and refines large amounts of oil for the U.S. market. It is the leading source of U.S. imports of oil and products, averaging 2,500,000 bbl/d (400,000 m³/d) in August 2007.^[119]

Total world production/consumption (as of 2005) is approximately 84 million barrels per day (13,400,000 m³/d).

Importation



Oil imports by country (barrels per day, 2006).

In order of net imports in 2011, 2009 and 2006 in thousand bbl/d and thousand m³/d:

#	Importing nation	10 ³ bbl/day (2011)	10 ³ m ³ /day (2011)	10 ³ bbl/day (2009)	10 ³ m ³ /day (2009)	10 ³ bbl/day (2006)	10 ³ m ³ /day (2006)
1	United States ¹	8,728	1,388	9,631	1,531	12,220	1,943
2	China	5,487	872	4,328	688	3,438	547
3	Japan	4,329	688	4,235	673	5,097	810
4	India	2,349	373	2,233	355	1,687	268
5	Germany	2,235	355	2,323	369	2,483	395
6	South Korea	2,170	345	2,139	340	2,150	342
7	France	1,697	270	1,749	278	1,893	301
8	Spain	1,346	214	1,439	229	1,555	247
9	Italy	1,292	205	1,381	220	1,558	248
10	Singapore	1,172	186	916	146	787	125
11	Republic of China (Taiwan)	1,009	160	944	150	942	150
12	Netherlands	948	151	973	155	936	149
13	Turkey	650	103	650	103	576	92
14	Belgium	634	101	597	95	546	87
15	Thailand	592	94	538	86	606	96

Source: US Energy Information Administration (<http://www.eia.gov/countries/index.cfm?topL=imp>)

¹ peak production of oil expected in 2020^[120]

Non-producing consumers

Countries whose oil production is 10% or less of their consumption.

#	Consuming nation	(bbl/day)	(m ³ /day)
1	Japan	5,578,000	886,831
2	Germany	2,677,000	425,609
3	South Korea	2,061,000	327,673
4	France	2,060,000	327,514
5	Italy	1,874,000	297,942
6	Spain	1,537,000	244,363
7	Netherlands	946,700	150,513
8	Turkey	575,011	91,663

Source: CIA World Factbook (<https://web.archive.org/web/20120127201212/https://www.cia.gov/library/publications/the-world-factbook/rankorder/2175rank.html>)

Environmental effects

Because petroleum is a naturally occurring substance, its presence in the environment need not be the result of human causes such as accidents and routine activities (seismic exploration, drilling, extraction, refining and combustion). Phenomena such as seeps^[121] and tar pits are examples of areas that petroleum affects without man's involvement.

Climate change

As of 2018, about a quarter of annual global greenhouse gas emissions is the carbon dioxide from burning petroleum (plus methane leaks from the industry).^{[122][123][note 1]} Along with the burning of coal, petroleum combustion is the largest contributor to the increase in atmospheric CO₂.^{[124][125]} Atmospheric CO₂ has risen over the last 150 years to current levels of over 415 ppmv,^[126] from the 180–300 ppmv of the prior 800 thousand years.^{[127][128][129]} This rise in temperature has reduced the minimum Arctic ice pack to 4,320,000 km² (1,670,000 sq mi), a loss of almost half since satellite measurements started in 1979.^{[130][131]}

Ocean acidification is the increase in the acidity of the Earth's oceans caused by the uptake of carbon dioxide (CO₂) from the atmosphere. This increase in acidity inhibits all marine life—having a greater impact on smaller organisms as well as shelled organisms (see scallops).^[132]

Extraction

Oil extraction is simply the removal of oil from the reservoir (oil pool). Oil is often recovered as a water-in-oil emulsion, and specialty chemicals called demulsifiers are used to separate the oil from water. Oil extraction is costly and often environmentally damaging. Offshore exploration and extraction of oil disturb the surrounding marine environment.^[133]

Oil spills

Crude oil and refined fuel spills from tanker ship accidents have damaged natural ecosystems and human livelihoods in Alaska, the Gulf of Mexico, the Galápagos Islands, France and many other places.

The quantity of oil spilled during accidents has ranged from a few hundred tons to several hundred thousand tons (e.g., Deepwater Horizon oil spill, SS Atlantic Empress, Amoco Cadiz). Smaller spills have already proven to have a great impact on ecosystems, such as the Exxon Valdez oil spill.

Oil spills at sea are generally much more damaging than those on land, since they can spread for hundreds of nautical miles in a thin oil slick which can cover beaches with a thin coating of oil. This can kill sea birds, mammals, shellfish and other organisms it coats. Oil spills on land are more readily containable if a makeshift earth dam can be rapidly bulldozed around the spill site before most of the oil escapes, and land animals can avoid the oil more easily.

Control of oil spills is difficult, requires ad hoc methods, and often a large amount of manpower. The dropping of bombs and incendiary devices from aircraft on the SS Torrey Canyon wreck produced poor results;^[134] modern techniques would include pumping the oil from the wreck, like in the Prestige oil spill or the Erika oil spill.^[135]

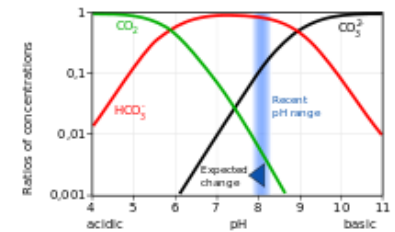
Though crude oil is predominantly composed of various hydrocarbons, certain nitrogen heterocyclic compounds, such as pyridine, picoline, and quinoline are reported as contaminants associated with crude oil, as well as facilities processing oil shale or coal, and have also been found at legacy wood treatment sites. These compounds have a very high water solubility, and thus tend to dissolve and move with water. Certain naturally occurring bacteria, such as Micrococcus, Arthrobacter, and Rhodococcus have been shown to degrade these contaminants.^[136]

Tarballs

A tarball is a blob of crude oil (not to be confused with tar, which is a man-made product derived from pine trees or refined from petroleum) which has been weathered after floating in the ocean. Tarballs are an aquatic pollutant in most environments, although they can occur naturally, for example in the Santa Barbara Channel of California^{[137][138]} or in



Diesel fuel spill on a road.



Seawater acidification.



Kelp after an oil spill.



Oil slick from the Montara oil spill in the Timor Sea, September, 2009.



Volunteers cleaning up the aftermath of the Prestige oil spill.

the Gulf of Mexico off Texas.^[139] Their concentration and features have been used to assess the extent of oil spills. Their composition can be used to identify their sources of origin,^{[140][141]} and tarballs themselves may be dispersed over long distances by deep sea currents.^[138] They are slowly decomposed by bacteria, including *Chromobacterium violaceum*, *Cladosporium resinae*, *Bacillus submarinus*, *Micrococcus varians*, *Pseudomonas aeruginosa*, *Candida marina* and *Saccharomyces estuari*.^[137]

Whales

James S. Robbins has argued that the advent of petroleum-refined kerosene saved some species of great whales from extinction by providing an inexpensive substitute for whale oil, thus eliminating the economic imperative for open-boat whaling.^[142]

Alternatives

In the United States in 2007 about 70 percent of petroleum was used for transportation (e.g. gasoline, diesel, jet fuel), 24 percent by industry (e.g. production of plastics), 5 percent for residential and commercial uses, and 2 percent for electricity production.^[143] Outside of the US, a higher proportion of petroleum tends to be used for electricity.^[144]

Vehicle fuels

Petroleum-based vehicle fuels can be replaced by either alternative fuels, or other methods of propulsion such as electric or nuclear.

Alternative fuel vehicles refers to both:

- Vehicles that use alternative fuels used in standard or modified internal combustion engines such as natural gas vehicles, neat ethanol vehicles, flexible-fuel vehicles, biodiesel-powered vehicles, propane autogas, and hydrogen vehicles.
- Vehicles with advanced propulsion systems that reduce or substitute petroleum use such as battery electric vehicles, plug-in hybrid electric vehicles, hybrid electric vehicles, and hydrogen fuel cell vehicles.



Brazilian fuel station with four alternative fuels for sale: diesel (B3), gasohol (E25), neat ethanol (E100), and compressed natural gas (CNG).

Industrial oils

Biological feedstocks do exist for industrial uses such as Bioplastic production.^[145]

Electricity

In oil producing countries with little refinery capacity, oil is sometimes burned to produce electricity.

International relations

Control of petroleum production has been a significant driver of international relations during much of the 20th and 21st centuries.^[146] Organizations like OPEC have played an outsized role in international politics. Some historians and commentators have called this the "Age of Oil"^[146] With the rise of renewable energy and addressing climate change some commentators expect a realignment of international power away from petrostates.

Conflict

Petroleum production is tightly linked with conflict:^[147] whether through direct aggression such as the U.S. invasion of Iraq, trade wars such as the 2020 Russia–Saudi Arabia oil price war, or by fueling conflict in regions such as funding Islamic State of Iraq and the Levant in the Syrian civil war.

OPEC

The Organization of the Petroleum Exporting Countries (OPEC, /ˈoʊpɛk/ OH-pek) is an intergovernmental organization of 13 countries. Founded on 14 September 1960 in Baghdad by the first five members (Iran, Iraq, Kuwait, Saudi Arabia, and Venezuela), it has since 1965 been headquartered in Vienna, Austria, although Austria is not an OPEC member state. As of September 2018, the 13 member countries accounted for an estimated 44 percent of global oil production and 81.5 percent of the world's "proven" oil reserves, giving OPEC a major influence on global oil prices that were previously determined by the so-called "Seven Sisters" grouping of multinational oil companies. A larger group called OPEC+ was formed in late 2016 to have more control on the global crude oil market.^[148]

The stated mission of the organization is to "coordinate and unify the petroleum policies of its member countries and ensure the stabilization of oil markets, in order to secure an efficient, economic and regular supply of petroleum to consumers, a steady income to producers, and a fair return on capital for those investing in the petroleum industry."^[149] The organization is also a significant provider of information about the international oil market. The current OPEC members are the following: Algeria, Angola, Equatorial Guinea, Gabon, Iran, Iraq, Kuwait, Libya, Nigeria, the Republic of the Congo, Saudi Arabia (the de facto leader), the United Arab Emirates and Venezuela. Former OPEC members are Ecuador, Indonesia and Qatar.^[150]

The formation of OPEC marked a turning point toward national sovereignty over natural resources, and OPEC decisions have come to play a prominent role in the global oil market and international relations. The effect can be particularly strong when wars or civil disorders lead to extended interruptions in supply. In the 1970s, restrictions in oil production led to a dramatic rise in oil prices and in the revenue and wealth of OPEC, with long-lasting and far-reaching consequences for the global economy. In the 1980s, OPEC began setting production targets for its member nations; generally, when the targets are reduced, oil prices increase. This has occurred most recently from the organization's 2008 and 2016 decisions to trim oversupply.

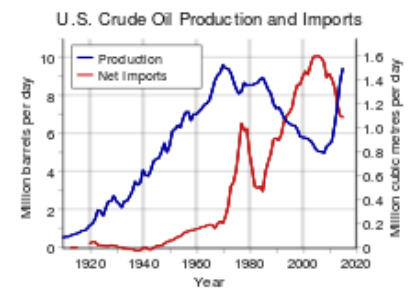
Economists often cite OPEC as a textbook example of a cartel that cooperates to reduce market competition, but one whose consultations are protected by the doctrine of state immunity under international law. In December 2014, "OPEC and the oil men" ranked as #3 on Lloyd's of London list of "the top 100 most influential people in the shipping industry".^[151] However, the influence of OPEC on international trade is periodically challenged by the expansion of non-OPEC energy sources, and by the recurring temptation for individual OPEC countries to exceed production targets and pursue conflicting self-interests.

In October 2019, Saudi Arabia invited Brazil to join OPEC.^[152] The president of Petrobras, Roberto Castello Branco, in an interview in New York, said that being a member of OPEC is not an option currently considered by the Brazilian federal government.^[153]

Future production

Consumption in the twentieth and twenty-first centuries has been abundantly pushed by automobile sector growth. The 1985–2003 oil glut even fueled the sales of low fuel economy vehicles in OECD countries. The 2008 economic crisis seems to have had some impact on the sales of such vehicles; still, in 2008 oil consumption showed a small increase.

In 2016 Goldman Sachs predicted lower demand for oil due to emerging economies concerns, especially China.^[154] The BRICS (Brasil, Russia, India, China, South Africa) countries might also kick in, as China briefly was the first automobile market in December 2009.^[155] In the long term, uncertainties linger; the OPEC believes that the OECD countries will push low consumption policies at some point in the future; when that happens, it will definitely curb oil sales, and both OPEC and the Energy Information Administration (EIA) kept lowering their 2020 consumption estimates during the past five years.^[156] A detailed review of International Energy Agency oil projections have revealed that revisions of world oil production, price and investments have been motivated by a combination of demand and supply factors.^[157] All together, Non-OPEC conventional projections have been fairly stable the last 15 years, while downward revisions were mainly allocated to OPEC. Recent upward revisions are primarily a result of US tight oil.



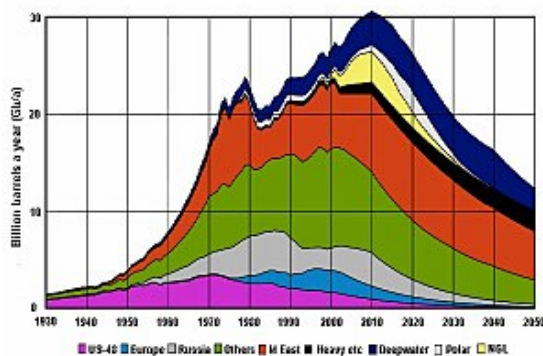
US oil production and imports, 1910–2012.

Production will also face an increasingly complex situation; while OPEC countries still have large reserves at low production prices, newly found reservoirs often lead to higher prices; offshore giants such as Tupi, Guara and Tiber demand high investments and ever-increasing technological abilities. Subsalt reservoirs such as Tupi were unknown in the twentieth century, mainly because the industry was unable to probe them. Enhanced Oil Recovery (EOR) techniques (example: DaQing, China^[158]) will continue to play a major role in increasing the world's recoverable oil.

The expected availability of petroleum resources has always been around 35 years or even less since the start of the modern exploration. The oil constant, an insider pun in the German industry, refers to that effect.^[159]

A growing number of divestment campaigns from major funds pushed by newer generations who question the sustainability of petroleum may hinder the financing of future oil prospection and production.^[160]

Peak oil



Global peak oil forecast.

Peak oil is a term applied to the projection that future petroleum production (whether for individual oil wells, entire oil fields, whole countries, or worldwide production) will eventually peak and then decline at a similar rate to the rate of increase before the peak as these reserves are exhausted. The peak of oil discoveries was in 1965, and oil production per year has surpassed oil discoveries every year since 1980.^[161] However, this does not mean that potential oil production has surpassed oil demand.

It is difficult to predict the oil peak in any given region, due to the lack of knowledge and/or transparency in accounting of global oil reserves.^[162] Based on available production data, proponents have previously predicted the peak for the world to be in years 1989, 1995, or 1995–2000. Some of these predictions date from before

the recession of the early 1980s, and the consequent reduction in global consumption, the effect of which was to delay the date of any peak by several years. Just as the 1971 U.S. peak in oil production was only clearly recognized after the fact, a peak in world production will be difficult to discern until production clearly drops off.^[163] The peak is also a moving target as it is now measured as "liquids", which includes synthetic fuels, instead of just conventional oil.^[164]

In 2020, according to BP's Energy Outlook 2020, peak oil had been reached, due to the changing energy landscape coupled with the economic toll of the COVID-19 pandemic.

While there has been much focus historically on peak oil supply, focus is increasingly shifting to peak demand as more countries seek to transition to renewable energy. The GeGaLo index of geopolitical gains and losses assesses how the geopolitical position of 156 countries may change if the world fully transitions to renewable energy resources. Former oil exporters are expected to lose power, while the positions of former oil importers and countries rich in renewable energy resources is expected to strengthen.^[165]

Unconventional oil

Unconventional oil is petroleum produced or extracted using techniques other than the conventional methods.^{[166][167]} The calculus for peak oil has changed with the introduction of unconventional production methods. In particular, the combination of horizontal drilling and hydraulic fracturing has resulted in a significant increase in production from previously uneconomic plays.^[168] Analysts expected that \$150 billion would be spent on further developing North American tight oil fields in 2015. The large increase in tight oil production is one of the reasons behind the price drop in late 2014.^[169] Certain rock strata contain hydrocarbons but have low permeability and are not thick from a vertical perspective. Conventional vertical wells would be unable to economically retrieve these hydrocarbons. Horizontal drilling, extending horizontally through the strata, permits the well to access a much greater volume of the strata. Hydraulic fracturing creates greater permeability and increases hydrocarbon flow to the wellbore.

In fiction

Petrofiction or oil fiction,^[170] is a genre of fiction focused on the role of petroleum in society.^[171]

See also

- | | | |
|-----------------------------------------------------------|---------------------------------------------|--------------------------------------|
| ▪ <u>Barrel of oil equivalent</u> | ▪ <u>List of oil fields</u> | ▪ <u>Petroleum politics</u> |
| ▪ <u>Filling station</u> | ▪ <u>Manure-derived synthetic crude oil</u> | ▪ <u>Petrocurrency</u> |
| ▪ <u>Gas oil ratio</u> | ▪ <u>Oil burden</u> | ▪ <u>Thermal depolymerization</u> |
| ▪ <u>List of oil exploration and production companies</u> | ▪ <u>Petroleum geology</u> | ▪ <u>Total petroleum hydrocarbon</u> |
| | | ▪ <u>Waste oil</u> |

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Footnotes

1. 12.4 gigatonnes petroleum (and about 1Gt CO₂eq from methane)/50 gigatonnes total

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Further reading

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External links

- Global Fossil Infrastructure Tracker (<http://ggon.org/fossil-tracker/>)
- API – the trade association of the US oil industry. (<http://www.api.org/>) (American Petroleum Institute)
- U.S. Energy Information Administration (http://www.eia.doe.gov/oil_gas/petroleum/info_glance/petroleum.html)
 - U.S. Department of Energy EIA – World supply and consumption (<http://www.eia.doe.gov/emeu/international/contents.html>)
- Joint Organisations Data Initiative | Oil and Gas Data Transparency (<https://www.jodidata.org/>)
- U.S. National Library of Medicine: Hazardous Substances Databank – Crude Oil (<http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@term+@na+@rel+Crude+oil>)
- "Petroleum" ([https://en.wikisource.org/wiki/The_American_Cyclop%C3%A6dia_\(1879\)/Petroleum](https://en.wikisource.org/wiki/The_American_Cyclop%C3%A6dia_(1879)/Petroleum)). *The American Cyclopædia*. 1879.
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